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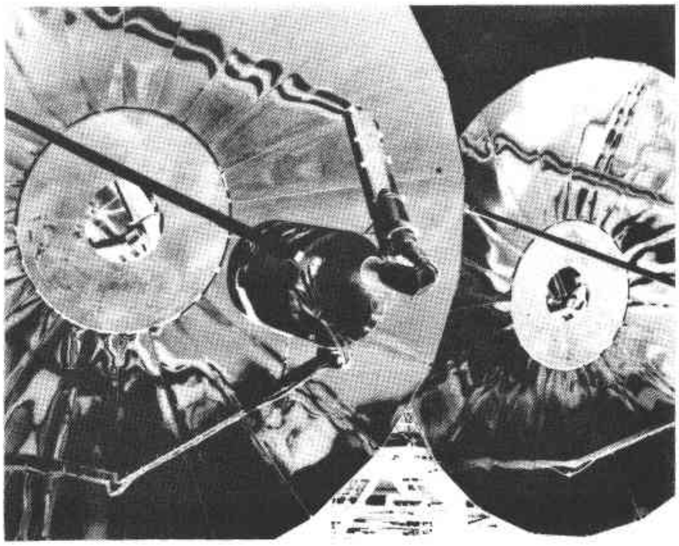
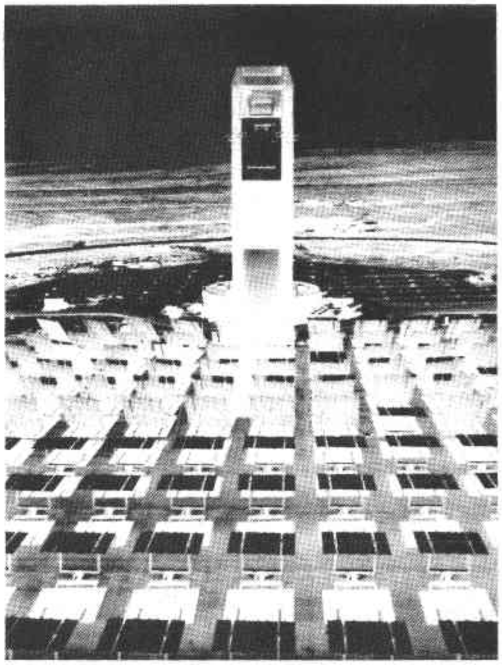
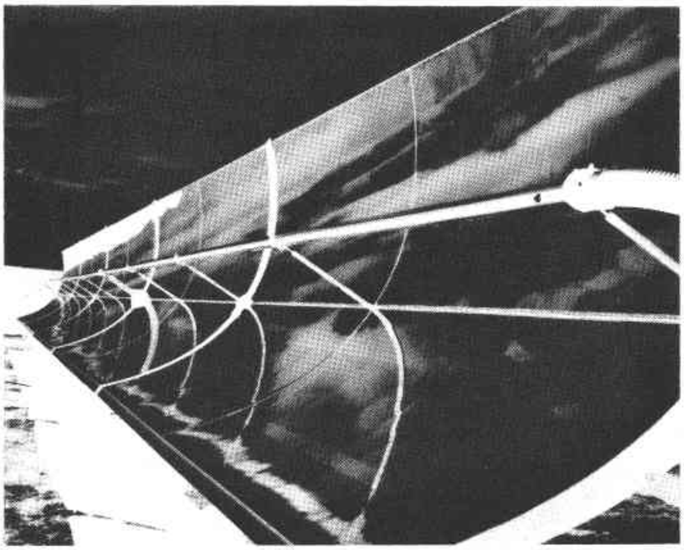


Solar Thermal Energy Systems

Annual Technical Progress Report FY 1980





Prepared for the U.S. Department of Energy
Assistant Secretary for Conservation and Renewable Energy
Division of Solar Thermal Energy Systems

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Solar Thermal Energy Systems

Annual Technical Progress Report FY 1980

Prepared by

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for the U.S. Department of Energy
Assistant Secretary for Conservation and Renewable Energy
Division of Solar Thermal Energy Systems
Under Contract No. EG-77-C-01-4042

FOREWORD

The Solar Thermal Energy Systems (STES) Program within the Department of Energy has its origins in the national solar energy research and development effort mandated by Congress in 1974 and initiated under the predecessor agency, the Energy Research and Development Administration. The STES Program is responsible for development of systems known collectively as concentrating solar collectors as well as development of salt-gradient solar ponds. The specific concentrating systems being pursued are: single-axis tracking parabolic troughs, stationary hemispherical bowls, heliostat-based tower-mounted central receivers, and double-axis tracking parabolic dishes. These approaches all use reflective collector surfaces to concentrate the sun's rays on a small area in a receiver to capture solar heat and increase its temperature dramatically. Salt gradient ponds rely on a physical phenomenon whereby salinity differentials suppress convection, enabling a saline pond both to collect and store energy.

These solar thermal concepts offer a versatile energy option because they can convert sunlight into heat within a wide range of temperatures, including those above 2,000 degrees Fahrenheit. The heat can be used directly, as in industrial processes, can be converted into mechanical or electrical energy, or can be used to drive chemical reactions that produce fuels.

Since our first Annual Technical Progress Report was issued (for Fiscal Year 1978), there has been considerable advancement in materials and components research. Fiscal Year 1980, which this report covers, is significant in that a substantial body of operating data from first-of-a-kind field experiments and other tests is becoming available. The particular technological concepts involved are parabolic troughs and hemispherical bowls. Complete parabolic dish and central receiver systems are under construction which will produce data in an industrial enivronment. (Their regular operation is scheduled to begin in FY 1982).

As will be observed in reading the FY 1980 Annual Technical Progress Report, the STES Program is supported by DOE field offices and national laboratories, which have contributed extensively to the Report. Their support is greatly appreciated by the STES Program. Also appreciated is their help in involving the private sector in the development of the several solar thermal concepts and in transferring the benefits of our research and development efforts.

Gerald W. Braun, Director
Division of Solar Energy Systems

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EXECUTIVE SUMMARY

FY 1980 SOLAR THERMAL ENERGY SYSTEMS PROGRAM

The U.S. Department of Energy's Solar Thermal Energy Systems Program uses phased research, development, and field tests to assist in establishing the system feasibility of low-, mid-, and high-temperature solar concentrating collector systems and solar salt-gradient ponds. Industrial acceptance of these systems will build on this base of component/subsystem research and development, data generated from test facilities, and field experiments. The program is now proceeding into a phase involving implementation of first-generation designs in field experiments and pilot plants. In parallel with these efforts, progress is being achieved on the development of second-generation concentrator and collector array designs which incorporate improved engineering, higher efficiency, and lower cost components.

Four classes of systems have been identified as having the potential to capture major shares of key sectors of the U.S. primary energy market. The suitability of these systems for the markets in question is based on their unique optical characteristics and modularity. The four major classes are line-focus distributed receivers (parabolic troughs and hemispherical bowls), point-focus distributed receivers (parabolic dishes), central receiver systems, and solar ponds. These systems will be used to produce electricity; provide process heat at its point of use for industrial applications; provide heat and electricity in combination for industrial, commercial, and residential needs; and drive endothermic processes for production of liquid and gaseous fuels and chemicals.

Solar thermal concentrating systems adapt well to existing industrial facilities and power plants. System-level feasibility is being established, and selected systems will be ready for use by industry in the early 1980s. Industrial process heat is a major market that can be penetrated in the near future by solar thermal systems supplementing conventional sources of thermal energy.

In the category of distributed receivers, the nucleus of a parabolic trough collector industry is emerging. A number of companies are manufacturing components and subsystems on a semi-production basis, and others have expressed serious interest in doing so. The industrial process heat field test projects as well as the system field experiments for irrigation at Willard, New Mexico, and Coolidge, Arizona, represent practical applications of line-focus technology from which operating data are being obtained. The first major installation involving dishes will be located at Shenandoah, Georgia, in a total energy mode to operate a knitting mill.

Central receiver technology also is becoming well developed. Construction of the 10-MW_e pilot plant near Barstow, Calif., is on track and scheduled for completion in 1981. Follow-up efforts establishing the connection between this pilot plant and initial utility repowering markets are under consideration.

Advanced development efforts are focusing on:

- Expanding and accelerating the development of technology by improving materials and component performance,
- Providing storage technology that enhances the solar capacity and its potential to displace fossil fuels, and
- Providing higher temperature technology for additional industrial process heat applications and, ultimately, for production of transportable fuels and chemicals.

As improved designs are defined and tested and production studies are completed, earlier favorable cost projections are holding firm and gaining credibility. Even though the first-of-a-kind pilot plant designs would cost several times the program goals if they were built today, improved designs, high-volume concentrator production, and systems-level experience will reduce the gap. Operating experience is also key to investment decisions that will initiate and broaden participation by industry.

This Annual Technical Progress Report presents descriptions of the research and development, systems application projects, and supporting activities carried out under the DOE Solar Thermal Energy Systems Program during FY 1980. The following summary highlights the most significant FY 1980 accomplishments of these activities.

POINT-FOCUS TECHNOLOGY

Technology Development

- Parabolic Dish Technology:
    - General Electric and Acurex Corporation selected as contractors for detailed design, fabrication, and installation of prototype low-cost dish concentrators.
    - Cost-effective, lightweight reflective gores with excellent optical qualities developed for advanced parabolic dishes.
    - Design by Ford Aerospace and Communications Corp. of first-generation organic Rankine-cycle receiver using toluene as the working fluid approved.
    - First steam-Rankine receiver delivered in May and tested on the test bed concentrator.
    - Second-generation receiver for the dish-Stirling system delivered in September.
    - Contract to design and fabricate an organic Rankine-cycle power conversion unit awarded to Barber-Nichols Engineering Co.
    - Contract to design an open-cycle air-Brayton engine awarded to Garrett Air Research Manufacturing Co.
- Test results published on developmental testing of the Omnium-G collector module.
- Small solar power system ranking study completed.
- Two 11.5-meter-diameter test bed concentrators installed and successfully calibrated at the Parabolic Dish Test Site.
- Storage Technology:
    - Computer program developed for latent heat buffer storage system modeling.
    - Six studies initiated in the area of thermal storage requirements, latent heat storage, and advanced concepts.
    - Study conducted to assess performance and costs of existing and advanced electrochemical storage and inversion/conversion systems.

Systems and Applications

- Applications Development Experiments:
    - Ford Aerospace and Communications Corp. authorized to proceed with design work on the concentrator, receiver, and power conversion unit for the Small Community Solar Thermal Power Experiment (SCSE).
    - Six candidate sites selected for the Small Community Solar Thermal Power Experiment.
- Seventeen bids received for the industrial applications experiment (EE-3 series).

- Responses from three contractors evaluated for the system design of the 100-kW_e Yuma Experiment (EE-2a).
- Solar Total Energy Project, Shenandoah:
  - System design completed and interface control drawings approved.
  - On-site tests of proposed collector foundations identified potential cost saving changes in design.
  - No problems have arisen during testing of four prototype Shenandoah collectors at the Midtemperature Solar Systems Test Facility.

CENTRAL RECEIVER TECHNOLOGY

Technology Development

- Central Receiver Technology Development:
  - Testing of the McDonnell Douglas Astronautics Co. receiver panel for the 10-MW_e Barstow pilot plant successfully completed at the Central Receiver Test Facility (CRTF).
  - Testing of a Martin Marietta molten salt receiver at the CRTF initiated.
  - Three improved water/steam receiver designs completed.
  - Interim structural design standards completed for central receivers.
- Heliostat Technology:
  - Final reports on new ideas for heliostats from five small and five large contractors show particularly encouraging results.
- Central Receiver Test Facility:
  - The heliostat field maintained a 95% or higher operational level.
  - Testing and data analysis completed for pilot plant prototype heliostats.
  - Facility modifications completed to accommodate testing of 10 prototype second-generation heliostats.
- Storage Technology:
  - Storage concept development completed for an organic fluid maintenance unit.
  - Concept development for internally insulated thermal storage containment for molten salt receivers at temperatures up to 566°C showed the concept to be viable.
  - Equipment built to measure viscosity, surface tension, and density of molten salts over a temperature range of 25° to 900°C and a pressure range of 1 to 10 atmospheres.

Systems and Applications

- 10-MW_e Power Plant:
  - Plant preliminary design work completed and production heliostat supplier selected.
  - Preliminary earthwork completed, site access road and administrative building constructed.
  - Collector field (heliostat) foundations installed and installation of heliostats begun.
  - Receiver panel construction begun.
  - Visitor information center opened.
  - Construction contracts awarded for a warehouse, collector field electrical wiring, receiver tower steel, thermal storage and plant support steel, thermal storage tank, and major mechanical components.
- Storage-Coupled Systems, Repowering, and Cogeneration:
  - Four candidate working fluids designed to increase the efficiency of storage-coupled systems (air, helium, molten salt, and sodium) selected for study.
  - Thirteen conceptual designs completed, seven for utility repowering and six for industrial process heat retrofit.

  - Seven proposals for cogeneration projects resulting from an RFP issued in April 1980 selected for negotiation.

- International Energy Agency Project:
  - Critical design reviews for both central receiver and distributed systems successfully conducted and plant construction begun.

LINE-FOCUS TECHNOLOGY

Technology Development

- Performance Prototype Trough:
  - Mass-production, automotive-type prototype tooling for 1 x 2-m stamped sheet metal and sheet molding compound reflector structures designed and fabricated. Reflector samples produced for testing in FY 1981.
  - Gravity sag and press forming techniques employed to form 1 x 1-m laminated glass reflector structures.
  - Collector pylons at the Willard project, instrumented to measure wind lift and drag forces, showed that peak lift forces were one-half the initial design requirements and drag forces one-quarter the requirement.
  - A nonevacuated tube receiver produced 63% of peak thermal efficiency at an output temperature of 315° C.
  - Size and performance requirements for line-focus collector drive mechanisms defined.
  - Design of a prototype tracker/controller utilized microprocessor computer technology.
  - Quantitative evaluation completed for heat loss in collector field components.
  - With construction completed, operation of the 20-m Analog Design Verification System hemispherical bowl at Crosbyton, Texas, began.

- Midtemperature Solar Systems Test Facility (MSSTF):
  - System Test Facility accomplishments included:
    1) demonstration that collectors are capable of greater than 60% noontime efficiency;
    2) establishment of more than 10 new test capabilities.
  - Collector Module Test Facility accomplishments included:
    1) characterization of collectors from more than fifteen suppliers; and
    2) characterization and testing of prototype trough structures, receivers, and tracking controls.

- Solar Energy Research and Applications in Process Heat Facility (SERAPH):
  - Detailed plans for the SERAPH physical plant completed and approved, permitting start of construction.
  - Major equipment for SERAPH contracted for, fabricated, and delivered.

- Storage Technology:
  - Construction completed for a laboratory-scale thermocline storage facility to evaluate diffuser designs.
  - A 4500-ℓ (1200-gal) engineering prototype thermocline storage tank designed, fabricated, and installed in the MSSTF.

Systems and Applications

- Shallow Well Irrigation—Willard, New Mexico:
  - Collector field operation exceeded 70% of possible time, and turbine operated for more than 400 hours.

  - Spring and summer solstice evaluation programs successfully completed.
- Deep Well Irrigation—Coolidge, Arizona:
  - Construction completed and operation begun, following dedication ceremonies.
  - System characterized and operated more than 85% of "good weather" time, supplying 117,795 kWh of electricity to the utility grid.
- Modular Industrial Solar Retrofit Project (MISR):
  - Project to develop low-cost modular line-focus solar thermal systems initiated during FY 1980. Four conceptual system design contracts awarded.
  - Preliminary conceptual design requirements established.
- Industrial Process Heat Field Projects:
  - Seven low-temperature hot water/hot air projects operating one year or longer show collector array efficiencies of 12% to 36% for these first-of-a-kind installations.
  - Four low-temperature steam projects operating or under construction.
  - Four intermediate-temperature steam systems designed in FY 1979 are under construction.
  - Preliminary design reviews completed for five low-temperature, cost-shared projects.
  - Draft final reports completed for design of four intermediate-temperature, cost-shared projects.

RESEARCH AND ADVANCED DEVELOPMENT

Advanced Components

- Receivers:
  - Sanders Associates ceramic matrix high-temperature receiver for point-focus collectors fabricated on schedule and ready for solar testing.
  - High-temperature copper receiver cast, fabricated and installed on a parabolic dish at the Advanced Component Research Facility test site. Testing in progress.
- Low Initial Cost Concentrators:
  - Development initiated for a folding facet reflector element (to reduce wind loads).
- Power Conversion Units:
  - Completed conceptual design study for a 15-kW$_e$ free-piston Stirling engine predicts a conversion efficiency of 60% at 840°C (1540°F).
  - Study of 15-kW$_e$ steam-Rankine reheat reciprocator heat engine predicts efficiency of 36% at 700°C (1292°F).
  - Rankine engine study by Jay Carter predicts an efficiency of 33% at 680°C (1250°F).
- Transport Subsystems:
  - Reversible chemical reaction screening studies conducted by Rocket Research Co. and JPL.
  - Feasibility testing of an SO_3 dissociation reactor successfully completed by The Naval Research Laboratory and New Mexico State University.
  - A Solchem receiver containing a CO_2-CH_4 reforming converter-heat exchange coil tested at the White Sands Solar Facility shows conversion efficiencies greater than 50%.
- Control Systems:
  - Test apparatus for evaluating single-axis sun trackers designed, built, and installed.
  - Published report describes major types of line-focus sun trackers.
- Facilities:
  - Four high-temperature experiments sponsored by the Solar Thermal Test

Facilities Users Association were completed at the Advanced Components Test Facility at the Georgia Institute of Technology (GIT/ACTF).

- Conversion of the north parabolic dish at SERI Advanced Component Research Facility to a high-temperature thermal test loop and connection of the south dish to an optical test fixture completed. Optical efficiencies of both dishes characterized.
- Installation of a new control room at the GIT/ACTF completed.
- Operation of the Midtemperature Component Research Facility (MTCRF) at SERI began.

Materials Technology

- Optical Materials:
  - Testing verified feasibility of using a CO_2 laser for cutting thin glass.
  - Performance and degradation models for polymers developed and a polymer development plan for low-cost dome concentrator systems prepared.
  - A technique using Fourier transform infrared spectroscopy (FTIRS) developed to study real-time degradation of polymers.
  - Agglomerated silver identified as a possible corrosion mechanism in silver mirrors.
  - National Bureau of Standards (NBS) developed and made available for sale to researchers two standards for high and low diffuse reflectance.
  - Improved method developed to measure mirror specularity of large panels.
  - Preliminary design information developed for use of cellular glass as a structural material in optical systems. Technical feasibility of sag-forming cellular glass verified.
- Thermal Materials:
  - Performance prediction modeling analysis of use of ceramics in high-temperature receivers developed.
  - Benefit analysis completed for improved selective absorber coatings.
  - Optical control of solution chemistry for electroplating black cobalt established. Evaluation of black cobalt as an absorber coating at 400° C completed.

Fuels and Chemicals

- Biomass Pyrolysis:
  - Laboratory apparatus for biomass pyrolysis built, installed, and tested. Various biomass feedstocks produced diesel precursors.
  - Design completed for high-temperature parabolic dish receiver for biomass pyrolysis.
- Oil Shale Retorting:
  - Analysis verified technical and economic feasibility of solar retorting of oil shale.
  - Demonstration of solar retorting of oil shale at the White Sands Solar Furnace (WSSF) resulted in yields of better than 110% Fischer Assay. (Conventional retorts yield 80% to 95%.)
- Coal Gasification:
  - Report presenting results of solar coal gasification tests at WSSF showed technical feasibility and high solar efficiency for solar coal gasification.
  - Experiments demonstrating gasification of carbonaceous materials conducted on 1-MW_t solar furnace at Odeillo, France.
  - Entrained flow gasification of coal experiments conducted by the Los Alamos Scientific Laboratory (LASL) showed promising results.

- Other Fuel and Chemical Highlights:
  - University of New Hampshire completed surveys, feasibility studies, and analyses for production of alternate fuels.
  - Lawrence Berkeley National Laboratory continued laboratory experiments and design of small particle heat-exchange receiver.
  - Quantities of furfural, an economically significant industrial chemical, produced from corn cobs. Design and fabrication of hardware completed for performing this process on a parabolic dish.
  - Technical feasibility demonstrated for reconcentrating spent sulfuric acid on a solar thermal system.

Supporting Programs

- Solar Thermal Test Facilities Users Association (STTFUA):
  - A Solchem receiver for CO_2-CH_4 reforming successfully tested at WSSF.
  - High-temperature advanced solar receiver developed by Solar Turbines International and successfully tested at GIT/ACTF produced steam at 1420° F and 1550 psia.
  - A fluidized bed receiver developed by Westinghouse underwent nearly 70 hours of testing and reached solar energy conversion efficiencies of 45% at 563° C at the GIT/ACTF.
  - Sodium heat-pipe receiver built by Dynatherm and tested at GIT/ACTF achieved maximum heat-pipe temperatures of 850° C and power throughput of 11 kW$_t$.
  - Flash pyrolysis of biomass successfully demonstrated at the GIT/ACTF by Princeton University.
- Insolation Resource Assessment:
  - Insolation data base produced for the National Solar Energy Information Data Bank (SEIDB).
  - Development of insolation algorithms and conversion of historical insolation data continued.
  - Advanced spectroradiometer for characterizing spectral distribution of direct, diffuse, and global insolation developed and manufactured.
- Thermal Systems Evaluation and Ranking:
  - Final report published on small power systems study of 0.1- to 10-MW$_e$ systems.
  - Preliminary results obtained for evaluation and ranking of 5-MW$_t$ systems for thermal applications.
- Quality Assurance and Standards:
  - A cross section of the solar thermal industry, canvassed to nominate standards development priorities, identified more than 1000 applicable standards.
  - Forty-four documents relating to solar energy are being drafted by ASTM Committee E-44.
- Environmental Control:
  - UCLA Laboratory of Nuclear Medicine and Radiation Biology (LNMRB) issued a study, "Worker Health and Safety in Solar Thermal Power Systems."
  - Laboratory and field studies by LNMRB continuing, covering effects of chemical contamination of soils by salts and fluids accidentally released by solar total energy systems; vegetation management at sites; environmental monitoring of the 10-MW$_e$ project near Barstow; ecological and microclimatic effects within heliostat arrays; and guidelines for community utilization of small-scale solar thermal energy systems.

INTRODUCTION

LEGISLATIVE BACKGROUND

Federal involvement in the national solar program began on June 14, 1971, with a Presidential message calling for programs to ensure an adequate supply of clean energy in the years ahead. A Solar Energy Panel formed in January 1972 identified the potential contribution of solar energy in meeting this goal, and on April 4, 1973, the National Science Foundation (NSF), designated by the President to be the lead federal agency in coordinating solar energy research and technology, assumed responsibility for the Solar Thermal program.

On October 26, 1974, the Solar Energy Research, Development, and Demonstration Act (Public Law 93-473) was signed into law. Its goal was to provide the nation with the option of using solar energy as a new source for meeting future requirements. The Energy Reorganization Act of 1974 (Public Law 93-438) authorized the new Energy Research and Development Administration (ERDA) to assume primary responsibilities for the Solar Thermal program for NSF on January 19, 1975. In response to the mandates of this act, major efforts were made within the Division of Solar Energy of ERDA to develop and introduce economically competitive and environmentally acceptable solar energy systems.

Following the signing of the Department of Energy Organization Act (Public Law 95-91) on August 4, 1977, these responsiblities were transferred to the new U.S. Department of Energy (DOE) on October 1, 1977.

The Office of Assistant Secretary for Energy Technology (SOLAR/ET) administered the Division of Central Solar Technology and the Division of Distributed Solar Technology, while the Office of Assistant Secretary for Conservation and Solar Applications (SOLAR/CS) administered the Office of Solar Applications. Both ET and CS contained elements of the current Solar Thermal Energy Program.

On October 1, 1979, organizational realignments abolished SOLAR/ET and renamed SOLAR/CS the Office of Assistant Secretary for Conservation and Solar Energy. All solar technology programs were transferred to this Assistant Secretariat.

Program planning continued under the guidelines established by Public Law 93-473 and by three other legislative acts passed by the 93rd Congress: the Solar Heating and Cooling Demonstration Act of 1974 (Public Law 93-409), the Energy Reorganization Act of 1974 (Public Law 93-438), and the Federal Nonnuclear Energy Research and Development Act of 1974 (Public Law 93-577). Together, these four laws grant DOE and other federal agencies the authority to pursue a research program aimed at effective solar energy use.

This report is the third Annual Technical Progress Report for the Solar Thermal Energy Systems Program. It is structured according to program organization and emphasizes technical progress rather than activities and individual contractor efforts. Each project description indicates its place in the Energy Program, and includes a brief history, significant achievements during FY 1980, future project activities, and a forecast of the significant achievements that are anticipated.

THE PROGRAM

The Solar Thermal Energy Systems Program is dedicated to establishing feasibility of cost-effective solar thermal systems producing heat in the low- through high-temperature range. Diverse potential applications exist for such systems, including provision of process heat for industry, electrical generation, and endothermic chemical reactions for the production of fuels and chemicals.

Systems under development differ significantly in their temperature capability, modularity, and adaptability to siting considerations. Concepts include heliostat-based central receiver systems, tracking parabolic trough and parabolic dish collector systems, stationary hemispherical bowl collectors, and solar ponds. System concepts are shown in Table 1.

Promising applications for solar thermal systems include:

- Large electrical applications, including repowering of gas- and oil-fired peaking electricity generating plants and storage-coupled power plants of intermediate capacity factor;
- Industrial process heat (IPH) systems;
- Remote electric power systems for irrigation, military sites, and other applications;
- Small community power systems, usually under 10 MW_e in size;
- Total energy systems that provide electricity, process heat, and space heating and cooling to industrial, commercial, and residential users;
- Ultimately, storage-coupled process heat for high capacity factor utility applications and production of fuels and chemicals.

The primary near-term market applications are utility repowering utilizing central receivers and parabolic troughs supplying low- to mid-temperature industrial process heat. Longer-term market areas involve new initiatives: in cogeneration that combines electrical generation with industrial process heat; and in parabolic dish electrical generation for small communities and isolated loads, including military applications and remote areas such as islands.

Today's focus is on system performance. An accelerated materials research and testing program is contributing to improved system performance, reliability, and life expectancy. Engineering feasibility problems are being addressed.

Federal expenditures for the Solar Thermal Energy Program rose from $13.2 million in 1975 to $143.2 million in 1980. The distribution of fiscal year 1980 appropriations within the Program is shown in Table 2.

Technology

Solar thermal energy systems discussed in this report utilize concentrating solar energy collection technologies for generation of heat and possible subsequent conversion of the heat to electricity or mechanical energy. These systems, modular over a wide range of sizes, are directly adaptable to existing equipment and processes requiring steam or hot air, including factories and utility power plants.

Table 1. Solar System Classification and Collector Design Concepts

System Classification	Collector Design Concepts
Point-focusing central receivers	Heliostat field with central receiver
Linear-focusing distributed receivers	Parabolic trough or hemispherical bowl
Point-focusing distributed receivers	Parabolic dish
Solar salt-gradient ponds	Still water

Table 2. FY 1980 Solar Thermal Energy Systems Budget
(in millions of $)

Research and technology	$ 73.9
Applications	66.2
Capital equipment	3.0
Total	$143.1

The technologies use collectors or reflectors to track the sun and fall under three broad categories: point-focus, line-focus, and central-receiver systems. Solar ponds, which are capable of producing usable heat energy up to 100°C (212°F) but which do not track the sun, are also included as a solar thermal technology.

Point-focus systems, with temperature capabilities up to 2000°C (3632°F), concentrate the solar flux incident on a parabolic mirror onto a receiver which converts the concentrated flux to heat energy. Point-focus systems can be used singly (typically 20-25 kW$_e$ per module) or in arrays, depending on the application desired.

In a line-focus parabolic trough system, the collector consists of one or more mirrored troughs which concentrate the solar flux on a line receiver at the focus of the parabola. A working fluid flows through the receiver. This heated fluid, reaching up to 300°C (572°F), is used for the specific application of the system. The other line-focus approach, stationary hemispherical bowls, concentrates the solar flux on a receiver at the solar flux on a receiver at the focus of the bowl. The receiver adjusts to remain in the focus. A single bowl can produce temperatures up to 538°C (1000°F).

A central receiver system consists of a tower surrounded by a field of tracking mirrors called heliostats, which direct and concentrate the sun's rays to a receiver mounted on the tower. The heat energy is transferred from the concentrated solar flux to a circulating heat-transport fluid and then used to power a turbine or an industrial process, or alternatively it can be transferred to a storage system for use during nonsolar hours. This type of system is capable of producing large quantities of power, with initial systems in the range of 10-300 MW$_e$. Temperature capabilities range from 315° to 815°C (600° to 1500°F).

Recent technical advances have made solar salt-gradient ponds a potentially attractive heat energy source. In a solar pond, the concentration of dissolved salt in the water increases with depth, raising the density of the water as the bottom of the pond is approached. Convection of heated water from the bottom of the pond is prevented by the density gradient, and the temperature there can approach the boiling point. The heated water is pumped from the pond to the point of use and returned to the pond.

ORGANIZATION

Overall management of the program is the responsibility of the Division of Solar Thermal Energy Systems Division, DOE Headquarters. Responsibility for day-to-day technical management has been delegated to lead technical centers and DOE field offices.

The two major subprograms are: (1) Research and Technology, and (2) Systems Development and Assessment. A program structure chart showing breakdown of these activities is detailed in Fig. 1.

Providing a strong solar thermal technology base is the responsibility of the Research and Technology Activity. To achieve this, the Research and Advanced Development (RAD) segment is seeking to accelerate and enhance the development of solar thermal energy systems by supporting applied research and determining new applications for solar thermal technology. RAD is also developing improved, durable, and reliable materials to reduce life-cycle costs of future solar thermal systems. The Technology Development segment is concerned with providing the technology upon which a vigorous U.S. solar industry can be based, and with ensuring the development of solar thermal products capable of meeting the needs of domestic industry for commercial applications.

The Systems Development and Assessment Activity has a goal of facilitating the industrial use of solar thermal systems. The Systems and Applications element is charged with constructing, operating, and testing solar thermal experimental and pilot plants which serve as prototypes for industrial processes, electric power generation, and processing agricultural products and fuels. The strategy is to develop the confidence of the user community by demonstrating the technical feasibility and economic potential of the systems. Facilitating early industrial acceptance and identifying nontechnical factors which affect penetration of solar thermal markets are the responsibilities of the Planning and Assessment segment.

GOALS

The overall goals of the Solar Thermal Energy Program are to demonstrate tech-

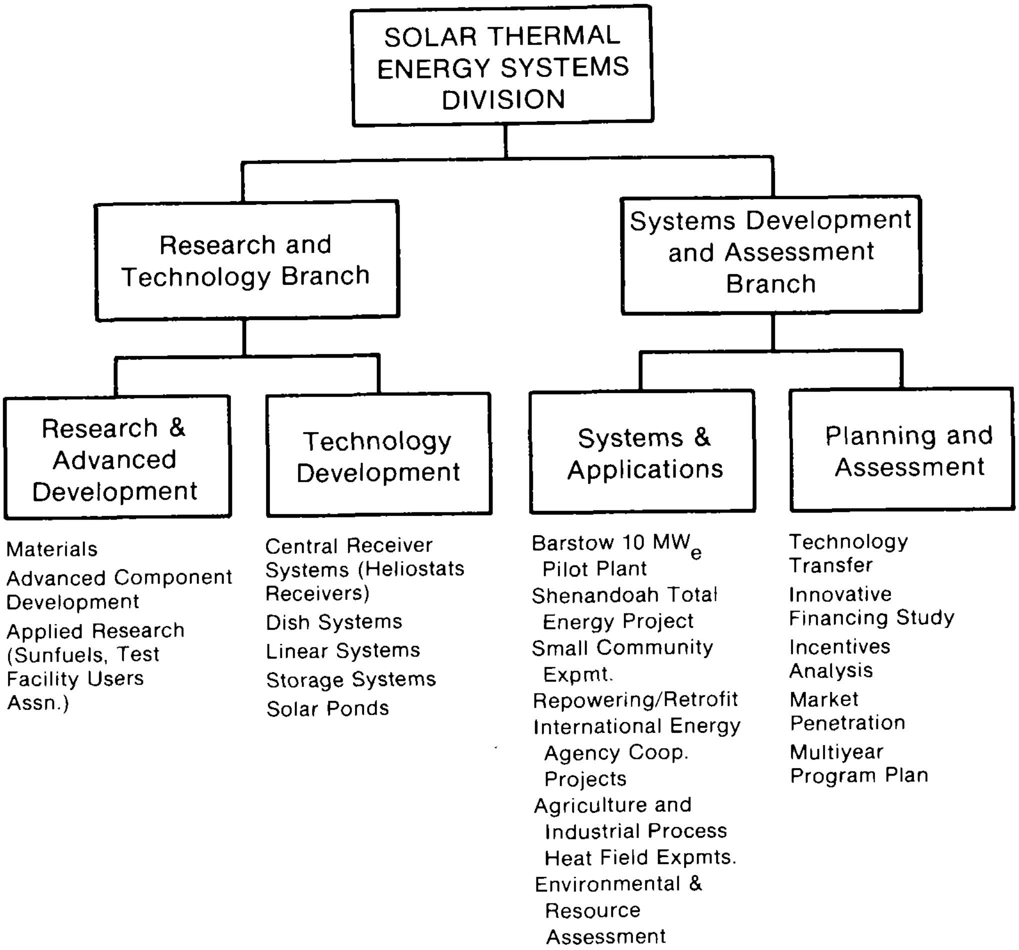

Figure 1. Solar Thermal Energy Systems Program Structure

ical performance and reduce uncertainties concerning the reliability of solar thermal energy systems, and to develop a life-cycle cost structure that is competitive with other energy sources and technologies. Overall cost goals for 1990 have been established for electricity generation and heat production. These goals are shown in Table 3.

The subprogram objectives that will contribute to achieving these goals are:

- Demonstration of the technical feasibility and economic potential of solar thermal energy systems in a range of applications;
- Encouragement of user confidence in solar thermal as a viable energy source through:
  - industrial participation in design, construction, and operation of field tests,
  - DOE/industry cost-shared applications.

Table 3. FY 1980 Cost Goals for Solar Thermal Energy

Application	1990 Goal (1980 $)
Electricity	140-160 mills/kWh*
Heat	$7-$10/MBtu**

*Levelized busbar costs (annualized life-cycle costs).
**Levelized energy costs after taxes.

SECTION 1.0

POINT-FOCUS TECHNOLOGY

1.1 TECHNOLOGY DEVELOPMENT

1.1.1 Parabolic Dish Technology

This technology encompasses a variety of systems that use a parabolic, dish-shaped concentrator as a basis for converting the heat of the sun into thermal or electric power. The program emphasizes point-focusing distributed-receiver systems. They consist of a field of sun-tracking modules, each composed of a concentrator, a receiver, and either a power conversion unit for electrical generation or a thermal transport network for industrial heat processes (see Fig. 1-1). NASA's Jet Propulsion Laboratory is responsible for developing parabolic dish technology for the U.S. Department of Energy (DOE), and the NASA Lewis Research Center provides support in power conversion development.

The parabolic dish power systems project consists of two main elements. The first, Technology Development, includes both near-term module development work and advanced subsystems development work. The second element, Applications Development, includes three series of experiments on applications of parabolic dish technology, with supporting activities. Major accomplishments of each element are summarized in this report.

Figure 1-1. Test Bed Concentrators

The goal of the effort is to establish the technical, operational, and economic readiness of parabolic dish systems for electric applications up to 10 MW_e (10 megawatts (electrical))* and thermal applications up to 30 MW_t [30 megawatts (thermal)], developing the technology to the stage where industry can apply it directly to commercial uses. An integral part of this activity is to foster industry participation in the technology development.

Three prerequisites are required to demonstrate the technological readiness of parabolic dish systems:

(1) Components must have high enough performance levels so that the overall system is economically viable.

(2) Components and modules must be durable and long-lived in operation so that they are cost-effective.

(3) It must be possible to produce quantities of components and modules at low cost.

Performance and price targets for the concentrator, receiver, and power conversion subsystems comprising an electricity-generating module are shown in Table 1-1, and corresponding targets for modules designed to generate process heat are shown in Table 1-2. Performance targets are

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*A 10-megawatt power plant will serve about 4000 homes.

Table 1-1. Preliminary Price and Performance Targets for Electric Power Generation (1980 $)

Subsystem	Dominant Parameters	First Generation (1983)	Second Generation (1987)
Concentrators	Installed price* Surface reflectance	$\$120$-$\$170/m^2$ 78%-90%	$\$80$-$\$120/m^2$ 92%
Receivers	Installed price* Efficiency	$\$45$-$\$70/kW_e$ 82%	$\$25$-$\$45/kW_e$ 87%
Power conversion	Installed price* Efficiency	$\$230$-$\$410/kW_e$ 25%-35%	$\$120$-$\$230/kW_e$ 35%-45%

*Based on the following assumed ranges of production:
First generation: 5,000-25,000 units/yr;
Second generation: 10,000-1,000,000 units/yr.

Table 1-2. Preliminary Price and Performance Targets for Process Heat Generation (1980 $)

Subsystem	Dominant Parameters	First Generation (1983)	Second Generation (1987)
Concentrators	Installed price* Reflector efficiency	$\$120$-$\$170/m^2$ 78%-90%	$\$70$-$\$120/m^2$ 92%
Receivers	Installed price* Efficiency	$\$18/kW_t$ 95%	$\$14/kW_t$ 96%
Thermal transport	Installed price* Efficiency	$\$32/kW_t$ 90%	$\$30/kW_t$ 93%

Note: These figures are for a module and do not include a ground heat transportation network.

*Based on the following assumed ranges of production:
First generation: 5,000-25,000/yr;
Second generation: 10,000-100,000/yr.

expected to be met by the years shown. Performance of prototype hardware will have been demonstrated by relatively brief tests at the JPL Parabolic Dish Test Site (PDTS) located at Edwards Test Station near Lancaster in the California desert.

In addition, studies will have defined ways to produce the hardware at the prices established as goals for the program. However, industrial mass-production will not occur by these target dates. The system will have achieved "technology performance readiness," but actual hardware lifetime and quantity production prices will not have been demonstrated.

Secs. 1.1.1.1-1.1.1.3 describe the hardware that composes a dish module in the chronological order of its development. The objectives, approach, status, and time horizon for reaching project goals are then discussed.

1.1.1.1 Concentrator Development

The concentrator development objective is to develop distributed-receiver, point-focusing concentrator technology that has the potential for low cost when mass-produced. This is particularly important because the concentrator accounts for over half the cost of a solar thermal module. This task is being carried out primarily through contracts with industry.

The concentrator development goals are to develop:

(1) concentrators for use as test beds in early test programs;

(2) first-generation, low-cost concentrators to operate efficiently in the 540° to 815°C (1000° to 1500°F) range; and

(3) second-generation concentrators.

This section describes significant accomplishments in test bed, low-cost, and advanced concentrator development. Second-generation concentrators will use the processes and techniques being developed by the advanced concentrator effort. During FY 1980, this effort emphasized the development of cost-effective, lightweight, reflective gores and supporting structures.

Two test bed concentrators (TBCs), built by E-Systems, Inc., were installed and tested during FY 1980 at the Parabolic Dish Test Site (Fig. 1-1). The TBCs are part of an early test program to obtain concentrator performance data and to test several types of receiver/power conversion subsystems. Developed from an existing antenna design, the TBCs were designed to: (1) accommodate JPL-developed mirror facets; (2) provide solar tracking; and (3) support a receiver/power conversion package of up to 500 kg (1100 lb) at the focal plane. Each TBC has a nominal 11.5-meter (m) diameter, 6.6-m focal length, and 82-kW_t [kilowatts (thermal)] output with clean mirrors at $1000\ \text{W/m}^2$ insolation.

Tests conducted at the Parabolic Dish Test Site provided data on the performance of the test bed concentrators under various conditions of insolation at wind speeds up to 10 miles per hour. Specialized instruments, such as a flux mapper and a cavity calorimeter, were designed and fabricated to measure TBC performance. These instruments are described in the receiver and heat transport section of this report.

A contract for the detailed design, fabrication, and installation of three prototype low-cost concentrators (LCCs) was awarded to General Electric Company during FY 1980. The completed design of this concentrator is shown in Fig. 1-2.

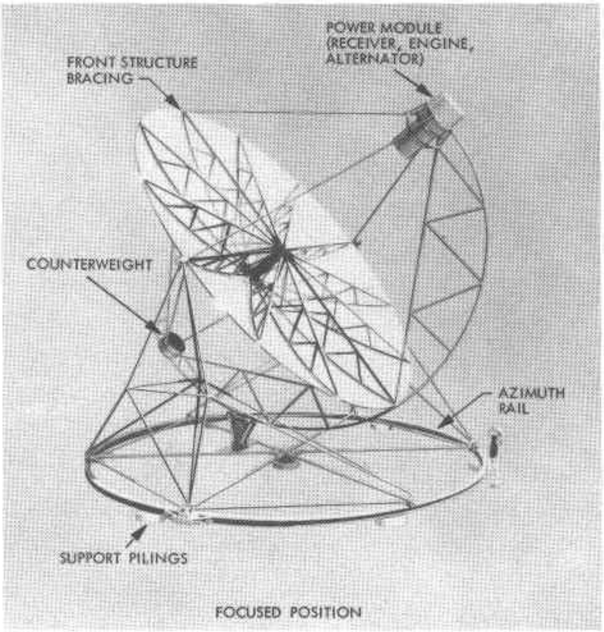


Figure 1-2. **General Electric Low-Cost Concentrator**

The first-generation low-cost concentrator has a diameter of 12 m and uses metallized plastic film bonded to a glass-reinforced plastic (GRP) sandwich substance as the reflector surface. It is projected that the concentrator will provide 80 kW_t at 1000 W/m^2 insolation to a receiver with a 33.7-centimeter (cm) diameter aperture operating at a temperature of 815°C (1500°F). It is planned that this concentrator will be used in the Small Community Solar Thermal Power Experiment and the Military Module Power Experiment, the first two Parabolic Dish Power Systems Engineering Experiments (these are described later in this report).

Acurex Corporation was awarded a contract to design, fabricate, and install an alternative first-generation LCC at the PDTS. The Acurex design, shown in Fig. 1-3, uses a compressed paraboloidal reflector. The reflector surface consists of a mosaic of second-surface glass mirrors bonded to glass-reinforced plastic substrates. This design has a projected performance of 80 kW_t at 1000 W/m^2 insolation, using a receiver with a 31.1-cm diameter aperture operating at a temperature of 815°C (1500°F).

A key accomplishment in advanced concentrators was the development at JPL of cost-effective, lightweight reflective gores using a sandwich construction (see Fig. 1-4). The processes and techniques developed by this effort have the potential for use in second-generation concentrators. To ensure the future commercial availability of the gores, Acurex Corporation was provided with the technology and the materials under a contract to develop a 1.5-mm (millimeter) (60-mil) thick back-silvered mirror. The mirror is cold-sagged and bonded to the paraboloidal surface of the structural cellular glass gore. These lightweight, structurally efficient gores are expected to yield excellent optical quality at low costs when mass-produced. The inherent rigidity of the gores permits significant reductions in the weight of the reflector support structure and, hence, reductions in cost.

Acurex evaluated concentrator design features and a selected concept that mini-

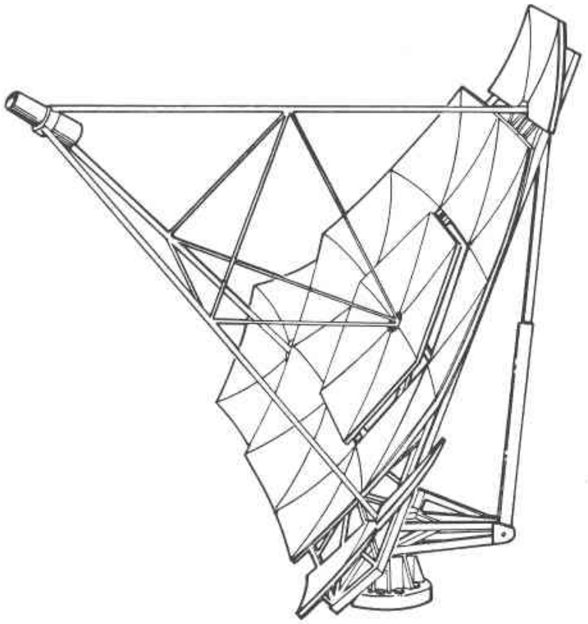


Figure 1-3. **Acurex Alternative Low-Cost Concentrator Design**

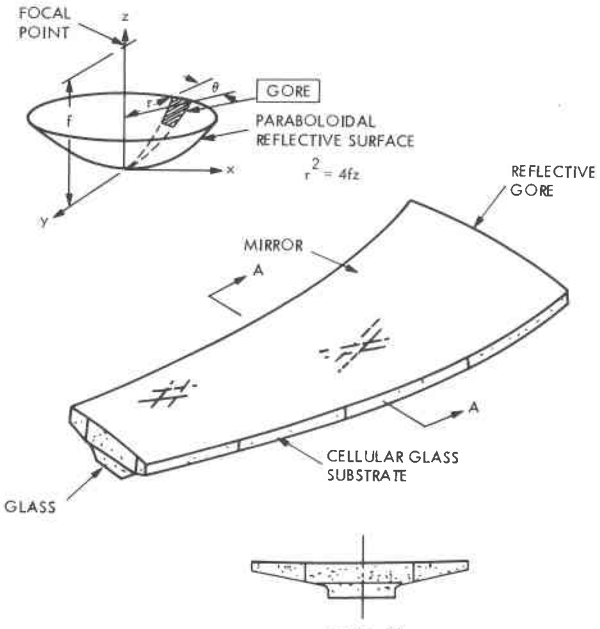


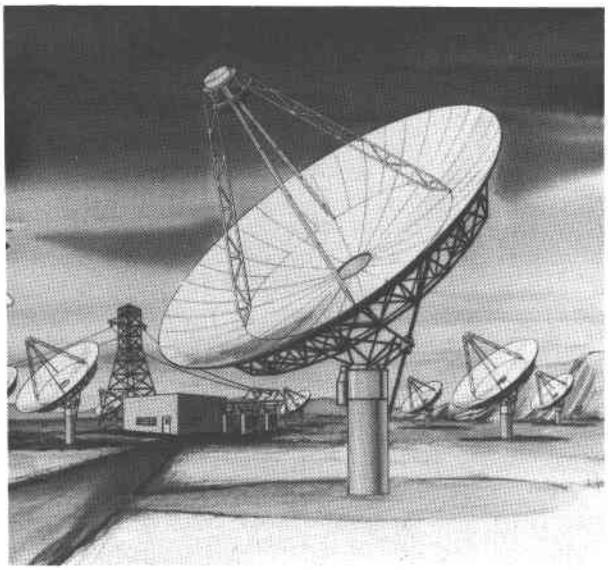
Figure 1-4. Reflective Gore Design

izes the total installed cost of the concentrator. This design concept (Fig. 1-5) features an 11-m diameter, single-pedestal concentrator. The costs of shipping, site preparation, foundation, installation, on-site assembly, and checkout were the major elements influencing concentrator costs. Consequently, the low installation costs associated with this design make it an attractive concept.

1.1.1.2 Receiver and Heat-Transport Network Development

Cost-effective receivers and heat-transport subsystems are required for parabolic dish systems. These subsystems must have long-term reliability at the temperature, pressure, and flow-rate conditions at which the system is expected to operate. The designs must be completely compatible with the other module components: concentrators, engines, controls, and storage.

The receivers currently under development employ steam, air, organic liquid, or liquid metal as the working fluid. These receivers are designed to operate at power levels that match the capabilities of the various concentrators being developed by the parabolic dish program. In modules designed to produce electricity, the receivers are matched to specific power converters, such as Rankine, Brayton, or Stirling cycle units.



igure 1-5. Acurex Advanced Low-Cost Concentrator Design Concept

A first-generation receiver using toluene as the primary working fluid was designed by Ford Aerospace and Communications Corporation (FACC). It is expected to be coupled with an organic Rankine engine for use in the Small Community Solar Thermal Power Experiment (SCSE). The receiver design was approved at the preliminary design review of the SCSE system in June 1980. The approved design (Fig. 1-6) consists of a single, stainless-steel tube that conducts the toluene and is embedded in a copper plate to provide temperature leveling and buffer storage for improved engine operation.

Near the beginning of the fiscal year, critical design reviews of first-generation air-Brayton and steam-Rankine receiver designs were conducted. The air-Brayton review was completed in late September and the steam-Rankine review in early October 1979. Both reviews were presented by Garrett Corporation, AiResearch Manufacturing Company of California. No major problems were discovered at these reviews, and the contractor was authorized to build two prototypes of each design.

The first steam-Rankine receiver was delivered in late May 1980. Figure 1-7 shows the receiver from the aperture end as it was being instrumented for testing at the PDTS. This receiver was installed on TBC-1 in September 1980 and tests were conducted through the end of the year. The first Brayton receiver was fabricated in early July 1980, and will be delivered to the PDTS for testing in early FY 1981. The remaining two prototype receivers will be delivered about a month later. Testing of the steam-Rankine receiver began in late September 1980, and early data reduction confirms the predicted performance. The characteristics of the

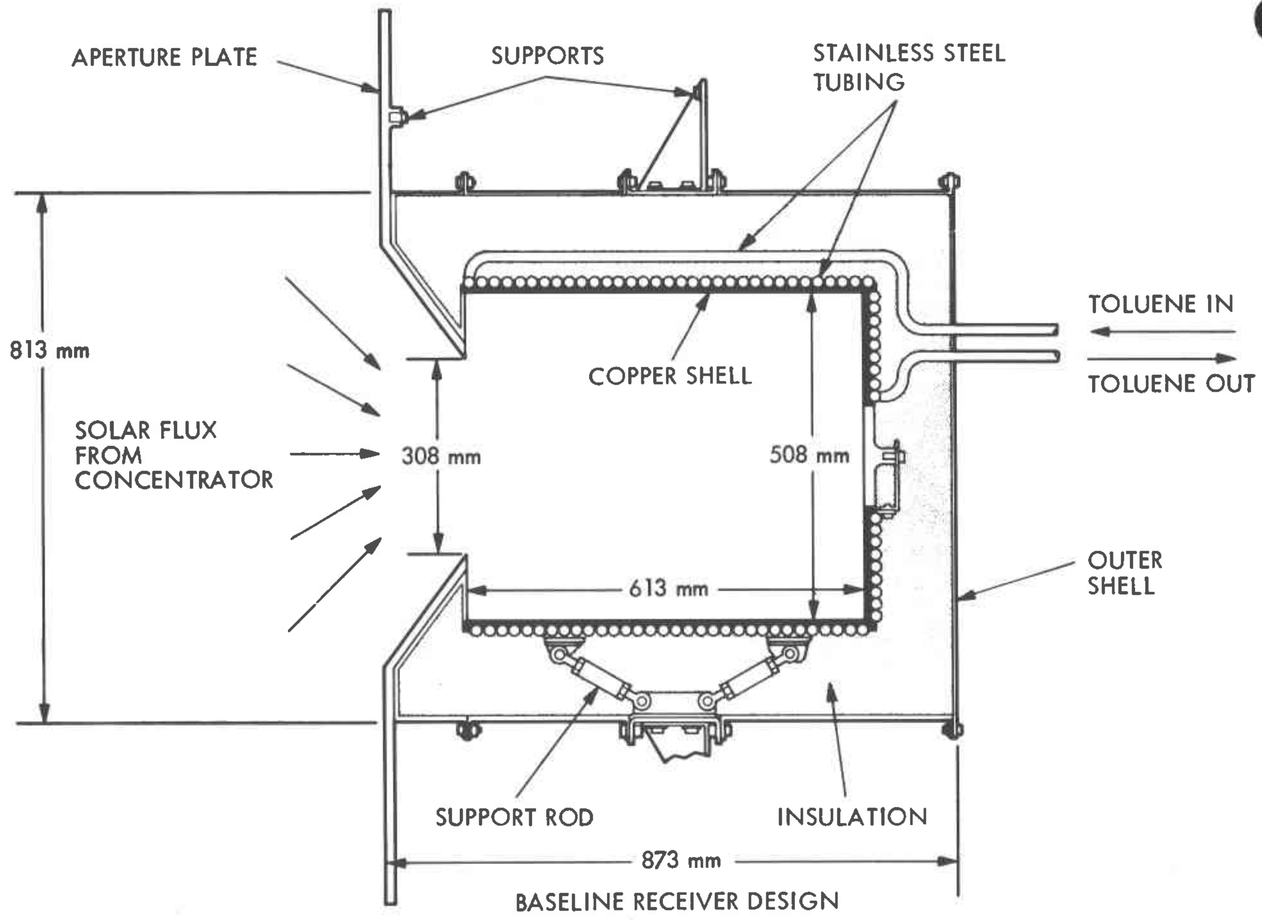


Figure 1-6. Ford Aerospace Receiver Design

steam and air receivers are presented in Table 1-3. Both were designed and fabricated by Garrett AiResearch.

A second-generation dish-Stirling solar receiver is being developed by Fairchild Stratos Division of Fairchild Industries, Inc., for direct coupling to the Stirling engine (Fig. 1-8). The conical receiver body uses copper for high thermal conductivity to the Stirling heat exchanger tubes. A fossil-fuel combustor is located behind the copper body to augment solar heat input. A detailed design review was held in October 1979, and hardware that will require long lead time was approved for fabrication. The remainder of the receiver was approved for production after a supplementary design review in December 1979. The receiver was delivered in September 1980, and was scheduled for shipment to United Stirling Sweden for integration assembly and test with the Stirling power conversion unit before delivery to the PDTS in mid-FY 1981. A contract was awarded to Advanco in late FY 1980 for subsystem integration and test support of the engine, alternator, receiver, and control system at the site.

The preliminary design of a ceramic receiver body to replace the metal receiver body was completed. The ceramic body is to be fabricated from silicon carbide with ceramic housing and heads for the Stirling engine. It will increase receiver life by eliminating creep problems associated

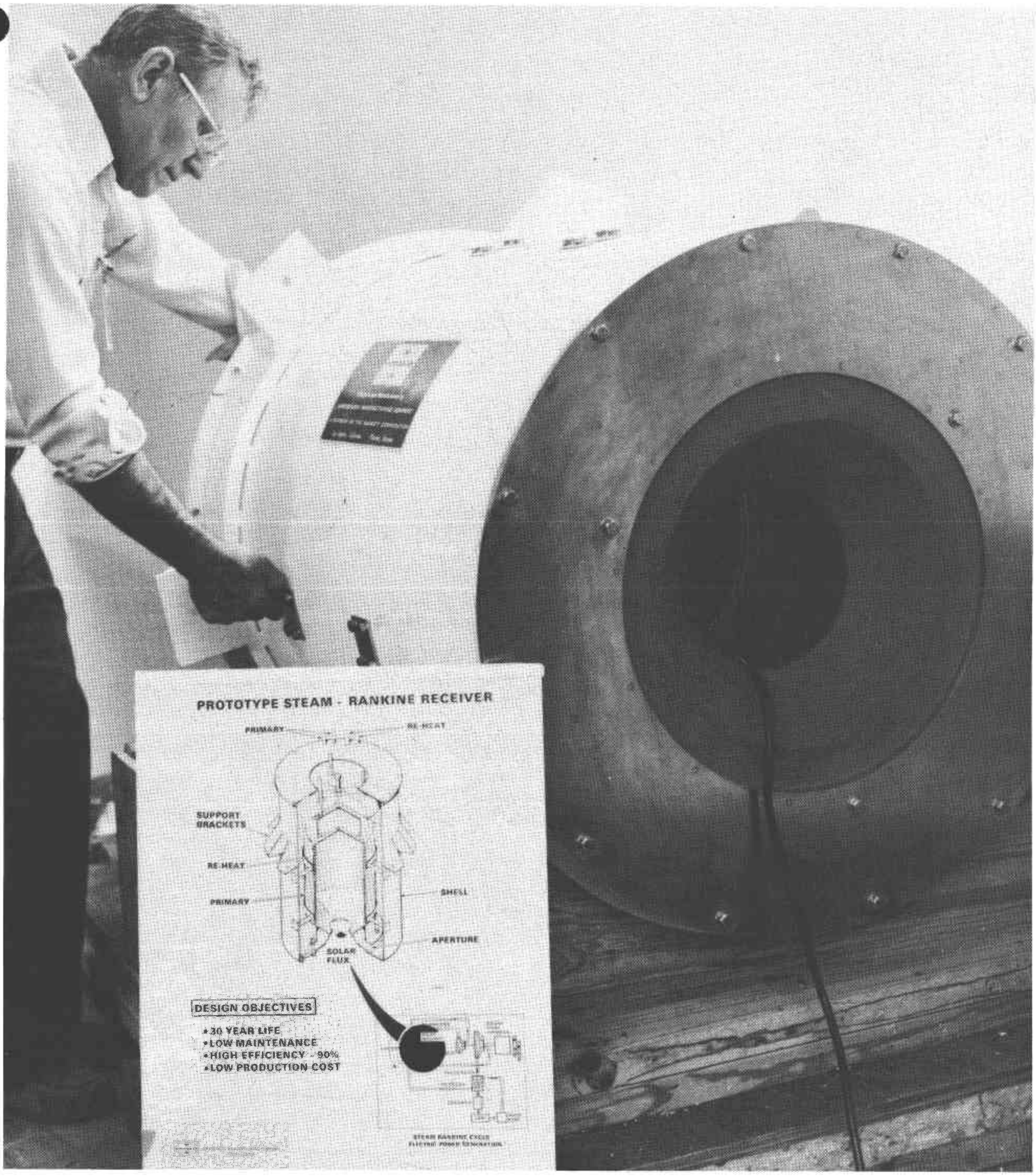


Figure 1-7. Steam-Rankine Receiver

Table 1-3. First Generation Steam-Rankine and Air-Brayton Solar Receiver Characteristics

Steam-Rankine Solar Receiver	
Temperature range	149° to 704°C (300° to 1300°F)
Efficiency	85%-90% (depending on environmental conditions)
Pressure range	0.345 mPa (50 psia) to 13.8 mPa (2000 psia)
Significance	Very versatile. Wide operating range. Will be useful in many applications of parabolic dishes in the generation of electricity and/or industrial process steam. High efficiency.
Air-Brayton Solar Receiver	
Temperature range	260°C (500°F) to 816°C (1500°F)
Efficiency	About 85%
Pressure range	Ambient to 0.345 mPa (50 psia)
Significance	Heats air or any other nonreactive gas up to 816°C (1500°F). Versatile development tool.

with metallic receiver materials. It will also eliminate or reduce the need to use high-cost strategic materials in the receiver.

The preliminary design of a heat pipe solar receiver with buffer* thermal energy storage has been completed by General Electric Company (Fig. 1-9). It will be used in an integrated, focus-mounted, hybrid, solar-Stirling power conversion subsystem employing sodium heat pipe thermal transport and latent thermal storage. This solar receiver consists of primary sodium heat pipes that capture the solar flux and transport the heat to a large secondary heat pipe containing: (1) latent thermal storage capsules of sodium fluoride-magnesium fluoride eutectic salt; (2) sodium-vapor, heat-exchanger tubes; and (3) wick-

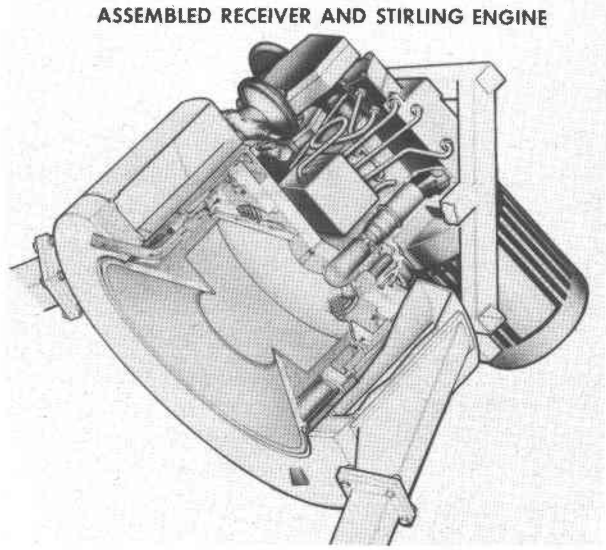


Figure 1-8. Dish-Stirling Solar Receiver

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*Buffer storage implies short-term energy storage of approximately one hour or less and is used to avoid effects of rapid temperature changes resulting from clouds passing over collectors.

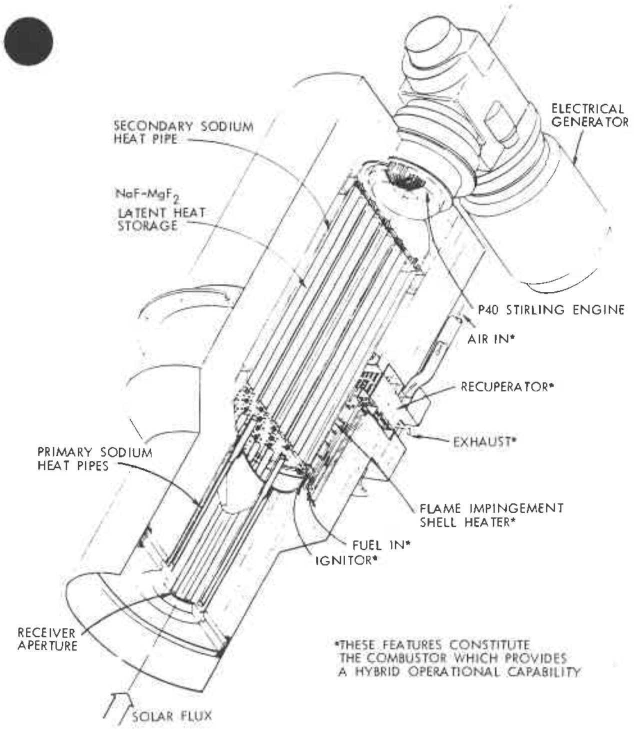

Figure 1-9. Heat Pipe Receiver with Thermal Energy Storage

ing necessary to deliver the liquid sodium to the various heat sources. A natural gas combustor with a set of tertiary heat pipes for transporting heat to the large secondary heat pipe permits hybrid operation with fossil fuel.

After testing the design-configuration primary heat pipes, the secondary heat pipe wicking was completed successfully. A modular test experiment was conducted, confirming the performance and defining the operating characteristics of the thermal transport and storage systems. The modular test demonstrates adequate thermal transport from the primary heat pipes to the secondary heat pipe at near-isothermal operation.

A preliminary design review of the heat pipe solar receiver was held in May 1980 and a detailed design review in September 1980. Fabrication was approved to allow a June 1981 delivery to the Parabolic Dish Test Site. The receiver is designed to operate at 830° C (1520° F) and to provide approximately 0.8 hours of thermal storage with 65-kW$_t$ input to the P-40 Stirling engine. The generator output will be 24 kW$_e$. The receiver efficiency will be in the 85%-90% range.

In June 1980 a statement of work was prepared for a parabolic dish heat-transport network development solicitation (RFP). The statement of work emphasizes unconventional technology for process heat production. The release date of the procurement was delayed to late FY 1981.

Activities during FY 1980 also included development of an analytical receiver model program and continued development of specialized instrumentation such as the flux mapper. The flux mapper, shown mounted on an Omnium-G concentrator in Fig. 1-10, has been used to characterize the TBC mirror system by mapping various zones; e.g., center mirrors, peripheral mirrors, and the entire array under different environmental conditions. An example of the flux mapping is given in Fig. 1-11, which shows the energy distribution at the focal plane of the TBC with

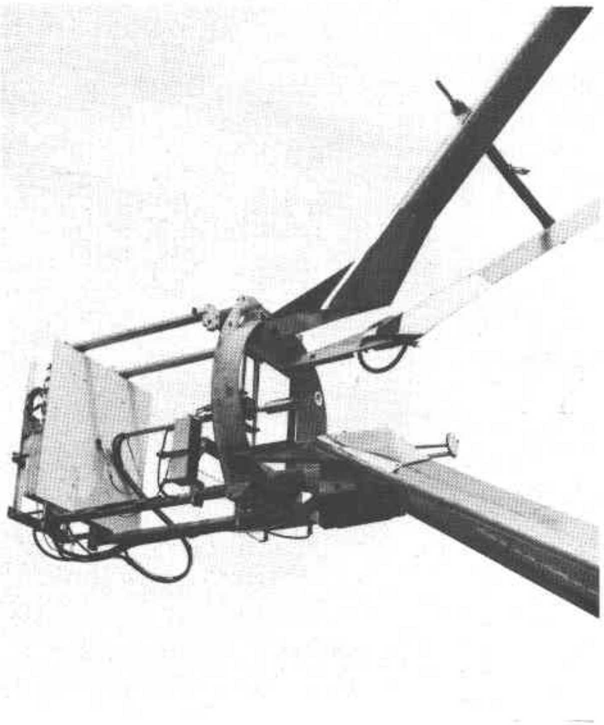

Figure 1-10. Flux Mapper

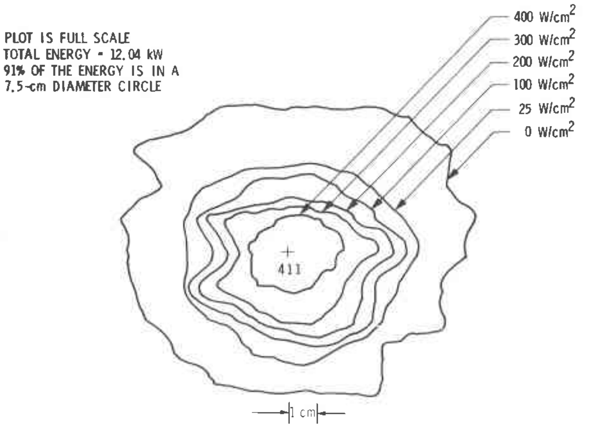

Figure 1-11. Energy Distribution at Test Bed Concentrator Focal Plane

36 of the center mirrors uncovered. From these various mappings, system performance can be determined and analytical methods can be field-verified.

With regard to thermal transport piping networks for industrial process heat (IPH) applications, studies [1] have shown that automated factory and semi-automated field assembly techniques can reduce costs by as much as 50% compared with conventional labor-intensive methods.

1.1.1.3 Power Conversion Development

Power conversion subsystems that will be coupled with solar receivers are being developed by both JPL and NASA Lewis Research Center. This section will discuss progress in the development of organic-Rankine, air-Brayton, and Stirling power conversion units.

An organic-Rankine cycle (ORC) power conversion unit was selected for use in the Small Community Solar Thermal Power Experiment (SCSE) by the SCSE system contractor, Ford Aerospace and Communications Corporation (FACC). Based on information supplied by a panel of representatives from FACC, SERI, NASA Lewis, and JPL, the ORC engine was selected because of its potential for high efficiencies at moderate operating temperatures. Barber-Nichols Engineering Company of Arvada, Colorado, was awarded a contract in early FY 1980 to design and fabricate an ORC power conversion unit. Figure 1-12 shows a cutaway of the FACC power conversion unit consisting of a FACC toluene receiver and the Barber-Nichols ORC engine assembly. A shaft-mounted permanent magnet alternator is coupled directly to the engine. The entire assembly will be hermetically sealed to increase efficiency. The permanent magnetic alternator, being designed and fabricated for Barber-Nichols by Simmons Precision of Norwich, New York, converts the mechanical output to high-frequency, three-phase alternating current (ac) that is converted to 600 volts direct current (Vdc) by a ground-mounted inverter. A preliminary design review was conducted in May 1980 and fabrication began in August. FACC expects the ORC engine to be delivered in mid-FY 1981 for assembly with their receiver and in-plant testing.

An open-cycle air-Brayton engine was selected for use in the Military Module Power Experiment (MMPE). The Garrett AiResearch Manufacturing Company of Arizona was awarded a contract in mid-FY 1980 to design the Brayton engine. The engine design, modeled after an existing Garrett engine, will operate at a maximum temperature of 815°C (1500°F) using either solar or fossil-fuel thermal input or both in a hybrid mode. An off-the-shelf Bendix Corporation generator with a gearbox will be coupled to the engine to provide high-efficiency, three-phase ac power. Preliminary and detailed design reviews were held in May and August 1980. A one-year delay in the start of the MMPE led to the decision to upgrade the engine before fabrication. The upgraded engine will be based on Garrett's advanced automotive turbine but will incorporate the features of a hybrid combustion chamber and nozzle, shaft-coupled permanent magnet alternator, foil bearings, and other features that will provide longer

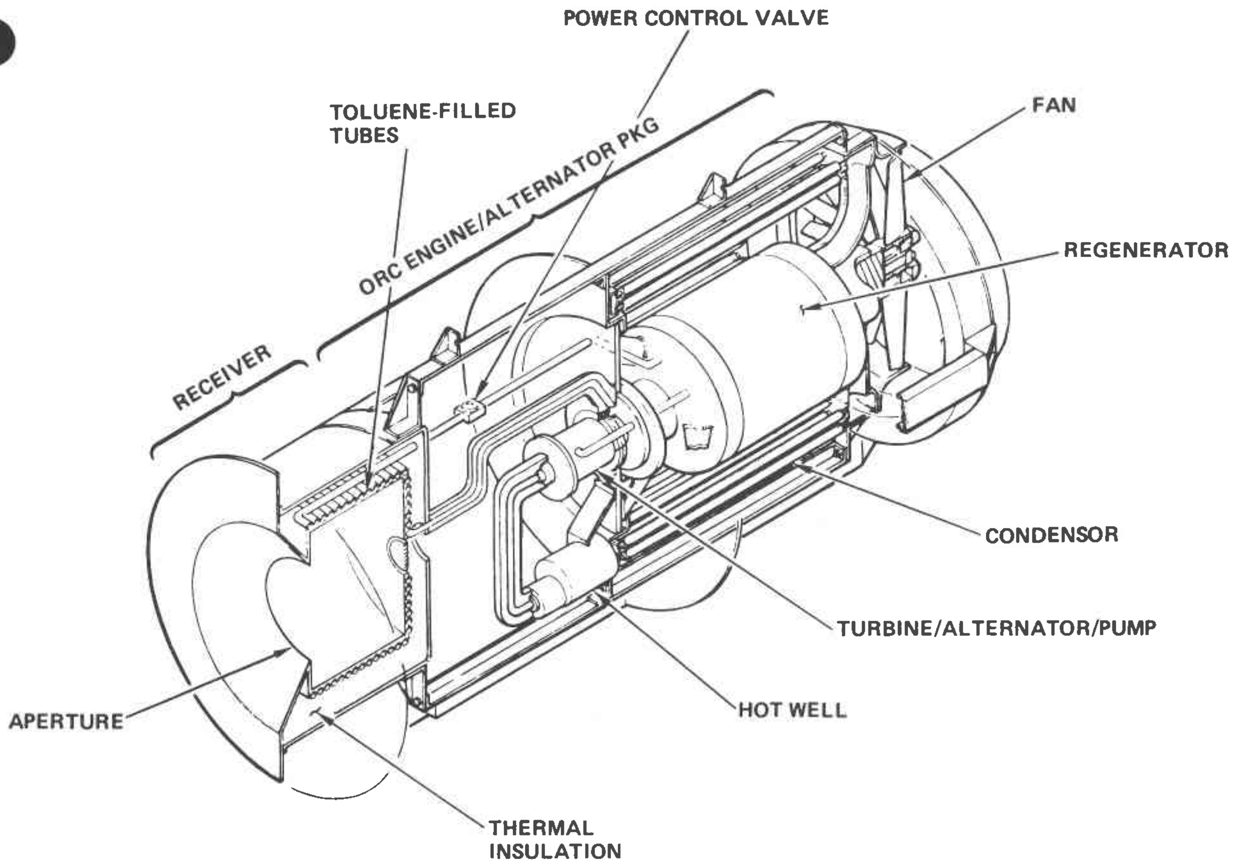

Figure 1-12. Organic Rankine Cycle Power Conversion Assembly

life, greater reliability, and a lower mass-production price. Garrett was directed to proceed with this change in August 1980.

Stirling engine technology is being considered for second-generation parabolic dish modules. Although Stirling engine development is not necessary, the automotive Stirling engine must be adapted to solar applications. The United Stirling P-40 engine was selected for solarization in FY 1980, and United Stirling performed the following modifications and studies:

(1) The oil tank, flow passages, and pumps were relocated for inverted operation.

(2) Seal and piston ring configurations and materials were selected for durability.

(3) The elimination of engine controls and the provision for hermetic sealing to increase simplicity, lower cost, and decrease maintenance were studied.

(4) The evaluation of engine design was considered in connection with the company's automotive engine program to determine cost-reduction potentials.

An option for hybrid operation is included in the receiver portion of the Stirling power module design.

Alternative advanced engines that may be developed for production by approximately 1990 are also being studied. The automotive program is developing a 60-kW$_e$ low-cost engine, and the application of simplified, higher efficiency drive systems to Stirling engines is being explored by several companies. (Examples of more efficient systems are the V-4 and in-line-4 configurations.) The applicability of these systems to parabolic dish modules requires careful evaluation. Advanced engines utilizing sodium-vapor heat-transfer techniques are expected to demonstrate engine efficiencies of 45% with 820°C (1500°F) thermal input.

Additionally, studies [2] have indicated that "solarization" of small gas turbines employing ceramic components, which are being developed for automotive applications, is an attractive option for parabolic-dish power converters.

1.1.1.4 Manufacturing Development

High-performance, point-focusing modules that can be manufactured in high production volumes at a low unit cost are essential for competitive success of parabolic dish systems. Consequently, a manufacturing development effort is being conducted to determine:

- independent cost and selling price estimates for dish components and systems;
- tooling, capital equipment, and facility costs required to produce dish modules;
- possible use of automation techniques to produce dish modules at a lower cost; and
- whether changes in product design, material, or manufacturing methods could result in a lower cost product.

This information will be obtained from three sources:

(1) the contractor responsible for subsystem development;

(2) an independent contractor having mass-production expertise; and

(3) government laboratory manufacturing engineering personnel.

During FY 1980, the report Cost and Price Estimate of Brayton and Stirling Engines in Selected Production Volumes (JPL Publication 80-42) was published. Findings are summarized in Fig. 1-13. This study estimated cost and price for 20-kW_e (peak output) Brayton and 30-kW_e (peak output) Stirling engines when produced in various quantities.

Pioneer Engineering and Manufacturing Company was awarded a contract to estimate the costs of the Garrett AiResearch receiver designed for use with an air-Brayton engine. In addition, a contract to analyze costs of the first-generation General Electric Low-Cost Collector was awarded to Pioneer.

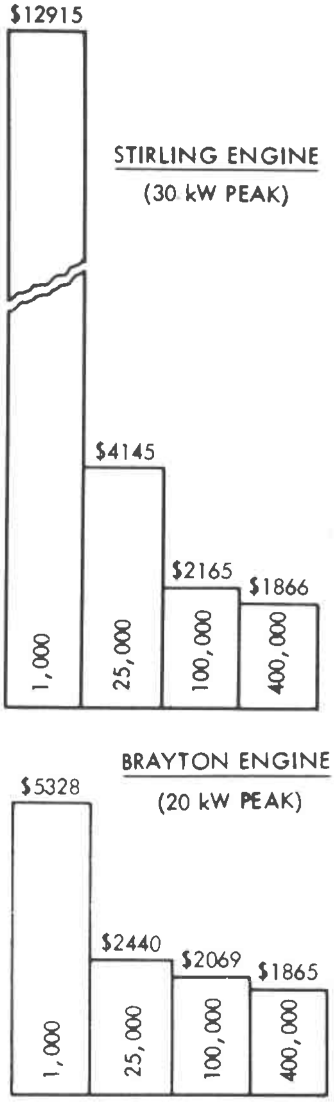

Figure 1-13. Engine Price as a Function of Annual Production

Competitive solicitations were prepared seeking industrial assistance to analyze costs for both the first-generation Brayton engine and the P-40 Stirling engine (modified for solar collector application) in selected annual production volumes.

Model factories were developed for dish module subsystems including engines, receivers, and concentrators. These models will be used to develop more accurate estimates of costs and selling prices for dish modules.

1.1.1.5 Systems Engineering

During FY 1980 systems engineering activities were conducted in system/subsystem integration, evaluation of ground rules for design of first-generation organic-Rankine and Brayton modules, assessment of organic-Rankine engine development, and review of the preliminary NASA Lewis Research Center Brayton receiver/power conversion unit (PCU) test plan. The Brayton PCU design-phase contract was reviewed and the results of continuing field tests of the Omnium-G module were analyzed.

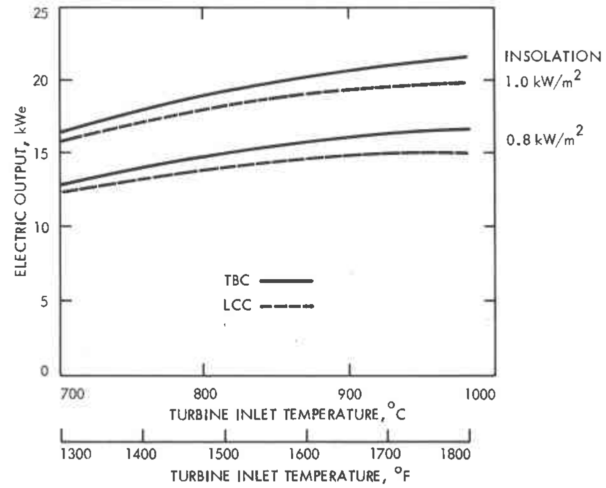

Figure 1-14. Performance Estimate for First-Generation Brayton Modules

Module performance estimates were made for a Brayton engine coupled with the TBC and the LCC. Module electric power outputs for these configurations are shown in Fig. 1-14 for varying turbine inlet temperature and for two values of insolation.

Results of a typical energy cost study for first-generation Brayton systems are shown in Fig. 1-15; energy cost values have been normalized relative to the value at 816°C (1500°F) and a production rate of 100,000 units per year. Increasing system efficiency results from increasing temperature, which tends to decrease energy cost, but this is offset by increasing capital costs associated with increasing subsystem replacement rates. These costing studies were conducted jointly with system performance analyses to determine which designs and operating regimes were most cost-effective.

A related cost study was conducted to determine whether escalating fossil fuel costs make thermal storage a more

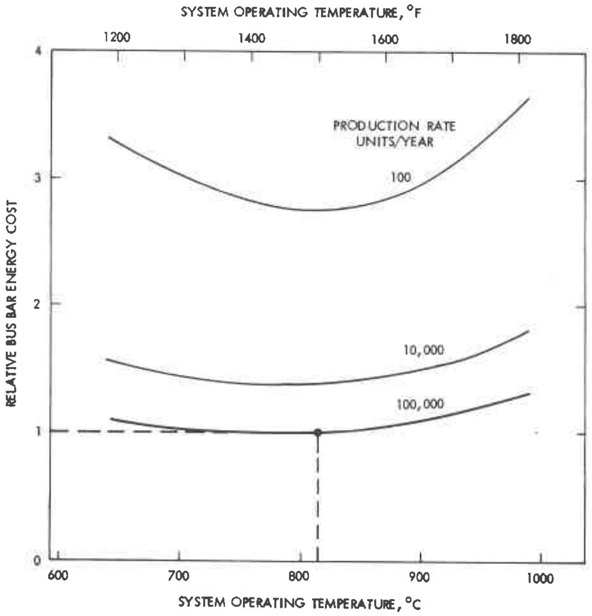

Figure 1-15. Relative Busbar Energy Cost for First-Generation Brayton Systems for a 5-MW$_e$ Plant

attractive alternative. To accomplish this, a parametric study was performed to determine the best mix for fuel-burning and thermal storage in a solar hybrid plant. The main parameters varied were storage size (capacity), cost, efficiency, and fuel cost. Figure 1-16 shows the region where thermal storage may be justified for a 5-MW_e plant. A curve for a conventional diesel plant is included. The horizontal dashed line indicates a solar plant with "ideal" storage; i.e., 100% efficient at zero cost.

A costing study that ranked 1- to 10-MW_e solar power systems, including dishes, troughs, compound parabolic collectors, bowls, and central receivers, was completed; the results are shown in Fig. 1-17. The study was a companion to studies conducted by SERI and Battelle Pacific Northwest Laboratory. The results were similar, although ranking positions differed for some systems. The JPL study concluded that point-focusing systems in general, and dish systems in particular, have the lowest levelized busbar energy costs. Studies conducted in support of the ranking study addressed balance-of-plant costs, plant equipment price, and performance.

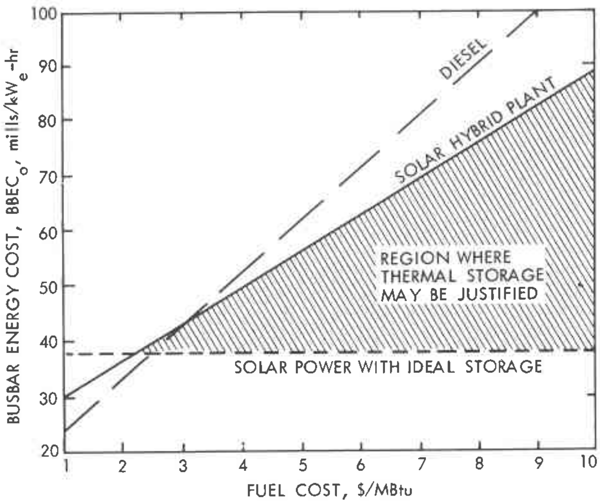

Figure 1-16. Sample Energy Costs for a 5-MW_e Solar Hybrid Plant with Thermal Storage

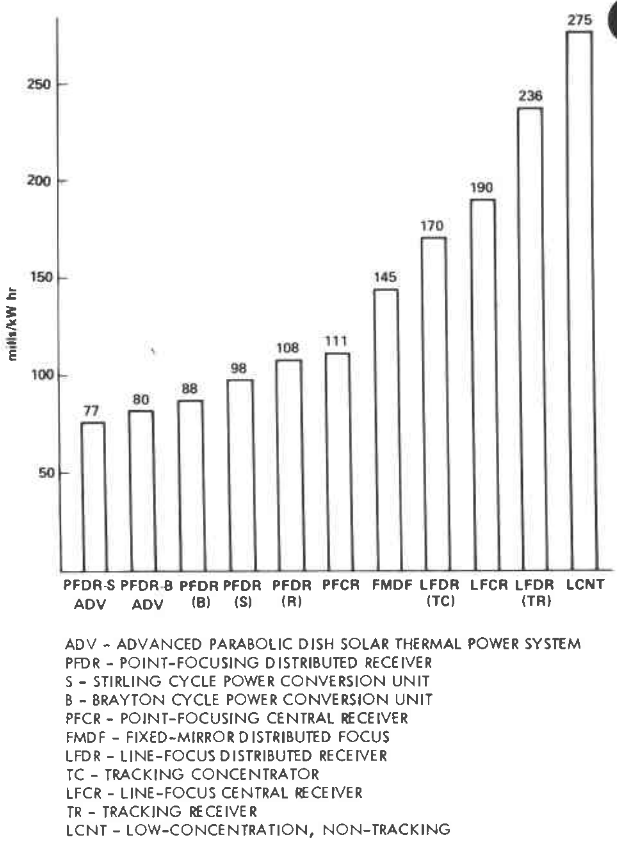

Figure 1-17. Cost of Power Provided by Various Solar Power Systems

Additional cost and performance studies were conducted. Energy cost targets were re-evaluated based on latest capital cost and performance data for both electric and thermal power output. Refinements were made to foundation and balance-of-plant costs. Second-generation cost and performance targets were refined to account for anticipated improvement in subsystem performance. Results will be published in FY 1981.

Test results of thermal power output by the Omnium-G module [3] are shown in Fig. 1-18. An early design receiver having a nominal 10.2-cm (4-in.) diameter was utilized as a calorimeter. Cold and hot receiver tests were run at approximately 93° C (200° F) and 204° C (400° F),

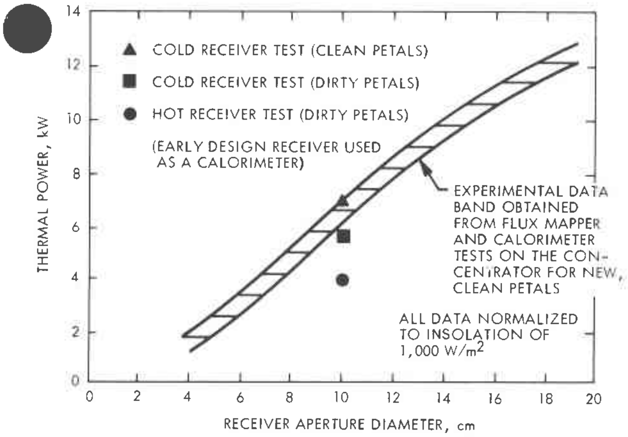

Figure 1-18. Thermal Power Test Results for Omnium-G Module

respectively. Test data presented in Fig. 1-18 were derived from the concentrator operating in the manual override mode owing to inconsistencies in the automatic tracking mode.

A number of 24-hour tests were performed on the Omnium-G module to gather operation and maintenance data. Thermal performance was assessed by using the Omnium-G 20.3-cm (8-in.) diameter aperture converter (receiver) as a cold water calorimeter. Most of these tests demonstrated a long-term thermal power performance in the 9- to 10-kW$_t$ range. This value is somewhat less than anticipated from previous investigations; more tests are planned to better understand the thermal power potential of the system.

1.1.1.6 Test and Evaluation

FY 1980 test and evaluation activities included installation and test of the test bed concentrators at the Parabolic Dish Test Site. The TBC mirrors were aligned and mechanical and electrical checkout of the TBCs was completed. A training class on TBC operation was conducted by Electrospace Systems, Inc., for PDTS operators. Flux-mapper testing of the TBCs yielded information on flux patterns and intensities at and near the focal point. In addition, cavity calorimeter testing of the TBCs provided data concerning thermal power output at the focal point.

A steam receiver was installed on one of the TBCs during late FY 1980 and testing of the steam-Rankine receiver was initiated. Preparations were begun for testing a high-temperature, air-Brayton receiver on one of the TBCs. It is a 1370°C (2500°F) ceramic receiver with a quartz aperture, developed by Sanders Associates. It will be field tested by JPL in FY 1981.

Detailed design work was started on the equipment required to test the Brayton engine. Preparations were made for testing the Stirling engine, receiver, and alternator on one of the TBCs. When fully operational, this system will be connected with the utility grid and net electrical power will be transmitted to the grid.

Testing of the Omnium-G parabolic dish unit at the system level using the 10.4-cm (4-in.) aperture receiver was completed. The long-term automated test of the Omnium-G unit was also conducted. This test provided data on the thermal power output of the receiver using a 20-cm (7.9-in.) aperture over extended periods in a fully automated operational mode.

A circumsolar telescope was installed at the PDTS. This instrument, on loan from Lawrence Berkeley Laboratory, is used to provide circumsolar radiation data to JPL. These data aid in evaluation of the performance of the Omnium-G unit and the TBCs.

Insolation and meteorological data at the test site were measured and recorded. Software was developed for displaying a monthly summary of this data.

Additional activities included:

- generation of a list of operations and maintenance parameters to be monitored;

- distribution of a PDTS Users Manual for internal review; and
- initiation of site modification designs for the low-cost collectors to provide for the addition of three concentrators and ancillary equipment.

1.1.2 Parabolic Dish Test Site

During FY 1980 the name of the Point-Focusing Solar Test Site, operated by JPL for DOE, was changed to the Parabolic Dish Test Site (PDTS).

The PDTS was established at Edwards Test Station in the California Mojave Desert to test point-focusing concentrator systems and related hardware for DOE. The site was selected to utilize an existing facility and high peak and total insolation levels.

The PDTS is located approximately 70 air miles north of Los Angeles in the high desert. It has an average rainfall of four in. per year. The site occupies approximately 10 acres of the 600-acre Edwards Test Station (Fig. 1-19). Ample adjoining acreage has been set aside for future growth. The primary purpose of the PDTS is to provide a site for the testing and evaluation of:

(1) concentrators,

(2) high flux density receivers,

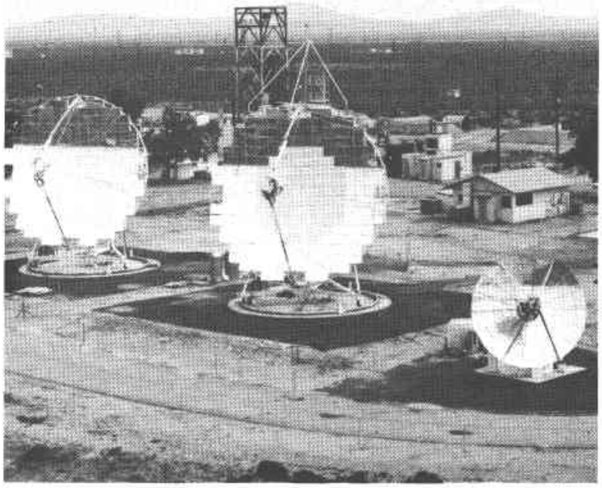

Figure 1-19. Parabolic Dish Test Site

(3) power conversion systems,

(4) concentrator-receiver power conversion systems,

(5) thermal transport, and

(6) hybrid systems using point-focusing solar concentrators and fossil fuels.

Several additions were made to the PDTS facility during FY 1980, including:

(1) an 18,921-liter (L) (5000-gal) water tank and pump installed for closed-loop calorimeter testing of the TBCs; and

(2) an engine/generator set installed to provide backup power for automatically slewing the TBCs off sun in the event of a facility power outage.

The objectives of the PDTS are threefold. First, the PDTS will support solar thermal development activities, primarily through testing and evaluation of hardware developed by industry under DOE sponsorship. Second, acceptance testing of prototype solar thermal power systems will be accomplished at the PDTS before full-scale production. Third, test and evaluation of point-focusing systems developed independently by industry will be accomplished at the PDTS as time and funding permit, and feedback will be provided to industry on the results of the tests.

A computer-based data gathering and processing (DGAP) system was designed and implemented at the PDTS to obtain formatted data for efficient analysis during performance testing of subsystems and systems. DGAP equipment is required to make parametric measurements periodically, display the data in real time, and to monitor and record data on mass storage.

The computerized data acquisition system at the PDTS includes a Digital Equipment Corporation PDP 1134A minicomputer with two RK05 disk drives, nine-track magnetic tape transport (on which all test data are stored), high-speed multiplexers, A/D converters, three Acurex Autodata Nine Data Loggers, CRT terminals, and a printer-plotter.

Insolation and meteorological data being measured at Edwards Test Station include:

(1) direct component of radiation, using two pyrheliometers;

(2) total sky radiation, using a pyranometer;

(3) wind speed and direction;

(4) temperature and dew point;

(5) barometric pressure; and

(6) circumsolar telescope data.

Three different cold-water calorimeters were designed and fabricated: coiled-tubing, flat-plate, and cavity calorimeters. These calorimeters measure the integrated thermal flux at the focal point of a concentrator.

A flux mapper was designed and fabricated for use in characterizing concentrator flux patterns and intensities. The flux mapper is a three-axis scan system for measuring the high radiant flux levels expected near the focal planes of high-concentration-ratio solar concentrators. Both the calorimeters and the flux mapper were tested and calibrated in FY 1980.

Testing at the PDTS has been and will continue to be performed almost exclusively on industry-supplied components, subsystems, and collector modules. The initial test series at the PDTS was devoted to an evaluation of the Omnium-G module manufactured in Anaheim, California. Many tests were performed on this module in FY 1980; testing will continue in FY 1981. Two test bed concentrators designed and built by E-Systems, Inc., of Dallas, Texas, were installed and calibrated for use in testing receivers and power converters. The controls for the TBCs were designed and built by Electrospace Systems, Inc., of Richardson, Texas. Calibration of the TBCs consisted of mapping the concentrated solar flux at the focal plane and measuring the total collected solar energy using a cold water cavity calorimeter.

Preparations are under way to test the following commercially built hardware in FY 1981:

- a steam receiver manufactured by Garrett AiResearch of Hawthorne, California;
- a modified Ferrier steam engine built by the Omnium-G Co.;
- 5-horsepower (hp) steam engine built by Jay Carter Enterprises, Inc., of Burkburnett, Texas;
- a 25-hp steam engine, also built by Jay Carter Enterprises, Inc.;
- an air-Brayton receiver designed and fabricated by Garrett AiResearch for operation at 815°C (1500°F);
- a ceramic air-Brayton receiver manufactured by Sanders Associates, Inc., of Nashua, New Hampshire;
- an organic Rankine cycle (ORC) receiver and power converter manufactured by Ford Aerospace and Communications Corp. of Newport Beach, California, using a turbine by Barber Nichols of Arvada, Colorado, an alternator by Simmonds Precision of Norwich, New York, and a static inverter by Nova Electric Manufacturing Co. of Nutley, New Jersey;
- a Stirling engine, designed by United Stirling of Sweden, which incorporates a receiver built by Fairchild Stratos Division, Manhattan Beach, California (the receiver and power converter module will be integrated by Advanco of El Segundo, California); and
- the low-cost concentrator (LCC) developed by General Electric, Valley Forge, Pennsylvania.

1.1.3 Storage Technology

There are several types of energy storage systems that could be considered for use in conjunction with solar thermal plants using point-focus systems. Among these storage types are thermal, electrochemical, pumped hydro, compressed gas, flywheels, and superconducting magnetic systems. This section will discuss thermal and electrochemical storage systems.

1.1.3.1 Thermal Storage

The thermal storage task supports the joint DOE Thermal Energy Storage for Solar Thermal Application Program in the specific area of dish-mounted, latent buffer storage subsystems.* The task includes the development of an appropriate background-technology data base to develop storage for parabolic dish solar power systems.

The general approach is to develop storage concepts and the necessary technology base, establish feasibility, then develop the required materials and subsystems. In addition, a subsystem research experiment will be conducted before commercial applications. Research and development efforts by industries, universities, and research institutions are necessary to accomplish these objectives.

The thermal storage effort consists of the following tasks:

(1) Preliminary Design, including the definition of system requirements, development of storage concepts, and estimating performance and cost;

(2) Small-Scale Experiment, comprising screening and the selection of potential material for phase change and containment; analyzing their heat transfer characteristics, degradation, decomposition, corrosion, and performance; and investigating solidification control; and

(3) Subsystem-Research Experiments, including designing the subsystem-research experiment, establishing of test objectives and procedures, and evaluating of test results.

During FY 1980, the following four industrial contracts were awarded:

(1) Three contracts were awarded for studies of storage requirements definition and subsystem research experiment design for Rankine, Brayton, and Stirling power conversion cycles as follows:

- Rankine cycle: Ford Aerospace and Communications;
- Brayton cycle: Garrett AiResearch; and
- Stirling cycle: General Electric.

The objectives of these studies are to define the requirements for latent thermal buffer storage subsystems and for the subsystem research experiments using dish-mounted receivers equipped with Rankine, Brayton, and Stirling power converters.

The storage requirements definition includes:

- thermodynamic and economic performance analysis to determine the need for thermal buffer storage;
- optimum size of buffer storage;
- identification of candidate storage concepts that meet program-specified cost and weight goals; and

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*Buffer storage implies short-term energy storage (approximately an hour or less).

- recommendations for specific component and subsystem development needs.

(2) A fourth contract directed to the study of advanced concepts for high-temperature thermal energy buffer storage was awarded to the Hanford Engineering Development Laboratory at Richland, Washington, in July 1980. The objectives of the contract are to identify concepts, perform some limited bench-scale tests, and recommend buffer thermal storage systems that are integrated with parabolic dish receivers for applications at a temperature of 1370°C (2500°F).

Studies conducted at JPL during FY 1980 included:

(1) Latent Heat Storage Media Chemistry and Corrosion Studies. The objectives are to:

- define the thermophysical properties of certain specified salt eutectics that are relevant to the latent heat storage requirements at approximately 440°, 550°, and 830°C (825°, 1025°, and 1525°F);
- analyze the results of 2000 hours of tests conducted at JPL of heating and cooling cycles of specified eutectic-salt-containment-material combinations, with and without corrosion inhibitors and impurities, to determine the thermodynamic stability and corrosion characteristics of the selected salt eutectic.

(2) Latent Heat Storage Solidification Control. The objectives of the study are to determine experimentally:

- effects of phase-change material (PCM) containment wall geometry and configuration, including concave and convex external and internal surfaces;
- additives that enhance thermal conductivity;
- types of surface finishing and coating of heat exchanger surfaces on PCM solidification; and
- identification of attractive solidification control options that will promote heat transfer in a distributed-receiver integrated system.

(3) Latent Heat Buffer Storage System Definition. This study assembled available thermophysical property data on fluorides and carbonates. Thermal conductivity, viscosity, and thermal expansion data are not readily available. Literature searches are continuing. In addition, the candidate salt-containment combinations shown in Table 1-4 were tentatively selected for more detailed investigation into their applicability as storage media for dish-mounted receivers.

(4) Material Evaluation. An in-house molten salt laboratory test program began that will include tests of three candidate salts. Tests will include differential thermal analysis, differential scanning calorimetry, #316 and #321 stainless-steel containment and cycling, alloy steel containment and cycling, #321 SS thermal loop test, and thermal conductivity of molten salts. This program will assist and complement the efforts of outside contractors.

(5) Latent Heat Buffer Storage System Modeling. A computer program, High Temperature Energy Storage (HTES), was developed and assembled to simulate a parabolic dish receiver with latent heat buffer storage capability. The model predicts the performance of the dish-mounted receiver under varying solar flux, ambient temperatures, latent heat buffer storage capacity, and thermal control techniques. The program handles the receiver-TES system on a nodal basis, and hence is capable of yielding local receiver and receiver coolant temperature variations for the transient

Table 1-4. Candidate Salt-Containment Combinations

Applications Temperature	Salt Composition (By Weight/%)	Melting Point	Containment Material
427°-454° C (800°-850° F) (Rankine)	61 KCl-39 $MgCl_2$	436° C (816° F)	316 & 321 SS Cr-Mo alloy steel
538°-566° C (1000°-1050° F) (Steam Rankine)	25.9 Na_2CO_3- 38.8 NaCl-35.3 NaF	557° C (1035° F)	316 & 321 SS, Cr-Mo alloy steel
802°-829° C (1475°-1525° F) (Brayton, Stirling)	66.9 NaF-33.1 MgF_2	813° C (1495° F)	316 & 321 SS
788°-829° C 1450°-1525° F (Brayton, Stirling)	75 NaCl-25 Na	795° C (1463° F)	321 SS
802°-829° C (1475°-1525° F) (Brayton, Stirling)	100 NaCl	802° C (1475° F)	9 Cr/1 Mo alloy steel

simulation. The benefits of buffer storage in attenuating variations in insolation owing to cloud passage were determined [4].

In addition, two related storage contracts were monitored. The first is with Sanders Associates and the second is with the General Electric Co.:

(1) Checker Stove* Power Module Design, Fabrication, and Testing. The objectives of this effort were to verify the performance of the selected components and to demonstrate that the checker stove concept represents a viable candidate for dispersed power systems applications. In FY 1980, prototype testing was conducted by Sanders Associates, Inc. Preliminary results indicate the performance is better than expected.

(2) Heat Pipe Receiver Module Design, Fabrication, and Testing. The objective of this contract is to design, fabricate, and acceptance-test a heat pipe receiver with TES to be used with a parabolic dish-Stirling solar power system in the 15- to 20-kW_e range (see Sec. 1.1.1.2).

1.1.3.2 Electrochemical Storage

An investigation and evaluation of existing and advanced electrochemical storage and inversion/conversion systems for use with solar thermal power systems is being conducted [5]. Specific objectives are to assess the status and performance of existing systems, establish current cost, and to project cost, performance, and availability of advanced systems. The results may be used to evaluate the impact

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*The checker stove is intended to save otherwise rejected heat by switching two thermal storage units between one position where waste heat is captured and another where it released to preheat the working fluids.

electrochemical storage systems upon near- and far-term solar thermal plants and to compare thermal and electric storage as applied to parabolic dish systems.

The investigation adopted a three-step approach. First, a review was made of the existing literature on electrochemical storage and inversion/conversion systems. Second, discussions were held with the manufacturers and developers of these systems to obtain an update on the status of these systems. Third, the information collected was reduced, tabulated, and analyzed.

Three categories of information were obtained. The first deals with the electrochemical or battery portion of the storage system. The second includes all components of the storage systems except the battery. The third category treats the solar thermal plant in its entirety, with electrochemical storage.

The lead-acid battery is the only electrochemical system presently considered technically ready for use in near-term demonstration programs. The specific lead-acid battery suitable for solar thermal applications is designed for repetitive, deep discharges (of 5- to 8-hours' duration daily) at moderate to high power densities. All of these characteristics are present in the "motive power" or "traction" type lead-acid battery. Depending on its duty cycle, this type of lead-acid battery will cost from \$190 to \$240/kW$_e$ (1980 \$), deliver 2000 cycles at 80% depth of discharge, and operate with an energy efficiency of 70% to 85%.

Several battery manufacturers are developing advanced lead-acid batteries for utility and electric vehicle applications. These advanced lead-acid batteries are expected to perform better, have lower maintenance requirements, and cost less than existing lead-acid batteries.

1.2 SYSTEMS AND APPLICATIONS

The viability of parabolic dish technology will be proven through field tests in typical user environments. These field tests, or applications experiments, are designed to verify the technical, operational, and economic feasibility of parabolic dish systems. This section describes accomplishments in: (1) the applications development activities being conducted by JPL; (2) the Shenandoah project being conducted by Sandia National Laboratories, Albuquerque; and (3) the Southern New England Telephone Company experiment.

1.2.1 Applications Development Experiments

The objective of the applications development work of the parabolic dish project is commercial readiness of parabolic dish systems. A series of engineering experiments are being planned to demonstrate the feasibility of complete parabolic systems in three applications: electric utilities, isolated areas, and industry. Each application is discussed in the subsections that follow.

1.2.1.1 Electric Utilities Experiments

The goal of the electric utility experiments is to provide bulk electricity for small communities and for repowering. The first experiment planned in this series is the Small Community Solar Thermal Power Experiment (SCSE). JPL awarded a contract for the design of a 1-MW parabolic dish power plant to Ford Aerospace and Communications Corporation in the first quarter of FY 1980. The subsystems that make up the parabolic dish module are included in the hardware elements discussed in the Technology Development discussion (Sec. 1.1) and are identified below.

The parabolic dish power plant (Fig. 1-20) designed by FACC for the SCSE is based on a module (Fig. 1-21) comprising a General Electric Low-Cost Concentrator and a power conversion assembly (Fig. 1-12) that consists of an organic-Rankine cycle engine and a cavity receiver. A typical installation of an SCSE in an industrial setting is shown in Fig. 1-22. In April 1980, FACC selected Barber-Nichols Engineering Company to design and fabricate the engine. The receiver is being developed in-house by FACC. Both JPL and FACC conducted a preliminary review of the SCSE design in June 1980.

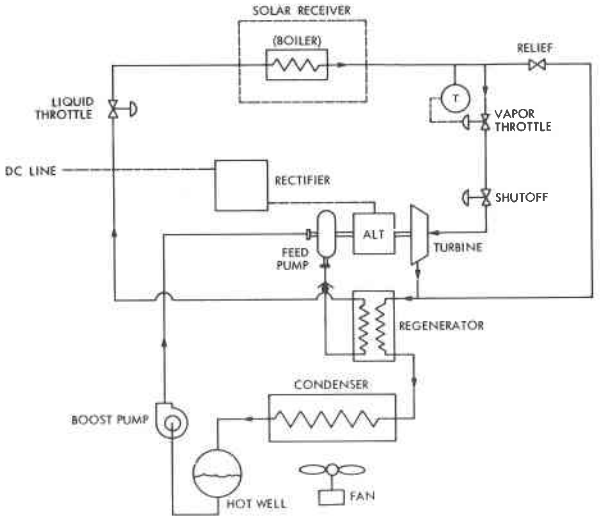

Figure 1-20. **Schematic Diagram of the Small Community Solar Thermal Power Plant**

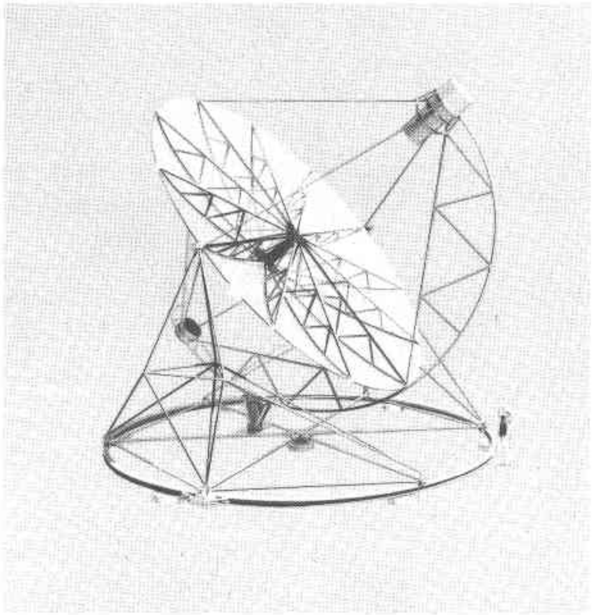

Figure 1-21. **Small Community Solar Thermal Power Experiment Concentrator and Power Module**

A site solicitation for the SCSE was issued by DOE/ALO in October 1979. Responses were received from 45 communities throughout the United States by January 1980. After review and evaluation of the proposals, DOE selected six candidate sites in June. The map of the United States in Fig. 1-23 identifies the 45 proposed sites and the six finalists.

1.2.1.2 Isolated Areas Experiments

The isolated applications effort is directed toward small, isolated communities; isolated sites; military bases; and developing countries. The initial experiment is designed to test an electric power plant in the 100-kW$_e$ class and is designated the Military Module Power Experiment (MMPE). The U.S. Marine Corps Air Station (MCAS) at Yuma, Arizona, was selected by the U.S. Navy as the site for the MMPE (Fig. 1-24). A solicitation was issued early in FY 1980 for system design and integration. The baseline configuration consists of either the General Electric Low-Cost Concentrator or the Acurex concentrator, a Garrett AiResearch air receiver, and a hybrid Brayton cycle engine, described in Sec. 1.1.

In mid-FY 1980 an evaluation team completed both technical and cost evaluations of industry proposals for the MMPE. Two system-integration contractors will be notified in early FY 1981 of the intent to negotiate a contract for design and integration of the 100-kW$_e$ hybrid, parabolic dish system consisting of modules, module control systems, tracking and drive command systems, power conditioning,

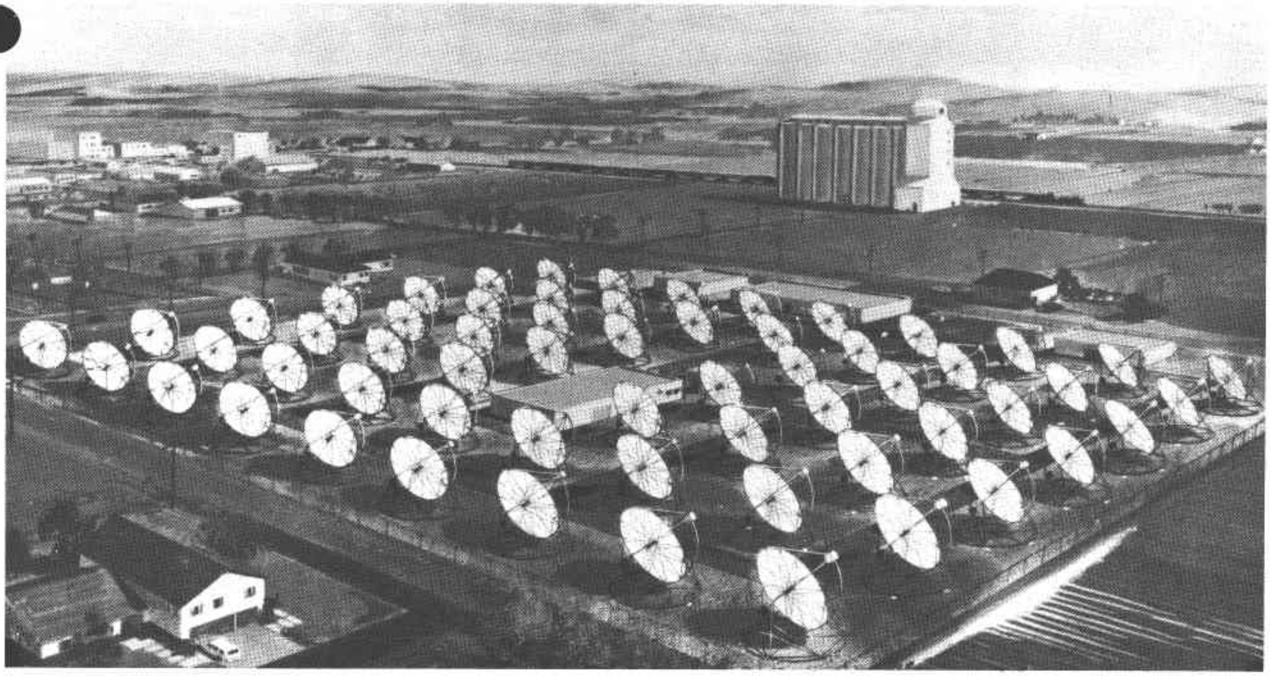

Figure 1-22. **Small Community Solar Power Experiment**
(Artist's Rendition)

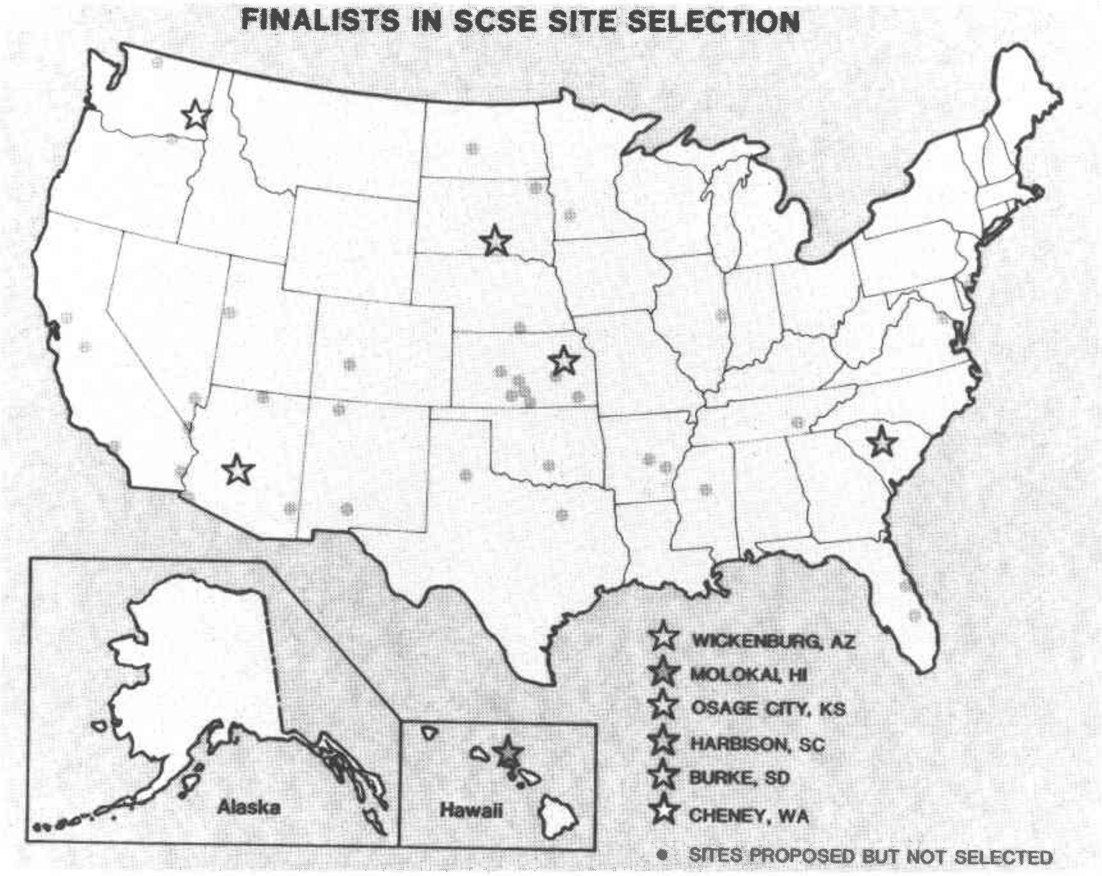

Figure 1-23. Small Community Solar Power Experiment Site Selection

Figure 1-24. Solar kW_e Electric Plant at the U.S. Marine Corps Air Station, Yuma, Arizona (Artist's Rendition)

and fuel storage for the MMPE. The procurement also includes analysis of central plant functions arising from the need to interface several modules and requirements for instrumentation, control, and plant safety. The plant is scheduled to become operational by CY 1984.

Diverse sites and applications are being explored for future experiments; among these are foreign markets, islands, mines, mills, U.S. Government sites, and isolated communities. In mid-FY 1980, two concept papers that address some of the issues involved in conducting a foreign solar power experiment were submitted to DOE [6].

1.2.1.3 Industrial Applications Experiments

The industrial applications experiments address the users' primary requirements for thermal or mechanical energy. These engineering experiments will provide partial and total displacement of fossil fuels for industrial processes.

Under the planned industrial applications experiments industry designs and selects the experiments, including dish systems, sites, and integrator. DOE funds hardware procurement but does not fund the development activities for these experiments. Industry retains proprietary rights to processes and inventions. Seventeen proposals were received in May 1980 in response to a Request for Proposals for the Thermal Systems Engineering Experiment. Three experiments are expected to be funded through contract awards early in FY 1981.

1.2.2 Solar Total Energy Project, Shenandoah, Georgia

The objectives of the Shenandoah solar total energy (STE) project are: (1) to promote engineering and development experience within industry with complete solar total energy systems, (2) to acquire data to reduce the uncertainties of cost and performance predictions, (3) to assess the interactions of solar total energy technology in an industrial application with an ectric utility interface, and (4) to ensure dissemination of technical data.

The project encompasses design, construction, operation, and technical and economic evaluation of a solar total energy system providing power to a knitwear factory. Studies and laboratory evaluation of the STE technology indicate promise of economic operation in the industrial sector. Georgia Power Company, the public utility, and Bleyle of America, Inc., owner of the knitwear factory, are the project participants. The project consists of a field of 114 parabolic dish collectors, each 7 m (23 ft) in diameter, which will supply 12×10^{12} J (joules) (11×10^{9} Btu) annually at 400°C (750°F) to a cascaded total energy system. The system is capable of supplying both electrical and thermal energy as follows:

Electrical: 400 kW

Thermal: Process Steam: 1380 lb/hr at 137 psi

Air Conditioning: 257 tons

1.2.2.1 FY 1980 Accomplishments

During the FY 1980 design phase of the Shenandoah project, interface control drawings that define the electrical and mechanical interface among the factory, the utility, and the solar total energy system were approved by all participants. Tests of the proposed collector foundations were conducted on site, results published [7], and the design changed to reflect possible savings as indicated by the test results. The design of the system by General Electric, Advanced Energy Department (GE-AED), was completed and a final report issued [8].

Four prototypes of the Shenandoah collector were installed at the Midtemperature Solar Systems Test Facility (MSSTF) at SNLA in FY 1979 (Fig. 1-25). Testing of this subsystem continued during 1980. The spacing, piping, controls, and other aspects are representative of the Shenandoah configuration. This quadrant test provided data for upgrading the Shenandoah system including reflector evaluation, receiver design, control philosophy, fault evaluation, component qualifications, and design corrections.

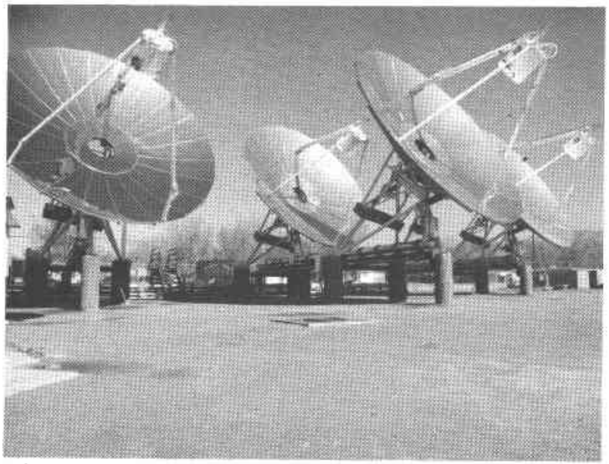

Figure 1-25. Shenandoah Collector Prototypes at the Midtemperature Solar Systems Test Facility

The Control and Instrumentation System design was completed by General Electric's Simulation and Controls Department (GE-SCD).

The turbine/generator, being developed under fixed-price contract by Mechanical Technology, Inc. (MTI), was assembled and tested at MTI (Fig. 1-26). The unit underwent a daily operational test in preparation for delivery to Shenandoah.

A systems integration and design contract for services during the fabrication and construction phase was awarded to Lockwood Greene Engineers. The contract for collector field construction (excluding collectors) was awarded to L. B. Samford Inc. The firm of Heery and Heery Architects and Engineers was selected to conduct inspection during construction. A contract for the Control and Instrumentation System was placed with GE-SCD.

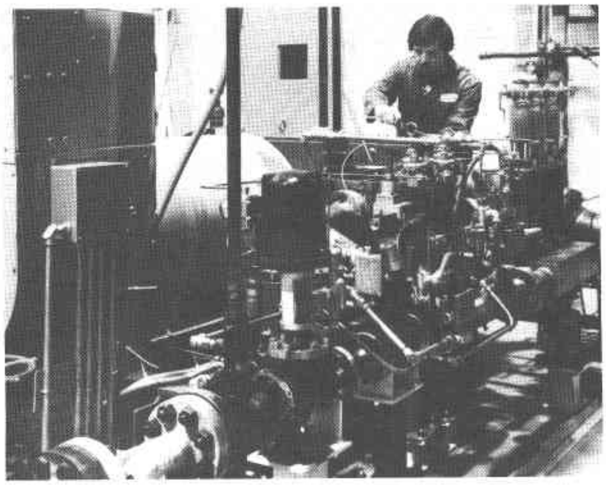

Figure 1-26. **Shenandoah Turbine/Generator Developed by Mechanical Technology, Inc.**

1.2.2.2 Projection of FY 1981 Accomplishments

A production collector will be assembled and tested at the MSSTF, and all collectors will be delivered and installed on site. Construction of the solar collector field and the building and mechanical area will be completed. All equipment will be installed except for the Control and Instrumentation System. The Control and Instrumentation System is scheduled for delivery in November 1981.

1.2.3 Southern New England Telephone Company Experiment

The Southern New England Telephone Company was awarded a $44,000 grant from DOE in 1979 toward the construction of a $100,000 parabolic dish system to provide power and space conditioning for a small switching station in Bethany, Connecticut. Ninety percent of the required cooling and 25% of the heating for the building were to be supplied. The telephone company awarded contracts to Omnium-G Co. of Anaheim, California, for the dish module, and to Stonier Service Co. of Milford, Connecticut, for site preparation and installation. The installation was completed early in FY 1980, followed by system check-out and personnel training. Testing throughout the spring of 198[illegible] revealed substantial problems. Although some were resolved, problems with the system still remain. Evaluation of potential system redesign to eliminate these problems is under way.

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SECTION 2.0

CENTRAL RECEIVER TECHNOLOGY

In a central receiver system, a field of computer-guided mirrors (heliostats) 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 it 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 to allow the power plant or factory to operate during nonsolar hours. Figure 2-1 shows a schematic of a central receiver system.

Repowering—the addition of a solar central receiver system to an existing fossil fuel plant—represents an opportunity for early use of central receiver technology.

The primary objective of the Solar Thermal Central Receiver (CR) Program is to develop a sound technological and industrial base that will result in large-scale self-sustaining application of CR technologies. The base thus established would actively involve utility and industry users and manufacturers in development of heliostats and other subsystems and would provide for expert installation, operation,

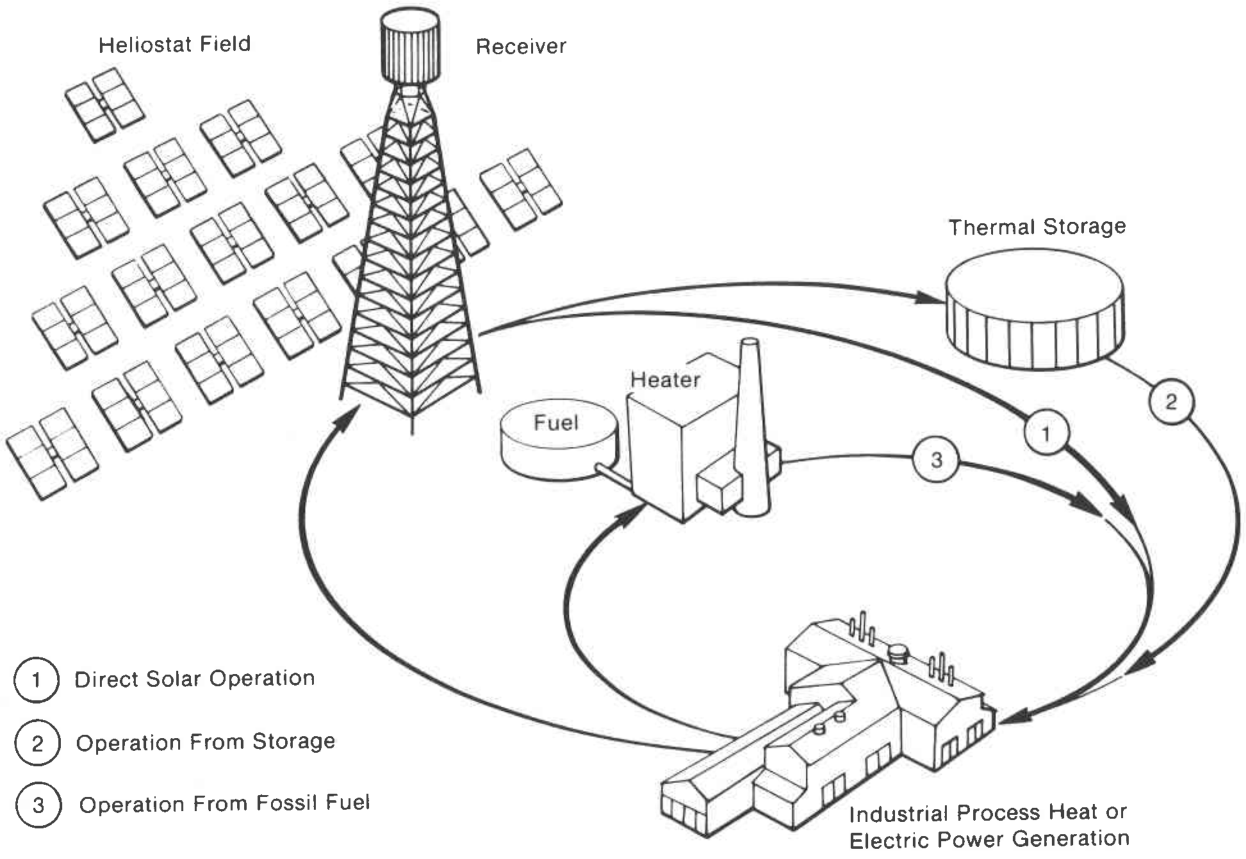

Figure 2-1. Schematic of Typical Central Receiver System Configurations

and maintenance procedures. In the near term, electric utilities should be able to repower some of their generating capacity with large-scale solar central receivers, and industrial users should be able to reduce consumption of significant amounts of centrally generated electricity in addition to supplying high quality industrial process heat (IPH) by retrofitting existing plants with central receiver systems. In the longer term, this technology should provide high-capacity electric generation and process heat as well as thermal energy for manufacturing energy-intensive chemicals and transportable fuels from renewable resources.

The program is directed toward determining, with both users and industry, the technical and initial cost readiness of central receiver systems to provide reliable energy in all forms over a wide range of market applications.

The specific objectives of the Central Receiver Program are to:

- develop cost-effective system designs for promising industrial process, electric, and electric/heat generation applications;
- develop equipment with potential industrial suppliers to establish a technical, cost, and manufacturing data base;
- validate hardware performance and cost data and establish the potential economic benefits of CR technology for private investors;
- increase reliability, durability, performance, capacity factors, and extended temperature capabilities of CR systems through technology development; and
- maximize the sharing of and participation in field experience with CR hardware by potential users and suppliers through pilot plant and field test projects.

A planned schedule for the Central Receiver Program is shown in Fig. 2-2.

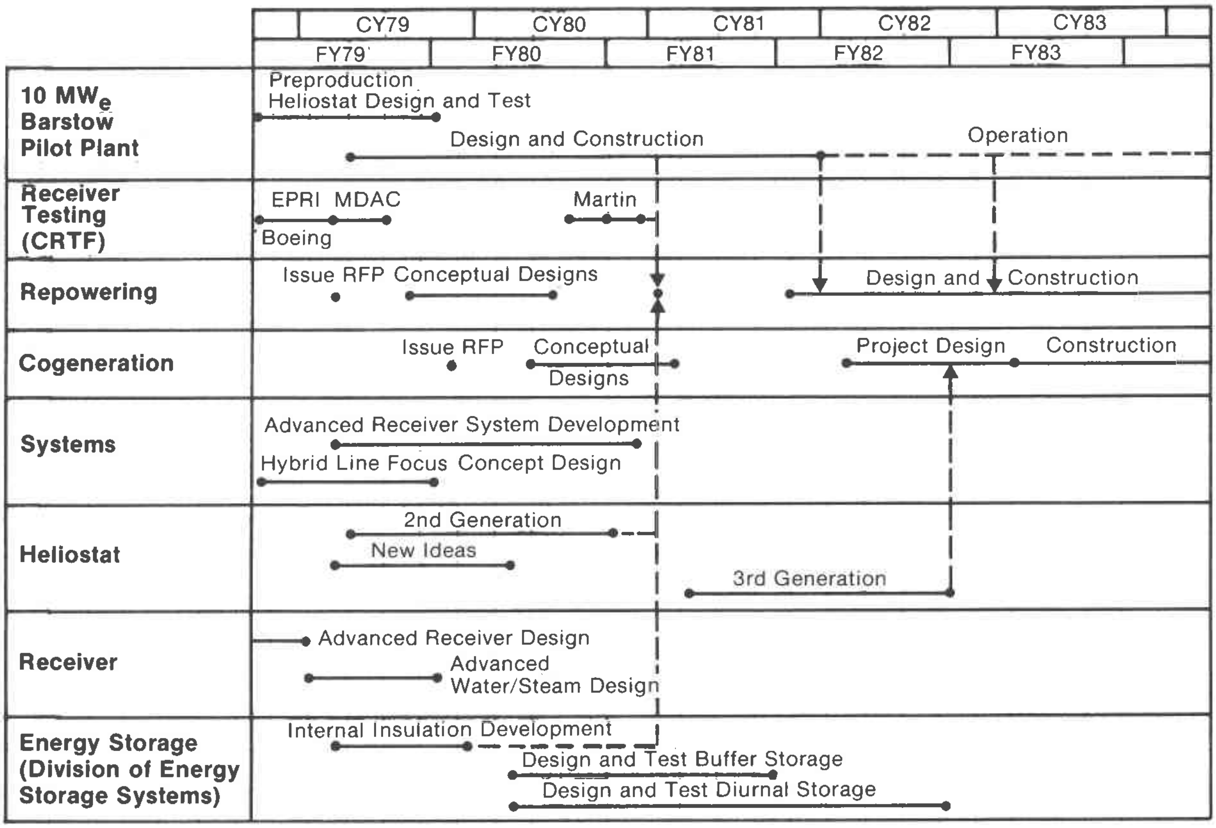

Figure 2-2. FY 1980 Central Receiver Systems Program Schedule

The development of first-generation receivers, heliostats, and energy storage subsystems has been completed, and the technology is being used in the design and construction of the 10-MW_e pilot plant near Barstow. Improved systems and component technology are being developed so that additional technology options will be available early in FY 1981.

2.1 TECHNOLOGY DEVELOPMENT

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

To answer these questions, two test programs have been conducted for the pilot plant configuration using a 5-tube panel and a 70-tube panel. The 5-tube panel was tested at the Sandia radiant test facility. The purpose of the test was to study the departure from nucleate boiling (DNB) phenomenon predicted to occur in the pilot plant boiler panels. The experimental data will be used to estimate the fatigue life of the pilot and commercial plants. The panel was fabricated and tested by MDAC originally and was extensively modified by Sandia National Laboratory Livermore (SNLL) for additional testing. Assembly and checkout of the test setup were completed in March 1979. Figure 2-3 shows the 5-tube test setup. Testing was completed in early FY 1980 and the data reduced. Figure 2-4 presents a preliminary assessment of the hydraulic stability attained by various orifice sizes. The ratio of orifice diameter to tube inside diameter is plotted against the ratio of test condition flux to pilot plot maximum flux. Stable operation can be maintained for all flux conditions when the orifice diameter is less than approximately one-third of the inside tube diameter. A full test report has been assembled and published.

McDonnell Douglas was placed under contract to retest their Subsystem Research Experiment (SRE) receiver (which included the 70-tube panel) at the Central Receiver Test Facility (CRTF) at Sandia National Laboratory in Albuquerque (SNLA). The testing was designed to generate data typical of a portion of the pilot plant receiver

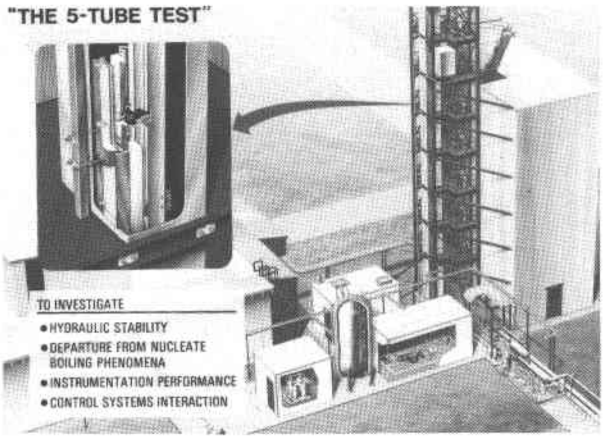

Figure 2-3. Five-Tube Receiver Panel Test

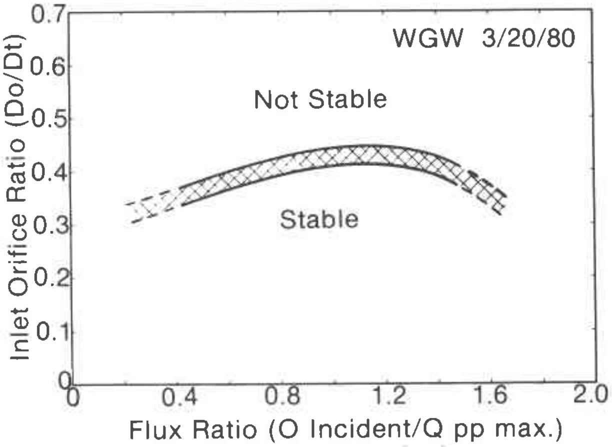

Figure 2-4. Five-Tube Test Preliminary Results

at Barstow. The testing emphasized the thermal hydraulic performance and the static and dynamic stability aspects of the design over the entire operating range. The test included operation during normal startup and shutdown, intermittent cloud conditions, and emergencies to determine transient and steady-state performance under conditions equal to or exceeding those expected in the pilot plant. The effects of variations in input and output conditions on receiver operation were also investigated. The testing started in March 1979, and was completed in early 1980. Figure 2-5 shows the receiver panel experiment mounted on the CRTF tower.

2.1.1 Receiver Development

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

- reduce weight and cost to a minimum,
- improve receiver efficiency, and
- obtain receivers that function well with other components, so that the overall efficiency of the system is high.

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

In support of the 10-MW_e pilot plant, receiver design reviews were initiated. Combustion Engineering and the General Electric Co. analyzed the thermal fatigue associated with the DNB and the flow stability of the designs of the MDAC water/steam receiver designs used in both pilot and commercial plants. Their results indicate that a receiver of pilot plant size should have a thermal fatigue life in excess of 30 years. An initial concern regarding the stability of the pilot plant panels under conditions of low flow and heat flux has been resolved by testing.

A number of advanced receiver studies are being conducted to establish the feasibility of developing a system that will significantly reduce the cost of electricity generated by solar central receivers. The

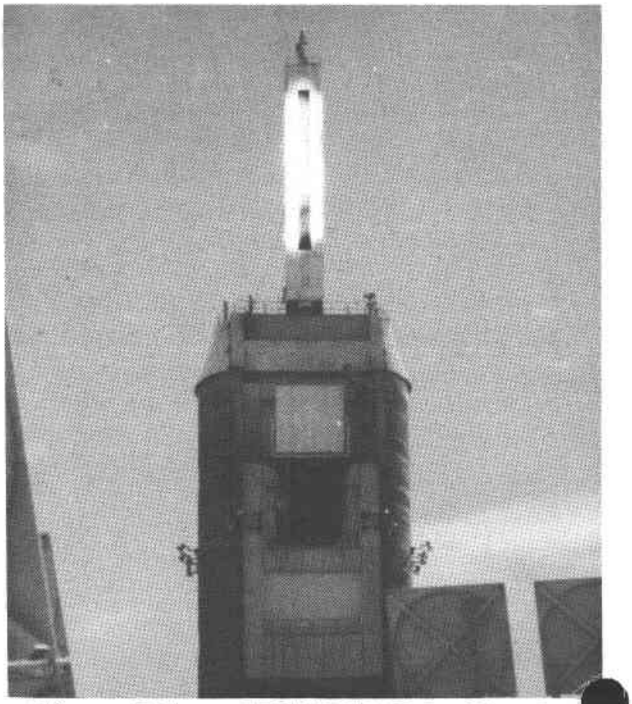

Figure 2-5. MDAC 70-Tube Receiver Panel Test

[illegible]r limitations of the water/steam pilot plant are the low maximum flux the receiver is capable of absorbing and low system efficiency imposed by the storage subsystem. Utilities have had extensive technical experience with water/steam, however, and this is a major advantage. Other receiver coolants such as liquid sodium, molten salt, air, and helium can lead to systems with higher efficiency requiring fewer heliostats, which in turn can lead to improved cost-effectiveness.

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

Major activities completed on the advanced receiver studies during FY 1980 include:

- Barstow water/steam receiver test conducted at CRTF,
- a 5-tube water/steam radiant panel tested,
- Martin Marietta molten salt receiver test initiated at CRTF,
- three improved water/steam receiver designs completed,
- General Electric turbine trade-off study completed,
- synthesis of improved water/steam systems completed,
- cryogenic wind tunnel testing completed at University of Illinois, and
- interim structural design standards completed.

Information developed in the program is reviewed annually, the relative advantages of each approach determined, and recommendations for future activities presented to DOE. The receiver designs that were selected as a result of the studi[illegible]conducted during FY 1979 are pres[illegible]ted in Fig. 2-6.

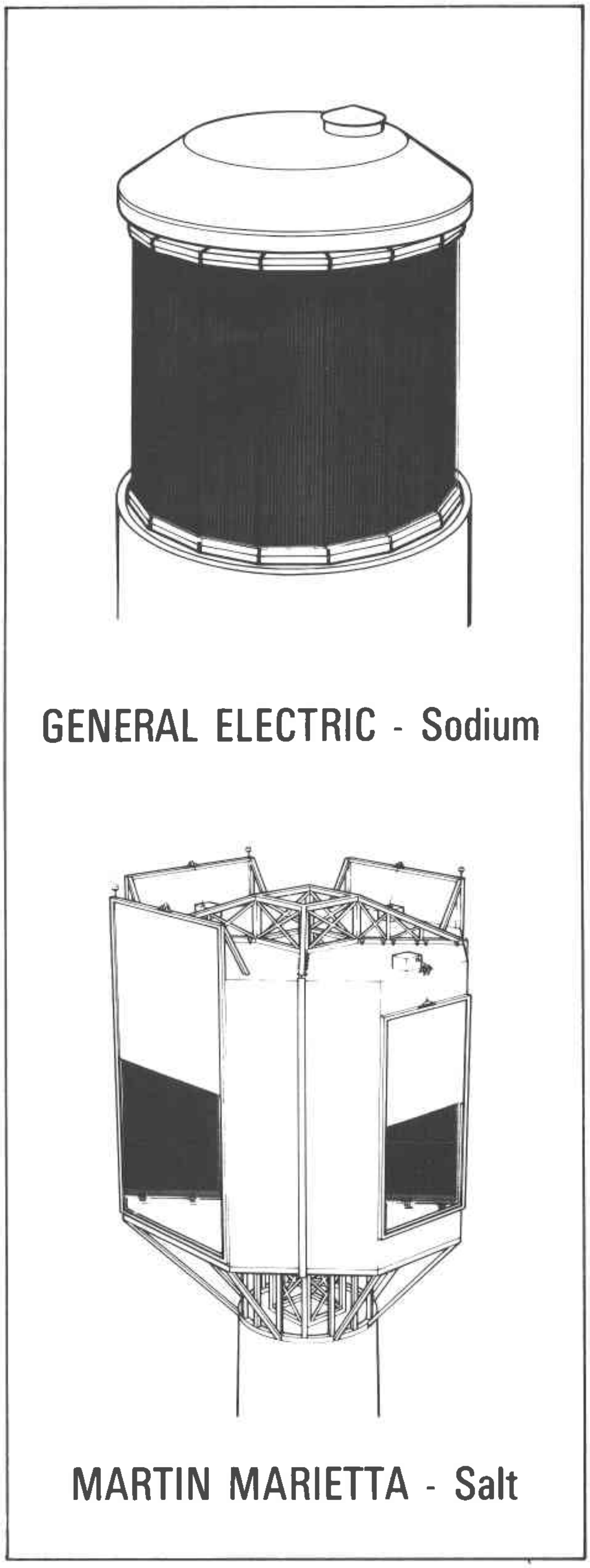

Figure 2-6. Current Advanced Receiver Concepts

Convective loss from a central receiver exerts a significant influence on the thermal efficiency of a solar thermal-electric power generation system. The magnitude of this loss is not easy to estimate because the high operating temperatures and large sizes of the receivers make experimental verification difficult. In addition, the interaction between free and forced convection mechanisms is not well understood. In FY 1979, a comprehensive program of analysis and experiments was initiated to predict the losses from cavity and external receivers. This study was continued at a reduced level of effort during FY 1980. Universities and industrial investigators were placed under contract to conduct a coordinated 3-year program covering the following:

- cryogenic wind tunnel testing (University of Illinois),
- convective losses from external receivers (Stanford/Nielsen),
- natural-forced cavity convection (U.C. Berkeley), and
- turbulent/natural convection heated cavity experiment (SNLL).

Planned accomplishments for FY 1981 in the Receiver Development Program are to:

- complete CRTF testing of molten salt and liquid sodium receivers;
- initiate molten salt steam generator development study, followed by a full-scale subsystem research experiment;
- initiate thin-wall tube joining fabrication development studies for molten salt and sodium receivers;
- initiate saturated steam receiver subsystem research experiment design for CRTF test;
- initiate second molten salt receiver design for CRTF test; and
- initiate hot gas IPH receiver system design.

2.1.2 Heliostat Technology

The extensive heliostat field required to collect sunlight, which has a low energy density, constitutes the largest portion of central receiver system cost. For this reason, reducing the life-cycle cost of heliostats is strongly emphasized. Goals for heliostat costs have been established by allocating overall power plant cost targets to the various subsystems. The goal of the heliostat development program is to achieve an installed cost of $80/m^2 (1980 dollars) of reflector area. The attainment of this goal, in conjunction with cost targets for other subsystems, should provide a competitive alternative to the use of oil and natural gas for utilities generating electric power in the late 1980s and the 1990s.

A concentrated heliostat development effort was initiated in 1975 when four contractor teams (Boeing Engineering and Construction Co., Honeywell Inc., Martin Marietta Corp., and McDonnell Douglas Astronautics) were funded to complete design studies for first-generation heliostats. These 2-year efforts culminated in the fabrication and testing of prototype heliostats based on the concepts developed. An extensive design critique and costing evaluation for each of the designs was undertaken to select the best heliostat approach for the Barstow, California, 10-MW$_e$ pilot plant. One of each of the prototypes developed by the four contractors was subsequently installed in Livermore, California, where testing and evaluation continued.

In mid-1978, Martin Marietta and McDonnell Douglas were contracted to develop competitive heliostat designs and prototype hardware for the pilot plant. Two prototypes from each contractor were tested and extensively evaluated.

Martin Marietta's design (Fig. 2-7) was judged to best meet the requirements for performance and cost. A contract for Martin Marietta to build and install 1818

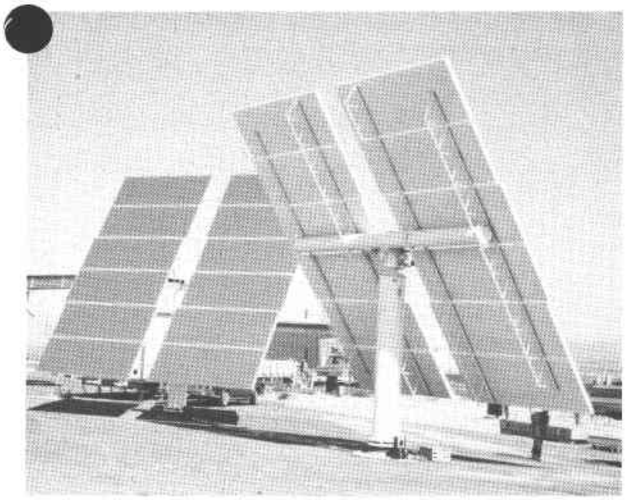

Figure 2-7. **Martin Marietta Pilot Plant Prototype Heliostat** (front and back view)

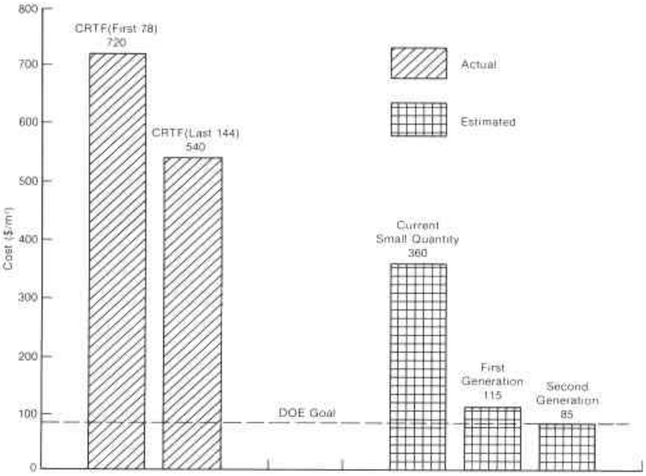

Figure 2-8. **Actual and Estimated Heliostat Costs**

heliostats at the pilot plant was initiated in late 1979; installation will start in FY 1981.

Before the development of heliostat designs for the 10-MW$_e$ pilot plant, limited production of a special Martin Marietta design for the unique requirements of the 5-MW$_t$ Central Receiver Test Facility was completed. A total of 222 heliostats were fabricated and installed during FY 1977 and FY 1978. Even though these heliostats have special features to serve the needs of the test facility, their recorded costs provide an upper benchmark against which cost estimates and ultimate goals can be compared. Figure 2-8 illustrates the installed costs of the heliostats at the Central Receiver Test Facility compared with anticipated future trends; these costs have been adjusted to 1978 dollars.

Conceptual designs for Phase I of second-generation heliostats were initiated in October 1977. Contracts were awarded to Boeing Engineering and Construction, General Electric, McDonnell Douglas Astronautics, and Solaramics, Inc.

The purpose of the program was to significantly reduce the cost of a heliostat field for a solar thermal power plant from the costs generated during the 10-MW$_e$ pilot plant preliminary design. Each contractor developed a heliostat design (Fig. 2-9) with associated manufacturing, assembly, installation, and maintenance approaches. Capital and operations and maintenance costs were estimated for one-time production of 2500 units and for continuous production rates of 25,000, 250,000, and 1,000,000 units per year.

In addition to the four designs entirely funded with federal dollars, an encouraging precedent in heliostat development occurred, as illustrated in Fig. 2-9. The design approach pursued by Westinghouse was entirely funded with their own capital. Under a no-cost agreement with Westinghouse, in exchange for receiving a critical review of their design progress and a test of the resulting prototype at the Central Receiver Test Facility in Albuquerque, they have publicly disclosed the design features of their heliostat.

Each of the contractors participating in the Phase I second-generation heliostat development effort projects mass-production costs near or below the DOE goal (Fig. 2-10). At higher production rates, four independent assessments of different approaches indicate that the cost goals can be reached. These costs represent 1980 dollars and assume stable production rates at the annual quantities plotted.

Objectives
- **Low-Cost Mass Production Design**
- **Detailed Cost Estimates**
- **Broad Industry Participation**
- **Identify Required R&D**

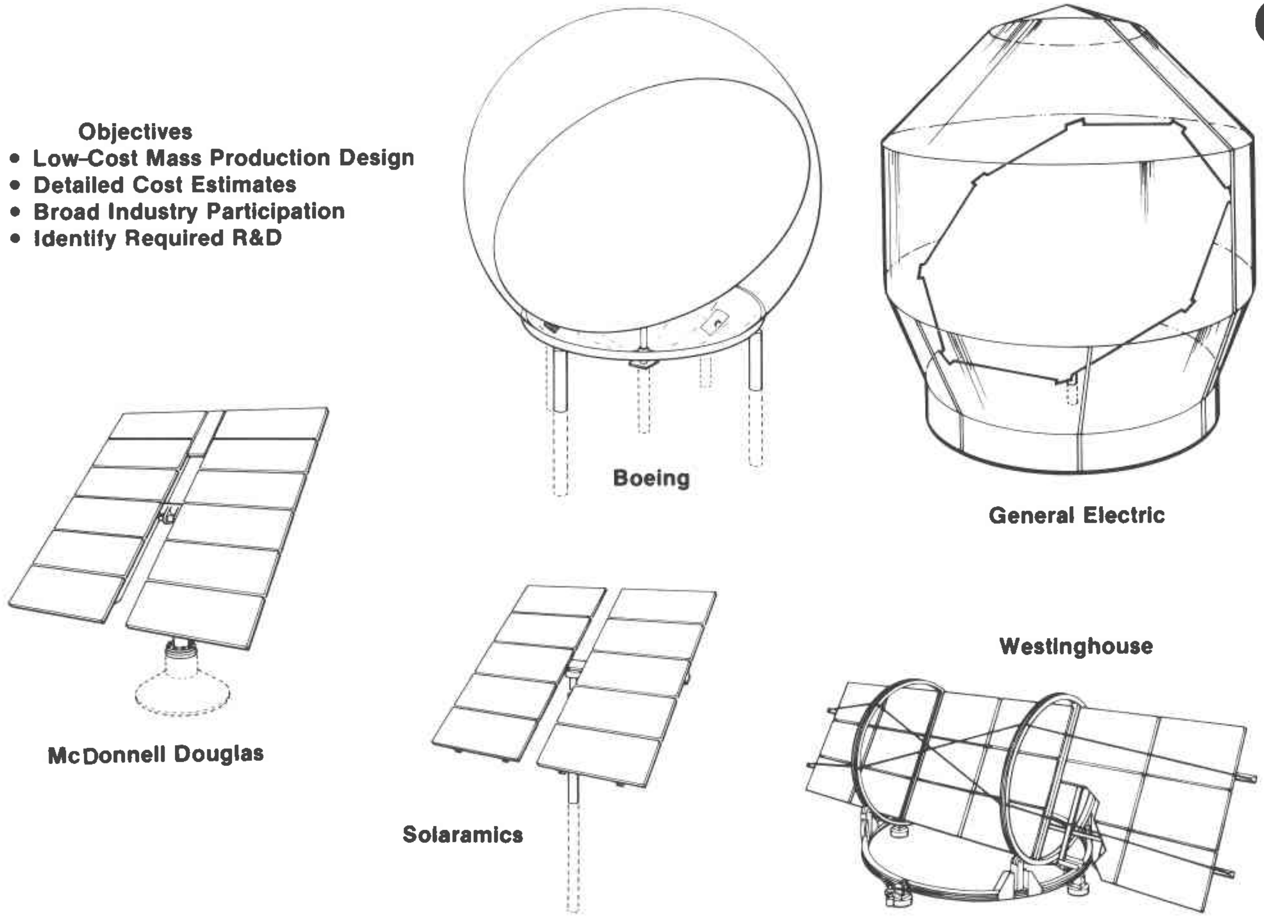

Figure 2-9. Central Receiver Systems Second-Generation Heliostats — Phase I

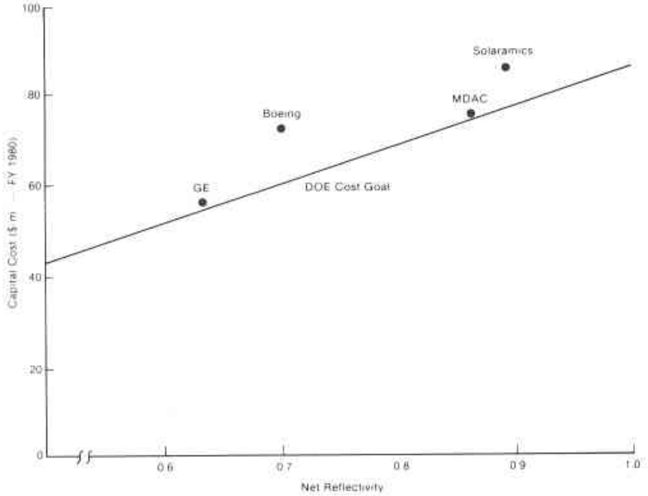

Figure 2-10. Phase I Second-Generation Heliostat Costs

Cost goals are reassessed annually to reflect the latest study results and economic trends.

The follow-up effort to check the designs and cost estimates in the second-generation studies will be limited to demonstrating the high-leverage component and materials developments. These will be selected after detailed evaluation of the designs submitted. A major tool used for evaluations is a new computer model, DELSOL, developed during FY 1978. This computer code can be used to synthesize a cost-optimal field layout and annual performance for each of the competing designs. Sensitivities in pointing accuracy, receiver size, and tower height were investigated to ensure that the comparison was not biased in favor of one design.

With the addition of DELSOL to DOE analytical capabilities, rapid comparison of competing design solutions can be made easily. The usefulness of this code for contractor users is also important; they have a better tool to provide trade-off studies. The code was documented and released in FY 1979.

Utilities have been faced with hard choices during the past few years in the selection of power plant types. All indications are that these decisions will become even more difficult in the future; hence, the need for credible source data places increasing demands on competing technologies. To meet the need for cost figures based on sound data and to foster competition, a new competitive solicitation entitled Preproduction Heliostat was issued early in FY 1979. The name was subsequently changed to Second-Generation Heliostat because it is essentially the second phase of the second-generation effort discussed previously. The objective of this solicitation was to open the competition with eventual funding of up to four contractors for low-cost designs that could be used to mass produce heliostats during the 1980s. Competitors for this procurement were provided with all data generated under DOE funding as well as critiques and evaluations. As a result, five contracts for second-generation heliostats were signed in August 1979. The winning competitors for 18-month contracts were Boeing Engineering and Construction, Martin Marietta Corp., McDonnell Douglas Astronautics, Northrup Inc., and Westinghouse (Fig. 2-11), although Westinghouse subsequently dropped out. Each of the designs

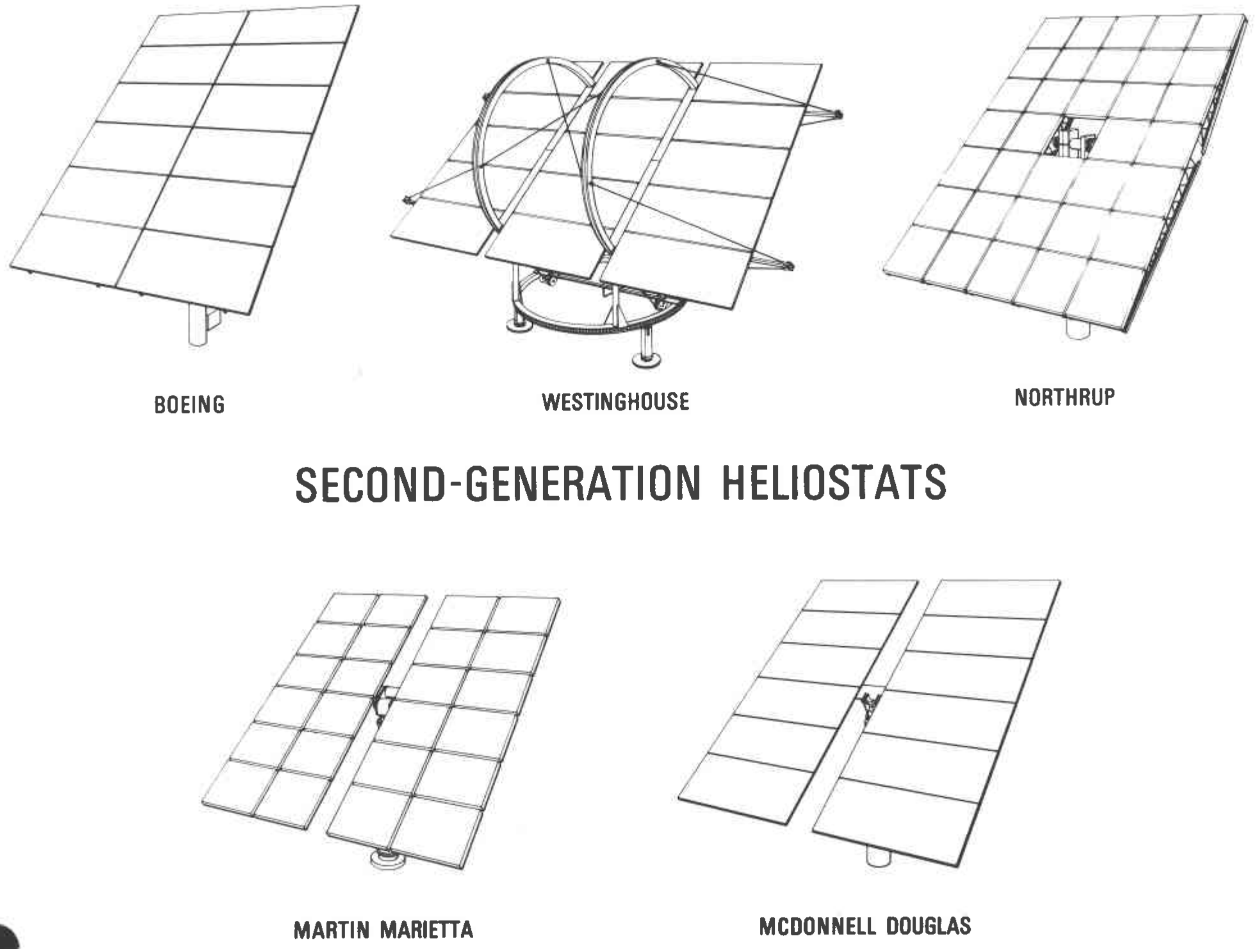

Figure 2-11. Central Receiver Systems Second-Generation Heliostats — Phase II

provided different concepts for all of the heliostat components. This effort has resulted in two prototype heliostats, a detailed design for a production heliostat, a conceptual design for a factory to produce 50,000 heliostats per year, and cost estimates. The cost estimates cover production costs as well as installation, operation, and maintenance costs. The prototype hardware will be tested side-by-side in early 1981 and thoroughly evaluated to provide potential users with data to assist them in selecting appropriate systems.

While the detailed design of mass-producible heliostats progressed, a New Ideas Heliostat Request for Proposals (RFP) was released, and contracts were awarded to develop new concepts and to obtain small business participation. Under the auspices of the New Ideas Heliostat RFP, new and novel approaches to solving heliostat problems are being pursued. Investigations are under way to develop new concepts for heliostat drives, mirror modules, cleaning methods, instrumentation, and materials. Improved plastics are being developed and evaluated for enclosed heliostats. Five small businesses and five large businesses were equally funded for contracts ending in FY 1980. The final design reports of these efforts are now available. Several of the efforts appear to have particularly encouraging results. The effort to develop plastics for heliostat enclosures has identified the material Kynar, produced by the Pennwalt Corp., as having potentially low life-cycle cost. Efforts in FY 1981 will continue accelerated exposure of samples of this material and will characterize its mechanical properties. Development of a new mirror module which has a lightweight molded plastic core is nearly complete and promises low cost when mass produced. This effort is intended to provide a precursor to third-generation heliostats. The total heliostat development program is attacking several fronts in an attempt to ensure that low-cost heliostats will be available for repowering and cogeneration projects, as well as other industrial applications that are not DOE funded.

Activities in FY 1981 will focus on the completion of prototype second-generation heliostats by the industrial contractors and extensive testing and evaluation by Sandia National Laboratories of the long-run potential of these designs.

2.1.3 Central Receiver Test Facility

Operation of the 5-MW_t Central Receiver Test Facility (CRTF) in support of central receiver designs and heliostat prototypes continued in FY 1980. The facility, operated by Sandia National Laboratories for DOE, consists of a 61-m tower, 222 sun-tracking mirrors, and a control and data computer system. First operation of the facility, shown in Fig. 2-12, occurred in late FY 1978 and test programs have continued throughout FY 1979 and FY 1980.

The primary objectives of CRTF are to provide timely testing and evaluation of solar receivers and heliostats and to provide operational experience with central receiver power plant designs. While these objectives are given first priority in facility operation and scheduling, the facility is also useful to a broad class of experiments that may require its unique high-temperature, high heat-flux environment. The Solar Thermal Test Facilities Users Association (STTFUA) interacts with the management of CRTF to assist in coordinating the needs and requirements of other tests and experiments with those performed as part of the primary program.

Two major test programs on receivers were undertaken in FY 1979. Evaluation of a gas-cooled cavity receiver, developed by the Electric Power Research Institute (EPRI) and tested by Sandia/DOE in a cooperative program, was completed in March 1979 with absorbed power levels exceeding 1 MW_t. Efficiencies that closely correlated with predicted values were measured, and stable control over a wide range of operating conditions was demonstrated. Tests on a panel from the water/steam receiver design to be used in

Figure 2-12. Central Receiver Test Facility

the Barstow 10-MW_e pilot plant were started in mid-FY 1979. The panel, shown under test atop the tower in Fig. 2-12, was a prototype of one of 24 such panels that make up the pilot plant receiver. The panels are designed to convert cooled water to superheated steam in one vertical upward pass. Test conditions at the CRTF, which were to confirm the design and control system and to provide operational experience, were selected to represent operation of panels which will be on the south, east or west, and north sides of the receiver. Absorbed power levels from 0.25 to 3.3 MW_t were achieved. The tests required varying numbers of preselected CRTF heliostats ranging from 20 to full operational field. For the highest power levels, water-cooled reflective mirrors were attached to the panel to capture energy which would otherwise spill over the sides of the long, narrow panel. Figure 2-5 shows the reflectors installed.

During FY 1979, development of a video-based heliostat evaluation system, called a Beam Characterization System (BCS), was completed. This system, whose control and display station is shown in Fig. 2-13, collects data on beam quality (i.e., flux density profiles and power measurements) and beam pointing (tracking accuracy) of heliostats. Both developmental and CRTF field heliostats have been evaluated using BCS. The system was used in FY 1979 as an integral part of the evaluation of prototypes supplied by contractors for the pilot plant. The BCS was also utilized to check and reset where necessary the targeting bias on the heliostats in the CRTF field. Before development of BCS, visual estimates of the beam centering were the only means of correcting drift in the heliostats.

Figure 2-13. BCS Control Display

During FY 1980 there were several facility improvements. The final construction of additions to the facility control building office and laboratory space for both CRTF staff and on-site experiment personnel was completed. Part of this addition, a 60-foot tower located above the facility control room, was utilized to house the heliostat evaluation equipment and controls. The BCS equipment, a Sandia-designed universal heliostat controller, and the control equipment provided by individual heliostat suppliers have been placed or will be placed in this BCS tower room.

A significant expansion of the facility data acquisition system capability was also initiated in FY 1980. This expansion will provide extended data reduction and presentations on a real time basis, capability to provide real time data trend plots, and an extended capability for remote control of experiment hardware.

During FY 1980, extensive use was made of flux gauges for measurements of flux density and total power conditions during tests. A development program was initiated to calibrate gauges in a solar environment and to measure the change in calibration for gauges whose surfaces had been exposed to a range of environmental conditions during extended test periods. Tests were conducted in the 30-kW$_t$ White Sands Solar Furnace and in a 5-kW$_t$ furnace developed at New Mexico State University with Sandia support. A parabolic concentrator has been obtained with a heliostat to form a solar furnace at CRTF. This experimental apparatus will provide flux density levels above 200 W/cm^2 and will be used to continue development of measurement techniques which provide the greatest precision possible during large-scale solar receiver tests.

Operation of the heliostat field in support of testing programs has continued to provide operation and maintenance data on the heliostats. The field is maintained at or above 95% operational and close to 100% operational capacity where required for maximum power tests. Failure modes include drive motors and encoders, printed circuit boards and relays, connectors, and intermittent temperature sensitivity failures. All experiences and data are given widespread distribution to designers of advanced heliostats for use in their design efforts.

Receiver testing in FY 1980 was devoted primarily to completion of testing on the pilot plant receiver panel and to installation, checkout, and solar operations of the salt-cooled receiver developed by Martin Marietta. Figure 2-14 shows the MMC receiver at the top of the tower. Ground level installation and checkout were completed in early July and elevation to the tower top occurred on July 22. Solar testing on the cavity configuration shown in Fig. 2-12 was initiated in early August 1980. Testing is expected to continue through the first quarter of FY 1981. In addition, a number of high heat flux tests were performed on a radome design proposed for a Navy missile.

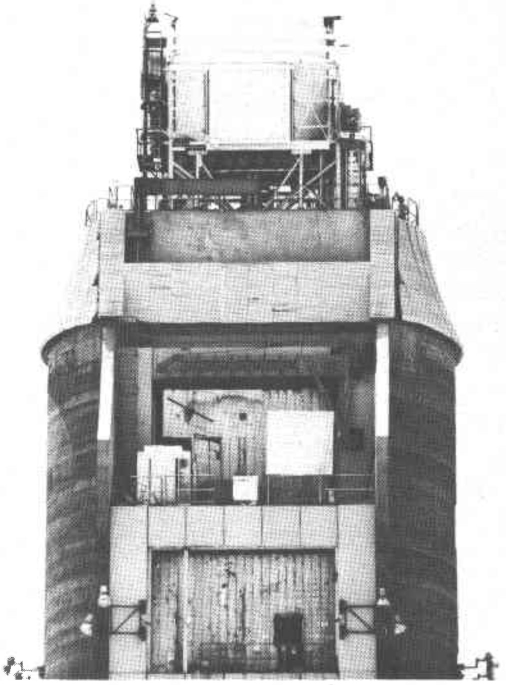

Figure 2-14. Martin Marietta Salt-Cooled Receiver Atop the CRTF Tower

Heliostat testing in FY 1980 centered around completion of data analysis from the test program on the pilot plant prototypes, together with facility expansion and preparation for the second-generation heliostat prototypes. Accelerated life-cycle testing of the tracking and control systems in the pilot plant prototypes has provided insight into their operational and potential maintenance characteristics. All operational irregularities have been provided to the heliostat designer (Martin Marietta) and to the pilot plant project office for consideration in design revisions. Facility modifications to accommodate two prototypes of each of the five second-generation designs were completed. A prototype of each design will be located at a 335-m slant range for tracking and beam quality evaluation. This program is expected to start early in FY 1981 and continue for several months thereafter. Life-cycle tracking and control tests are also scheduled to continue throughout FY 1981.

Activites projected for FY 1981 include completion of the Martin Marietta salt-cooled receiver tests—including utility personnel having the opportunity to operate it, installation and testing of a sodium-cooled receiver panel designed and fabricated by ESG, and installation of one of two receiver units developed through the sponsorship of the Electric Power Research Institute. Other activities include second-generation heliostat testing and completion of two small test programs coordinated for the CRTF by STTFUA. In addition, material and flux gauge testing will continue at the CRTF, at the White Sands Solar Furnace, and at the New Mexico State University solar furnace.

2.1.4 Storage Technology

The objective of the energy storage technology development effort for central receivers (managed by SNLL) is to demonstrate commercially viable storage technology for use with Solar Central Power Systems. These applications include solar stand-alone, cogeneration, repowering/industrial retrofit, or hybrid power plants. The level of technology to be considered must be consistent with commercial availability between 1985 and 1990.

The activities of the program are keyed to storage development for specific central receiver technologies. These are:

- storage for water/steam-cooled central receivers,
- storage for molten-salt-cooled sensible heat receivers,
- storage for liquid-metal-cooled sensible heat receivers, and
- storage for gas-cooled sensible heat receivers.

2.1.4.1 Storage for Water/Steam-Cooled Receivers

During FY 1980, second-generation storage developments began, designed to match performance of either saturated steam receivers for industrial retrofit applications or superheated steam receivers for retrofit and repowering applications. A competitive procurement is to result in contract awards for storage concept development studies. These studies are to be completed in FY 1981.

Storage concept development for an organic fluid maintenance unit was also completed in early FY 1980. Hydrocarbon-based oils at or near 316°C (600°F) are being used in solar thermal power plant development, such as the 10-MW_e Barstow pilot plant. An experimental and analytical research program has been conducted by Martin Marietta and SNLL to develop an understanding of Exxon's Caloria HT-43 oil thermal decomposition process, predict fluid replenishment requirements, and develop methods to reduce its degradation rate.

2.1.4.2 Storage for Molten-Salt-Cooled Sensible Heat Receivers

Concept development of internally insulated thermal storage containment was completed in early FY 1980. The purpose of this program, which was conducted by Martin Marietta, was to define a cost-effective thermal storage system for a central receiver power system using molten nitrate salt stored in internally insulated carbon steel tanks at temperatures up to 566° C (1050° F).

Molten nitrate salt storage subsytem development was initiated in FY 1980. A contract was awarded for the design, construction, testing, and evaluation of a molten salt subsystem research experiment. This study will be completed in mid-FY 1982.

Several materials studies were also performed to resolve technical issues for molten nitrate salt storage systems. During FY 1980, a molten salt chemistry study was initiated by EIC Corp. to develop a thorough understanding of the interactions of molten $NaNO_3$-KNO_3 mixtures with water vapor and carbon dioxide in the air. The results of this study will help to determine whether an open, closed, or breathing system is needed for storage. The results of the chemistry study, which will be completed in FY 1981, will be evaluated to identify any need for a study of techniques for regeneration of the salt.

Several materials studies were initiated during FY 1980 to evaluate corrosion behavior of high-temperature structural alloys in molten nitrate salts. These include: (1) electrochemical analyses; (2) thermal convection loop tests of both closed (at Oak Ridge National Laboratory) and breathing (at SNLL) systems to determine if thermal-gradient mass-transfer phenomena affect the corrosion behavior of three alloys, SS 304, SS 316, and Incolloy 800. The thermal convection loop tests will be completed in FY 1981. At that time the need for forced convecti[illegible] loop tests of these alloys or thermal co[illegible]vection loop tests of alternative alloy-salt combinations will be assessed. The electrochemical studies performed at SNLL in FY 1980 emphasized the development of species-specific indicator electrodes that can serve as on-line salt monitors. In FY 1981 these will be used to study and identify chemical species present in nitrate melts. A contract with the University of New York at Buffalo was initiated in the third quarter of FY 1980. The purpose is to study the effects of temperature, oxygen, and impurities on the salt melt and the formation of a passivating film on Incolloy 800. This work will continue through FY 1981.

In FY 1980 the development of equipment to measure viscosity, surface tension, and density of molten salt over a temperature range of 25° to 900° C (77° to 1652° F) and a pressure range of 1 to 10 atmospheres was completed at SNLL. Preliminary data on the viscosity of molten $NaNO_3$ mixtures were obtained. During FY 1980, heat capacity measurements were also performed on $NaNO_3$ and KNO_3 at SNLL, and a contract was awarded for thermal conductivity measurements of molten nitrate salts. In FY 1981 the thermophysical property measurements will be completed except for thermal conductivity. The latter will be completed in FY 1982.

2.1.4.3 Storage for Liquid-Metal-Cooled Sensible Heat Receivers

In FY 1979 Energy Systems Group (ESG) of Rockwell International performed a conceptual design of an air/rock thermocline storage system as part of the Advanced Central Receiver Program. This system has potential for low cost but requires experimental verification. Before the consideration of any contracted large-scale development effort, SNLL is performing laboratory tests to study the effect of thermal cycling on ro[illegible] strength. The preliminary data show littl[illegible] evidence of rock fracture when thermally cycled (approximately 600 cycles) from 316°C (600°F) to 593°C (1100°F) while under a mechanical load. Additional tests are being performed to allow a greater number of samples to be simultaneously tested.

2.1.4.4 Storage for Gas-Cooled Sensible Heat Receivers

The air/rock storage concept proposed for liquid-metal-cooled receivers may also be applicable to gas-cooled receivers. This concept has the potential for very low media cost, and for low pressure systems it would have very low containment costs. During FY 1980 preliminary studies were performed to investigate thermal cycling of rocks. In FY 1981 the development of the air/rock storage concept will focus on air/rock heat transfer studies needed to establish the feasibility of the concept. This work is being coordinated with activities described under storage for liquid-metal-cooled receivers.

2.2 CENTRAL RECEIVER SYSTEMS AND APPLICATIONS

2.2.1 10-MWe Solar Thermal Central Receiver Pilot Plant

2.2.1.1 Background

The 10-MW_e Solar Thermal Central Receiver Pilot Plant is a first-of-a-kind systems experiment that will apply the results of development experiments to a solar-powered electrical generation pilot plant to provide operational data. The technology has not previously been integrated into a full system for operation as a utility.

The primary objectives of the 10-MW_e experiment are:

- to establish the technical feasibility of a solar thermal steam plant of the central receiver type, including collection of data for utility and industrial process heat applications;
- to obtain sufficient development, production, and operating data to indicate the potential economic operation of commercial plants of similar design; and
- to determine the environmental impact of solar thermal central receiver plants.

Responsibility for the project has been assigned to the DOE Division of Solar Thermal Energy Systems within the Office of Solar Industrial Applications. A Solar Ten Megawatt Project Office was established by the DOE San Francisco Operations Office (SAN) with responsibility for the day-to-day planning, direction, execution, and control of the project within the approved envelope of technical objectives, cost estimates, and schedule milestones.

The project is a joint utility- and government-funded project. The Associates, composed of Southern California Edison Company, the Los Angeles Department of Water and Power, and the California Energy Commission, are participating in the engineering, management, and construction activities of the project in accordance with a cooperative agreement between DOE and the Associates. Figure 2-15 shows a model of the plant, which will be built on Southern California Edison

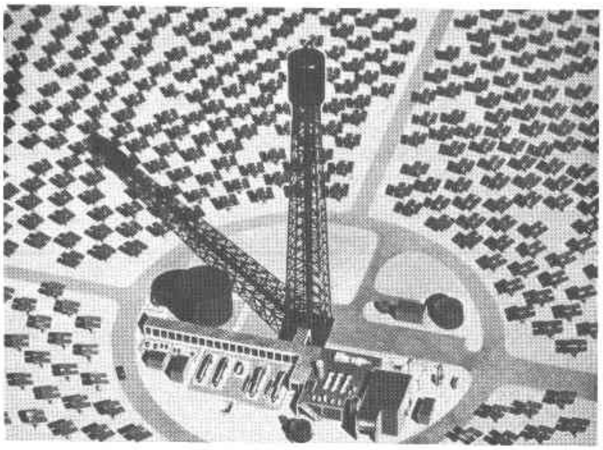

Figure 2-15. Model of 10-MW_e Solar Thermal Central Receiver Pilot Plant

property east of Barstow at Daggett, California. Figure 2-16 illustrates how radiant energy will be converted to electricity.

The plant will be operated and maintained by Edison operations personnel. The overall project milestones are:

- DOE selects site and utility partner, January 1977
- DOE selects solar contractors, August 1978
- Start plant construction, September 1979
- Complete construction, September 1981
- Steam-to-turbine/Initiate check-out, December 1981
- Complete integrated plant acceptance, June 1982
- Complete 5-year test phase, June 1987

Highlights of the past fiscal year are shown in Table 2-1.

2.2.1.2 Summary of Current Status

Preliminary design was completed on the plant in November 1979. All solar facility construction package designs have been completed, and the turbine-generator construction designs are approximately 90% complete.

Final software preparation for the control computer is under way. The master con-

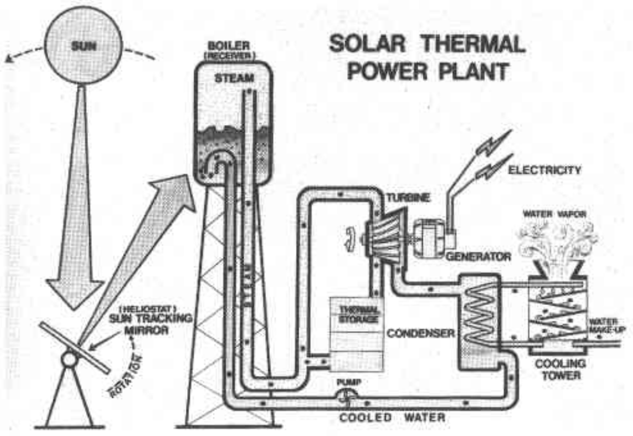

Figure 2-16. Ten-MW_e Pilot Plant Schematic

Table 2-1. Highlights and Accomplishments During FY 1980

Completed plant preliminary design	November 1979
Selected heliostat production supplier	November 1979
Completed preliminary earthwork	December 1979
Completed receiver tests at CRTF	January 1980
Started receiver panel fabrication	January 1980
Completed site access road and administrative building	January 1980
Authorized DOE construction manager to subcontract solar facilities construction	February 1980
Awarded tower steel, tower foundation, and water tank construction contracts	March 1980
Awarded collector field electrical construction contract	April 1980
Completed heliostat foundation installation	May 1980
Awarded thermal storage and plant support structural steel and foundation construction contracts	June 1980
Awarded thermal storage tank construction contract	July 1980
Opened visitor's information center	July 1980
Awarded mechanical construction package	September 1980

trol system hardware and software will be checked out under laboratory conditions before shipment to the site next year.

Field construction has been under way since late last fiscal year. Site activities this year concentrated on earthwork, foundations, structural steel, and electrical wiring installation.

2.2.1.3 Collector Subsystem

The thirteen-month final design and preproduction fabrication phase was completed on schedule in October 1979 by Martin Marietta Aerospace and McDonnell Douglas Astronautics. This phase included three months of DOE performance testing on full heliostats and associated controls as well as component structural/environmental assessments on drives and mirror modules. Test data were analyzed as part of the production phase contractor evaluation. DOE selected Martin Marietta to fabricate, install, and check the full heliostat field in late November 1979.

The Martin Marietta heliostat is shown in Fig. 2-17. The reference design is characterized by the following features:

- Mirror Module—Each of the twelve heliostat mirror modules consists of a low-iron float glass mirror 0.125 in. thick by 43.0 in. by 120.0 in., backed by 2.60 in. of aluminum honeycomb, and surrounded by a galvanized steel pan. The glass surface area per heliostat is 430 ft^2. A double seal of silicone and polyisobutylene provides a moisture barrier between the glass edge and the metal pan.
- Drives—Both azimuth and elevation drives are contained in the same housing and are gear type.

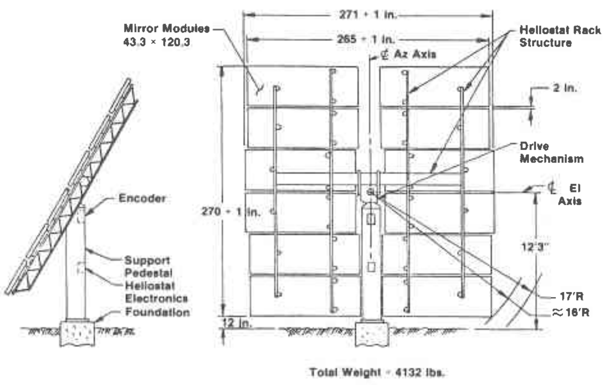

Figure 2-17. 10-MW_e Collector Subsystem Heliostat

- Support Structure—The elevation drive is attached to a vertical tube from which four horizontal trusses are attached for mirror module mounting.
- Controls—The individual heliostat controllers are located inside the galvanized steel pedestal. Up to 32 heliostat controllers are connected to each field controller which are connected to the redundant heliostat array controller located in the central control room.

2.2.1.4 Collector Field

Field configuration calculations were based on a 42-m^2 (450-ft^2) heliostat and were constrained by shadowing, blocking, and an allowable heliostat swing-radius. Following selection of Martin Marietta, the required number of heliostats was determined to be 1818 to meet the plant performance criteria of four hours of 10-MW_e operations on the least favorable winter day. Assumptions used in the field sizing analysis included:

- Insolation value: 917 W/m^2
- Heliostat mirror reflectivity: 0.89
- Receiver absorptivity: 0.95
- Receiver losses: 4.7 MW_t*
- Receiver absorbed thermal power: 34.1 MW_t*
- Plant parasitic power: 1.7 MW_e*

The field configuration with a radial stagger layout is shown in Fig. 2-18. Figure 2-19 shows the segmentation concept developed by the Solar Facilities Design Integrator to control the heat flux on the receiver. Up to five aim points will be used along the vertical axis of the receiver.

2.2.1.5 Cloud Measurement Experiment

Rapid variations of insolation in both time and space have been identified as a potentially important concerning the design and operation of the Solar 10-MW_e Pilot Plant. These rapid changes will affect the design of the master plant control system, the individual receiver panel controls, and the operating modes of the plant. The variations must also be accounted for in estimating the thermal fatigue of critical receiver elements.

A review of available insolation data revealed little directly applicable information on variations during cloudy periods, but FAA meteorological data indicate that there is cloud cover during a significant percentage of the daylight hours at Daggett.

A cloud measurement experiment was identified as a means for obtaining data on the characteristics of the clouds at the pilot plant site. The object of the experiment was to obtain insolation data with satisfactory temporal and spatial resolution for thermal transient analysis and control studies. The experiment was sponsored by DOE and set up at the Southern California Edison Coolwater Generating

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*MW_t is a measure of heat energy. MW_e is a measure of electric energy after the heat energy has passed through the turbine generator set.

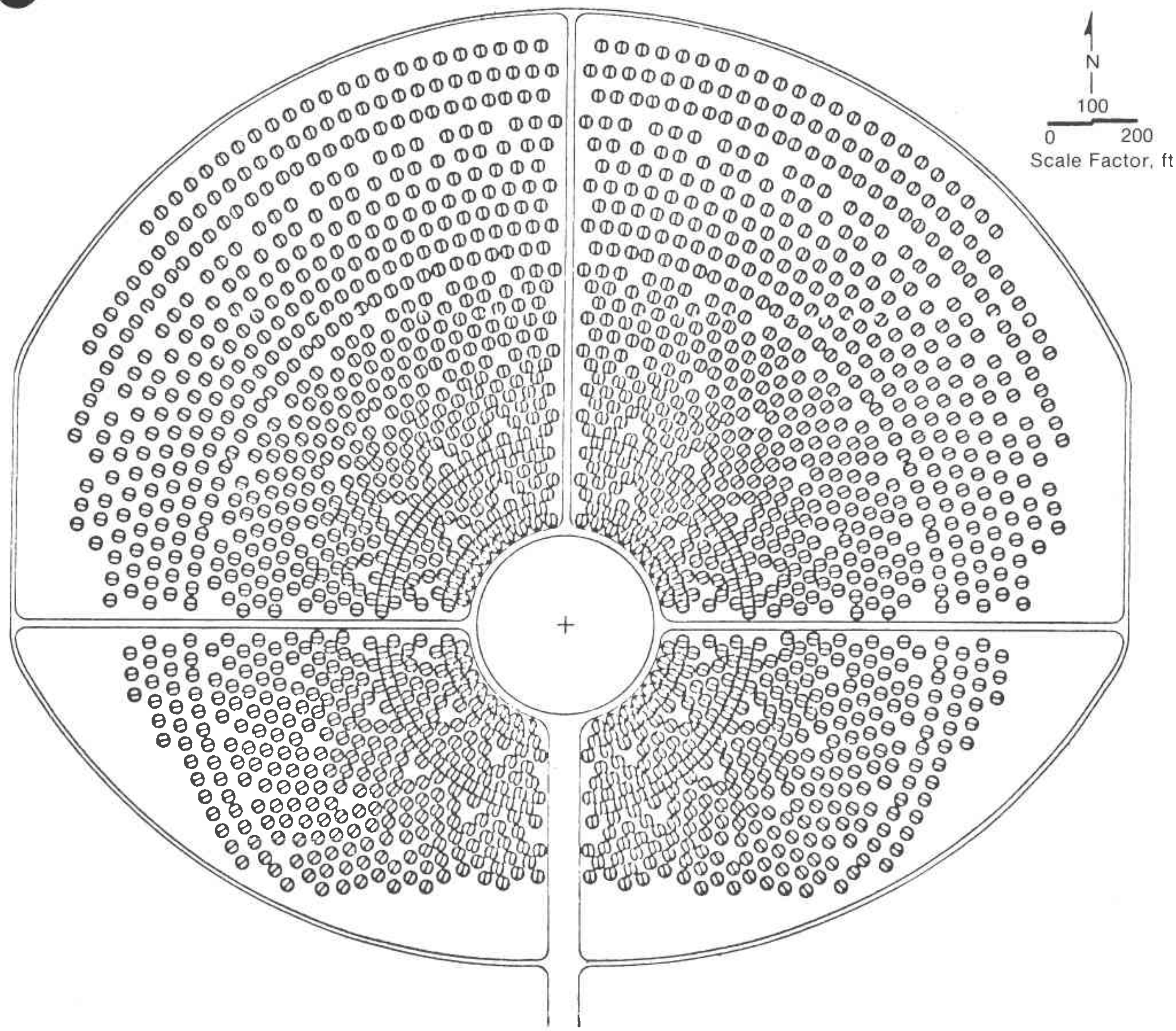


Figure 2-18. Ten-MW$_e$ Pilot Plant Collector Field Configuration

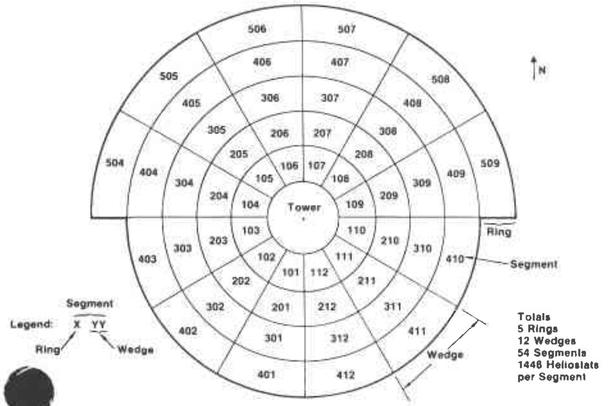


Figure 2-19. Collector Field Segmentation Concept

Station, adjacent to the site of the Solar 10-MW$_e$ Pilot Plant. The experiment was run for a little over one year, and the results are presented in terms of eight typical cloud conditions or scenarios which were used by McDonnell Douglas in their design analysis for the pilot plant. This data updates all previous data and assumptions on the characteristics of the clouds at Daggett. The final report and data sets are available from McDonnell Douglas. Findings on the frequency of clouds are:

- During 90% of the winter months, clouds are present 15% to 25% of the time.

- During 90% of the summer months, clouds are present 10% to 20% of the time.
- During 90% of all the months, at least 10% to 15% of the daylight hours will be partly cloudy.

2.2.1.6 Master Control System

The control, protection, and data acquisition of the plant are accomplished by the Master Control System. The hierarchical structure of the Master Control System has been chosen to provide maximum reliability and availability during startup and acceptance testing and to provide single-operator capability when plant operational procedures have matured.

The basic control and protection functions are performed by the subsystem distributed process controller and the interlock logic system. These can be controlled directly by the plant operators through the subsystem colorgraphics terminals or by the operational control system computer. Continuous monitoring and alarm functions will accomplish an orderly shutdown in case a subsystem malfunctions.

The collector subsystem is controlled through the heliostat array controller computers. The data acquisition system is designed to collect, arrange, and store up to 1,000 channels of data in addition to the data available from the operation control system. Data acquisition system sample rates vary from one second to ten minutes during normal operation. In the event of a plant malfunction, a selected set of parameters are monitored at a much faster rate (e.g., 100 milliseconds) as a diagnostic aid.

The operation control system will be capable of fully automatic coordinated control for a clear day scenario, with provisions included for future expansion to intermittent cloudy day automatic control.

2.2.1.7 Receiver Subsystem

The full size, 70-tube prototype panel test was completed at DOE's Central Receiver Test Facility (CRTF). The tests were extremely beneficial in promoting understanding of the ability of the control system to maintain steam and panel-surface temperature within required limits. As a result of the tests, the pilot plant control approach has been modified to include the following input parameters:

- discharge steam temperature,
- panel tube and "back wall" temperature,
- incident flux, and
- water flow.

2.2.1.8 Electric Power Generating Subsystem

Approximately 90% of the design effort was completed by the end of FY 1980. In addition to the turbine generator, which is being fabricated by General Electric, long-lead procurements were placed for all hardware including pumps, tanks, feedwater heaters, deaerator, cooling tower, condenser, demineralizer, electrical cable, transformers, switching gear, and an uninterruptible power supply.

2.2.1.9 Site Construction

- Solar Facilities—The preliminary earthwork, Visitors' Center, collector field foundations, and receiver tower foundations were completed this year. Awards were made and work was also begun on additional construction packages including collector field electrical wiring, warehouse, receiver tower steel, thermal storage and plant support steel and foundations, the thermal storage tank, and major mechanical components. Figures 2-20 and 2-21 show FY 1980 construction progress and the on-site Visitors' Center, which opened in July.

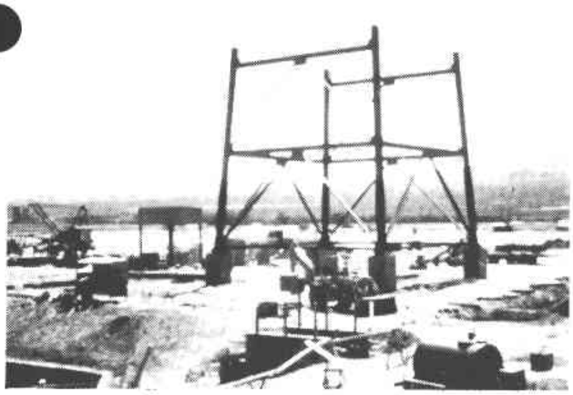


Figure 2-20. Ten-MW$_e$ Receiver Tower Under Construction

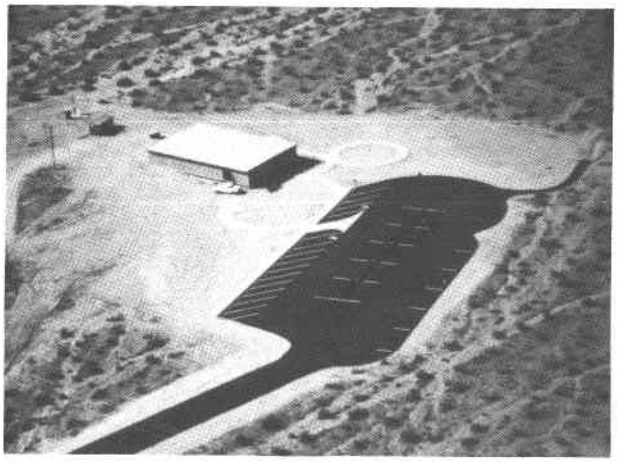


Figure 2-21. Visitors' Center at the Pilot Plant Site

The heliostat mirror assemblies are being fabricated at Pueblo, Colorado, and will be shipped to a Daggett, California, airport hangar for final heliostat assembly. On-site installation will begin in FY 1981.

- Turbine-Generator Facilities—The first phase of site activities was completed in April. Construction included water wells, an access road, administration building, temporary electrical power, and site perimeter fencing. The second phase of site activities will be initiated shortly after the beginning of the next fiscal year and will include mechanical hardware installation, piping, control building, and electrical construction.

2.2.2 Storage-Coupled Systems

The goal of the studies on the storage-coupled systems is to develop technologies for improving the cost effectiveness and increasing the potential breadth of application of the central receiver. Five receiver heat-transport fluids—water, salt, sodium, air, and helium—have been proposed for storage-coupled applications. A simplified schematic of a first-generation water/steam system is presented in Fig. 2-22. This design limits the system performance because it contains two separate steam loops: steam from the receiver and steam from storage. The steam generated from the receiver is at a higher temperature and pressure than the steam generated from storage (520°C/10 MPa compared with 280°C/3 MPa). The steam generated from storage is at the lower temperature because (1) the maximum operating temperature of the storage fluid is 300°C, and (2) there is a temperature drop associated with the transfer of energy in the two heat exchangers. A dual-admission turbine is required to efficiently accept the steam at the two different inlet temperatures and pressures.

Even though the cost of the turbine in an electrical generating system is a small percentage of the total system cost, it is cost-effective to increase the turbine efficiency primarily because it reduces the number of heliostats required for a given output. Thus, emphasis has been placed on minimizing heliostat costs and developing techniques for improving the efficiency of solar central systems. Three promising technologies for improving the efficiency were defined in preliminary studies conducted by Aerospace, Sandia, and others. These studies indicate that it may be possible to improve the efficiency of solar central receivers by using alternative "working fluids" in the receiver. Specifically, four candidate materials were selected: air, helium, molten salt, and sodium. The air and helium are coupled to a Brayton-cycle turbine; the draw salt and sodium are coupled to a Rankine-cycle turbine.

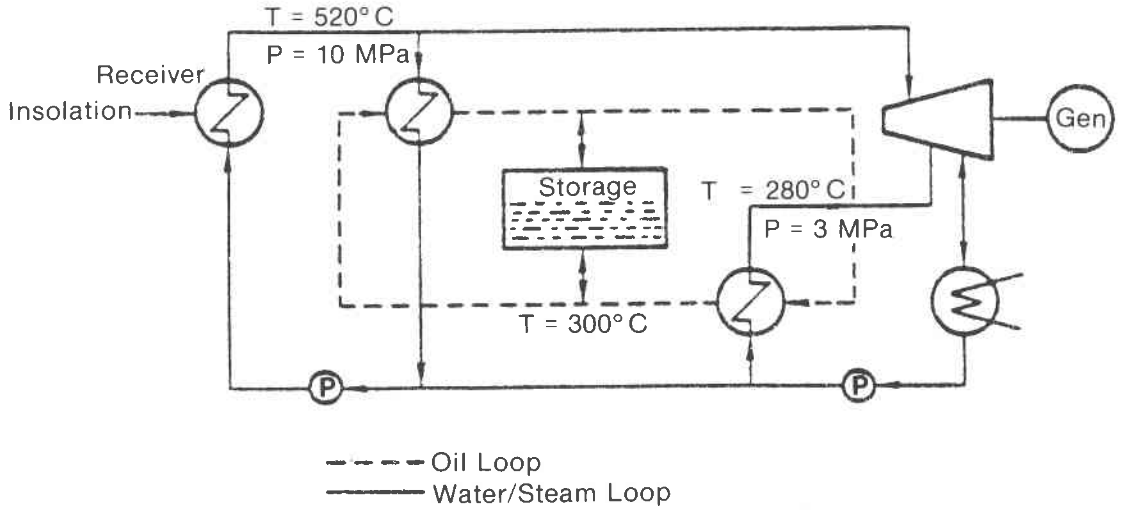


Figure 2-22. First Generation Water/Steam System

In the Brayton system, Fig. 2-23, the heat transport fluid is also used to charge and discharge the storage medium. Brayton turbines are desirable because they are compatible with cyclic loading and have high efficiencies. In the sodium and salt systems, Fig. 2-24, the working fluid may be used as the storage medium; however, a heat exchanger is required to transfer the energy to a Rankine-cycle turbine loop. This configuration is highly desirable because it is possible to have high-temperature storage and the turbine need only operate from steam at one temperature and pressure. Thus, high efficiency reheat turbines can be used. In addition, the turbine is isolated from the short-term insolation transients imposed on the receiver.

2.2.3 Repowering/Retrofit

A step toward the realization of large-scale application of solar energy was taken when DOE issued a solicitation in March 1979 for conceptual design studies of utility repowering/industrial retrofit systems employing solar central receivers. Twenty-two responses were evaluated, and twelve were selected for funding. These studies are augmented by one conducted in 1978 [1] and by a privately funded design study.

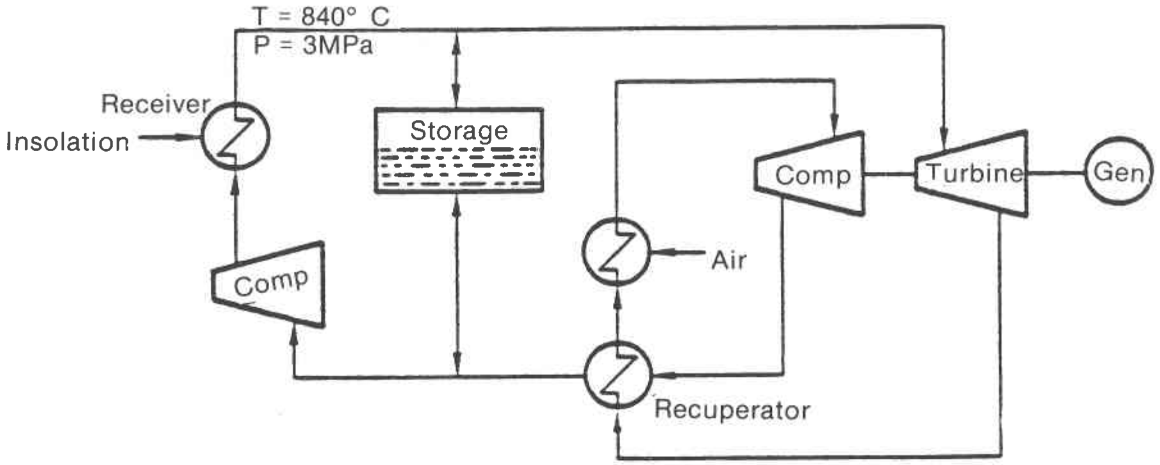


Figure 2-23. Brayton System

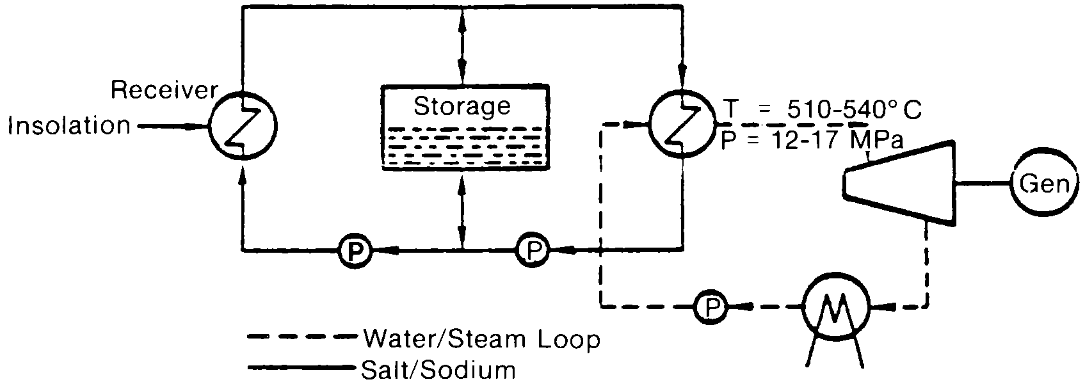


Figure 2-24. Salt/Sodium System

Eight of the 14 studies are for electric utility repowering of existing oil or natural gas generating plants. The other 6 are the first site-specific studies of the use of solar central receiver systems for industrial process heat. These 14 studies examine a wide range of different designs, working fluids, and applications. The industrial processes include gypsum board drying, oil refining, enhanced oil recovery, uranium ore processing, natural gas processing, and ammonia production. Two poster board displays of these conceptual design studies are in active use in public meetings around the country. A map showing the site locations for the design studies, including the earlier study at Albuquerque, New Mexico [2], is shown in Fig. 2-25, and summaries of the projects are presented in Tables 2-2 and 2-3. Brief summaries of the 14 projects follow.

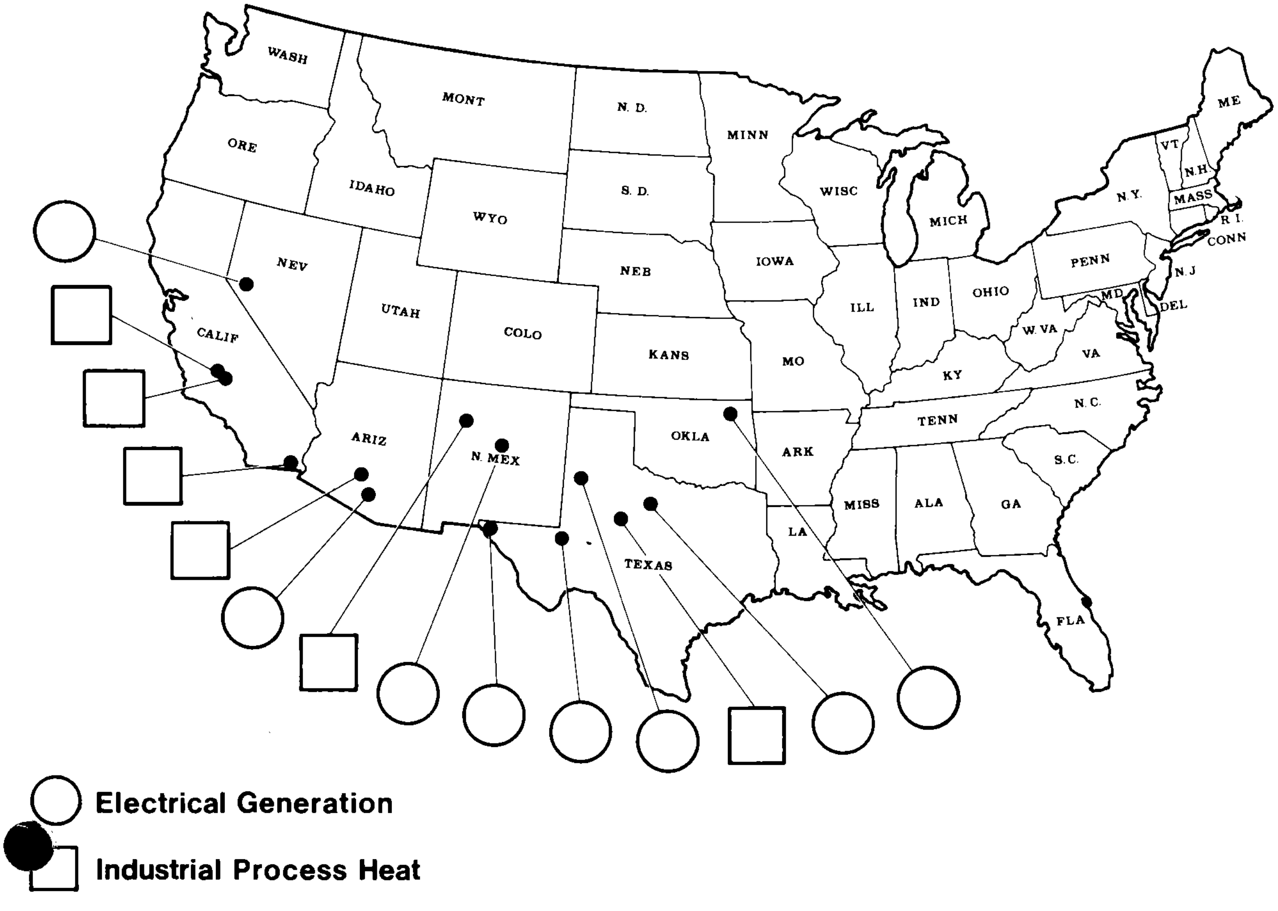


Figure 2-25. Site Locations for Utility Repowering/Industrial Retrofit Systems

Table 2-2. Electrical Repowering Conceptual Designs

Plant	Solar Size	Number of Heliostats	Receiver Type	Receiver Temperature	Tower Height (m)	Storage (h)
Arizona Public Service	110 MW_e	10,500	Cavity Salt	1050	155	4
El Paso Electric	41 MW_e	2776	External-Water	1020	146	0
Public Service of New Mexico	25 MW_e	4086	External-Water	1050	129	0
Public Service of Oklahoma	30 MW_e	2255	External-Water	1012	110	0
Sierra Pacific Power (NV)	77 MW_e	8411	External-Salt	1050	150	6
Southwestern Public Service (TX)	57 MW_e	4809	External-Sodium	1100	95	Buffer
Texas Electric Service	50 MW_e	4742	External-Sodium	1100	110	1
West Texas Utilities Co. (Privately funded)	60 MW_e	7882	External-Sodium	1100	154	4

Table 2-3. Retrofit Industrial Process Heat Conceptual Designs

Plant	Solar Size	Number of Heliostats	Receiver Type	Receiver Temp. (°C)	Tower Height (m)
ARCO-Natural Gas Refinery (CA)	9.5 MW_t	320	External-Oil	560	61
Exxon-Oil Recovery (CA)	29.3 MW_t	818	Cavity-Water	567	90
Gulf R&D-Ore Refinery (NM)	13.9 MW_t	383	External-Water	399	37
Provident Oil Refinery (AZ)	43 MW_t	1174	External-Water	520	93
U.S. Gypsum (TX)	10.5 MW_t	469	Cavity-Air	1335	61
Valley Nitrogen (CA)	34 MW_t	1040	Cavity-Gas	1450	76

.2.3.1 Electrical Repowering Projects

Arizona Public Service

Prime Contractor: Arizona Public Service Co.
Subcontractors: Martin Marietta Corp., Badger Energy, Inc., Gibbs & Hill, Inc.

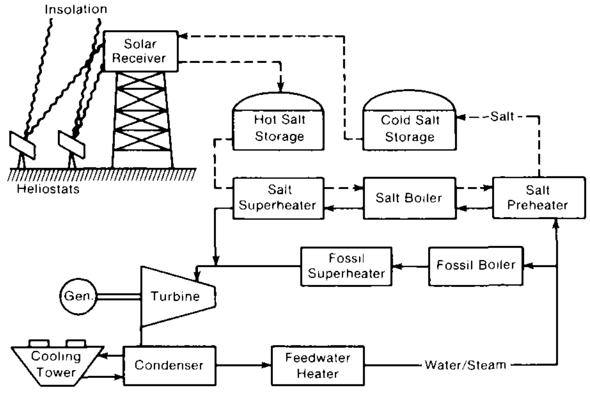
The plan developed for this solar repowering project uses a central receiver power tower with molten salt (60% $NaNO_3$, 40% KNO_3) as the receiver heat transport fluid. Four hours of thermal storage at 112 MW_e is provided by a storage subsystem composed of an internally-insulated hot salt tank and an externally-insulated cold salt tank. The solar plant interfaces with the original main steam line to the turbine inlet and the feedwater line to the fossil fuel steam generator.

A schematic of the Arizona Public Service Company Project, shown in Fig. 2-26, is typical of all the electrical repowering projects.

El Paso Electric Co.

Prime Contractor: El Paso Electric Co.
Subcontractors: Stone & Webster, Westinghouse

The preferred configuration for solar repowering of the plant is an advanced external water/steam central receiver with pumped recirculation. This technology, under development by DOE, can provide 538°C (1000°F) main and reheat steam at 10.17 MPa (1450 psia) to the turbine-generator. This technology, known throughout the utility industry, was selected to utilize commercial/utility boiler design approaches using conventional boiler materials with known properties. Thermal energy storage systems are not required, and their absence lowers cost and increases reliability.



igure 2-26. Arizona Public Service Company Solar Repowering Project Schematic

Public Service Co. of Oklahoma

Prime Contractor: Black & Veatch
Subcontractors: Public Service Co. of Oklahoma, Babcock and Wilcox Co., Bailey Controls Co.

The conceptual design includes an external water/steam receiver configured as a sector of a right circular cylinder. The solar receiver generates superheated steam that is piped to the fossil boiler. The solar and fossil steam generators will operate in parallel, resulting in a hybrid plant. In this operating mode thermal storage is not required. There are two solar receivers for this project, one for the main steam supply and the second for the reheat steam supply. Solar steam generation for the plant is expected to displace the equivalent of at least 100,000 barrels of oil per year.

Sierra Pacific Power Utility

Prime Contractor: McDonnell Douglas
Subcontractors: Sierra Pacific Power Co., Stearns-Roger Services, Desert Research Inst., Foster Wheeler Development Co., University of Houston, Westinghouse Electric Co.

The conceptual design is a molten salt, storage-buffered system. The fluid is heated in the partial cavity receiver 566°C (1050°F). The hot molten salt flows to the thermal storage tanks where a storage capacity of approximately six hours is provided. Salt is withdrawn from storage to generate steam for the turbine.

Southwestern Public Service Co.

Prime Contractors: General Electric Co., Energy Systems Programs Department.
Subcontractors: Southwestern Public Service, Kaiser Engineers

The baseline conceptual design is a sodium-cooled solar central receiver. The storage provided for the plant will be limited to approximately 10 minutes, a level sufficient to buffer the total plant output from solar transients. The 10-minute system will function the same as a larger storage system and thus will demonstrate adequately the storage concept for future plants.

Texas Electric Service Co.

Prime Contractors: Rockwell International, Energy Systems Group
Subcontractors: Stearns-Roger Services, McDonnell Douglas, University of Houston

The receiver is the external type, and heat is absorbed by the liquid sodium flowing through the receiver. Thermal storage acts as a buffer between the receiver and steam generator, minimizing the effects of any receiver thermal transients. The solar portion of the plant is integrated into the existing plant by a tee in the feedwater line so the flow can be split between the boiler and the sodium-to-water evaporator unit, in accordance with the relative powers to be extracted from each.

West Texas Utilities Co.

Participants (privately funded): Energy Rockwell International Systems Group, West Texas Utilities Co.; University of Houston

The solar central receiver system consist of a sodium-cooled receiver. Therma storage is buffered between the receiver and steam generator, minimizing the effects of receiver thermal transients. The solar portion of the plant is integrated into the existing plant by a tee in the feedwater line so the flow can be split between the boiler and the sodium-to-water evaporator unit.

Public Service Co. of New Mexico

Prime Contractor: Public Service Co. of New Mexico
Subcontractors: Stearns-Roger Services, Westinghouse

The baseline central receiver design is a once-through type water/steam boiler. The design of the collectors and the solar receiver was based on the preliminary design of the 10-MW_e Barstow, California, pilot plant. The conceptual design for this system was completed in September 1978.

2.2.3.2 Industrial Process Heat Repowering Retrofit Systems

ARCO Oil and Gas Co., North Coles Levee, Plant No. 8

Prime Contractor: Northrup, Inc.
Subcontractor: ARCO Oil and Gas Co.

This solar retrofit system is being designed to raise the temperature of a reservoir of heat medium oil (HMO) (something like 10-40 motor oil) directly. At design conditions (noon, summer solstice) the solar system will supply 9.5 MW_t or approximately 90% of the heat normally supplied by the plant's existing gas-fired heaters. The project includes construction of a 19-heliostat pilot module during the design phase. This towerless module will be interfaced with the existing plant, and will provide four months of operating experience before the start of the full project construction. The total project could be designed and built i about three years.

During periods of sufficient insolation, all the HMO that normally flows to the heaters is diverted through the receiver and back to the heaters. The heaters then top off the heat required to maintain an outlet temperature of 302°C (575°F). Fuel flow to the heaters is automatically controlled to ensure the correct heat input, or to carry the entire plant load during periods of insufficient insolation. This method of interfacing the solar and nonsolar HMO system offers several advantages: all solar energy collected is used; all heat supplied by heat recovery units is used; direct heaters are maintained at operating temperature and can respond rapidly to transient conditions; system control is extremely simple; and there is minimum interruption of existing plant operation. A schematic of this project is shown in Fig. 2-27.

Exxon Corp., Edison Field

Prime Contractor: Martin Marietta Corp.
Subcontractors: Exxon Corp., Foster Wheeler, Black & Veatch

The particular concept being studied utilizes a central receiver solar thermal power system to replace the combustion of oil for generation of steam used for Solar Thermal Enhanced Oil Recovery operation. Standard pumping techniques can produce only a small portion of the crude oil from underground reservoirs.

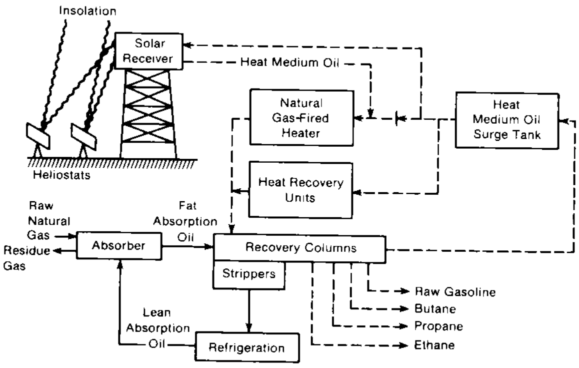


Figure 2-27. Arco Oil and Gas Company Solar Repowering Project Schematic

The decrease in ground pressure, coupled with a high flow resistance in the oil-bearing formations, causes production rates to fall below economic levels while abundant amounts of oil remain. Furthermore, a larger portion of the world's known reserves consist of particularly heavy, viscous crude that cannot be pumped at all. As available crude oil reserves are depleted and prices escalate, various methods of enhancing production capability have been developed. The most cost-effective process is the injection of steam into the reservoir. This heats and pressurizes the formation, allowing the oil to flow to recovery wells where it is pumped by normal means. Steam generators with output ratings of 22 MBtu/hr and 25 MBtu/hr are presently used at Edison Field. The baseline design solar system would produce 23-Btu/hr average over a typical year. Peak noon winter solstice output would be 29.3 MW (100 MBtu/hr). This project could be designed and built in less than three years.

Oil-bearing geological formations provide a high heat capacity and low-thermal-loss buffer thermal storage capability, so that intermittent shutdown at night and during cloudy periods can be tolerated. A schematic of this project is shown in Fig. 2-28.

Gulf Research and Development Co., Mt. Taylor Uranium Mill

Prime Contractor: McDonnell Douglas
Subcontractors: Gulf Research, Foster Wheeler, University of Houston

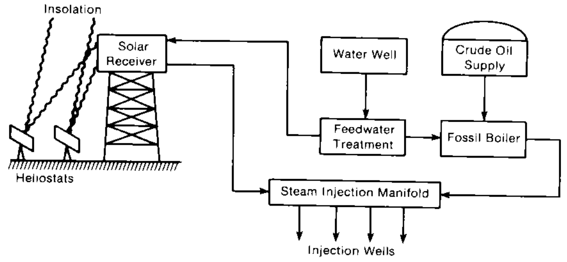


Figure 2-28. Exxon Corporation's Edison Field Oil Recovery Solar Repowering Project Schematic

A solar central receiver will operate in parallel with two oil-fired boilers to provide steam to a uranium mill. Solar energy will be used to produce at least 20% of the plant's annual steam requirements. The solar energy will displace 22,600 barrels of No. 2 fuel oil annually. This project could be designed and built in about three years.

The receiver is a natural circulation boiler that will supply saturated steam at 150 psig to the mill processes. The fossil boilers, with a 13.5:1 turndown ratio, will be operated in parallel with the solar central receiver steam generator. Steam demand and available insolation will determine the ratio of use of solar steam. No storage is necessary for this demonstration project. A schematic of this project is shown in Fig. 2-29.

Provident Energy Co., Mobile Refinery

Prime Contractor: Foster Wheeler Development Corp.
Subcontractors: Provident Energy Co., Inc., McDonnell Douglas, Foster Wheeler

The objective of this project is to prepare a conceptual design for a central receiver system that will provide practical and effective use of solar energy in an oil refinery. The net annual input from the solar plant, 359 x 10^9 Btu, will supply 20.8% of the annual refinery steam demand. The proposed solar plant would displace about 445 x 10^9 Btu, or about 71,400 barrels per year of the fuel oil produced by the refinery that would otherwise be burned in the fossil boiler. This project could be designed and built in about three and a half years.

The proposed baseline solar energy system consists of a tower-mounted, natural-circulation water/steam receiver with an exposed flat-panel absorber. The receiver generates saturated steam that is superheated to the desired temperature in a separate oil-fired superheater before it enters the main refinery superheated steam header. As currently planned, the refinery's fossil boilers will be operating during solar operation, but at a very low output. The control system's function is to modulate the fossil boiler output in response to the steam header pressure to vary steam flow to satisfy refinery demands. A 3-minute pressurized water buffer storage is provided to protect the refinery from cloud transients. A schematic of this project is shown in Fig. 2-30.

United States Gypsum Co., Sweetwater, Tex.

Prime Contractor: Boeing Engineering
Subcontractors: U.S. Gypsum Co., Institute for Gas Technology

The solar retrofit system will supply solar-heated air during insolation hours to a wallboard-drying kiln at the USG Sweetwater plant in place of air heated by

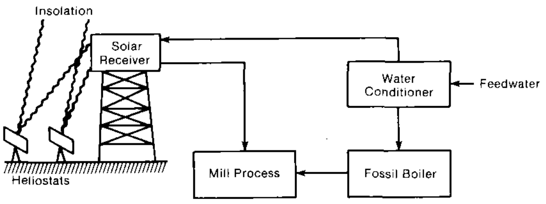


Figure 2-29. **Gulf Mineral Resources Company's Mt. Taylor Uranium Mill Solar Repowering Project Schematic**

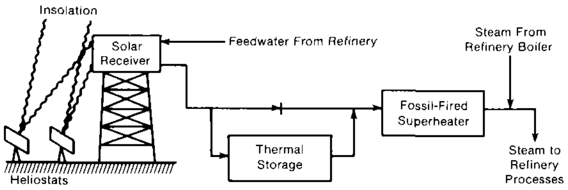


Figure 2-30. **Provident Energy Company's Sweetwater Plant Solar Repowering Project Schematic**

tural gas combustion. For the No. 2 kiln, this would represent a savings of about 25% of the yearly gas usage. The solar-heated air would be mixed with kiln recirculating air and passed over wallboard moving through the kiln in a 14-high deck arrangement. This hot air dries the board as it moves through the 61-m (200-ft) long kiln. This project could be designed and built in about two years.

Compressed air would be heated to a maximum of 724°C (1335°F) in the receiver, expanded through a turbine which drives the compressor, and delivered to the two furnaces of the board kiln at temperatures up to 500°C (932°F). A schematic of this project is shown in Fig. 2-31.

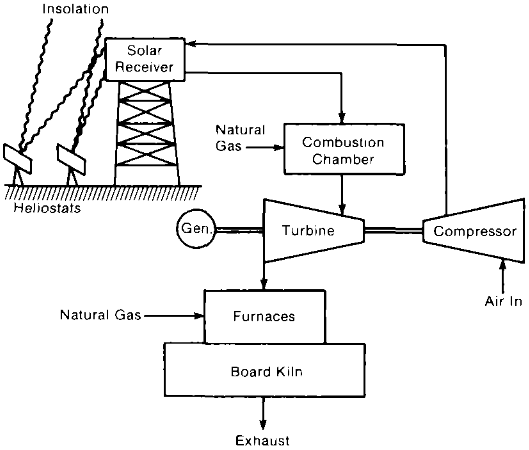


Figure 2-31. U.S. Gypsum Company's Sweetwater Plant Solar Repowering Project Schematic

Valley Nitrogen Producers, El Centro Ammonia Plant

Prime Contractor: PRF Engineering Systems, Inc.
Subcontractors: Valley Nitrogen, McDonnell Douglas

The objective of this solar repowering project is to displace natural gas presently used in the combustion chamber of the primary methane-steam reformer. A solar central receiver is the baseline system. It will operate in parallel with the existing fossil-fired reformer. This configuration will provide a peak solar utilization of 34 MW_t, or a total annual contribution of 23%. Other than the production of steam in a separate boiler, the reformer is the only major energy consumer in the fertilizer manufacturing plant. This project could be designed and built in about four years.

The proposed baseline system employs a solar central cavity-type receiver operating in parallel with the existing fossil-fired reformer. Methane and steam flowing inside the receiver tubes react catalytically to form a hydrogen-rich product gas utimately used to prepare ammonia. The solar retrofit's characteristics and its interface with the existing plant are simple, incorporating state-of-the-art components with proven technology. The retrofit does not alter the normal plant operation. No storage system or complex control is required. The solar reformer will be directly connected to the fossil reformer by an insulated piping system. During the day, a fraction of the process flow will be routed to the solar reformer and the energy will be provided by the heliostat field. At night, all of the process flow is routed to the existing fossil reformer, and the solar reformer is shut down. A schematic of this project is shown in Fig. 2-32.

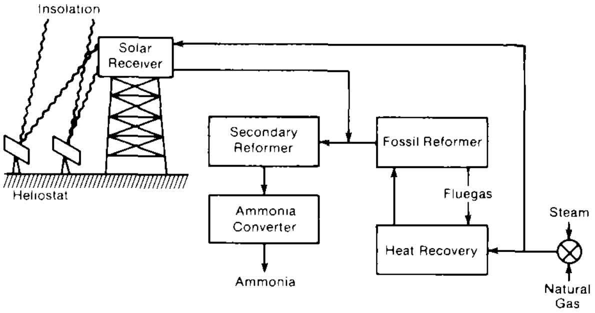


Figure 2-32. Valley Nitrogen Producer's El Centro Ammonia Plant Solar Repowering Schematic

2.2.4 Cogeneration

Cogeneration refers to the combined production of electrical and/or mechanical energy and other useful heat energy. The expected increased efficiency and the potential fuel savings in systems making use of cogeneration applications and the identification of industrial process heat markets for solar cogeneration resulted in DOE initiating a solar cogeneration solicitation through the Solar Central Receiver program. A Request for Proposals was issued in April 1980; in July, seven proposals for design studies were selected for negotiation.

The seven proposals selected include a wide range of geographic areas and address several potential applications not previously explored; i.e., sulfur mining, copper smelting, enhanced oil recovery, natural gas processing, sugar mill operations, and space heating and cooling.

Solar cogeneration offers several potential advantages over conventional power generation: the use of solar energy can reduce the consumption of fossil fuels; the heat produced as a by-product of the electric power generation can be usefully applied rather than simply being dissipated as waste; and the higher efficiencies inherent in cogeneration can reduce the amount and cost of the solar collection equipment required.

Each of the proposals was submitted by a designer/builder for a particular existing industrial or commercial application. The designer/builder, application, and site for each proposal follow.

- General Electric Co., with Texas Gulf Chemicals Co., will study using solar hot water and steam for electricity and process heat for sulfur mining wells at Fort Stockton, Texas.
- Gibbs and Hill, Inc., with Phelps Dodge Corp., will study using solar heated air for electricity and copper smelting at Playa, New Mexico.
- Exxon Research and Engineering Co., with Pacific Gas and Electric Co., will study using solar steam for electricity and enhanced oil recovery at Exxon's Edison oil field near Bakersfield, California.
- Bechtel National, Inc., with Amfac Sugar Co., will study using superheated solar steam for electricity, mechanical energy, and process steam at the Pioneer Sugar Mill on Maui, Hawaii.
- Black & Veatch, Consulting Engineers, with Central Telephone and Utilities Corp., will study using solar steam for natural gas processing at an existing gas/electric utility cogeneration plant in southwest Kansas.
- Westinghouse Electric Corp. and the United States Air Force Logistics Command will study using solar steam to produce electricity and space heating and cooling at Warner Robins Air Force Base, Georgia.
- McDonnell Douglas Corp., with the Department of the Army, will study using solar-heated molten salt to provide steam for electricity and for heating and cooling at Fort Hood, Texas.

2.2.5 WPRS Study

Following initial discussions with ERDA and DOE, first begun in 1975, regarding the potential application of solar thermal central receiver electric power generation technology to meet increased power demand in the Southwest, an Interagency Agreement was executed February 9, 1979, between the DOE San Francisco Operations Office and the Lower Colorado Regional Office of the Bureau of Reclamation (now the Water and Power Resources Service—WPRS), Department of the Interior (DOI). To implement this agreement, $200,000 in operating expenses was jointly funded by DOE and DOI. This provided for a one-year "appraisal" (equivalent to "concept definition" in DO[illegible] terminology) of the feasibility of interating a 100-MW$_e$-scale central receiver power plant into the Hoover-Parker-Davis hydroelectric grid, in a way that would use reservoir storage capacity in place of thermal storage or fossil-fired backup capacity. The appraisal, completed in February 1980, concluded that 100 MW$_e$ of solar peak capacity could be readily accommodated without modification of current hydroelectric, conservation, water allocation, or recreation commitments, and identified prime and back-up sites on Federal land at Yuma, Arizona, and Mormon Mesa, Nevada (at the northern end of Lake Mead).

The solar plant would be installed somewhere in the Lower Colorado Region. When the sun is shining, power from the solar plant would be carried by a connecting powerline to a nearby substation. When the sun is not shining, power would come from the hydroelectric generators. The reservoirs in the hydroelectric system would store energy in the form of retained water when the solar plant is operating, and generate power when the sun is not shining. Power from the hydroelectric generators would be carried to the substation by existing powerlines. The substation would be the common point for the two generating sources—the solar plant and the hydroelectric generators. In this way, power customers would be assured a continuous, dependable power supply.

The report of the WPRS study, released at the end of September, was used as the basis for a Service budget submission for the next, "feasibility," stage (i.e., preliminary design, cost estimates, and economic analysis). In mid-September, the Service was advised that the Congress would authorize the feasibility study; it is not yet known whether the required funds will be provided in the regular or supplemental FY 1981 budget for the Service.

2.3 INTERNATIONAL ENERGY AGENCY PROJECTS

The International Energy Agency (IEA) is an association of countries established to promote international cooperation in the research and development of energy systems. Participating countries in the solar thermal IEA program are Austria, Belgium, Germany, Greece, Italy, Spain, Sweden, Switzerland, and the United States. IEA projects were initiated in October 1977; the initial term of the program is 6 years. The total anticipated construction cost is \$30 to \$40 million, and the U.S. share is 20%.

The primary objective of the Small Solar Power Systems (SSPS) Project is to demonstrate the feasibility of small central station electricity generation from a solar heat source. Two different engineering concepts have been selected to compare performance, reliability, and economics at the same site. The particular design features have been chosen with a view complementing rather than duplicating experience to be derived from other national solar power projects now being planned or under construction. They are to employ available technology with a minimum of component research and development. The site chosen is near Almeria, Spain.

Engineering design was conducted to identify as accurately as possible the estimated project cost. In March 1978, two design contracts were placed and were awarded. The central receiver design concept was awarded to an industrial consortium headed by the German firm Interatom. The distributed receiver design concept was awarded to a consortium headed by the American firm Acurex.

2.3.1 Central Receiver System

An array of sun-tracking mirrors focuses solar radiation onto a small receiver centrally located at the top of a high tower (Fig. 2-33). The heat collected in the receiver is transferred to a working fluid (liquid metal) which, in a suitable engine, provides the mechanical energy to drive the electric generator.

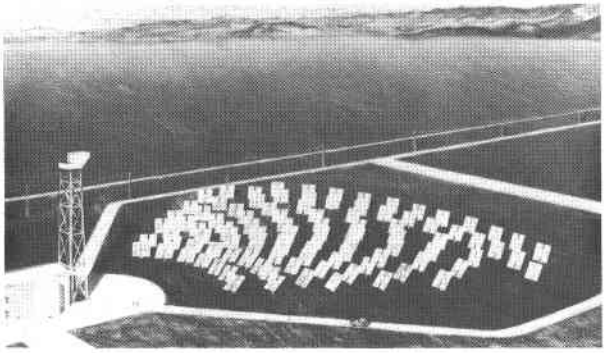


Figure 2-33. IEA Central Receiver Project

The final SSPS Central Receiver System has an estimated output of 500 kW_e. The anticipated lifetime is 10 years, and operation time is more than 2500 hours annually at rated output in interconnected grid or stand-alone mode (variable output 10% to 100%). In this power plant, solar radiation is concentrated by a heliostat field with 3660 m^2 of reflective surface. The 93 individual heliostats of the Barstow pilot plant design are arranged to maximize the solar energy input to the cavity receiver (9.7-m^2 aperture) located 43 m above ground in the tower. Sodium is the heat transfer medium for the cavity receiver. Temperatures at inlet and outlet of the cavity receiver are 270° (518°F) and 530°C (986°F), respectively. A two-tank thermal storage system is proposed to be used with this system having sodium as a storage medium. The steam outlet temperature is 510°C (950°F) with a net electric output of 517 kW_e.

The data collection is performed by a computer and covers the real-time data acquisition, data conversion, and display, as well as plant performance analysis. Assumptions of these calculations are to be proven by the operation of the project in Spain.

2.3.2 Distributed Collector System

Solar radiation falling onto a large number of mirrors (Fig. 2-34) of short focal length is concentrated onto pipework containing a working fluid to which the heat is transferred. The fluid then transfers its heat to a conventional steam turbine. Owing to the large amount of pipework required, the design rating of 500-kW_e output is considered the largest practical size in which this design concept can be constructed and operated.

An important feature of the design is the side-by-side location of two collector fields of equal size that use different approaches. One field consists of 10 loops of 60 collectors manufactured by Acurex, the other field consists of 14 loops of 6 collector modules developed by MAN.* Both are the line-focusing parabolic trough type. The Acurex collectors track the sun in a single-axis mode. The MAN collectors employ two-axis tracking to maximize daily energy collection.

The field area for Acurex and MAN collectors are 2674 m^2 and 2688 m^2,

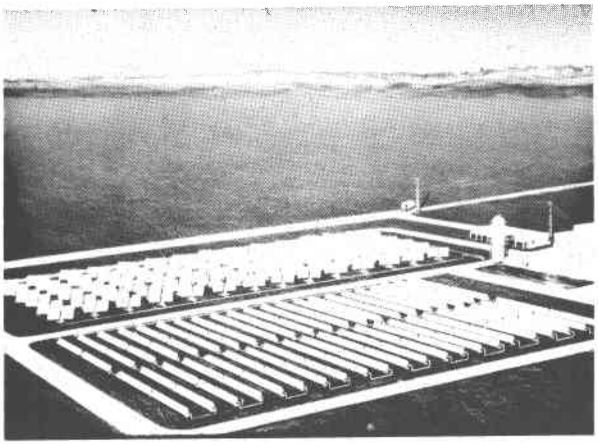


Figure 2-34. IEA Distributed Collector Project

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*MAN-Neue Technologie, a German firm that is part of the consortium headed by Acurex.

espectively; the total aperture area is 5362 m^2. Collector outlet temperature is 295°C (563°F). Systems make use of one-tank thermocline thermal storage with thermal oil as storage medium.

The heat transfer and power conversion system has been designed with three heat transfer loops. The first loop circulates low-temperature oil through the collector field to the top of the storage tank, the second is the sensible heat oil storage loop, and the third circulates water/steam which transfers heat from storage through the turbine to drive the electric generator.

2.3.3 Progress During FY 1980

During FY 1980, the major achievements for the IEA Central Receiver and Distributed System Project were:

- completion of critical design reviews for both the central receiver system (CRS) and distributed collector system (DCS) plants,
- start of construction for both CRS and DCS plants,
- completion of CRS heliostat field foundations and field wiring,
- completion of DCS collector foundations and field wiring, and
- start of installation of both CRS and DCS equipment at the site.

Important planned activities for FY 1981 are:

- completion of all site civil work,
- installation of all CRS and DCS equipment and components,
- complete functional testing and acceptance testing of both the CRS and DCS plants, and
- beginning the planned two years of test and operations of both the CRS and DCS plants.

SECTION 3.0

LINE-FOCUS CONCENTRATING COLLECTOR PROGRAM

The Line-Focus Concentrating Collector Program of the Solar Thermal Energy Systems Division is responsible for the development of mature line-focus concentrating collector technology that can be used in thermal energy applications between 100° C and 550° C. The major objective of the program is to provide reliable energy from solar radiation for appropriate utilization sectors at the lowest possible cost. Accomplishing this objective will permit line-focus systems to enter the market at the earliest point that they become competitive with other energy suppliers.

Experiments using the technology in particular applications are being sponsored to ensure the development of complete systems that use line-focus concentrating collector technology to maximum advantage. These experiments, which are conducted in a nonlaboratory environment, will encourage the private sector to develop engineering capabilities for designing and constructing commercial systems and will educate the entire community in operating and maintenance requirements.

The Solar Thermal Line-Focus Concentrating Collector Program is structured around two major technical tasks:

- technology development that includes the development and evaluation of components and subsystems of line-focus solar energy systems; and
- systems and applications development that includes system-level analytic and engineering activities together with the planning and implementation of field application projects for line-focus systems.

3.1 LINE-FOCUS SYSTEMS TECHNOLOGY DEVELOPMENT

The goal of this program element is to develop components and subsystems that use midtemperature line-focus solar collection and conversion technologies. The objectives of the effort are (1) to bring the applicable technologies to a final state of development and (2) to determine the performance, durability, and operation and maintenance characteristics of the components and subsystems. Specific summaries of FY 1980 activities and FY 1981 plans are presented for (1) Linear Concentrator Technology, (2) Hemispherical Bowl Technology, (3) the Midtemperature Solar Systems Test Facility, and (4) Storage Technology.

3.1.1 Performance Prototype Trough

Development of the performance prototype trough began in 1979 as an effort to apply lessons learned during the development of first-generation parabolic trough collectors. The effort undertook to improve peak performance to 60% from the 40% to 50% performance of first-generation troughs. Also, durability in terms of component life was to be improved from less than 3 years to 20 years. First-generation designs did not lend themselves to mass production, a feature necessary for achieving low cost; consequently, the new effort emphasized improved designs that would be suitable for mass production.

The first step in this project was in-house development. That resulted in the engineering prototype trough which achieved 60% peak efficiency. At the same time, different manufacturing concepts were investigated to adapt trough designs to mass production processes. Four different structural designs were obtained from industry. Prototypes of the designs were fabricated from soft tooling and were tested as described below. The final step in the Performance Prototype Trough Project will be to assemble each of the four designs into 24-m (80-ft) drive strings, integrate them in a delta T string* with tracking and control systems, and perform system tests. This process will provide reliable performance, operation, maintenance, and cost data.

Work performed on this project during FY 1980 is summarized in the sections that follow.

3.1.1.1 Sheet Metal Reflector Structure

Using a mass-production automotive-type sheet metal stamping technology for the fabrication of the solar collector reflector structure apparently offers a low-cost approach to the major cost item in the collector. During FY 1980, the Budd Company designed and fabricated prototype tooling for 1- x 2-m linear parabolic stamped sheet metal structures (Fig. 3-1) with adhesively bonded glass mirrors. Evaluations of tool-made samples of these structures indicate that this mass-production technology can meet the goal for surface contour accuracy. During FY 1981, the 1-x 2-m reflector structures will be assembled into a complete collector for evaluation of thermal, structural, and environmental performance. The Budd Company will gain sufficient experience with this manufacturing process so that reliable production cost estimates can be made.

Figure 3-1. Sheet Metal Reflector Structure

3.1.1.2 Sheet Molding Compound (SMC) Reflector Structure

Utilization of mass-production automotive-type sheet molding compound technology for the fabrication of the solar collector reflector structure offers another low-cost approach to the major cost item in the collector. In this approach, the glass mirror can be molded into the structure, thereby eliminating the need for subsequent bonding operations. During FY 1980, the Budd Co. designed and fabricated tooling for 1- x 1-m linear parabolic SMC structures with molded-in glass mirrors (Fig. 3-2). Tool-made samples of these structures were evaluated, indicating that this mass-production technology can meet the criterion for contour accuracy. During FY 1981, the 1- x 1-m reflector structures will be assembled into a complete collector for evaluation of thermal, structural, and environmental performance.

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*A delta T string is a group of collectors assembled together or controlled in such a way as to provide a specified difference in temperature between the inlet of the group and the outlet from the group. The difference in temperature is dictated by the thermodynamic requirements of the design and the application.

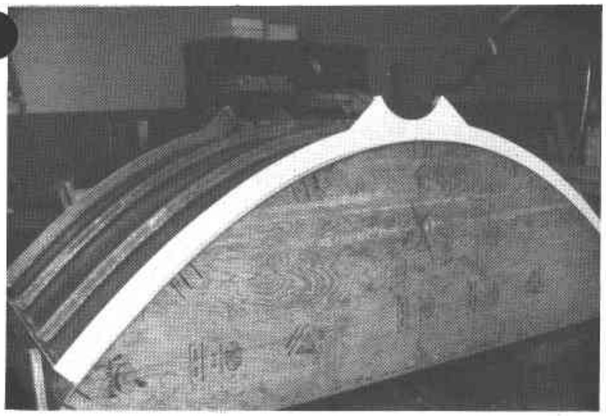

Figure 3-2. **Sheet Molding Compound Reflector Structure**

3.1.1.3 Sandwich Reflector Structure

Using sandwich structures permits the fabrication of the collector reflector structure in full-size modules of 2 x 6 m. During FY 1980, evaluation was continued of steel-skinned/aluminum-cored honeycomb structures fabricated by Hexcel (Fig. 3-3). Experience has shown that the parabolic contour remained stable and there was no breakage of the chemically strengthened glass mirrors fabricated by Corning. During FY 1981, Parsons will develop 2- x 6-m honeycomb reflector structures in which glass mirrors will be bonded to aluminized steel skins in the flat before forming the structure. These reflector structures will be assembled into a complete collector for evaluation of thermal, structural, and environmental performance.

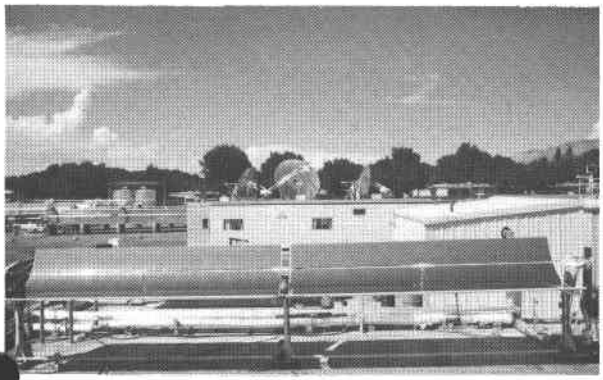

Figure 3-3. **Hexcel Sandwich Reflector Structure**

3.1.1.4 Laminated Glass Reflector Structure

Mass production automotive-type windshield manufacturing technology can be utilized to thermally form and laminate glass mirrors which can then be supported by a steel space frame. During FY 1980, Ford Glass Division and Pittsburgh Plate Glass Industries sagged 1- x 1-m glass sheets using the gravity-sag and press-forming techniques with production-type tooling. Evaluation of prototype mirrors indicates that the contour accuracy goal has almost been reached. A mockup of the space frame to support the glass mirrors was completed (Fig. 3-4). During FY 1981, both Ford and PPG will develop laminated mirrors using a thin silvered glass sheet laminated to a thick glass sheet for structural stiffness. These reflector laminates will be assembled into a complete collector for evaluation of thermal, structural, and environmental performance.

3.1.1.5 Wind Loads Definition

The determination of wind loads on collectors is necessary to engineer them with sufficient structural strength in the collector design while minimizing the amount of material used. During FY 1980, pylons for the collectors at the Willard Project were instrumented to measure lift and drag forces to verify wind-tunnel measurements taken the previous fiscal year by Colorado State University. Wind tunnel tests showed that peak lift and drag forces

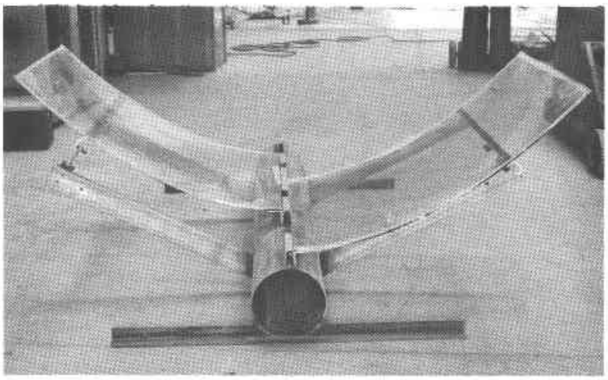

Figure 3-4. **Laminated Glass Reflector Structure**

were factors of 2 and 4, respectively, less than had been used in the design of first-generation collectors. Instrumentation checks at Willard confirmed the wind-tunnel data.

During FY 1981, pressure distribution will be measured on full-scale collectors to correlate with pitching moment coefficients measured in the wind tunnel.

3.1.1.6 Receiver Development

The nonevacuated parabolic trough receiver has been identified as having the best cost/performance ratio for the immediate future. During FY 1980, testing at the Midtemperature Solar System Test Facility (MSSTF) using this receiver design and Custom Engineering, Inc. reflectors (Fig. 3-5) have resulted in 63% peak noon thermal efficiency at an output temperature of 315°C. Antireflection-coated glass jackets were tried to see whether performance of receivers improved. Receiver performance did improve, from 62% to 64%, at 315°C. Mechanisms designed to accommodate receiver expansion are being evaluated on an accelerated-time tester designed and fabricated by EG&G. During FY 1981, receiver assemblies will be evaluated for thermal and environmental performance.

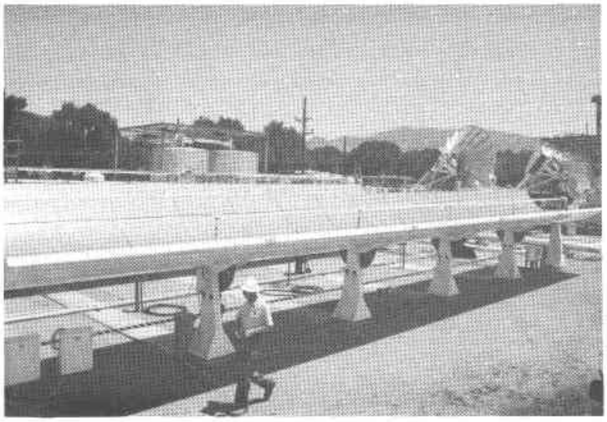

Figure 3-5 Nonevacuated Parabolic Trough Receiver Testing at the Midtemperature Solar Systems Test Facility

3.1.1.7 Black Chrome Selective Coating Development

Receivers for parabolic trough collectors require a coating with high absorptance in the visible spectrum and low emittance in the infrared spectrum. Black chrome has been utilized widely as a selective coating, but its durability at temperatures above 260°C is a significant problem. During FY 1980, laboratory research programs have systematically examined cause and effect relationships in plating chemistries so that the best plating process can be specified. During FY 1981, the process specification will be checked in an industrial plating shop using full-scale tanks.

3.1.1.8 Insulated Metal Hose for Thermal Transport

Insulated metal hoses are used to convey heat transfer media between the solar receiver and the field distribution piping. The hose does not interfere with the receiver tracking motions, and is not affected by the thermal expansions and contractions of the thermally cycled elements of the field. During FY 1980, proposals were solicited from leading hose manufacturers for a development and testing effort to determine the impact of variables in the design and deployment of hoses upon their durability. In the absence of acceptable proposals, a test program was undertaken to determine how long candidate products would last in typical use. A tester was designed and built, and hoses from various manufacturers are currently undergoing testing. During FY 1981, testing will continue to determine the best deployment configuration, define expected hose life, and evaluate insulating materials for cost-effective conservation of collected energy.

3.1.1.9 Drivers

The driver for line-focusing collectors is a mechanism for rotating a string of collectors for tracking the sun and for stowing the collectors in a particular orientation. Activity during FY 1980 concentrated on defining the size and performance requirements, investigating potential suppliers, and developing a test stand (Fig. 3-6) which has the capability of measuring performance of drivers under various load conditions. During FY 1981, drivers will be procured, tested on the test stand, and incorporated into a collector system for evaluation of mechanical and environmental performance.

3.1.1.10 Tracker/Controller

The tracker/controller performs the integrated functions of collector tracking, fluid control, system safeties monitoring, and system status display. During FY 1980, Honeywell designed a prototype tracker/controller utilizing microprocessor computer technology. During FY 1981, breadboard and production prototype versions of the tracker/controller will be evaluated.

Figure 3-6. Test Stand for Measuring Performance of Drivers

3.1.1.11 Fluid Control

Control of the heat transfer fluid temperature is necessary to obtain the highest possible temperature without exceeding the temperature limits of the fluid and receiver tube. Control is also required to maintain relatively constant output temperature under widely varying conditions of solar input. During FY 1980, computer simulation studies of a proposed control concept were completed. The concept consists of a motor-driven control valve in each delta T string of the collector field. A simple proportional control algorithm operating off the output temperature of the delta T string was used to control the motor-driven valves. The simulation results indicated that the objectives of holding the outlet temperature within 2.8°C (5°F) under steady conditions and within 28°C (50°F) under transient conditions could be satisfied with the proposed control concept. Tests of the proposed concept were performed on a 73-m (240-ft) string of collectors at the MSSTF. The test results confirmed the simulation studies showing that stable control within the desired temperature tolerances can be achieved. During FY 1981, efforts will consist of incorporating these fluid control concepts into Honeywell's Tracker/Controller design.

3.1.1.12 Piping Layout Studies

A parallel study focusing on the piping layout for a modular 4645-m^2 (50,000-ft^2) parabolic trough collector field was conducted during FY 1980 at Jacobs Engineering and Sandia National Laboratories, Albuquerque (SNLA). The modular design concept is desirable because the high costs of custom system designs can be eliminated and the uniformity and reliability of solar collector fields will be increased. Design points used in the study were concerned with thermal and electrical parasitics, capital costs, and collector performance. The annual parasitic cost of operating the modular field was used as the criterion for determining the best modular field design. Various field designs were considered by changing the pipe and insulation sizes, the length of the delta T string, and the spacing between rows of collectors. Sensitivity analysis was used to determine how well the minimum-annual-cost modular field performs under different operating conditions. During FY 1981, a design manual for piping layouts will be developed.

3.1.1.13 Heat Loss in Collector Field Piping Installations

The effects of thermal conditions of collector field components—such as piping, valves, and receiver tubes—on daily integrated field heat loss was evaluated quantitatively during FY 1980 in the Heat Loss Test Loop (Fig. 3-7) of the MSSTF. Significant thermal losses were found to occur (1) in piping manifolds*; (2) in valves, gauges, and pipe anchors; and (3) from thermosiphoning in pipes. Computations of solar collector field performance typically underestimate the magnitude of thermal losses over the entire field because they ignore the effects of these components.

Heat loss in piping manifolds is a principal parasitic factor that decreases the thermal efficiency of parabolic trough

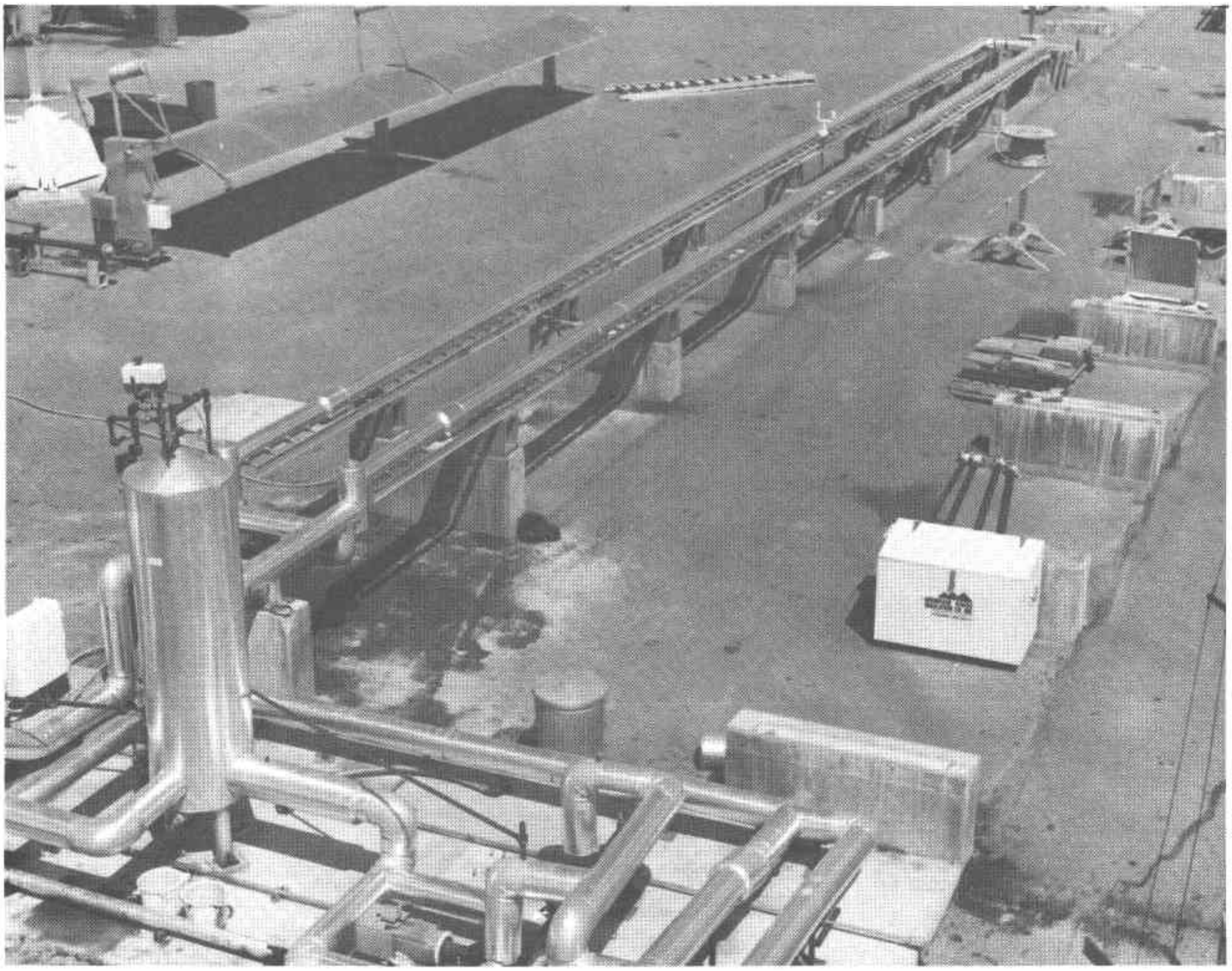

Figure 3-7. Heat Loss Test Loop at the Midtemperature Solar Systems Test Facility

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*A manifold is a pipe with several lateral outlets for connecting one pipe with others.

collector fields. Valves, gauges, and pipe anchors can also have major effects because they are usually highly conductive and uninsulated. They act as a direct heat path from the piping through the pipe insulation to the outside air. In a well-insulated piping installation, such components may, in fact, represent the dominant path for thermal heat loss in a collector field. They not only cause thermal loss while the fields are operating, they also accelerate thermal losses overnight as the collector field and associated piping cool.

Another primary source of accelerated thermal loss during overnight cooldown is thermosiphoning, a mechanism whereby convective currents circulate within the hot fluid as a result of the temperature difference set up by colder components. Thermosiphoning also occurs between cold receiver tubes and hot, insulated piping manifolds.

During the first part of FY 1981, a report will be produced that summarizes this work and that addresses general heat loss in parabolic trough collector fields. In addition, new pipe anchor designs will be evaluated.

3.1.2 FMDF Hemispherical Bowl Technology

DOE has examined fixed-mirror, distributed-focus (FMDF) technology development at the Crosbyton Solar Power Project, supplemented by a low-priority line-focus technology development program. These are discussed in the sections that follow.

3.1.2.1 FMDF Technology Development Project

Fixed-mirror, distributed-focus solar energy technology uses large, hemispherical, fixed-aperture collectors to concentrate solar energy on tracking linear receivers. FMDF systems operate at temperatures up to 750°C and have a broad range of applications. However, because of their fixed apertures, their annual energy production on a unit basis is less than that for tracking systems. Using an FMDF, therefore, is economical only if systems can be produced at low cost so that performance/cost ratios are competitive with other solar energy technologies.

During FY 1980, FMDF technology development consisted of preparing a program plan and a simulation model of a 5-MW_e power plant and investigating stresses in spherically curved glass mirrors. The program plan emphasizes design and development of components, subsystems, and systems to improve both performance and economic potential. The plan entails a low-cost program and provides for cost-sharing projects with the private sector when analyses show that the economics are favorable. The plan is being amended on a relatively low priority in line with changing solar energy policies.

The simulation model employs SOLTES, a general-purpose code for evaluating the performance of solar energy systems. The code was used with a 5-MW_e power plant. SOLTES incorporates a variable, small-community electrical load and the TMY weather data. The model includes the major components of a power plant—collectors, turbines, etc.—and a complete two-phase piping network and thermocline storage. At the end of FY 1980, the model was complete except for the thermocline storage. Work is continuing on the mathematical model of the storage component.

To keep the cost of FMDF systems low, elastically formed, commercial-grade float glass was used as the reflective material for FMDF 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 local low-level temperature radiation caused by multiple-bounce reflections on the surface of FMDF collectors. In FY 1980, two contracts were placed to analyze stresses in spherically curved glass mirrors. The first, with Shelltech Associates, is for an analytical determination of stresses; the other, with the Naval Research Laboratory, is to determine stresses experimentally. These contracts will be completed in FY 1981.

3.1.2.2 Crosbyton Solar Power Project

The Crosbyton Solar Power Project began in 1976 with an effort to develop a conceptual design for a 5-MW_e solar power plant to serve the city of Crosbyton, Texas. That conceptual design was the basis for the design of the Analog Design Verification System (ADVS), for which construction was completed in FY 1980.

The ADVS (Fig. 3-8) is a scaled-down version, 20 m in diameter, of a 60-m-diameter collector planned in a 10-module array for the Crosbyton solar power plant. The ADVS consists of 438 spherically curved glass mirror panels, each about 1 m^2, that focus incoming sunlight onto a 5.5-m-long receiver made up of two helically wound 0.635-cm (0.25-in.) ID tubes. These tubes are the same diameter and length (122 m) as those projected for the full-scale system. In line with the bowl collector concept, the mirror panels are fixed, providing potentially low-cost, rugged mirror structures. Tracking the sun is accomplished by moving the receiver. The receiver operates as a boiler heating incoming water to provide steam up to 538° C (1000° F) and 6.89 MPa (1000 psi).

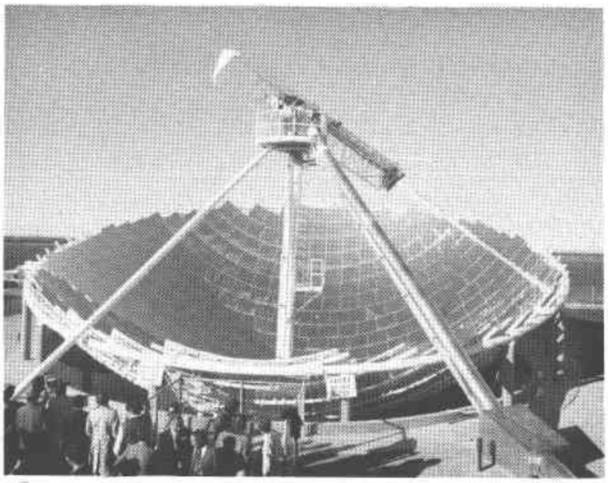

Figure 3-8. Analog Design Verification System 20-m Bowl Collector

The ADVS has provided experimental data for more than a year [1]. The most important finding is that a bowl collector can be built that produces usable energy as efficiently as prior studies had predicted. At solar noon on July 29, 1980, the sun passed normal to the ADVS's aperture, and the collector thermal efficiency was measured at 63%.

Experimental data have shown a very high degree of accuracy in analysis techniques and computer codes used in the early phases of the project. The data will make possible even more detailed performance and design analyses as the project proceeds toward construction of the full-scale system. Operation of the ADVS has provided many practical insights that can be incorporated in subsequent plans and designs. Continued operation will add to the body of experience and data that will (1) provide detailed information about the bowl collector concept and its potential application and (2) serve as the basis for the final design of the Crosbyton solar power plant.

Some technical questions about bowl technology remain unanswered; the largest uncertainty in the technology's commercial future is its cost. A preliminary design of the full-scale collector that will be developed will identify in detail significant elements of fabrication and construction costs.

3.1.3 Midtemperature Solar Systems Test Facility

The Midtemperature Solar Systems Test Facility (MSSTF) (Fig. 3-9) at SNLA supports the DOE National Solar Thermal Program [2]. First called the Solar Total Energy Test Facility, it was established as

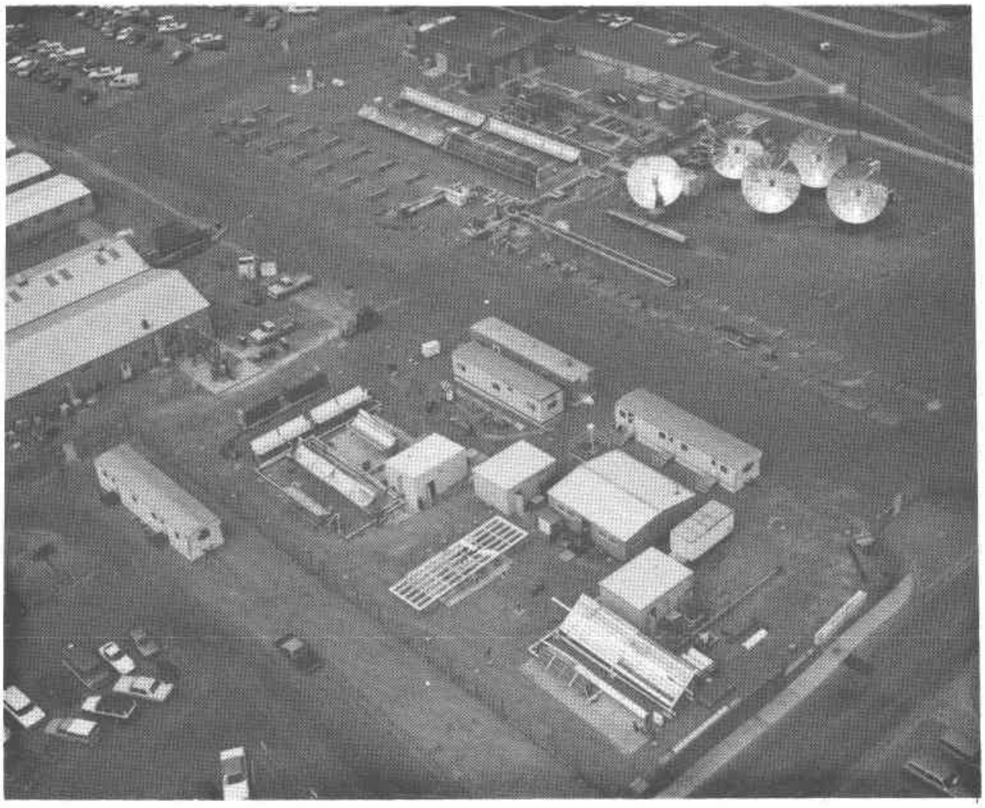

Figure 3-9. Midtemperature Solar System Test Facility

a national test laboratory (1) to develop technology that applies solar energy principles and (2) to demonstrate the feasibility of the solar total energy concept. After this objective was met, the name was changed in March 1978 to the Midtemperature Solar Systems Test Facility.

Research, development, and testing of materials and components at MSSTF provide data and experience that are important to larger system designs and commercial uses. Although MSSTF personnel manage the project and are responsible for system engineering, many private industries have provided equipment and helped install it at the test facility. By encouraging their participation, SNLA and DOE promote solar technology within the private sector.

3.1.3.1 Description

Two independent installations make up the MSSTF: (1) the Subsystem Test Facility (STF) and (2) the Collector Module Test Facility (CMTF).

The Subsystem Test Facility. The STF now operates as a multipurpose system and subsystem facility. Specifically, it supports research and development, including service-life evaluation and integration of components, subsystems, and systems. STF programs are:

- Performance Prototype Troughs
- Performance Prototype Trough Component Life Test
- Modular Industrial Solar Retrofit Systems Qualifications
- Pipe Heat Loss
- Thermal Siphon Program
- Mirror Cleaning Test Series
- Thermocline and Multitank Storage Test Series
- Shenandoah Prototype Dish Evaluation Program

The Collector Module Test Facility. The CMTF supports the development and evaluation of collector components, subsystems, and systems. Current CMTF programs are:

- Power Requirement Definition
- Collector Component/Subsystem/System Development
- Commercial Collector Evaluation
- Receiver and Tracker Evaluation
- Azimuth Tracking Collector Mounting Platform Operation (Aztrak)

3.1.3.2 MSSTF Major Accomplishments—FY 1980

Significant accomplishments at the STF include (1) demonstrating that commercial collectors have greater than 60% noontime efficiency; (2) defining heat losses from pumps, thermal siphoning, valves, and other components, so that these losses can be reduced in future field designs; and (3) establishing more than 10 new test capabilities in support of line-focus component/subsystem development. The CMTF accomplishments include (1) supporting more than 15 commercial suppliers in testing and development; (2) testing and collecting data on engineering prototype trough structure, receivers, drives, and tracker controls; and (3) qualifying two commercial test laboratories (DSET and Wyle). Detailed projects within the jurisdiction of the MSSTF during FY 1980 included:

(1) Systems Development:
  (a) 150-kW Solar Irrigation Project, Coolidge, AZ
    - Construction completed
    - Operation begun
    - System performance predictions validated
  (b) Operation of Willard and Gila Bend Irrigation Systems terminated

(2) Subsystems Development:
  (a) 60% efficiency performance goal demonstrated with engineering prototype and commercial troughs
  (b) Shenandoah dish prototype evaluation completed
  (c) Qualification of two private test laboratories, Wyle and DSET
  (d) Published annual thermal performance predictions for 8 line-focusing, concentrating solar collectors based on module test results
  (e) Multitank storage system characterized and control strategies investigated
  (f) Completed Raytheon Dish Test Program and qualification tests of IEA collector
  (g) Completed characterization tests of 6 commercial collector modules

(3) Components Development:
  (a) Thermal loop assembled and piping heat loss and thermal siphon mechanisms explained
  (b) Accelerated flex-hose testing initiated
  (c) Black-chrome thermal aging experiment initiated
  (d) Operation of Collector Drive Test Facility initiated
  (e) Pump heat loss testing initiated
  (f) Completed pump power and collector foundation tests

3.1.3.3 Progress in Relation to Goals

In FY 1980, a number of parabolic trough designs tested at the subsystem level exceeded 60% peak efficiency at 315°C, the 1980 performance goal. This accomplishment involved the use of silvered glass reflectors and improved receiver designs tested at the MSSTF. Also in FY 1980, the ability to accurately predict the thermal performance of entire systems, given accurate performance data on trough modules, was demonstrated. Based upon this predictive capability and the demonstration of much improved collector module performance, the next generation of collectors, which use glass reflectors, should exceed the 1980 performance goal of 3 million Btu/m^2 per year and may exceed the 1982-1985 goal of 3.3 million Btu/m^2 per year. A number of the Cycle 4 IPH experiments that are now being installed and the small power system being built by IEA should provide opportunities to confirm this level of energy production.

3.1.3.4 Future Activities

FY 1981 activities will include (1) continued test support for collector component development, (2) commercial support, (3) setup and evaluation of production prototype structures and associated components, and (4) setup and evaluation of modules supplied through the Modular Industrial Solar Retrofit Project (MISR).

3.1.4 SERAPH

The SERI Solar Energy Research and Applications in Process Heat (SERAPH) Facility has as its objective the investigation of technical concerns of low- and midtemperature solar thermal technologies. Specifically, these concerns are related to the design, operation, and maintenance of systems for industrial applications. SERAPH will increase experience in solar-powered industrial process heat generation. This experience will help to:

- improve understanding of system characteristics;
- resolve problems experienced in field tests;
- confirm analytical modeling tools;
- evaluate thermal conversion hardware;
- judge the relative merits of competing solar systems; and
- establish operating and control strategies.

It was decided during FY 1979 that SERAPH would be constructed at the SERI Field Test Site, which was to be on the land deeded to DOE by the State of Colorado. Reference 3 describes implementation plans and Ref. 4 discusses relevant control techniques. Figure 3-10 shows an artist's conception of how SERAPH will look when it is completed.

3.1.4.1 FY 1980 Activities

Efforts concentrated on SERAPH implementation tasks during FY 1980. The performance of the two major equipment subcontractors was monitored and redirected when technical insights caused the original equipment specifications to change.

SERI's architectural/engineering firm for facilities prepared a construction document package for the SERAPH physical plant. This package detailed the site layout, building plan, utility hookup, and collector field support system. The documents were modified to provide for installation at the SERI Field Site.

Major equipment fabrication and procurement for SERAPH were completed in FY 1980. Physical plant construction documents were released for contractor bidding in September 1980. A Safety Analysis Review, an Environmental Assessment, and a Safe Operating Procedure were prepared for DOE comment and review. It was determined that SERAPH operations do not depart significantly from the risks present in many routine industrial processes. The overall facility capabilities of SERAPH are discussed in detail in Ref. 3, and relevant analytical techniques are contained in Ref. 6.

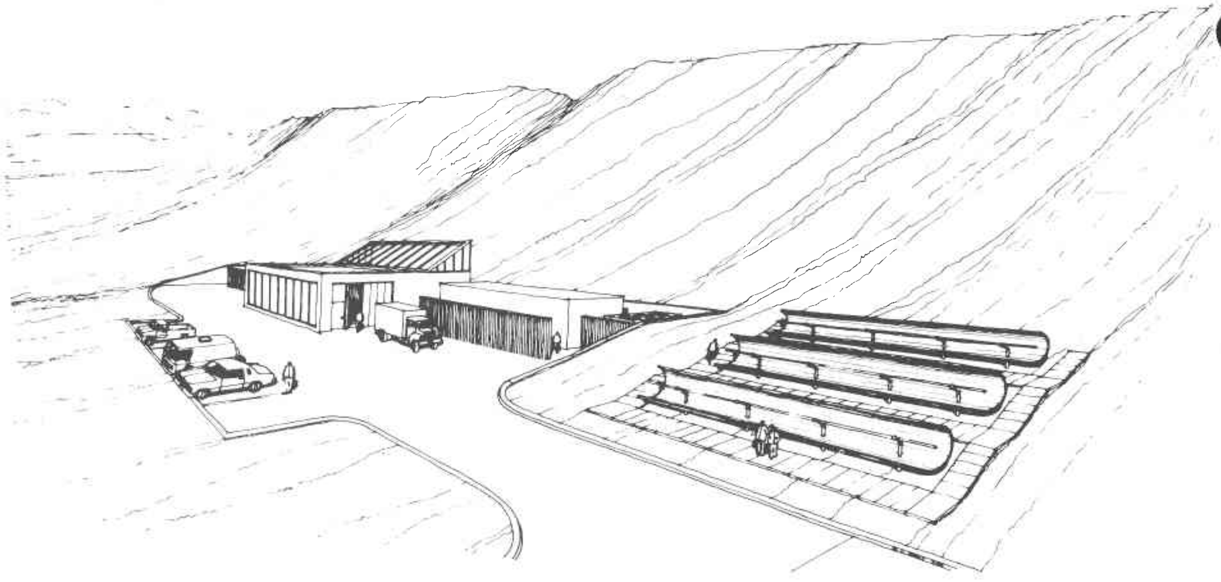

Figure 3-10. Artist's Drawing of SERAPH Facility

3.1.4.2 Future Activities

Construction of the SERAPH physical plant and equipment installation is scheduled for early FY 1981. Check-out and shakedown tests are to be carried out in the second quarter, and normal operations will follow. Initial use of the SERAPH facility will be directed at low-temperature (< 200° C) solar systems for industrial process heat. It is anticipated that other collector and storage devices will be added to the facility for evaluation when used with typical IPH thermal loads. Improved control strategies will be implemented when necessary or when promising techniques evolve.

3.1.5 Storage Technology

The development of storage subsystems that work effectively with parabolic trough solar collector fields is needed to provide an energy buffer during intermittent cloud cover, to extend periods of operation to nondaylight hours, and to provide energy for long periods of inclement weather when there is no insolation. Sensible heat storage presently is the most highly developed storage technology, and thermocline storage (Fig. 3-11) has the potential for meeting the cost requirements for use in commercial systems. During FY 1980, laboratory-scale facilities have been constructed for evaluation of diffuser designs. A 4.5-m^3 (1200-gal) engineering prototype thermocline storage tank was designed, fabricated, and installed in the Midtemperature Solar System Test Facility. Instrumentation and initial checkout have been completed. Testing will proceed through FY 1981;

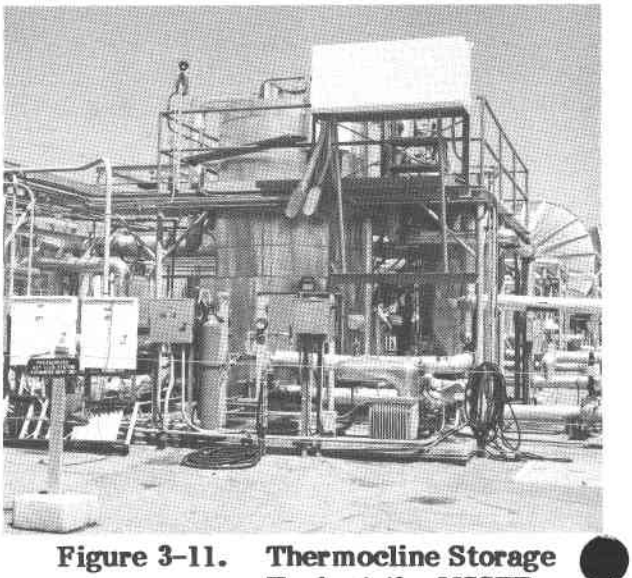

Figure 3-11. Thermocline Storage Tank at the MSSTF

principal areas of interest are diffuser effectiveness, heat-loss mechanisms, thermocline stability in both static and dynamic situations, and response of the thermocline to variations in collector field operation.

3.2 SYSTEMS AND APPLICATIONS

The objective of this program element is to develop solar energy systems for on-site applications through systems analysis, systems engineering, and experiments sponsored partially or entirely by DOE and performed in conjunction with the private sector. The experiments, in which conventional power is displaced by solar power, provide a focus for solar development, generate performance and cost data, and provide operating and maintenance experience.

3.2.1 Shallow Well Irrigation—Willard, New Mexico

At the Shallow Well Irrigation Project located near Willard, New Mexico (Fig. 3-12), the energy collected from 1200 m^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 request of New Mexico irrigation farmers. These farmers were hurt by the oil embargo, but threats of a natural gas shut-off made the situation even more serious. Gas shut-off of only a few days can ruin a crop—a farmer's only income for the year. Because of that situation, the State of New Mexico and DOE entered into a joint solar irrigation project. Sandia Laboratories and New Mexico State University were assigned the responsibility for conducting the project. Sandia was to design, construct, and operate an 18-kW solar thermal system to drive a deep-well turbine pump. NMSU was to conduct associated agricultural experiments.

The system was dedicated on July 8, 1977. The system used line-focus solar collectors manufactured by Acurex Corporation and an organic Rankine-cycle turbine manufactured by Barber-Nichols Engineering Corporation. It also incorporated 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 gpm) of water into a ground level reservoir from a depth of 30

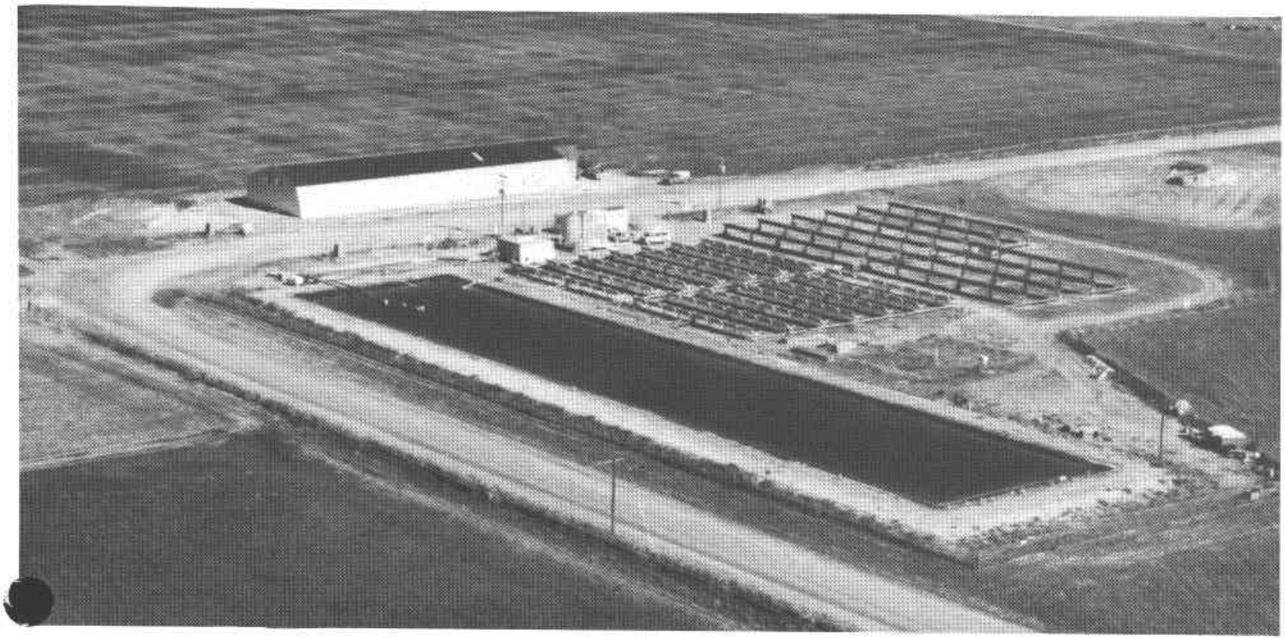

Figure 3-12. Shallow Well Irrigation, Willard, N.M.

m (100 ft). NMSU pumped the water from the reservoir as they wished to conduct agricultural experiments.

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 (1000 ft^2) of collectors manufactured by Solar Kinetics. Replacing the heat engine with a 38-kW engine was planned, but the best proposal was an engine just like the one there, but twice as powerful. Because of high costs and no new technological developments, plans for the new engine were dropped. A low energy center pivot irrigation system was added to the experiment to demonstrate how little energy was actually needed for irrigation. The new system operated as designed with a heat engine efficiency of 15%, the highest known for engines operating at the experiment conditions. The center pivot system required only a third of the power required by conventional systems. 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.

For purposes of economy, the operation of the system was contracted to NMSU in 1980. The farmers added a potato storage shed next to the solar experiment so that the solar system could furnish electrical energy to it during nonirrigation periods. An induction generator was added to the heat engine for this purpose. The system worked satisfactorily when in operating condition. However, the turbine would not operate more than 200 hours without major repairs. Flex hoses that connected the solar collector receiver to the manifolds also began to fail. These were replaced with more reliable flex hoses with multiple metal bellows.

Much valuable experience was gained from the solar irrigation 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. Many farmers in the experiment area now use the low-energy sprinkler systems.

NMSU is in the process of removing the experimental system from the site. The removal will be completed by August 1, 1981. A final experiment report [8] is being prepared by SNLA and NMSU.

3.2.2 Gila Bend Solar-Powered Irrigation Pumping Project

3.2.2.1 Background

The Gila Bend Solar-Powered Irrigation Pumping Project [9] was a cooperative venture of the Northwestern Mutual Life Insurance Company (NML) and Battelle Memorial Institute (BMI). The project was initiated in 1975 to provide a solar alternative to conventional energy sources for irrigation throughout the United States. The purpose of the project was to design, build, and operate a solar-powered irrigation pumping system. The system was installed at the NML Paloma Ranch near Gila Bend, Arizona, and operation was started in early 1977.

Operation during 1977 demonstrated that irrigation pumping using solar energy was feasible. Initial system problems were resolved and unattended operation was also demonstrated to be possible. Although the projected capital cost indicated that there would not be an mmediate market for the system, during system operation the functional requirements for practical solar irrigation systems became evident. Several modifications were needed for the system to meet these requirements.

In 1978, the project obtained DOE funding, and under the joint support of SNLA and NML, the system was modified to address early problems. Improvements included replacing a portion of the absorber tubes and housings, installation of a new tracking system, and addition of an electrical motor that could be used in conjunction with solar power or independently to drive the pump. BMI reported that the modifications made in 1978 did not improve the operation of the system, but merely substituted a new set of problems for the old ones [9]. Nevertheless, the system operated for 188 hours and pumped 32.8 million gallons of water, and significant information was gathered on hardware performance, component life, and maintenance requirements. BMI concluded that modest development work and extensive field testing are still required before farmers will accept solar-powered irrigation.

3.2.2.2 Description

The solar-powered irrigation pumping system, located on Paloma Ranch near Gila Bend, Arizona, is a commercial agricultural operation owned by NML. The ranch is approximately 70 miles southwest of Phoenix.

The solar irrigation pumping system returns tail water from a collection sump to a system of concrete-lined distribution ditches. Water is supplied to the irrigation system from a series of deep wells. The water is applied to the fields from the distribution ditches by siphons, in an amount approximately 10% above that required by the crop, and the resulting 10% runoff is recovered from the graded fields in a series of tail-water ditches. The solar irrigation pump returns the tail water, which collects in a sump, to irrigation ditches, servicing an area of approximately 5000 acres. The lift from the tail-water sump to the distribution ditches varies daily, ranging from 7 to 12 ft.

The system uses 511 m^2 of first-generation Hexcel (now Suntec) parabolic trough collectors on north-south axes. The reflective surface is FEK aluminized acrylic. The receiver is a 0.04-m (1-5/8-in.) copper collector tube with a black absorptive coating. The operating temperature is 150°C (302°F). Energy from the collector field powers a Rankine cycle turbine which can deliver 10,000 gallons of water per minute.

3.2.2.3 Operation During FY 1980

The objectives during FY 1980 included obtaining additional operating and maintenance experience and determining ways of improving the potential for unattended operation. Battelle Columbus Laboratories was responsible for operation and maintenance of the site under contract to Sandia National Laboratories. The contract, which ended in December 1979, resulted in July-November seasonal operation where the solar system operated in excess of 50% of the "good weather" time and pumped nearly 20 million gallons of irrigation water. The contract was terminated upon a final report from Battelle. Operation has been discontinued and there are no further plans for the system.

3.2.3 150-kW Solar Irrigation—Coolidge, Arizona

The Coolidge Solar Irrigation Project (Fig. 3-13) 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

Figure 3-13. Deep-Well Irrigation, Coolidge, Ariz.

run three 50-hp irrigation pumps located on the Dalton Cole Farm.

The facility is 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 as well as the supplier of the solar collectors. The major subcontractors to Acurex are Sunstrand Corporation and Sullivan and Masson Consulting Engineers. Sunstrand is the supplier of the organic Rankine-cycle power generation unit. The team of Sullivan and Masson and Acurex was responsible for the detailed design.

3.2.3.1 Description

The collector field is made up of 2140.49 m^2 (23,040 ft^2) of Acurex line-focus parabolic trough collectors arranged in eight loops having a north-south orientation. The collectors use Coilzak, an anodized polished aluminum, for their reflective surface. The reflectivity of the Coilzak, measured by a portable reflectometer, is 60%. The performance of this subsystem can be substantially improved by the use of better reflector materials. 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 exchange unit, 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 exchange unit to vaporize it 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 is Fig. 3-14.

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-volt ac, 60-hertz, 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. Various pumps, valves, and auxiliary tanks are included, and an underground tank is provided for the makeup heat transfer oil.

The control subsystem monitors and controls collection and storage of solar energy and generation and supply of electric power. In addition, the subsystem protects against system-related anomalies such as high temperatures in the collector field and natural events such as high, gusty winds.

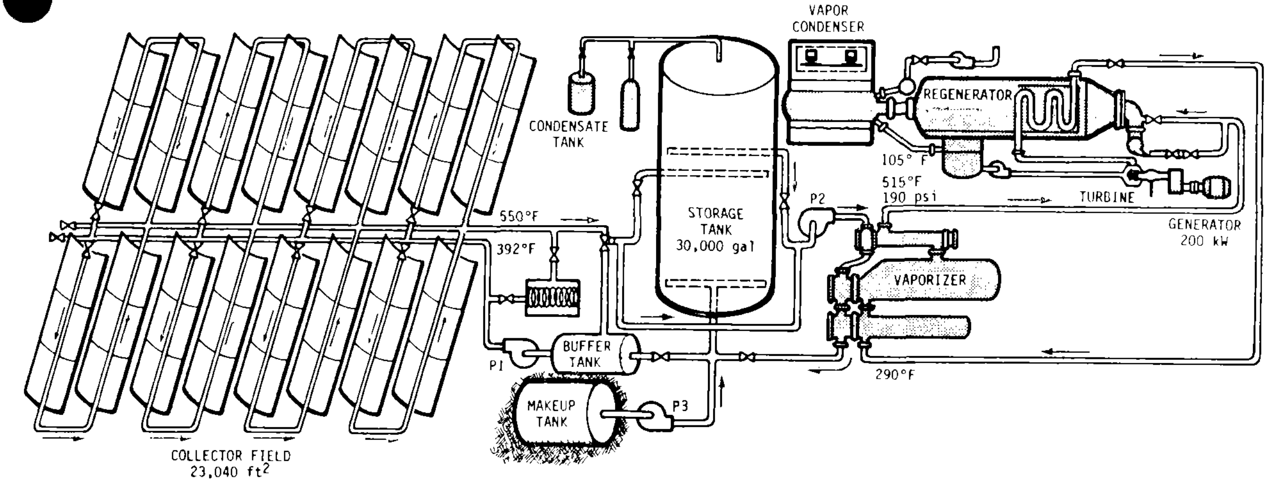

Figure 3-14. 150-kW$_e$ Solar-Powered Irrigation Facility Flow Diagram

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 consumer by the system.

3.2.3.2 Accomplishments—FY 1980

During FY 1980 the facility was dedicated and operation was begun; performance data were collected through the winter and summer solstices and through the spring and fall equinoxes; complete performance characteristics were determined for all elements of the system; and the system operated in excess of 85% of the good weather time, supplying 117,795 kWh of electricity to the utility grid.

System Performance. System performance for FY 1980 is summarized in Table 3-1. The line-focus solar collectors were oriented in a north-south direction to maximize the amount of energy collected in the summer when irrigation demands are highest. This orientation results in reduced energy collection in the winter. The use of Coilzak as the reflector material for the solar collectors contributes to poor winter performance because that material has low reflectivity. Year-round system performance can be improved by using better reflector materials. During January and February, 3787 kWh of electrical energy, in addition to that shown in Table 3-1, were produced from operating the gas-fired heater experimentally. Energy production in February and March was abnormally low because of problems with the pump seals in the collector field pump and in the turbine pump.

Operation and Recurring Maintenance Costs. Operation and recurring maintenance costs have been broken down into weekly costs for summer and winter. The costs cover operation 7 days per week. Operational costs include the man-hours required to initiate facility operation daily and to monitor operation. The power conversion system required operator attention during startup and some manual control. Direct operational costs include cooling water for the turbine's condenser, nitrogen for the expansion volume on top of the thermal storage tank, CO_2 for cooling the pump seals, and electricity for air conditioning the control room.

The labor for operation amounted to 30 hours per week. Direct costs are itemized in Table 3-2.

Table 3-1. Coolidge Collector Field Performance

Time of Year	Peak Efficiency (%)	All-Day Efficiency (%)
Winter Solstice	20	9.9
Spring Equinox	38	30.0
Summer Solstice	42	36.9
Fall Equinox	36	31.4

Monthly Operation	O	N	D	J	F	M	A	M	J	J	A	S
Electricity Produced (kWh)	1730	2850	2060	0	510	1440	12,480	19,250	22,000	20,895	18,530	16,050
(% of Time Solar Available)	89	95	82	91	49	60	93	95	93	98	100	95

	Total (W/m^2)	Pipe Loss (W/m^2)	Receiver Loss (W/m^2)
Collector Field Heat Loss	125	35	90

Table 3-2. Weekly Costs of Plant Operation

Operation Components	Summer	Winter
Water (municipal)	$20	$ 5
Water treatment	35	10
Nitrogen	5	5
CO_2	8	6
Electricity (air conditioning)	10	—
Total cost per week	$78	$26

Recurring maintenance costs include labor and the cost of supplies and replacement materials for those efforts. Table 3-3 lists a summary of the average weekly costs over the year, broken down for various subsystems.

Experience and Insights. Summarized here are lessons learned from the construction and operation of the facility.

(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 (TIG) 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.

Table 3-3. Weekly Costs of Recurring Maintenance

	Man-Hours	Materials
Solar collector	8.0	$15.20
Fluid loops	4.8	1.60
Power conversion	4.8	15.90
Total cost per week	17.6	$32.70

(f) Manholes on the side of a thermal storage tank are undesirable since 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, and 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 startup in cold weather using warm weather techniques has proven to be no problem.

3.2.3.3 Future Plans

During the coming year, system performance will continue to be monitored, and a report summarizing the first year of operation will be published [10]. In addition, the tests remaining in the test plan will be conducted. Some changes will be made to the facility to upgrade performance and to reduce operating problems. These changes will include the installation of FEK-244 reflective surfaces on the collectors and modifications to the plumbing system. The replacement of the present Coilzak reflector material with FEK-244 will improve the reflectivity of the collector surfaces from 60% to 85% when the surfaces are clean. A significant improvement in system performance is anticipated with the FEK-244.

The plumbing modifications will include (1) elimination of the buffer tank at the inlet to the collector field pump, (2) replacement of the present three-way butterfly diverter valve with a conventional spool-type three-way diverting valve, and (3) plumbing of the gas-fired heater in series with the collector field. Elimination of the buffer tank will also eliminate a source of heat loss and should shorten the warmup time of the collector field. The new three-way valve will eliminate leakage problems experienced with the old valve. (The old valve was allowing about 0.0006 m^3/s (10 gal/min) of oil to be diverted to the top of the storage tank during warmup when the oil is circulated through the collector field.) With the gas-fired heater operating in series with the collector field, it will be possible to generate electrical power throughout the winter, and the collector field ring will be used to preheat the Caloria.

Operation and recurring maintenance costs will be watched during the coming year to determine ways to reduce them. With cost minimization in mind, further steps will be taken toward complete automation of the facility.

Grain alcohol production processes and hardware are being studied to determine the feasibility of installing a facility on site for producing alcohol to fuel farm machinery. Alcohol would be produced using a portion of the energy collected by the solar collectors.

3.2.4 Modular Industrial Solar Retrofit (MISR) Project

MISR is a DOE project to develop modular solar thermal systems for use in industrial process heat (IPH) applications. The project is based on line-focus collector technology suitable for retrofitting low- to midtemperature thermal energy applications currently burning premium fossil fuels such as oil and natural gas.

3.2.4.1 Background

Much experience was gained in the application of line-focus solar energy systems from the shallow-well experiment at Willard, New Mexico; the deep-well experiment at Coolidge, Arizona; and from several solar IPH experiments. It became evident that installation costs were too high and that operational reliability was lower than the state of the technology indicated it should be. Also, the experiments showed that retrofit of low- to medium-temperature IPH applications are a logical next step for line-focus technology.

The MISR project developed from this experience. Its purpose is to develop modular solar thermal systems using line-focus solar collectors. Industry will perform the design work and conduct experiments to obtain system cost and performance data.

The U.S. industrial sector is currently responsible for about 25% of total U.S.

energy consumption. Of this amount, 65% is used to generate heat for industrial processes. Approximately 30% of all process heat requires peak temperatures of 315°C (600°F) or less. This percentage increases to 52% when preheating applications are included; hence, a significant amount of thermal energy is used in industrial processes and at temperatures that can be supplied by parabolic-trough solar collectors. Thus, a significant displacement of fossil fuels can be achieved by matching line-focus solar technology with industrial process heat applications.

3.2.4.2 Project Description

The project is planned as a sequence of three cycles, each consisting of system design and qualification and field experiments at industrial sites. Both suppliers of modular systems and users of industrial process steam will participate in the experiments.

A modular design approach was chosen to minimize system cost and to improve operational reliability. Modular design should result in reduced cost and improved reliability for solar thermal systems through standardization by individual suppliers on proven designs using qualified components. Reduction in cost is also anticipated because of factory prefabrication of standardized components and subsystems, thereby reducing custom engineering and on-site installation costs. The MISR project goals are to validate the potential of modular design, to reduce installation costs to 10% or less of total system cost, and to achieve energy costs of $10/MBtu ($\$0.034/\text{kW}_t$) by 1985.

The activities of the project are shown in Fig. 3-15. Inputs include (1) technology developed by both government and industry, (2) lessons learned from previous solar experiments, (3) industrial user requirements, (4) industry experience, and (5) systems analysis. These inputs will be used to determine the modular system size and operating characteristics from which a set of specifications will be generated. In addition, a sample design of a modular system will be prepared. The sample de-

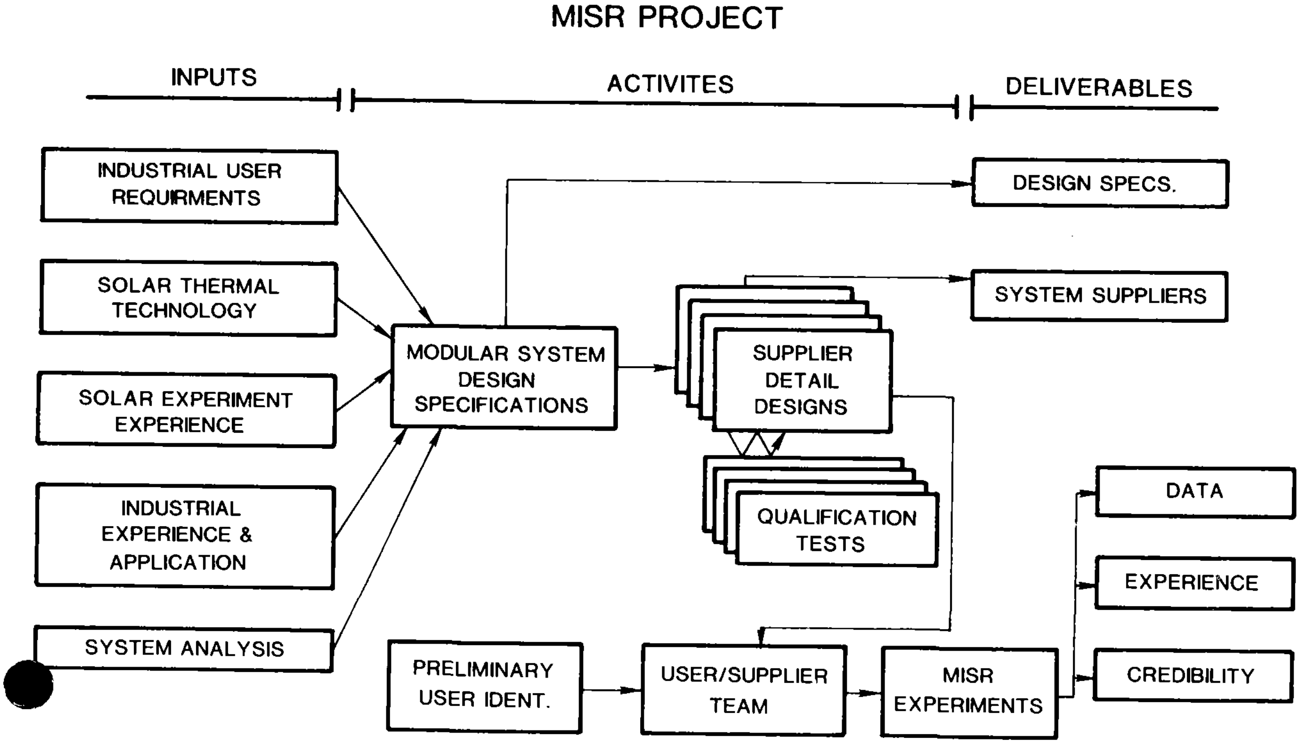

Figure 3-15. MISR Project Activities

sign is a vehicle for transferring line-focus technical information to industrial designers. Stearns-Roger, a commercial A&E firm, was selected to assist in developing the MISR specifications and the sample design. Stearns-Roger is responsible for using standard A&E practice in the design and for specifications that will ensure high system operational reliability and reasonable costs. The specifications and sample design will be supplied to prospective bidders in a Request for Proposal (RFP) which will be used to solicit proposals for detailed modular system designs and qualification hardware.

Up to six proposals will be selected, and contracts will be awarded for system designs and for hardware for qualification testing. The qualification tests will be conducted to determine that the specifications of the RFP have been met. Only those modular systems meeting the specifications will be eligible for the MISR field experiments.

Experiments have been considered for operation at industrial sites on a cost-sharing basis with DOE. DOE first will solicit companies that use process steam and are interested in participating in the experiments. From these companies, DOE will select industrial participants who will familiarize themselves with the system designs and observe the qualification testing. Industry will then submit proposals to DOE for conducting the experiments. Up to 10 of these companies may be selected for field experiments using their choice of qualified modular systems. If field experiments are pursued, it is expected that a data acquisition system will be furnished by DOE for collecting data during the 2-year DOE-supported operating period. Thus, system cost and performance data would be obtained by users in real industrial environments.

3.2.4.3 FY 1980 Accomplishments

The authorization to proceed with MISR was received from DOE in February 1980. Contracts have been placed with Acurex Corp., Del Manufacturing, Solar Kinetics, Inc., and Suntec Systems, Inc., for the preliminary conceptual designs of modular solar thermal systems. These contracts serve as a vehicle for industry input into modular system requirements and specifications being developed by SNLA with the assistance of Stearns-Roger Services, Inc. The system requirements will combine line-focus collector technology, industrial process heat user requirements, and industry design and construction practices into a set of minimum specifications that systems must meet to be acceptable for MISR applications.

3.2.4.4 Future Activities

The MISR specifications and sample design are scheduled to be completed by March 1981. RFPs for industry-designed modular systems will follow immediately. Qualification tests of the accepted proposals are scheduled to be completed by November 1982, and user experiments should begin operation in 1984. Results of the experiments will be available in 1985 and 1986. The schedule for Cycle 1 is shown in Fig. 3-16.

3.2.5 Industrial Process Heat Field Projects

During FY 1980, as a result of a DOE reorganization, the responsibility for industrial process heat field projects was transferred into the Division of Solar Thermal Energy Systems, where it continued as a separate entity in the Systems and Applications Branch.

3.2.5.1 Objectives

Objectives of the 29 IPH field projects are:

- to accelerate development of a solar thermal industry via cost-shared system

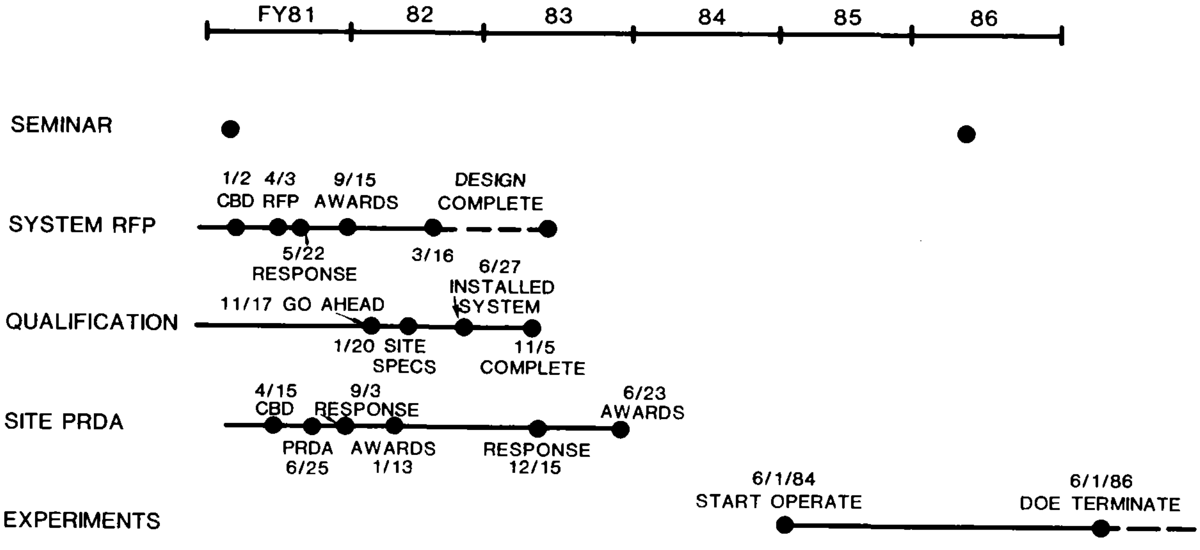

Figure 3-16. MISR Schedule, Cycle 1

application field tests targeted to near- and mid-term markets;

- to achieve substantial system cost reductions through the accumulation of system design, engineering, construction, and operating experience; and
- to stimulate demand for solar thermal systems in order to develop a self-sustaining solar industry and user community.

The field projects are divided into six categories according to their temperature ranges and end uses. Category descriptions and the current status of the projects follow.

3.2.5.2 Low-Temperature Hot Water/Hot Air

Currently, there are seven low-temperature IPH field tests that have been in operation for one year or longer (see Table 3-4). Three of these are hot water systems and four are hot air systems. All supply process heat at temperatures below 100°C (212°F). Flat-plate, evacuated-tube, and line-focus collectors are all represented, with collector array areas nging from 232 to 1951 m^2 (2500 to 21,000 ft^2).

These seven solar IPH systems represent first-of-a-kind installations, since there have been very few large-area industrial solar systems. These first field tests have identified many design and operation problems that could not have been brought forth without the actual construction and operation of the systems [11,12]. Some of these problems included wet insulation, contamination of reflective and absorber surfaces, excessive thermal losses, freezing, overheating, and various control problems. As IPH field tests, they are serving as valuable learning experiences for users of low-temperature solar industrial applications, providing important data in solar system design and solar/industrial process interfacing. Future field tests will incorporate the lessons learned from these projects, thus providing users with more cost-effective, reliable systems.

3.2.5.3 Low-Temperature Steam

There are four low-temperature IPH steam projects currently under construction or operational to date (see Table 3-5). Like the low-temperature hot water/hot air projects, these four low-temperature steam systems are the first of their kind to be built.

Table 3-4. Low-Temperature Hot Water/Hot Air IPH Projects

Industrial Site	Application	Systems Designs	Delivery Temperature	Field Size/ Collector Type	Status
Campbell Soup Sacramento, Calif.	Can washing	Acurex Corp.	85° C (185° F) hot water	704 m^2 (7578 ft^2) Flat plate/Trough	Operational
York Building Products Harrisburg, Penn.	Concrete block curing	AAI Corp.	71° C (160° F) hot water	855 m^2 (9200 ft^2) Multiple reflector	Operational
Riegel Textile LaFrance, S.C.	Textile dyeing	General Electric	88° C (190° F) hot water	622 m^2 (6700 ft^2) Evacuated tube	Operational
J.A. LaCour Kiln Service Canton, Miss.	Lumber drying	Lockheed MSC	71° C (160° F) hot air	232 m^2 (2500 ft^2) Flat plate	Operational
Lamanuzzi & Pantaleo Fresno, Calif.	Raisin/prune drying	Cal-Poly University	66° C (150° F) hot air	1905 m^2 (20,500 ft^2) Flat plate	Operational
Gold Kist, Inc. Decatur, Ala.	Soybean drying	Teledyne Brown	60° C (140° F) hot air	1217 m^2 (13,104 ft^2) Flat-plate	Operational
Gilroy Foods, Inc. Gilroy, Calif.	Onion & garlic drying	Trident Engineering	93° C (200° F) hot air	553 m^2 (5950 ft^2) Evacuated tube	Operational

Table 3-5. Low-Temperature Steam IPH Projects

Industrial Site	Application	Systems Designs	Delivery Temperature	Field Size/ Collector Type	Status
West Point Pepperell Fairfax, Ala.	Fabric drying	Honeywell, Inc.	157° C (315° F) steam	772 m^2 (8313 ft^2) Parabolic trough	Operational
Home Laundry Co. Pasadena, Calif.	Commercial laundry	Jacobs-Del	172° C (341° F) steam	604 m^2 (6496 ft^2) Parabolic trough	Construction
Johnson & Johnson Sherman, Tex.	Gauze bleaching	Acurex Corp.	174° C (345° F) steam	1070 m^2 (11,520 ft^2) Parabolic trough	Operational
Tropicana Industry Bradenton, Fla.	Processing fruit juice	General Electric	182° C (350° F) steam	929 m^2 (10,000 ft^2) Evacuated tube concentrator	Construction

These low-temperature steam field tests have served to identify design and operational problems and give contractors experience in their design and construction. In addition, these projects are instructive in pointing out those parts of the systems that require substantial cost reductions.

3.2.5.4 Intermediate-Temperature Steam

In 1979, designs for 7 intermediate-temperature (182° to 288°C) steam field test projects were completed. Of these 7 designs, 4 were funded for construction (see Table 3-6).

These projects were designed by various private contractors to provide a portion of the process steam requirements used in a variety of industrial processes including oil heating, latex production, oil refining, brewing, chlorine manufacturing, and potato processing. For all but one of the seven designs, two system configurations have been used: (1) pressurized water, circulated through a collector field and then flashed to steam in a low-pressure chamber; or (2) an organic heat-transfer fluid, circulated in the collector array and then fed to a steam generator where the fluid serves as a heat source to produce steam.

Table 3-6. Intermediate-Temperature Steam IPH Projects

Industrial Site	Application	Systems Designs	Delivery Temperature	Field Size/ Collector Type	Status
Dow Chemical Co. Dalton, Ga.	Latex production	Foster-Wheeler	186°C (366°F) steam	929 m^2 (10,000 ft^2) Parabolic trough	Under construction
Southern Union Co. Hobbs, N.M.	Oil refining	Energetics Corp.	193°C (380°F) steam	892 m^2 (9,600 ft^2) Parabolic trough	Under construction
Lone Star Brewery San Antonio, Tex.	Brewing beer	Southwest Research	178°C (353°F) steam	957 m^2 (10,296 ft^2) Parabolic trough	Under construction
Ore-Ida Foods Ontario, Ore.	Potato frying	TRW	214°C (417°F) steam	929 m^2 (10,000 ft^2) Parabolic trough	Under construction
Stauffer Chemical Henderson, Nev.	Chlorine manufacturing	Chilton Engineering	187°C (368°F) steam	861 m^2 (9,268 ft^2) Parabolic trough	Not funded
Ergon, Inc. Mobile, Ala.	Oil tank heating	Acurex Corp.	185°C (365°F) steam	1873 m^2 (20,160 ft^2) Parabolic trough	Not funded
NL Industries Newberry Springs, Calif.	Hectorite ore processing	Jacobs-Del Solar	186°C (366°F) steam	1427 m^2 (15,360 ft^2) Parabolic trough	Not funded

Early experience in the design and construction phases of the intermediate-temperature steam projects, together with experience obtained from the previous generation of low-temperature experiments, suggests that technology research and development are still required in specific areas:

- reflective materials and coatings, to overcome the potential difficulties posed by harsh industrial environments;
- collector washing systems and solvents, to maintain original material properties and performance parameters; and
- collector controls and mechanical components, to make systems more efficient and reliable.

A standardized real-time minicomputer-based data acquisition system is being developed by the Lawrence Livermore Laboratory using commercially available hardware. Similar data systems are currently used by each of the intermediate-temperature steam projects. The data acquisition system will ensure a solid data base with which to analyze, compare, and monitor these systems after their completion. Thus, operational results will continue to identify specific areas in which future solar IPH systems can be improved.

3.2.5.5 Low-Temperature, Cost-Shared Designs

DOE has funded, through competitive procurement, five large-scale, low-temperature, cost-shared IPH field test designs. These designs began in early 1980 and were completed near the end of the year. These systems employ 3242 to 4645 m^2 (35,000 to 50,000 ft^2) of collector array area to supply hot water at 52° to 99°C (125° to 210°F) to industrial processes.

At the end of the design phase, DOE selected one of these systems for possible funding through construction and operation phases. The five programs are summarized in Table 3-7.

3.2.5.6 Intermediate-Temperature, Cost-Shared Designs

DOE has funded four detailed designs for cost-shared IPH projects in the intermediate-temperature range [100° to

Table 3-7. Low-Temperature, Cost-Shared IPH Projects

Industrial Site	Application	Systems Designs	Delivery Temperature	Field Size/ Collector Type	Status
Oscar Mayer & Co. Des Moines, Ia.	Meat processing	Team, Inc.	82°C (180°F) hot water	3746 m^2 (40,320 ft^2) Parabolic trough	Not funded
Nestle Enterprises, Inc. Santa Isabel, Puerto Rico	Fruit juice pasteurization	General Electric	99°C (210°F) hot water	4645 m^2 (50,000 ft^2) Evacuated tube	To be determined
Stauffer Chemical Co. Oxnard, Calif.	Food ingredients processing	Wormser Scientific Corp.	99°C (210°F) hot water	3530 m^2 (38,000 ft^2) Flat plate	Not funded
Salz Leathers Santa Cruz, Calif.	Leather tanning	Pacific Sun	60°C (140°F) hot water	3270 m^2 (35,200 ft^2) Flat plate	Not funded
Tyson's Foods, Inc. Springdale, Ariz.	Poultry scald water	Lockheed MSC	60°C (140°F) hot water	4682 m^2 (50,400 ft^2) Fresnel concentrator	Not funded

288°C (212° to 550°F)]. The four contractors were selected by competitive procurement and began their designs in late 1979. At present, construction funding for all but one of the projects (Hilo Coast) has been provided. Descriptions of the four systems can be found in Table 3-8.

3.2.5.7 Enhanced Oil Recovery

When heavy oil (viscous crude oil) fields are developed, there are usually three sequential phases that take place. First, the well is drilled and the natural reservoir pressure forces the oil up out of the well. (This is usually a relatively small percentage of the recoverable oil.) Second, steam is injected into the well to decrease the viscosity of the oil. The resultant mixture of steam and oil can then be forced back out of the same well by the increased pressure from the steam. The first two steps can be alternated for months or even years, producing significant amounts of oil. The third phase uses the fields' multiple drillings to force additional oil out. Since a field usually has more than one drilling, alternate wells in a pattern are designated either as steam injectors or as oil producers. Steam is continuously forced down an injector to drive the resulting oil-steam mixture up and out of a nearby producer.

These latter two stages have been identified as a strong potential market for solar thermal technology for the following reasons:

- The conventional method of producing steam on site is to burn crude oil. Thus, over the life of the oil field, about one-third of the produced oil is burned to provide heat for the injection steam.

Table 3-8. Intermediate-Temperature, Cost-Shared IPH Projects

Industrial Site	Application	Systems Designs	Delivery Temperature	Field Size/ Collector Type	Status
U.S. Steel-Chemical Haverhill, Ohio	Polystyrene production	Columbia Gas	189°C (373°F) steam	4645 m^2 (50,000 ft^2) Parabolic trough	Construction
Bates Container, Inc. Ft. Worth, Tex.	Cardboard corrugation	BDM Corporation	188°C (371°F) steam	3226 m^2 (34,720 ft^2) Parabolic trough	Construction
Caterpillar Tractor San Leandro, Calif.	Engine parts washing	Southwest Research	113°C (235°F) steam	4582 m^2 (50,400 ft^2) Parabolic trough	Construction
Hilo Coast Processing Co. Pepeekeo, Hawaii	Sugar processing	TEAM, Inc.	204°C (400°F) steam	4682 m^2 (50,400 ft^2) Parabolic trough	Not funded

- Most of the heavy oil fields in this country are located in high insolation areas, such as Kern County, California.
- The high concentration of oil-fuel steam generators in a heavy oil reservoir can cause significant environmental problems.
- The land above these oil reservoirs is relatively inexpensive and reasonably available, although large regular collector arrays often cannot be used because of existing oil-field equipment.
- There is continual demand for the process steam, so storage is not required. Very little buffer storage is needed since the oil-fuel steam generators can respond to insolation variations very rapidly.

DOE has worked to facilitate the use of solar thermal technology in this industry by funding study and design programs (see Table 3-9) to determine the projected costs and performance of systems used in this manner.

Table 3-9. Enhanced Oil Recovery Projects

Industrial Site	Application	Systems Designs	Delivery Temperature	Field Size/ Collector Type	Status
Petro-Lewis Bakersfield, Calif.	Enhanced oil recovery	General Atomic	174°C (545°F) steam	21,832 m^2 (235,000 ft^2) FMSC collector	Design completed
Exxon Bakersfield, Calif.	Enhanced oil recovery	Foster-Wheeler	260°C (500°F) steam	23,597 m^2 (254,000 ft^2) Parabolic trough	Design completed

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SECTION 4.0

RESEARCH AND ADVANCED DEVELOPMENT

The major objective of the DOE Research and Advanced Development (RAD) Branch is the development of a technology base, within industry, for advanced solar thermal systems that will forge the basis for growth of solar thermal technology into a major energy source for this nation by 1995. During FY 1980, the RAD Program encompassed four major areas: advanced components and applied research, materials research and development, fuels and chemicals, and supporting activities. Accomplishments and descriptions of each of these areas follow.

4.1 ADVANCED COMPONENTS AND APPLIED RESEARCH

Activities within the advanced components area are directed toward identifying the critical building blocks that will form the base for significant progress in future solar thermal subsystems. To achieve this purpose it is necessary to recognize current limitations in technology and to proceed with innovative designs that will remove or circumvent the limitations. This research is directed toward increasing component efficiency and durability and lowering costs.

4.1.1 Receivers

Receiver design is one of the key elements in attaining high system efficiency for electric power generation and industrial process applications. The primary function of a receiver in a solar thermal system is to capture concentrated energy from a solar collector and transfer it to the working medium inside the receiver with minimal energy losses.

While existing technology is being used in solar thermal application programs for receivers wherever feasible, development and application of advanced technology for receivers is required to achieve improved performance and lower costs. The objective of the advanced receiver technology subprogram is to identify and develop the receivers necessary to achieve low-cost systems. The focus of the program is on technology development for receivers that operate from 315° to 1370°C (600° to 2500°F).

FY 1980 Accomplishments

The Sanders Associates ceramic matrix high-temperature [1370°C (2500°F)] receiver (see Fig. 4-1) was selected for development and is ready for solar test at the Parabolic Dish Test Site. The testing will demonstrate the suitability of this concept for selected solar thermal applications.

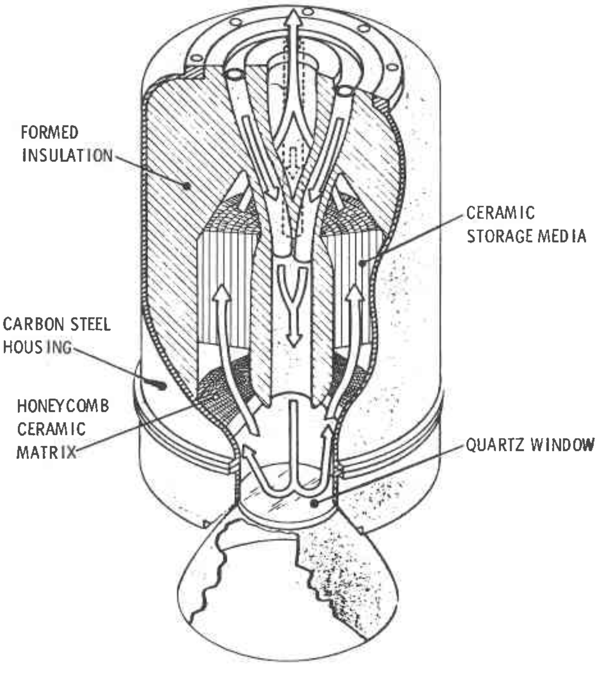

Figure 4-1. **Sanders Ceramic Matrix Receiver**

Feasibility tests on ceramic extrusion were initiated for the General Electric Co. ceramic coil high-temperature receiver (see Fig. 4-2). This production technique has potential for low-cost, high-performance components. Both the Sanders and General Electric receivers are sized for 80 kW_t.

Development of a high-temperature receiver/reactor is needed for biomass-pyrolysis with operating temperatures above 750°C (1380°F). Initial work indicates that, since the ultimate use of the receiver is to heat a chemically reacting fluid, a thermal mass concept should be used. This concept calls for a receiver with cooling coils immersed in a thermal mass which distributes the heat flux and smooths solar flux transients to the receiver.

For maximum efficiency in the transfer of heat, the material used for the thermal mass must have a high thermal conductivity. This consideration, along with the required operating temperatures, led to the choice of copper for the thermal mass material. The resulting receiver consists of a copper mass with stainless steel cooling coil cast in place (Fig. 4-3).

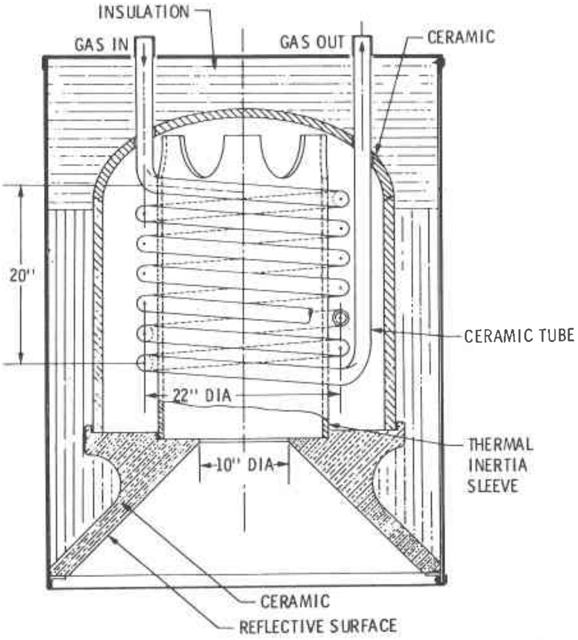

Figure 4-2. **General Electric Ceramic Coil Receiver**

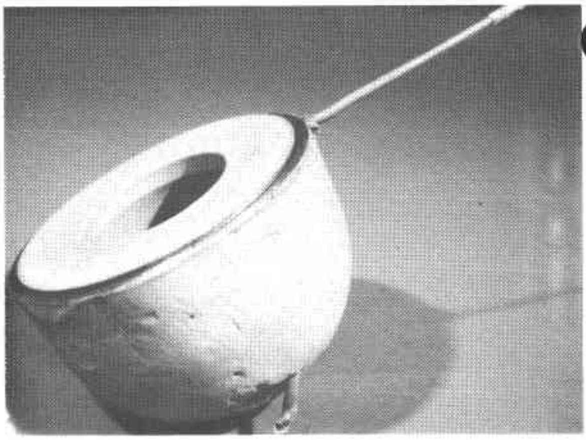

Figure 4-3. **Receiver with Copper Mass and Steel Cooling Coil**

Problems solved during FY 1980 included the difficulty of casting copper, oxidation protection for the copper, and cooling tube survival during casting.

In late FY 1980, the completed receiver (Fig. 4-4) was tested at the SERI Advanced Components Research (ACRES) test facility for optical and thermal efficiency.

FY 1981 Plans

In 1981, testing and characterization of the Sanders ceramic-matrix high-temperature [1370°C (2500°F)] receiver will be

Figure 4-4. **Advanced Thermal Receiver Under Test at SERI**

completed for advanced Brayton engines and for other industrial and chemical applications. Feasibility tests of the ceramic-coil extrusion process for the high-temperature coil receiver will be completed and a decision on prototype development will be made.

In addition, contracts for fabrication of a state-of-the-art ceramic receiver element will be awarded. This effort is expected to demonstrate that a ceramic receiver can be fabricated for a wide range of applications using current ceramic technology.

4.1.2 Low Initial-Cost Concentrators

The development of low initial-cost concentrators is one of the keys to expanding the solar thermal market for industrial process heat, fuels and chemicals, and advanced electric systems. The emphasis of this effort has been on the identification and development of low-cost optical elements. There are two basic kinds of concentrators—reflective and refractive. The optical surfaces may be smooth or a mosaic of flat optical elements (Fresnel). The mounting of most concentrators allows for movement to compensate for the apparent motion of the sun. Figures 4-5 and 4-6 are Fresnel concentrators of the refractive and reflective types respectively. Figures 4-7 and 4-8 are thin-film concentrators of the supported and stretched configurations, respectively. All concepts are for point-focusing applications.

FY 1980 Accomplishments

Sunpower Corp. began development of a unique folding-facet reflector element. Under high wind conditions, the reflecting elements fold to avoid wind loads. Concept screening studies performed by the University of Arizona indicated that the faceted reflector concept has potential for meeting concentrator cost targets. Three contracts were awarded (Boeing, AAI, and E-Systems) to explore new optical concepts for concentrators.

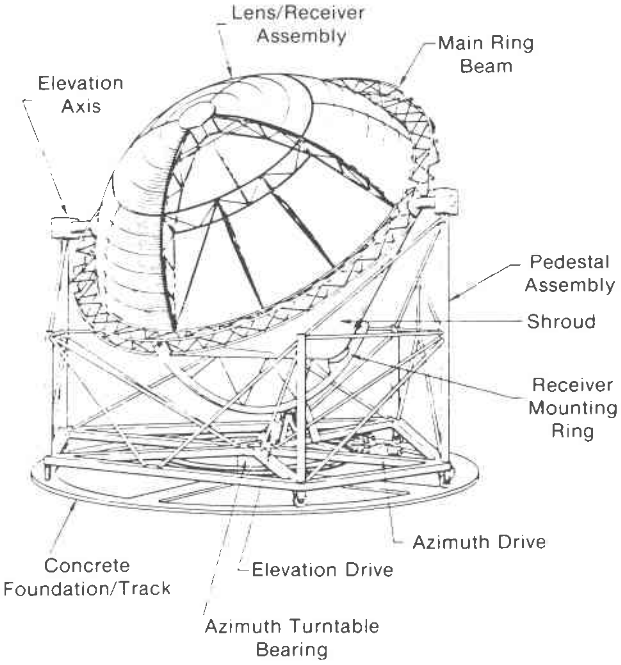

Figure 4-5. Short Focal Length, Dome-Type Refractive Fresnel Lens Concentrator

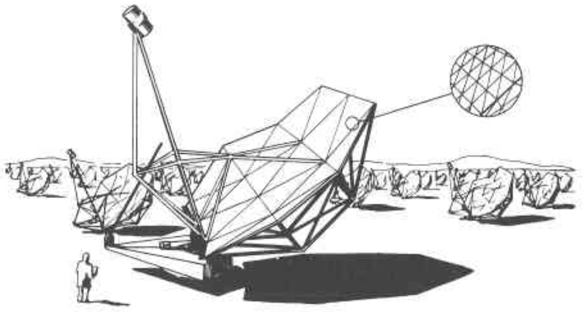

Figure 4-6. Reflective-Type Fresnel Concentrator

FY 1981 Plans

Fresnel lens and thin film optical-element concepts with good potential for low initial cost will be selected and fabricated, and they will then undergo optical testing. A prototype secondary concentrator

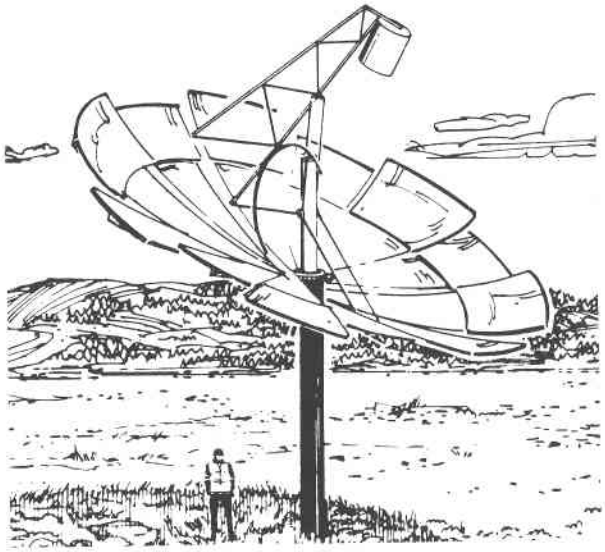

Figure 4-7. Faceted Thin-Film Concentrator

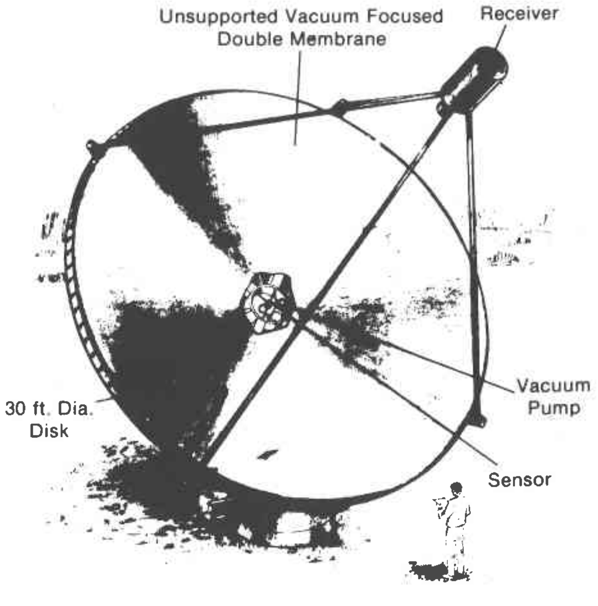

Figure 4-8. Stretched Thin-Film Concentrator

will be designed, fabricated, and evaluated. A successful effort will require low-cost, high-performance optical elements, lightweight structures, and tracking and control systems that are economical and reliable.

4.1.3 Advanced Heat Engines

Improvement of heat-engine technology applicable to solar thermal electric power systems is a key factor in achieving high system efficiency and thereby reduces the cost of electricity. The production of electricity from sunlight via heat requires a subsystem to convert thermal energy to electrical energy. This power conversion subsystem consists of a heat engine, a generator, and auxiliary components.

Existing engine technologies are being used, wherever possible, to achieve significant developmental cost reductions for solar thermal application programs. The goal of the advanced heat-engine subprogram is to identify and adopt technologies being developed for automotive and other programs, to achieve efficient, low-cost, reliable systems for solar thermal applications. The subprogram's emphasis is on relatively small power-conversion subsystems to generate nominal power levels of approximately 20 kW$_e$, with operating temperature ranges from 315° to 1370°C (600° to 2500°F).

FY 1980 Accomplishments

Energy Research and Generation, Inc. performed a conceptual design study of a 15-kW$_e$ free-piston Stirling engine. The engine/alternator is predicted to achieve a conversion efficiency of 60% at 840°C (1540°F). The conceptual design involves nonstrategic materials. Some of its other advantages are an isothermalizer, self-pressurized gas bearing, and system stability.

The Foster-Miller Associates, Inc. completed a 15-kW$_e$ steam Rankine reheat reciprocator system for solar thermal power conversion. The design study estimated a heat-engine efficiency of 36% at 700°C (1292°F). Testing is being carried out and will be completed this year. Critical technical issues for this engine concept are the expander performance and system durability.

[illegible]y Carter Enterprises completed a Rankine engine study. The design study estimated a heat engine efficiency of 33% at 675°C (1250°F). The expander is an adaptation of an existing automotive engine and it has counter-rotating, counterbalance shafts to eliminate vibration. The study concluded that, because of the great departure from automotive technology, the development of an expander for reheat cycle operation will incur higher risk and require more development effort than the simple cycle.

4.1.4 Transport Subsystem

4.1.4.1 Thermochemical Transport

The use of reversible chemical reactions to transport collected solar energy is being actively investigated because of its promise of substantial cost savings compared with conventional thermal transport. Possible applications include production of fuels and chemicals as well as industrial process heat. The cost savings should be possible because transport line and storage temperatures will be near ambient, thus minimizing thermal losses and piping and insulation costs.

Reversible chemical reactions can be run in either of two directions, usually with the aid of catalysts, and will either absorb or release energy as heat. In solar applications, energy will be absorbed in a receiver using an endothermic reaction, transported to its point of use at low temperature, and released using an exothermic reaction.

The purpose of this investigation is to demonstrate the technical feasibility and economic attractiveness of this method of transport. Emphasis is on selecting the most promising reactions from technical and economic points of view, demonstrating technical feasibility through analysis and solar testing, and determining economic attractiveness through comparative cost studies.

FY 1980 Accomplishments

Reaction screening studies performed previously at Rocket Research Co. and JPL have indicated that the most promising candidate reactions are sulfur trioxide decomposition, carbon dioxide reforming of methane, and steam reforming of methane.

The Naval Research Laboratory (NRL) has been pursuing SO_3 dissociation studies for the past several years. In 1980, they completed feasibility testing of a quartz SO_3 reactor at New Mexico State University.

JPL has conducted a stainless-steel reactor validation test of SO_3 dissociation at New Mexico State University and compared it with a coupled kinetic heat-transfer computer model.

A Solchem receiver containing CO_2-CH_4 reforming converter-heat exchange coils was operated at the White Sands Solar Furnace by New Mexico State University during December 1979. Energy conversion rates of approximately 33% of the incident energy were observed using stainless-steel converter heat exchangers. Work during May 1980 (under contract to SERI) included a detailed experimental investigation of nickel-coated Raschig-ring catalyzed stainless-steel receiver elements using 3:1 and 5:1 mixtures of CO_2 and CH_4, respectively. It was concluded that catalyst damage caused by the energy conversion chemical reactions occurred during these tests. A Kanthal SO_3 receiver element containing a ruthenium catalyst carried on small stainless-steel saddles was also tested during May 1980. Energy conversion rates greater than 3 kW were observed with heat-to-chemical conversion efficiencies of greater than 50% and little or no damage to the catalyst.

Westinghouse Corporation (under contract to JPL) has completed fabrication and begun testing of an SO_3 receiver module made of stainless steel. This module is illustrated in Fig. 4-9. The test objective was to evaluate heat-exchange/catalyst-interaction experimentally.

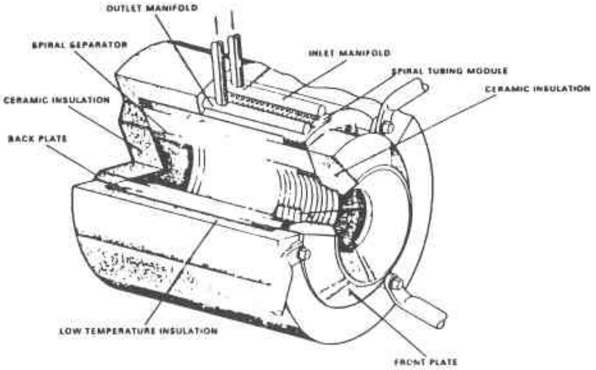

Figure 4-9. Westinghouse SO_3 Receiver Module

FY 1981 Plans

New Mexico State University will continue testing the Naval Research Laboratory Kanthal SO_3 reactor, conduct further tests with the stainless-steel reactor supplied by JPL, and perform additional testing of the Westinghouse reactor. These experiments will provide verification of analytical methods and serve as the basis for the design of solar receivers for the dissociation of SO_3.

4.1.4.2 Thermal Transport

Thermal transport for dish systems is accomplished by a network of pipes, pumps, and controls. The pipe diameter and distribution of insulation thickness is optimized by the method of Lagrange Multipliers, within the constraints of specified pumping power and thermal loss. Emphasis has been placed on identifying low-cost advanced techniques for pipe installation. Conventional methods are quite labor-intensive, requiring field installation, manual welding techniques, and nonautomated construction of pipe supports. Advanced techniques that hold promise for reduced costs include (1) factory fabrication of risers/downcomers as an integral part of the dish structure, (2) automated manufacture of network pipe components and subassemblies in a factory, (3) semi-automated field assembly, and (4) use of flexible metal hose technology. Use of these advanced techniques has the potential to reduce the installed pipe network costs by 50%, compared with conventional labor-intensive methods.

4.1.5 Control Systems

FY 1980 Accomplishments

Testing of single-axis sun trackers began in FY 1980 to support the line-focus technology development program. A test apparatus was designed, built, and installed at the SERI Interim Test Facility. Both commercially available sun trackers and prototypes of sun trackers still under development are being tested. A description of the major types of line-focus sun trackers and some recent tracker improvements was published [1].

Activity Description

Sun trackers have been troublesome components for line-focus concentrating collector systems. The problems have included poor accuracy, component failures, false locks on clouds, and restricted tracker operating ranges. In response to these tracking difficulties, a variety of improved sun trackers has been developed. The testing program at SERI determined the tracking accuracy of this new generation of sun trackers. Each system of tracker electronics was installed on a highly controllable, hydraulically driven test stand. The electronics of the tracker control a hydraulic rotary actuator, which turns the collector. A precision shaft encoder (resolution better than 0.05°) generates pointing angle signals to an on-site computer. These measurements are taken over several days to ensure repeatable results. Of particular interest is tracking performance for the range of sky-cloud conditions that operating sys tems encounter. Each sun tracker was tested until its performance was characterized as a function of cloud cover, insolation level, and time of day.

FY 1981 Plans

Although all the tracking accuracy data have not been fully evaluated, it is clear that several sun trackers offer excellent tracking performance. While improvements aimed toward cost-reduction or field durability will be beneficial, improvement of current tracking accuracy does not appear warranted. Current tracking concepts have been sufficiently developed from a performance standpoint.

Controls development is needed in the area of systems integration. There is a need for better field control/local control integration. Designs that minimize wiring lengths and reduce control installation costs would be significant improvements.

4.1.6 Facilities

4.1.6.1 Advanced Component Research Facility (ACRES)

The purpose of the Advanced Component Research Facility at SERI is to provide the capability to test and develop advanced components related to point-focus solar concentrating collectors. These components include receivers, optics, tracking mechanisms, and energy-transport methods.

In late FY 1979 and continuing through FY 1980, two 6-m dishes were converted into flexible test loops to provide the aforementioned test capability. The north dish was converted into a high-temperature thermal test loop with the ability to deliver a wide range of coolant flow rates, pressures, and temperatures for testing receivers over a wide variety of operating conditions. The south dish was converted into an optical test fixture with the development of several test techniques including a real-time flux mapper, a technique for optical alignment (reverse reflection method), and the development of a cold-water calorimeter. The facility is shown in Fig. 4-10 and results from the flux mapper are shown in Fig. 4-11.

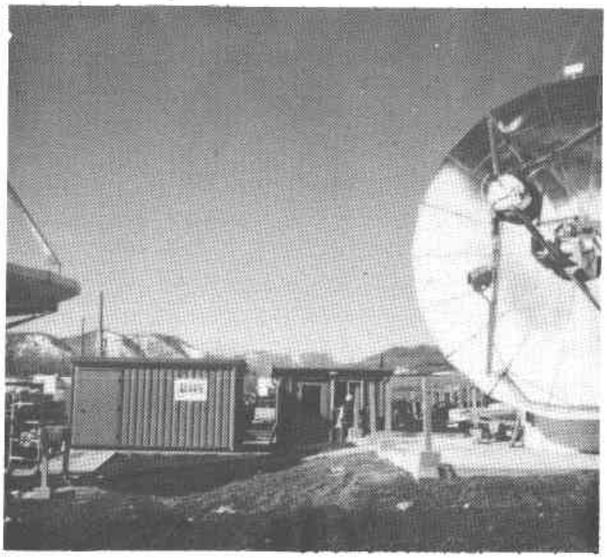

Figure 4-10. SERI's Advanced Component Research Facility (ACRES)

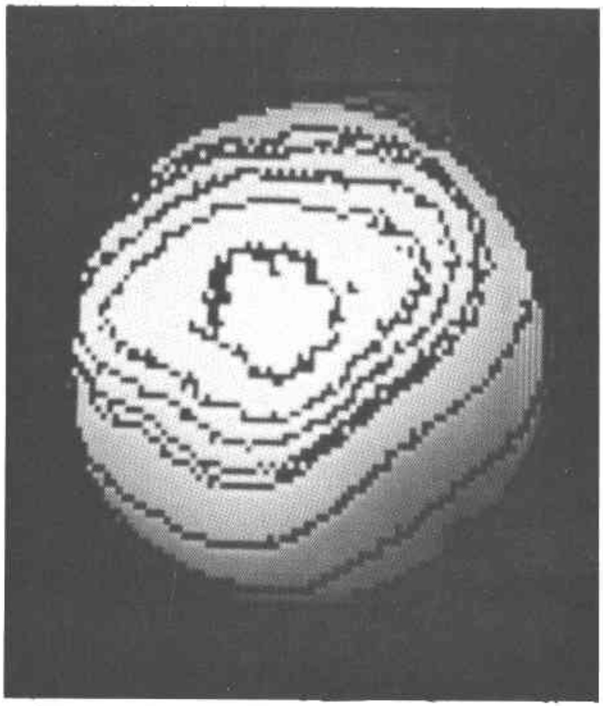

Figure 4-11. Flux Map of Point-Focus Solar Collector

In late FY 1980, the optical efficiency of the south dish was characterized with the cold-water calorimeter. Also, testing of a high-temperature cavity receiver developed at SERI began.

4.1.6.2 DOE Advanced Components Test Facility (ACTF)

The Advanced Component Test Facility, operated for DOE by the Georgia Institute of Technology Engineering Experiment Station, under contract to SERI, uses an arrangement of tracking mirrors surrounding a central tower to provide concentrated solar flux at the focal zone. In addition, a sophisticated computer-based data collection system at the facility permits timely recording and presentation of experiment results. Figure 4-12 shows the facility.

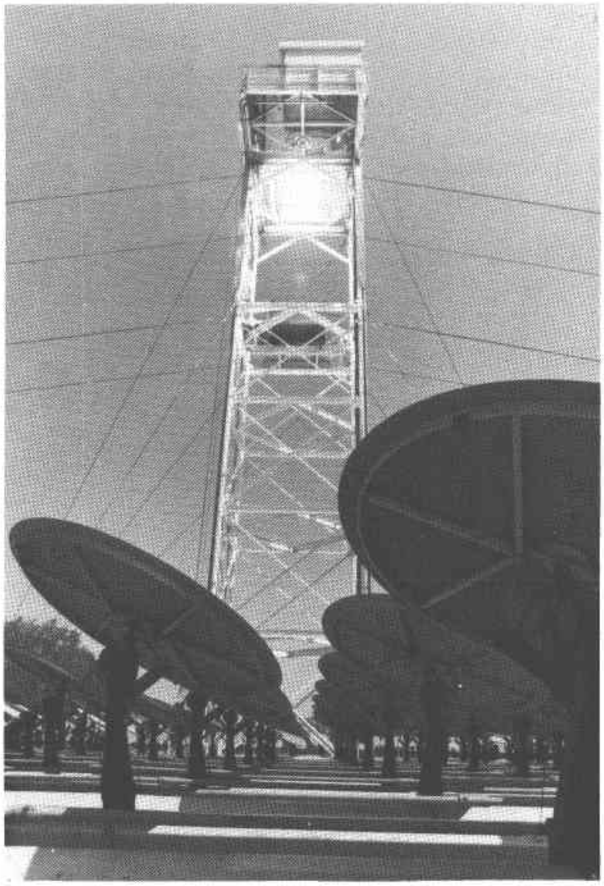

Figure 4-12. View of the Advanced Components Test Facility

The ACTF, located on the Georgia Tech campus, has as its primary purpose the encouragement of research and development in the area of high-temperature solar technology. It serves as a flexible, convenient test facility, accessible to both public and private research and development organizations.

The current configuration of the ACTF makes it particularly well suited for the testing of:

- moderate-scale central receivers and central receiver components such as steam, air (gas), and liquid heating devices;
- high-temperature materials, both metallic and nonmetallic;
- photovoltaic conversion systems;
- high-temperature chemical reaction systems and components;
- total energy systems powered by solar energy alone or hybrid systems of solar and fossil fuels;
- thermal pulse-shaping devices; and
- hardware response to thermal pulses.

The heliostats are electrically driven by their mechanical supports so that the focal zone remains stationary throughout the day. The radiation flux density in the focal zone is on the order of 125 W/cm^2 (seasonally dependent) and the corresponding total power is 325 kW_t for an average insolation of 900 W/m^2 on the mirrors.

FY 1980 Accomplishments

Four high-temperature experiments sponsored by the Solar Thermal Test Facilities Users Association were conducted on the ACTF during FY 1980. These tests are described in Section 4.4.1 of this report.

A new control room (Fig. 4-13) was constructed in 1980. This building has a raised "computer room" floor to facilitate

Figure 4-13. Advanced Components Test Facility Control Room

the installation of user experimental hardware and controls, and it houses the collection and processing portion of the facility's data system. Large windows in the east wall of the new control room permit an unobstructed view of the heliostat field and the central tower. Mirror tracking improvements were also completed during FY 1980.

FY81 Planned Activities

A major program to improve mirror shape is in progress and is to be completed in 1981. This program involves possible hardware replacement (mirrors and/or frames) as well as the in-depth assessment of current mirror focusing methods and hardware which is now under way. In addition, in-house research in the area of high-temperature, solar-compatible instrumentation is currently being planned for 1981.

The ACTF is now a fully operational major solar thermal test facility. The in-house research programs as well as the ongoing and proposed facility improvements will enhance the capabilities of the facility in the coming year.

4.1.6.3 SERI Mid-Temperature Collector Research Facility

The Midtemperature Collector Research Facility (MTCRF) (Fig. 3-11) at the Solar Energy Research Institute is a versatile test facility dedicated to research relating to the optical and thermal performance of concentrating solar collectors. Both basic and applied research problems can be addressed with the MTCRF.

The collector test loop is currently installed at SERI's Interim Field Test Site in Golden, Colo. Initial design services were procured in May 1978, with bids for construction solicited in November 1978. A contract for fabrication was placed in January 1979. The test loop was completed and shipped in November 1979. The test loop (Fig. 4-14) became operational in June 1980.

The present configuration of MTCRF is a single collector module test loop capable of thermal performance measurements on a variety of collector types over the mid- and low-temperature range. Basic features are:

- Number of collector work stations: 3
- Number of collectors active at any time: 1 (FY 1980), 2 (FY 1981)
- Maximum collector area serviceable (based on peak performance of two collectors): 37.2 m^2 (400 ft^2)
- Fluid flowrate: 0.8-38 L/m (0.2-10 gpm) per collector
- Operating temperature range:
  Water: 66°-232°C (150°-450°F)
  Heat transfer fluid: 66°-343°C (150°-650°F)

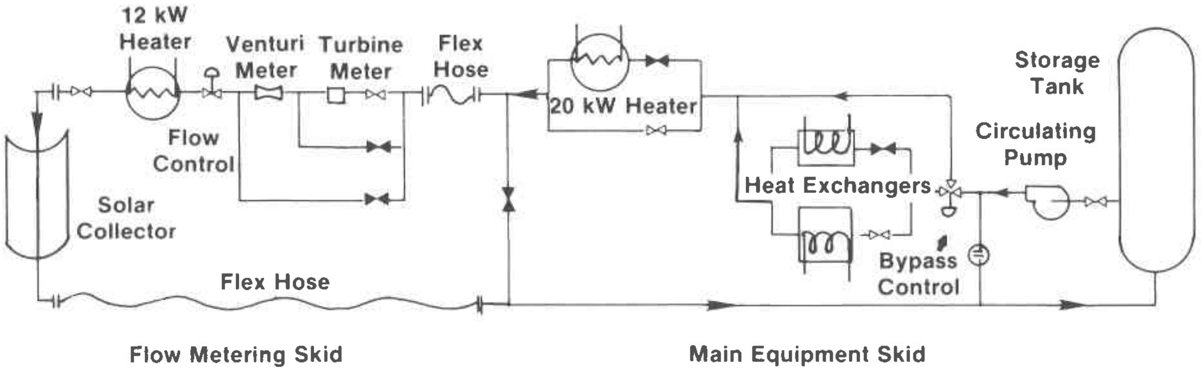

Figure 4-14. MTCRF Test Loop Schematic

FY 1980 Accomplishments

The major FY 1980 accomplishment was the achievement of operational status for the MTCRF test loop. This occurred in June 1980 after fabrication and delivery of the test loop, completion of the interim field site construction, and initial debugging of test loop operation and data acquisition software.

Initial test plans call for a series of experiments to support development of a thermal performance test method for concentrators. The test plan has been based on continuing participation in standards organizations, primarily ASTM. Participation on ASTM Committee E-44 on Solar Energy began after evaluation of test methods showed inadequacies when applied to concentrating solar collectors. A draft standard has been under development based on input from committee members representing consumers, producers, and researchers who have a direct interest in concentrator testing. This draft will eventually lead to agreement on a standard for thermal performance testing of concentrators.

Research on standards covers the broad categories of testing techniques, instrumentation, and data analysis. Some specific issues include:

- Alternate methods of collector efficiency measurement, namely the reference-heat-source calorimetric-ratio technique.
- Off-peak performance of both tracking and nontracking concentrators, including the effects of and compensation for end effects.
- "Time constant" measurement and its role in evaluating performance.

The reference heat source is of special interest since the MTCRF has the first such apparatus to operate over the mid-temperature range. This technique offers a potentially attractive alternative to the traditional $mc_p \Delta T$ method for measuring collector useful-energy gain. These issues are of importance not only to the standards development process, but to other research areas within the solar thermal arena.

4.2 MATERIALS RESEARCH AND DEVELOPMENT

The objective of the Materials R&D Subprogram is to accelerate the development and acceptance of solar thermal energy systems by establishing the technical feasibility of applicable materials and processes technology. Attaining this objective will minimize the life-cycle cost of delivered energy by optimizing the cost, performance, and reliability of materials subsystems. The Materials R&D Subprogram is divided into two sections: Optical

Materials and Thermal Materials. The strategy for Optical Materials is to develop, through industry, high-performance, low-cost, durable systems for domes and mirrors and low-cost optical support materials; evaluate metallization processes for glass and polymers; and develop and verify fabrication/assembly processes and associated materials that will permit cost-effective construction of glass or plastic concentrators. The strategy for Thermal Materials is to improve the efficiency by which absorber materials convert solar energy to thermal energy and improve the durability of the absorber in use and develop durable alloys or alternate containment materials.

During FY 1980, planning for this program was conducted by the Solar Energy Research Institute (SERI), Sandia National Laboratories at Livermore (SNLL), Jet Propulsion Laboratory (JPL), and Pacific Northwest Laboratories (PNL). Research and development was conducted by these laboratories and through subcontracts to private industries and universities. SERI was responsible for managing the program. The FY 1980 progress of these combined efforts follows.

4.2.1 Optical Materials Element

The Optical Materials Program includes work on reflectors, support substrates, and transmitting materials for concentrators in solar thermal systems. Materials research continued in FY 1980 on reflector, transmitter, and structural technology applicable to these concentrator design options. Examples of these are shown in Fig. 4-15.

In the area of transmitting materials, research was conducted on glass and polymers. In FY 1979, a test run was completed with glass made by Corning Glass to specifically address these issues. This glass has a 10% higher solar transmittance and an 11% higher fracture toughness than soda-lime float glass and can be fabricated in thicknesses of less than 1.5 mm.

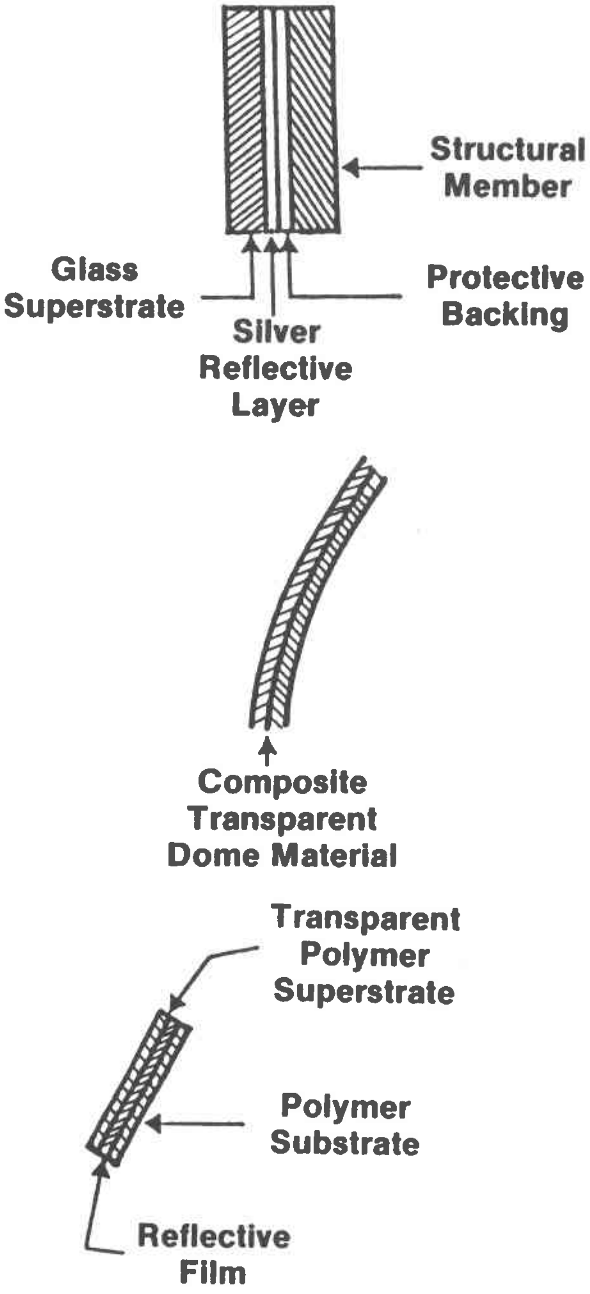

Figure 4-15. Optical Materials Elements

This glass was distributed to numerous manufacturers and designers for testing and evaluation. The results of their experiences will be compiled in a report in early FY 1981. Because of the high transmissivity and thinness of this glass (Corning 7809), a new cutting procedure for production applications was required. Tests in FY 1980 have shown preliminary feasibility for the CO_2 laser cutting of the glass.

Polymeric materials are another option for transmitting materials. A major consideration with these materials is the improvement of long-term stability and durability.

SERI has developed a technique using Fourier Transform Infrared Spectroscopy (FTIRS) which is extremely sensitive to changes in polymer chain chemistry. This permits the study of mechanisms of real-time polymer degradation. JPL developed maximum valid acceleration factors for the evaluation of ultraviolet (UV) degradation in various polymeric materials. This in turn defines the extent to which degradation may be accelerated and still provide valid life-prediction estimates. Experimental verification of this model will continue in FY 1981. A model specific to the photodegradation of polymethylmethacrylate acrylics (PMMA) was also developed by JPL allowing long-term durability predictions. This model is being used to modify PMMA acrylics and develop polymers of increased durability.

In concentrating systems a key element is the reflector surfaces. These can be of two designs: (1) second-surface mirrors of glass or polymer, usually metallized with such metals as aluminum or silver, or (2) first-surface mirrors with the metallized surface exposed, though perhaps with a protective coating.

Reactions at the silver/glass interface have been studied to improve the adhesion and degradation resistance of the reflector. PNL has found that lanthanide treatment of the glass before metallization improves the durability of the reflector, although the mechanism is not clearly understood. Silver agglomeration has been identified by SNLL as a possible degradation mechanism. Studies at SNLL and SERI indicate some migration of copper from the mirror back to the silver/glass interface which may affect mirror lifetime. SERI determined that under some conditions copper can promote electrochemical degradation of the silver reflector. Preliminary data from SNLL also indicate that moderate temperatures [100° C (212° F)] induce a reduction of the solar reflectance of mirrors. These findings will be studied more extensively in FY 1981.

Although wet-process silver/glass mirrors are presently the industry standard, alternate processes such as vacuum-evaporative and sputtering techniques may offer advantages. One possible alloy is silver-aluminum, which promises the improved durability of aluminum with reflectance approaching that of silver. Cornell University, a SERI subcontractor, examined the idea of alloying aluminum with various rare earths to improve the reflectance. It was determined that such an improvement with rare earth is theoretically impossible.

SERI has initiated a testing program of the broad spectrum of optical materials in a variety of environments to gain real-time data and information for a materials performance handbook. This program will be expanded in FY 1981 to include industrial process heat sites.

Accurate measurements of optical properties are critical to optical materials design. SERI has developed a spectrometer with an improved integrating sphere which permits extended measurement capability in the infrared spectrum. A fully automated spectrometer measuring solar-weighted absorbtivity, emissivity, and reflectivity has been developed at PNL. PNL has designed a two-dimensional laser contour-mapping system, which measures the spacial specularity of a reflector. Reflector fidelity can also be measured using a mirror figure apparatus developed at PNL. A moiré pattern is projected on a mirror and any deviation from flatness causes distortion in the pattern which can then be measured electronically.

Critical evaluation and testing requires accurate, reproducible standards. Under SERI contract, the National Bureau of Standards has developed two standards for high and low diffuse reflectance. Designated SRM 2019-2020 and 2021-2022, respectively, these standards may be purchased through the Office of Standard Reference Materials. A specular reflectance standard is under development and will be available for purchase from NBS in FY 1981.

Lightweight structural materials of high dimensional stability and moderate costs are necessary for a variety of optical elements. JPL has demonstrated technical feasibility of SFG-forming cellular glass with densified face skin to improve durability and lifetime. Preliminary design for incorporation in concentrator design has been completed. A study was also completed that identifies generic cost-performance optimization for flat or curved panels.

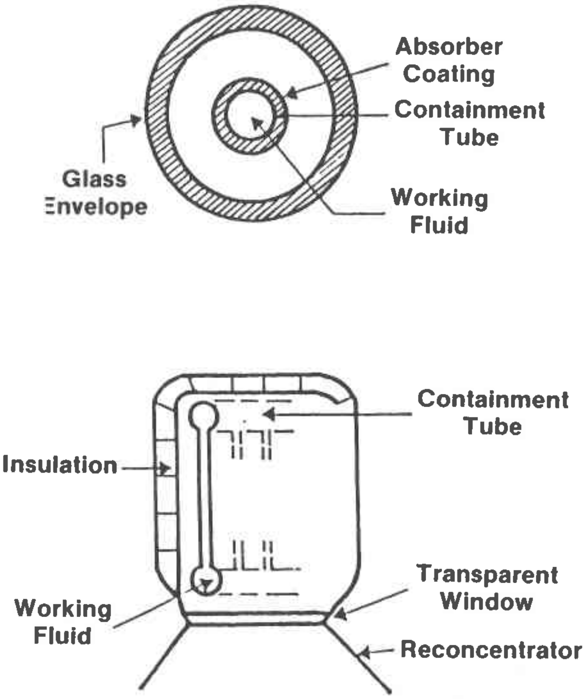

Figure 4-16. Thermal Materials Elements

4.2.2 Thermal Materials

Materials developments in this area relate to the requirements for receivers, as well as associated containment and heat-transfer materials. Figure 4-16 illustrates examples of these materials systems. Through multilaboratory cooperation, a containment materials research and development plan was completed that outlines a comprehensive program for containment materials development and evaluation [2]. JPL developed a performance prediction modeling analysis of the use of ceramics in high-temperature receivers.

One portion of the receiver which has been under development is a selective absorber coating stable at temperatures up to 500° C. Two options for selective absorber coatings identified in FY 1979 were evaluated in FY 1980. Subcontracts were awarded to Telic, Inc. and Raytheon Co. to evaluate the commercial production feasibility of vacuum deposition or chemical vapor deposition to deposit absorber coatings. This evaluation will be completed in FY 1981. Efforts to characterize black chrome degradation continued. Under a SERI subcontract the University of Houston proposed a model and degradation mechanism for black chrome. The theory is that at elevated temperatures particulate chromium is gradually oxidized, resulting in the reduction of optical performance. Efforts to evaluate black cobalt as an alternative coating continued. Research results at SERI indicate that the coating is stable to 600° C if the substrate is stable to that temperature. SERI also established optical criteria for the control of the solution chemistry of black chrome and black cobalt deposition. A patent disclosure for this process filed. A test facility to screen absorber coatings to 550° C was also completed at SERI which includes a variable environment, thermal cycling, and up to 100 X exposure. This equipment will be utilized in FY 1981 to evaluate currently available absorber materials.

4.2.3 Data Base

Collection of information for a materials data base was initiated at SERI for materials in both optical and thermal systems. This information is scheduled to be available through SERI's Solar Energy Information Data Bank in FY 1981.

4.3 FUELS AND CHEMICALS

A large portion of the fuels and many of the chemicals made today are the products either of refining operations or endothermic reactions, both of which require heat. Solar thermal technology can be used as an environmentally benign and clean source of energy to produce many of these fuels and bulk chemicals. Current practices in synthetic fuel processing of nonrenewable feedstocks (e.g., coal, lignite, and oil shale) require that a portion of the feedstock be burned to supply heat; using solar thermal as the heat source can extend these limited resources by as much as 40%. Other endothermic reactions using only renewable feedstocks such as water, CO_2, and biomass also can be coupled with solar thermal to produce fuels and chemicals. In addition, the very high-temperature heat and concentrated photoenergy available from solar thermal technology may be applied to explore new, advanced endothermic reactions.

Specific objectives of the fuels and chemicals program are:

- use of solar thermal energy to produce conventional fuels utilizing domestic nonrenewable feedstocks to replace imported fuels, with initial commercialization by the early 1990s;
- use of solar thermal energy for production of selected heavy chemicals and fertilizers by the early 1990s;
- demonstration of the feasibility of fuel and industrial feedstock production from domestic, renewable resources by 1990; and
- continued exploration of the unique capabilities of solar thermal energy in high-temperature thermochemistry and high-intensity photochemistry for manufacturing new fuels, ceramics, and chemicals.

In FY 1980 the DOE San Francisco Operations Office was given the responsibility for managing the fuels and chemicals program. Program elements will be conducted by industrial contractors, universities, and other government laboratories.

A summary of progress made during FY 1980 follows.

4.3.1 Biomass Pyrolysis

Project Description

The objectives of the solar thermal fuels and chemicals effort at SERI is to establish the technical and economic feasibility of using high-temperature solar thermal energy in a process for converting agricultural waste products such as wheat straw into liquid hydrocarbons and alcohols for use as fuel. This task involves several concepts. All rely on the basic principle of storing solar energy as chemical bond energy via endothermic chemical reactions. One concept is the integral chemical reactor/receiver whereby the endothermic reaction is carried out within the solar receiver. Another concept is to produce diesel fuel from biomass materials through pyrolysis and synthesis. The latter is being researched at Arizona State University using conventional energy sources. The final concept is to apply the technology to the agricultural sector. A diagram of the process is shown in Fig. 4-17.

In FY 1980 the laboratory apparatus was fabricated and installed (Fig. 4-18). The apparatus is instrumented to provide data on temperature, flow rates, and power

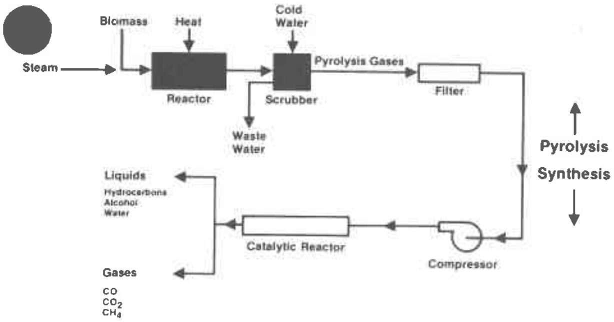

Figure 4-17. **Biomass Pyrolysis/Fuel Synthesis Loop**

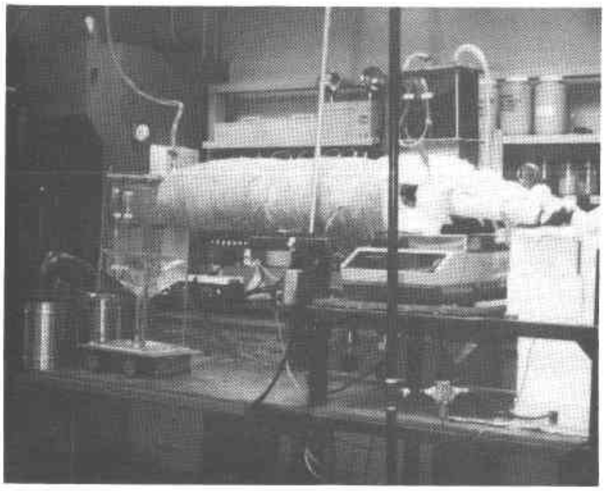

Figure 4-18. **High-Temperature Applications Laboratory Apparatus**

requirements of the pyrolysis reaction. An energy and preliminary economic analysis of the process indicates that the solar process is competitive with using biomass as a heat source when the cost of heliostats is $\$85/m^2$ and biomass costs \$65/t. A solar receiver for pyrolyzing biomass (based on the copper receiver described in Sec. 4.1.1) using a 6-m-diameter parabolic dish at the SERI ACRES test site was designed and built. Simulated pyrolysis gas was used in the laboratory to produce diesel fuel in a Fischer-Tropsch catalyst reactor. A chromatogram of the synthetic diesel and commercial diesel No. 2 is shown in Fig. 4-19.

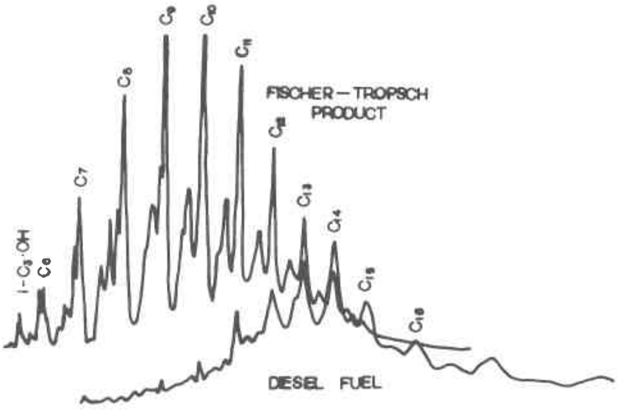

Figure 4-19. **Chromatogram of Synthetic Diesel and Commercial Diesel No. 2**

4.3.2 Solar Thermal Fuels and Chemicals at Lawrence Livermore National Laboratory

An overall analysis of how solar energy could be applied to the production of fuels has been performed with the aid of a net energy analysis study performed by the Colorado Energy Research Institute. The net energy analysis study identified energy losses in the production of fuels by conventional techniques. Using this study, Lawrence Livermore has identified four areas where solar thermal energy could be used to assist the processing of fossil feedstocks into fuels with a major improvement in the efficiency of using the depletable fossil feedstock. They are solar coal gasification, solar retorting of oil shale, solar steam flooding of oil fields, and solar steam reforming of methane.

4.3.2.1 Solar Retorting of Oil Shale [3,4]

A detailed analysis of the technical and economic feasibility of solar retorting of oil shale was performed. This analysis shows that such a process should be technically feasible and, depending on the grade of the shale, should improve the exportable fuel yield from the oil shale by

10% to 40%, compared with the best competing (nonsolar) surface process. A preliminary economic analysis shows that the improved oil yield should more than pay for the incremental cost associated with adding the solar collector system.

A demonstration experiment using focused solar energy to retort oil shale was performed at the White Sands Solar Furnace. The experiment was a success in that oil yields of better than 110% Fischer Assay were demonstrated with a retort design that used a window to allow direct heating of the shale particles as they passed through the solar focus. This can be compared with conventional surface oil shale retorts, which typically yield 80% to 95% Fischer Assay. (Fischer Assay is a standard oil shale testing procedure commonly used to characterize different oil shales.)

4.3.2.2 Solar Coal Gasification [5,6,7,8]

The report on the solar coal gasification work done in FY 1979 was issued. This report presented experimental results, obtained at the White Sands Solar Furnace, which showed technical feasibility and very high solar efficiency for solar gasification of coal, activated carbon, coke, and coal and biomass mixtures.

A number of experiments were run on a 2-kW solar furnace at Odeillo, France, where the carbonaceous materials—charcoal, wood, and paper—were gasified. In these experiments, the steam needed for the gasification reaction was generated by injecting water on the hot, solar-heated fuel. In the case of charcoal, approximately 30% of the incident solar energy was stored as chemical energy in the product gas, and 55% of the injected water was consumed. A fluidized bed of char was also gasified (fluidized with CO_2) with approximately 10% of the solar energy being chemically stored in the product gas. These experiments represent the first exploration of the use of water spray and fluidized bed techniques. The water spray worked very well, but the fluidized bed technique needs considerably more development before this approach could be considered promising.

4.3.2.3 Projected Potential Impact of Solar Coal Gasification and Oil Shale Retorting

The projected potential energy impact of solar coal gasification and solar retorting of oil shale is presented as a function of year in Fig. 4-20. The numbers used to generate the figure were arrived at as follows:

1. Total Synthetic Fuel Production Rate: Lawrence Livermore National Laboratory has had an energy planning group for more than five years. One of the major efforts of this group has been to develop a model for projecting future energy requirements and the potential impact of new energy processes. The curve presented here for the total synthetic fuel production rate is the best projected estimate using the model. This projection has price assumptions built into it, and takes into account a multitude of processes for producing syn-

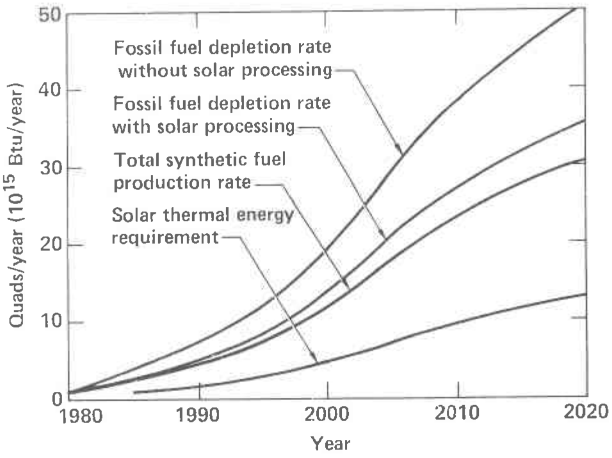

Figure 4-20. **Projected Potential Impact of Focused Solar Thermal Production of Fuels from Fossil Feedtock (Coal and Oil Shale)**

hetic fuels. Approximately one-half of the synthetic fuels will come from oil shale and the other half will be derived from coal. Fuels derived from biomass are projected to be a very small contributor. The projected usage will change with pricing, increasing with decreasing costs, and solar processes have not been introduced into the model. Therefore, Lawrence Livermore has used this projected use rate, which is the best estimate at this time, and estimates the potential impact if all the synthetic fuels were derived from solar coal gasification and solar oil shale retorting processes instead of the assumed conventional gasification and retorting processes.

2. Fossil Fuel Depletion Rate without Solar Processing: This is the rate at which the fossil fuel resources will have to be consumed to produce the projected synthetic fuel production rate. This is estimated by assuming both the coal and oil shale processes are approximately 60% efficient in converting raw feedstock into synthetic fuels. This is a reasonable assumption based on many articles about the various processes.

3. Solar Thermal Energy Requirements: This is the estimated focused solar thermal energy requirement delivered to a point in space by fields of heliostats or dish systems. It is assumed that 60% of that focused energy is absorbed into the processes, and the chemistry is that reported in Lawrence Livermore's solar coal gasification and solar oil shale retorting reports.

4. Fossil Fuel Depletion Rate with Solar Processing: This is the estimated depletion rate of fossil fuels which would result if all the synthetic fuels derived from coal and oil shale used the solar coal gasification and oil shale retorting instead of the alternate nonsolar processes. The difference between this curve and the curve for the depletion rate without solar processing is the projected impact of the solar processing on reducing the consumption of fossil fuels.

These projections assume that all of the coal gasification and oil shale retorting needed for synthetic fuel production uses solar processing. However, the actual fraction of the production that will be solar will be a function of the price of the product. Researchers at Lawrence Livermore are now working on estimating that fraction as a function of product price.

4.3.3 Solar Coal Gasification Program at Los Alamos Scientific Laboratory

In October 1978, the Applied Photochemistry Division of Los Alamos Scientific Laboratory was funded through the Office of Energy Research to investigate the gasification of coal using a CO_2 laser as a solar simulator. The gasification process envisioned for solar adaption is called entrained-flow gasification. In this process the coal is pulverized to a fine powder and entrained in a stream of reactant gas such as H_2O, CO_2, or H_2 and then passed through a reaction chamber where the energy to drive the endothermic chemistry is supplied by concentrated sunlight. The entrained-flow gasification concept was chosen because it offers several advantages over other gasification techniques. Some of these advantages are:

- the process permits rapid pyrolysis and thus a high gas yield;
- this process has been shown to be capable of handling both caking and noncaking coals;
- the gasifier is compact and can be designed for low thermal inertia;
- processing of slag and ash from this process is much simpler than for other gasification methods; and
- this process will permit easy adaption to the use of concentrated solar energy as the heat source.

To work toward the proof of this concept of solar gasification, the investigators chose to use a laser to simulate concentrated sunlight because this would permit cost-effective rapid-turnaround experiments in the laboratory. The first year of the project was devoted to constructing the equipment and diagnostics for conducting pyrolysis and gasification experiments on static samples of finely powdered coal. The equipment that was assembled for these experiments was constructed in modules for easy transport to existing solar furnaces for verification of the laser results. The diagnostics included a portable mass spectrometer, an optical pyrometer, thermocouples, and Validyne pressure transducers. A cross section of the reaction chamber is shown in Fig. 4-21, and details of the sample geometries used in the experiments are presented in Fig. 4-22.

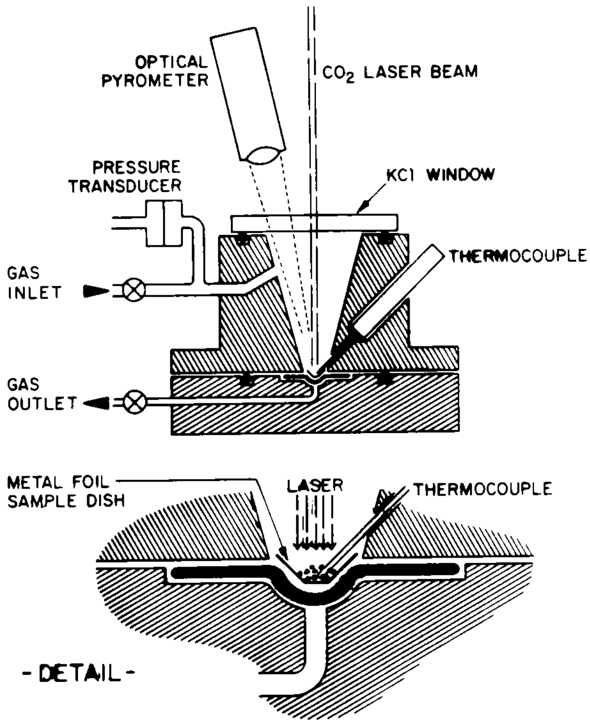

Figure 4-21. Laser Pyrolysis Cell with Its Associated Diagnostics

The cell was constructed of brass and the sample pan of molybdenum foil. The dark band in the detail represents zirconia felt paper, which serves to insulate the pan from the cell base.

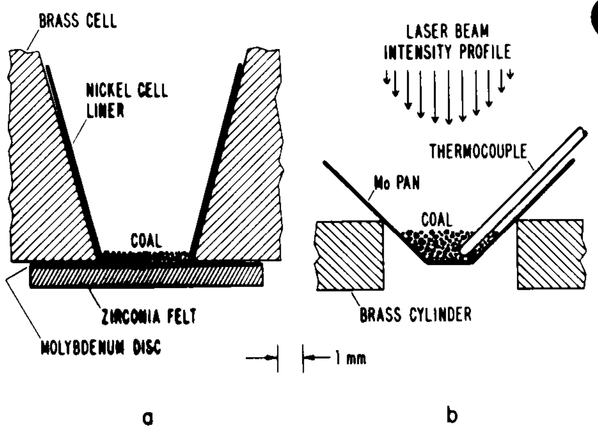

Figure 4-22. Two Sample Geometries Used in Laser Pyrolysis Experiments

In (b) a 5.0 mg sample of 50- to 100-mesh coal (0.15- to 0.30-mm particle diameter) is held in a molybdenum pan of 9-mm diameter and 0.25 mm wall thickness and weighing 33 mg. The coal sample is approximately 3.8 mm in diameter at the top, 1.2 mm deep, and has a surface area of 0.10 cm^2. The pan rests on the edge of a brass cylinder to minimize heat transfer. A sheathed micro-miniature thermocouple of 0.36 mm diameter extends to the bottom of the sample. In (a) the coal is held in place on a 0.25 mm thick molybdenum disk by a tight-fitting nickel cell liner of the same thickness. The 5.0 mg coal sample is approximately 4.0 mm in diameter at the top and 0.65 mm thick (half as thick as in (b).

With the equipment described, experiments were carried out to determine the total gas yield and the yield of specific gases with laser flux level and surrounding gas pressure. These results show that the maximum gas yield and highest heating value are achieved for laser fluxes of about 250 W/cm^2 with a gas overpressure of 1 atm. The results of these investigations are discussed in detail in a recent paper [9]. The pyrolysis of coal was studied in considerable detail because it is the first step in coal gasification. Results were extended to the second step of gasification by investigating the gasification of laser-produced char in an atmosphere of CO_2.

In the current effort, laboratory-scale apparatus was constructed that will permit laser pyrolysis and gasification of powdered coal entrained in reactant gases. A schematic of the apparatus is shown in Fig. 4-23. Since the start of this effort in April 1980, the first trial set of equipment has been designed, constructed, and assembled. Some very preliminary results on pyrolysis of coal in the entrained flow apparatus have been obtained.

In FY 1981 parametric studies on the entrained-flow apparatus will be completed, and experiments are planned at an existing solar furnace that will permit verification of the laser results.

4.3.4 Production of Alternate Fuels Studies at the University of New Hampshire

Accomplishments during fiscal 1980 on the project "Alternate Fuels Manufactured from High-Temperature Solar Thermal Systems" at the University of New Hampshire include the following:

- A survey was made of conventional gasification systems suitable for use in conjunction with solar energy to conserve nonrenewable fuels.
- A gas-recirculation-type hybrid gasification system was identified. In the hybrid unit, a high-temperature solar

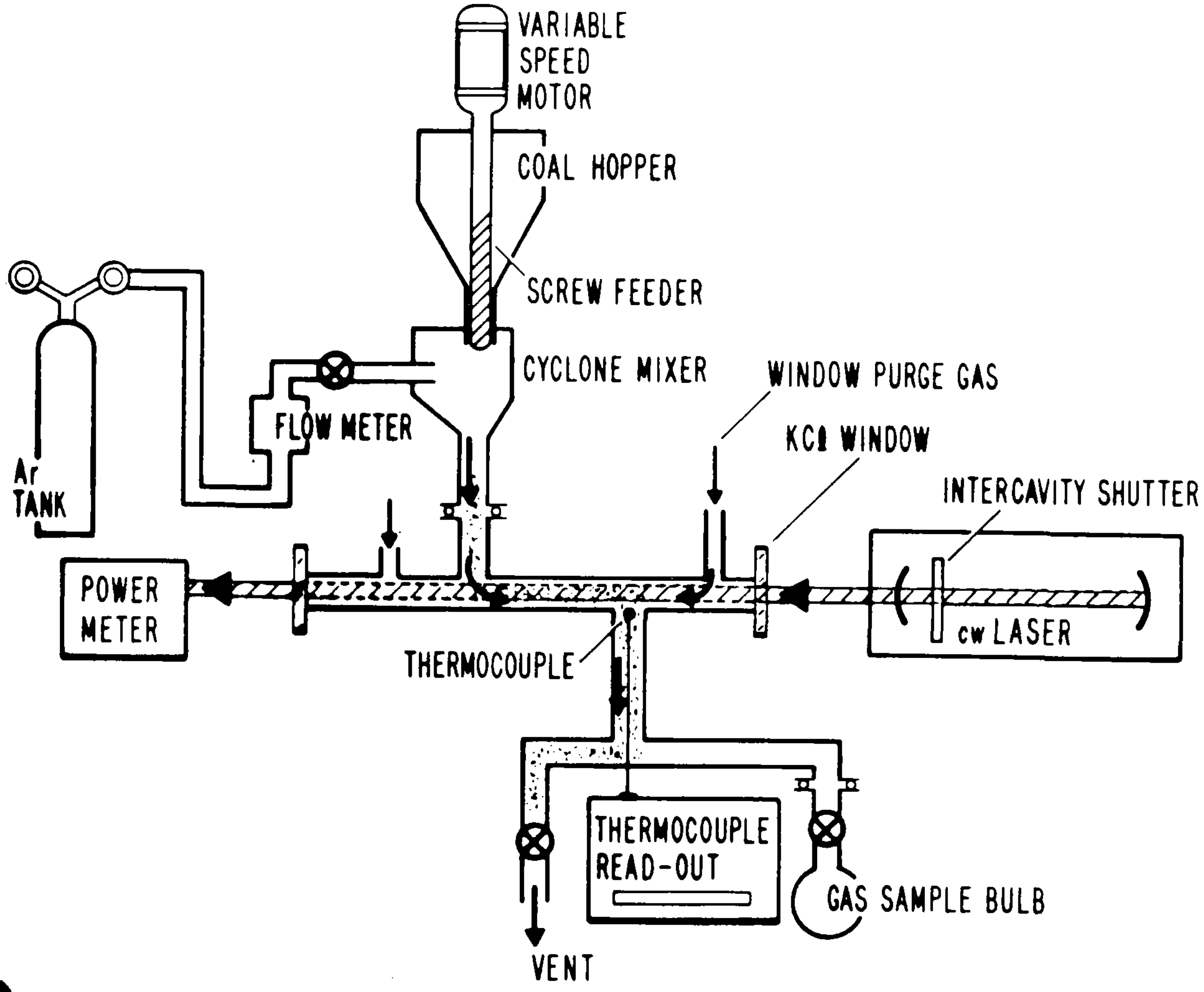

Figure 4-23. Schematic of Laser Pyrolysis and Gasification Apparatus

thermal system will supply the necessary energy to sustain the endothermic reaction, to produce steam required for the process and for generating power required for the plant operation.

- A cost analysis for conventional as well as hybrid gasification units using wood, peat, lignite, and coal as feedstock was made. Total capital investment (including working capital) and operating cost for the production of 250-MM SCF/day of pipeline gas (methane) were estimated, and an economic feasibility study for different hybrid systems was performed.
- A computer program was developed for calculating the cost of synthetic natural gas for the gasification systems discussed, and the effects of the costs of raw materials and changes in the plant investment on the cost of synthetic natural gas were analyzed. The data generated are stored in computer files for easy evaluation.
- Design of a two-stage bed-gasification unit was completed. This system consists of two fluidized bed reactors. The stage I reactor is a hydrocarbonizer. The product char from stage I is fed to the stage II reactor where gasification with steam is carried out. Part of the gas from stage II is removed as product and the rest is preheated in a solar receiver or coal combustion unit and fed to stages I and II. The gaseous products from stages I and II can be utilized as fuel or for the production of synthetic natural gas or chemicals.
- Methods and costs to transport coal to solar-intensive regions were studied. Transport by barges and unirail will be economical, and coal slurry transport is another possible option.
- Sizing of plants was studied. There are many industries whose requirement of fuel gas may be about 25 x 10^9 Btu per day. The cost of producing gaseous fuel from such small units was estimated.
- Two papers have been presented [10,11] on this work, to disseminate information as widely as possible.

Future Plans

- A bench-scale hybrid unit will be fabricated and experiments will be carried out to study the various aspects of the gas-recirculation hybrid system.
- Plans for tests at the Georgia Institute of Technology Advanced Component Test Facility will be completed. A preproposal for testing the bench-scale unit at the ACTF using the ceramic honeycomb matrix solar receiver developed and tested by Sanders Associates has been prepared and submitted. The use of this receiver was discussed with Sanders Associates; the firm agreed to collaborate in the use and testing of its receiver.
- Economic feasibility assessments for hybrid solar units with respect to export potential will be made, together with a preliminary survey of hydrocarbon (fossil and biomass) resources in foreign sunbelt countries.

4.3.5 Development of a New High-Temperature Gas Receiver Using Direct Absorption by Ultrafine Particles at Lawrence Berkeley National Laboratory (LBNL)

The purpose of this work is to develop a new type of solar thermal receiver that is placed at the focus of a central tower or a parabolic dish concentrator system. The principle of operation differs from other advanced receiver designs under development in that the solar-to-thermal conversion is accomplished by a dispersion of ultrafine particles suspended directly in a gas to absorb radiant energy from concentrated sunlight. The very large ratio of surface area to volume exhibited by small particles makes them ideally suited for this application.

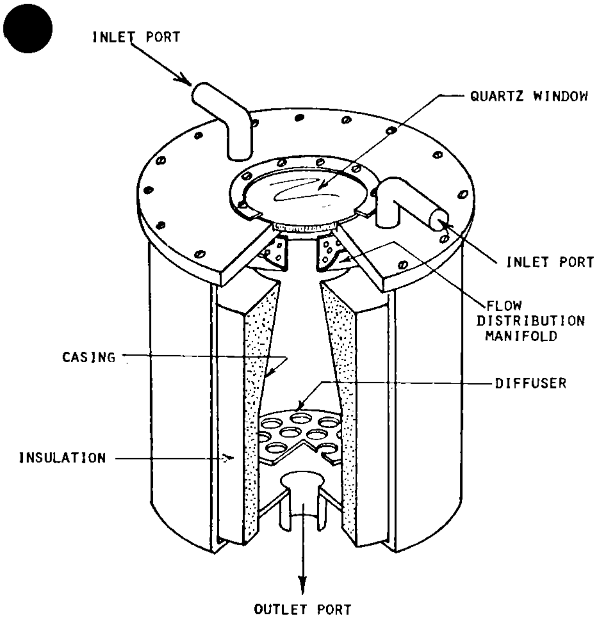

Figure 4-24. Design of a Laboratory Model of a Small-Particle Heat-Exchanger Receiver

The Small-Particle Heat-Exchange Receiver (Fig. 4-24) can be used to power a Brayton-cycle engine, supply industrial process heat, or directly heat a gas to provide energy for a chemical reaction. Small-particle heat-exchange receivers should prove suitable for a wide range of sizes and a variety of applications. The advantages of these receivers are their simplicity, low pressure loss, light weight, high optical efficiency, lower chamber temperatures for a given gas temperature, and lack of problems associated with heat exchanger lifetime.

The feasibility of the concept has been under investigation for the past two years at Lawrence Berkeley [12]. The approach is to investigate the particle production methods, study the optical and physical processes of absorption and heating of the particles, design and build a receiver chamber, and conduct laboratory and field [illegible]ts of the complete system.

4.3.5.1 Technical Progress [13,14]

The FY 1980 experimental program had three main thrusts: particle production, particle characterization, and the design and construction of a bench-test receiver to determine the performance of the particle-gas mixture as a heat exchanger.

Work was performed on three alternative methods of producing carbon particles. They included the use of an enclosed-diffusion flame, a high-intensity arc in an inert gas atmosphere, and the pyrolysis of hydrocarbon gases. The last method appears especially attractive because it offers a high-yield particle source that can easily be incorporated into the receiver design.

After production, the particles are routed directly to a test fixture to determine the opacity of the suspension and the mass per unit volume. Samples of the particles are taken for spectroscopy, microscopy, and chemical testing. Laboratory measurements have yielded extinctions in excess of 99% for light paths of 30 cm with specific extinction coefficients of 15 to 20 m^2/g. These results are extremely encouraging, since they establish that the particles have four times greater absorption than predicted by Rayleigh scattering theory. This higher extinction coefficient has the effect of reducing the already extremely low requirement for particles.

To demonstrate the operation of the major components and of the small-particle heat-exchange receiver (SPHER) and to obtain laboratory data on its operation, a bench-test receiver is being constructed (Fig. 4-24). It consists of a window, a chamber to confine the gas-particle mixture, and a manifold to conduct the mixture to the receiver. The inherent simplicity of the design is apparent from the sketch.

The analytic effort is continuing to investigate several unique aspects of the SPHER concept. These include the determination of the particle temperature for various operating conditions, the absorption and scattering properties of small-particle suspensions illuminated by concentrated sunlight, and the investigation of the three-dimensional flux distribution inside the receiver cavity.

4.3.5.2 Future Plans

The goal of the program is to demonstrate the operation of a practical high-temperature gas receiver based on the direct absorption of small particles. Toward that end, plans call for the detailed laboratory testing of the bench receiver. The experience gained from these tests will provide the information necessary to design a SPHER suitable for testing at a National Solar Test Facility.

4.3.6 Solar Fuels and Chemicals Activity at JPL

In FY 1980, fuels and chemicals research was undertaken at JPL in the following areas:

- solar production of furfural;
- reconcentration of spent sulfuric acid;
- incineration of toxic chemicals; and
- wet-air oxidation.

Efforts were also made to identify areas of future research that look promising. The primary concepts which emerged involved production of alcohols by solar driven processes using feedstocks of coal, peat, lignite, and biomass.

4.3.6.1 Furfural Production

Small quantities of furfural were made in preliminary laboratory tests using corn cobs as the feedstock. A small pilot plant was also built and tested using an electric steam generator. This experimental setup is shown in Fig. 4-25. Results of the tests were very encouraging in terms of both yield and quality of furfural.

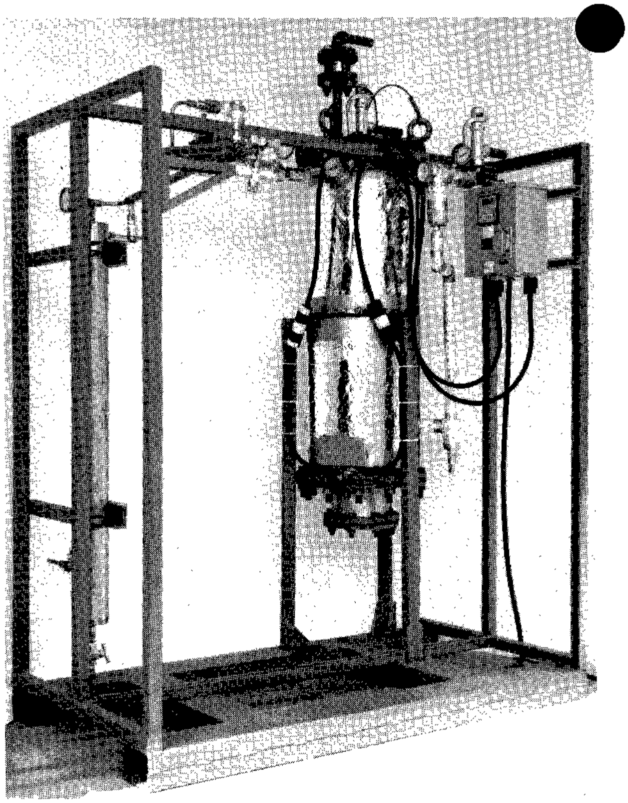

Figure 4-25. The Solar-Powered Reactor for the Production of Furfural

Efforts are currently under way to interface this plant with a test-bed concentrator (TBC) at the Parabolic Dish Test Site at Edwards, California. It will be ground-mounted and fed by steam from the parabolic TBC. Work was begun to design a larger pilot plant, also to be interfaced with the TBC. When this is accomplished, the smaller plant will be returned to JPL. It will be used, with the electric steam generator, for refinement of process conditions and testing of new furfural feedstock materials.

The only commercial manufacturer of furfural in the U.S. is the Quaker Oats Co., and they have shown an interest in its production by solar means. In the JPL wor it was recognized that residues from t furfural process can be used as a feedstock for the production of alcohols or acetone. This is readily done using the residue that results from the first step in the furfural process—an initial hydrolysis of the polysaccharides from corn cobs.

4.3.6.2 Reconcentration of Spent Sulfuric Acid

The reconcentration of spent sulfuric acid has attracted increasing interest in recent years. This process involves vaporization of the acid and decomposition to sulfur dioxide, followed by processing in an ordinary contact-process plant to yield new acid. As a result of preliminary studies, a direct-radiant boiling concept was selected to cause the initial vaporization of the acid. This approach avoids the use of solid heat-transfer surfaces in contact with the liquid acid. An apparatus of bench scale, as shown in Fig. 4-26, was constructed. It uses a 61 x 45 cm Fresnel lens to concentrate the sun's rays onto an insulated glass vessel. The entire assembly was attached to a polar mount to track the sun.

The setup was tested first with distilled water and then with reagent-grade 98% sulfuric acid. Inorganic salts were added to increase absorption of the solar flux. Boiling took place throughout the fluid volume at the normal boiling point of the fluid. Boiling of sulfuric acid by this method proceeded very smoothly, in contrast to the distilled water which splattered violently. Thermal efficiency of this small-scale vaporization method was approximately 50% based on incident solar radiation at the surface of the lens.

4.3.6.3 Incineration of Toxic Chemicals

Possible applications of the high-temperature capabilities of parabolic dish collectors for incineration of toxic chemicals were examined. An extensive literature survey was conducted, and small quantities of some of the chemicals were acquired for the purpose of determining for each the chemical kinetics of thermal degradation. Investigations were also initiated to identify likely catalysts effective in decomposition and detoxification processes. These data will be needed in further studies of solar thermal processes for the destruction of toxic wastes.

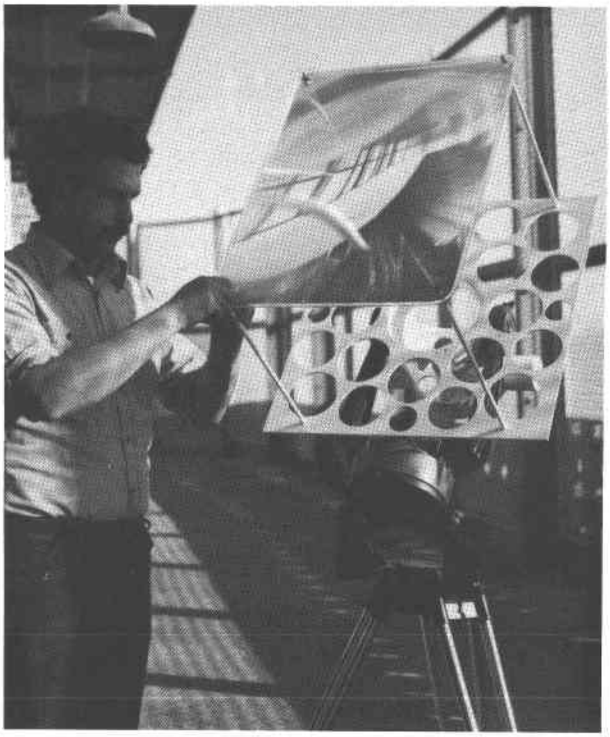

Figure 4-26. The Fresnel System for Reconcentration of Spent Sulfuric Acid

4.3.6.4 Wet-Air Oxidation

Wet-air oxidation is an efficient and safe means of incinerating an oxidizable substance in an aqueous environment. For dilute waste streams, especially those containing highly toxic chemicals, it is superior to conventional incineration in that it does not require preconcentration of wastes prior to treatment, thus eliminating the need for evaporation equipment. The waste stream is held in contact with oxygen (or air) at temperatures between 250° and 325°C (485° and 620°F) under pressures sufficient to maintain only the liquid state. Wastes such as cyanides, phenols, and chlorinated hydrocarbons are oxidized to carbon dioxide, water, chlorides, and other nontoxic compounds.

For water streams containing less than about 3% organic contaminants, energy must be supplied to drive the process. Parabolic dish collectors can be run at constant power at any desired temperature within a wide range, and thus are readily adaptable to the wet-air oxidation process. Batch processing on a diurnal cycle is compatible with the chemical kinetics involved.

In FY 1980, detailed studies of existing methods of wet-air oxidation were conducted, and a laboratory-scale experiment was designed. The reactor vessel is a key element, and its preliminary design was based on the heat flux available from the Omnium-G concentrator, which has been undergoing tests at the Parabolic Dish Test Site.

4.4 SOLAR PONDS

Feasibility studies of a solar pond at the Salton Sea in California were conducted in which performance, cost, and environmental factors were examined. A water clarity problem was identified and assessed. A preliminary design study of a field test pond of 5-MW_e capacity was conducted, having baseload characteristics and a capacity factor of 0.75. A 600-MW_e commercial plant was analyzed for which installed costs were estimated to be \$1,830/kW_e.

4.5 SUPPORTING PROGRAMS

4.5.1 Solar Thermal Test Facilities Users Association (STTFUA)

Solar thermal research is being conducted at experimental facilities in the United States and France. The experiments were recommended by the Solar Thermal Test Facilities Users Association (STTFUA) following a competitive solicitation and evaluation, and are sponsored by DOE. Technical monitoring and direction to the resulting subcontractors was provided by the Solar Energy Research Institute.

All of the activities were highly experimental and utilized one of three high-temperature solar facilities in FY 1980: the Georgia Institute of Technology 400-kW_t Advanced Components Test Facility (ACTF), the White Sands 30-kW_t Solar Furnace (WSSF), and the French CNRS (1.5- to 6.5-kW_t) Vertical Solar Furnace. Table 4-1 provides an overview of the FY 1980 program experiments. Table 4-2 lists the specifications for all of the STTFUA facilities. The objectives and current progress of each experiment are discussed in the narratives that follow, beginning with progress for those experiments completed or partially completed and later describing the objectives of the planned activities.

- Coal Gasification. Coal and oil shale were gasified at the White Sands Solar Furnace in June-July, 1979. Initial efforts demonstrated the successful production of medium-Btu gas from coal and biomass feed materials. Later efforts used oil shale as feedstock. Preliminary data indicated that 60% of the solar energy that entered the reactor was chemically stored.
- Calcium Carbide Production. Solar-powered production of calcium carbide was successfully accomplished at the French CNRS Vertical Furnace with a 30% to 40% calcined lime-coke mixture converted to carbide in a heated crucible. Production at 1980°C (3600°F) and above was repeated several times during October 1979 to obtain data on the effects of mixture, composition, temperature, and heating rate.
- CO_2-CH_4 Reforming. Initial testing, during December 1979, involved a Solchem receiver containing two reform-

Table 4-1. STTFUA Experiments—Advanced Components

Experiment	Test Location	Contractor	Perf. Period	Budget-$k	Objective/Scope
Coal Gasification	WSSF	Lawrence Livermore Lab	6/79 - 7/79	23	Demonstrate production of hydrocarbon-rich synthesis gas from coal and biomass exposed to solar energy.
Calcium Carbide Production	CNRS	Institute of Gas Technology	9/79 - 2/80	37	Demonstrate and measure calcium carbide production in a solar facility.
CO_2-CH_4 Reforming	WSSF	New Mexico State University	9/79 - 12/80	80	Quantify solar thermochemical energy capture using CO_2-CH_4 gas reforming.
High-Temperature Solar Receiver	ACTF	Solar Turbines International	11/79 - 7/80	62	Design, fabricate, test a high-temperature (1500° F) solar receiver/steam generation system for solar central receiver applications.
Heat-Pipe Tech.	ACTF	Dynatherm	9/79 - 11/80	67	Design, fabricate, test a small representative heat-pipe solar receiver.
Fluidized Bed Technology	ACTF	Westinghouse	9/79 - 9/80	87	Investigate application of fluidized bed technology to solar central receivers.
Cadmium Oxide Decomposition - H_2 Production	WSSF	Institute of Gas Technology	9/79 - 9/80	104	Quantify thermochemical conditions in cadmium oxide decomp. as a step in producing hydrogen.
Flash Pyrolysis of Biomass	ACTF	Princeton Univ.	10/79 - 10/80	109	Design and test a vortex flow reactor to process kinetic information in biomass pyrolysis.
Solar Processing of Ores	WSSF	Los Alamos Scientific Lab.	2/80 - 1/81	98	Demonstrate feasibility of continuous processing of molybdenite ores in a solar receiver.
Sulfuric Acid Decomposition-H_2 Production	ACTF	General Atomic	5/80 - 2/81	98	Demonstrate use of solar energy in decomposing H_2SO_4 to produce H_2 based on water-splitting cycle.

Table 4-2. Approximate Specifications for STTFs and Solar Furnaces

Facilities	SNLA CRTF	Georgia Tech ACTF	White Sands Solar Furnace	JPL PDTS	CNRS Odeillo	
Configuration	Central Receiver	Central Receiver	Horizontal Furnace	Tracking Parabola	Horizontal Furnace	Vertical Furnaces
Total Thermal Energy, kW	5000	325	30	85	1000	1.5 to 6.5
No. of Heliostats	222	550	1	NA	63	1
Heliostat or Parabola Size, m	6 x 6	1.1 D	11 x 12	11 D	6.0 x 7.5	1.5 to 4 D
Total Solar Collecting Area, m^2	8257	532	132	95	2835	1.8 to 12
Test Area Diameter, m	2-3*	0.5-1.0*	0.08-0.15*	0.09-0.17*	0.25-1.0*	.006 to .07
Peak Flux,** W/cm^2	240	125	400	1000	1600	1500 to 500
Cal/cm^2 s	57	30	96	239	382	358 to 119
Maximum Temperature, ** K	2600	2100	2900	3600	4100	3200

*The first number is area receiving approximately 50% of total energy; second number is area capturing 95% of total energy.

**Small area at center of beam.

ing-converter/heat-exchanger coils operated at the White Sands Furnace. The feedstocks ratio used was 3 parts CO_2 to 1 part CH_4, with nominal mass flows of 3 g/s and 5 g/s. Energy conversion rates of 5-kW_t were observed with a 15-kW_t focused solar beam entering the receiver cavity.

- High-Temperature Solar Receiver. A high-temperature solar receiver was tested during March-April 1980 at Georgia Tech and demonstrated that steam could be produced at 770°C (1420°F) and 10.7 MPa (1550 psia) under steady-state conditions. The receiver utilized Hastelloy heat exchanger tubing in the once-through steam generator design. Figure 4-27 shows the hardware installed at the Advanced Components Test Facility tower.
- Fluidized Bed Technology. A fluidized bed receiver was tested at the Georgia Tech Advanced Components Test Facility during May and June 1980. A 4-ft long by 1-ft diameter quartz tube was used to contain several different bed materials through which air was blown to provide the fluidization. Bed materials were sand, silicon carbide, alumina, copper shot, fused silica, and mixtures of these materials. Bed temperatures reached as high as 563°C (1045°F), and the amount of incident energy transferred to the fluidized gas was as high as 45%. A total of nearly 70 test hours was compiled and 76 data points were collected.
- Flash Pyrolysis of Biomass. This experiment was conducted at the ACTF in August 1980. Individual experiments were performed on wood, corn cob, cellulose, and lignin-based feedstocks. Hydrocarbon-rich synthesis gases and combustible syrups adaptable for several energy-related operations were obtained from all of the feedstocks except lignin.
- Sodium Heat-Pipe Solar Receivers. This test program was conducted at the ACTF in October 1980. A maximum heat-pipe power of 11 kW_t was achieved, which was 2 kW_t lower than the desired power level. In addition to steady-state testing, transient testing was performed that included diurnal startup tests, several ramp tests, and a failure-mode experiment in which one heat pipe was purposely failed. Maximum heat-pipe temperatures of 850°C (1562°F) were reached during steady-state operation. A schematic of the heat-pipe receiver is shown in Fig. 4-28.

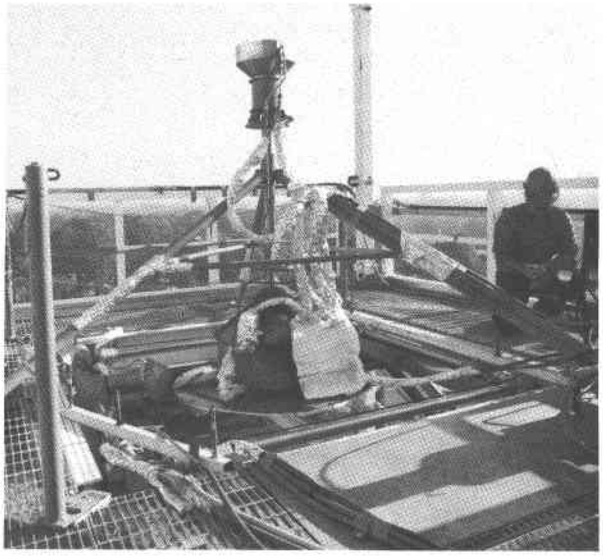

Figure 4-27. Solar Turbines International Steam System Installed on the GIT/ACTF Tower

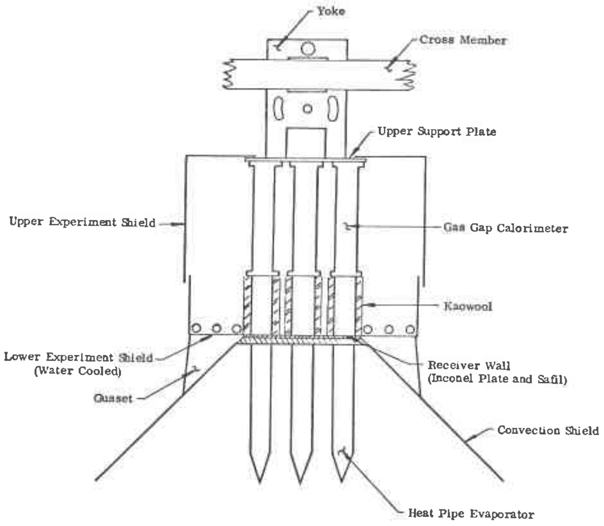

Figure 4-28. Schematic of Heat-Pipe Receiver

he programs that follow are in the planning, pretest phases:

- Cadmium Oxide Decomposition in Hydrogen Production. Tests were conducted in the White Sands Solar Furnace during the fall of 1980 to determine decomposition rate, temperature, and pressure of cadmium oxide as an intermediate step in the thermochemical production of hydrogen. A reaction chamber will be designed and reactors fabricated to carry out the decomposition process at expected temperatures between 982°C and 1482°C (1800°F and 2700°F).
- Solar Processing of Ores. Design, fabrication, and testing of a rotary kiln for processing molybdenite ores in batch quantities. Tests began at the White Sands Solar Furnace in August 1980. Testing during FY 1981 will include various flux and temperature levels and differing ore feedrates to assess rotary kiln capacity for continuous processing of molybdenite ore.
- Sulfuric Acid Decomposition. The objective is to demonstrate that hydrogen can be produced using solar energy in a thermochemical water-splitting cycle ultimately decomposing sulfuric acid vapor. The test was carried out at the Georgia Tech ACTF in November 1980. A reaction involving H_2O, I_2, and SO_2 has been investigated on a laboratory scale and defined as a promising thermochemical-producing cycle candidate.

Future Solar Thermal Test Facility Users Association activity will be directed toward development of advanced components and identification of processes that will make significant contributions to future solar thermal programs. These future efforts are directed toward new concepts not previously tested or demonstrated. The categories of research are enhanced heat-transfer mechanisms, advanced processes for producing fuels nd chemicals, innovative solar thermal hardware designs, thermochemical transport concepts, and other research areas not yet categorized.

4.5.2 Insolation Resource Assessment

The DOE Insolation Resource Assessment Program (IRAP) consists of efforts and activities to develop and provide accurate and standardized insolation data bases, characteristics, prediction and forecasting techniques, improved instrumentation, and assessments of national insolation energy resources.

IRAP consists of several elements conducted by other agencies, institutes, universities, and the private sector. The overall field management is assigned to the Renewable Resource Assessment Branch of SERI. The major elements are:

- historical data bases,
- national insolation-monitoring network,
- insolation data archiving and dissemination,
- Solar Energy Resource Atlas (assessment),
- insolation models and algorithm research,
- education and training,
- insolation research data collection and analysis, and
- development of improved instrumentation.

The following sections summarize the progress made during FY 1980 in each program element.

4.5.2.1 Historical Data Bases

The National Oceanic and Atmospheric Administration (NOAA), the National Climatic Center (NCC), the NOAA Air Resources Lab, and the NOAA Environmental Research Labs conducted an extensive effort to produce a national historic insolation data base. This computerized, standardized data base is known as SOLMET.

Such data bases are available from the National Climatic Center, Computer Products Branch, Federal Building, Asheville, North Carolina 28801, (704) 258-0203. The data are in the form of computer-compatible, 9-track, 1600 B.P.I. EBCDIC Format. The station locations are shown in Fig. 4-29. The National Climatic Center subsequently produced a monthly summary version of the SOLMET/ERSATZ data base [15]. This tabulated summary (or magnetic tape) contains:

- daily maximum normal temperature (°F),
- daily minimum normal temperature (°F),
- monthly normal temperature (°F),
- normal degree days (heating and cooling, base 65° F), and
- mean daily global horizontal insolation (Btu/ft^2, kJ/m^2, langleys).

During FY 1980, SERI produced an Insolation Data Base (INSOL) for the national Solar Energy Information Data Bank (SEIDB). It represents an expansion of the NCC monthly summary [15]. The INSOL data base contains:

- daily maximum normal temperature (°F and °C),
- daily minimum normal temperature (°F and °C),

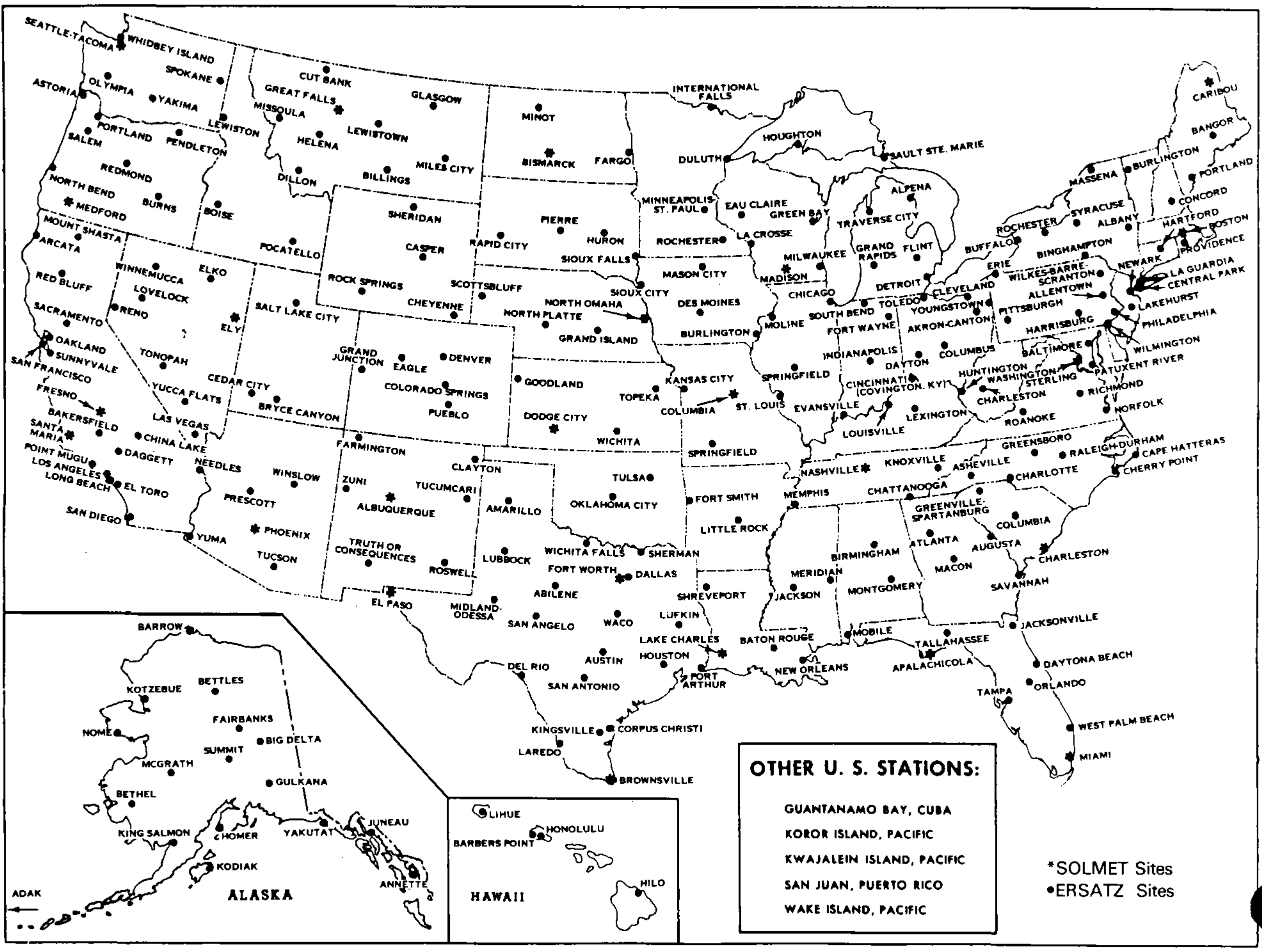

Figure 4-29. Historical SOLMET (26) and ERSATZ (222) Data Base Sites

- monthly normal temperature (°F and °C),
- normal degree days (heating and cooling, base 18.3°C),
- mean daily global horizontal insolation (Btu/ft^2, kJ/m^2, langleys), and
- global, mean daily, K (cloudiness index).

The SERI Renewable Resource Assessment Branch generated the K_T (cloudiness index) parameter for all 248 stations. K_T is defined as the fraction of extraterrestrial global horizontal insolation that reaches the earth's surface. During FY 1981 SERI will add monthly values of K_T for the direct beam insolation, as part of the INSOL data base. The INSOL data base is available through the SEIDB.

As a result of production of the Solar Energy Resource Atlas, some additional data base products have been produced. Typical Meteorological Years containing both global horizontal and direct-beam insolation have been produced for a total of 202 stations. These represent the only data for solar thermal direct-beam insolation other than the original 26 rehabilitated stations. During FY 1981, SERI and NCC will perform quality control checks on these new TMYs and then release them to the public.

4.5.2.2 National Insolation Monitoring Network

NOAA (National Weather Service) initiated operation of a 38-station solar radiation monitoring network during January of 1977. During 1978, direct insolation monitoring equipment was installed. The NCC has been publishing monthly summaries of these new data [16], including insolation for each hour of each day of each month. The hourly mean, daily totals, and mean daily insolation are also given. This summary is also available from NCC.

4.5.2.3 Insolation Data Archiving and Dissemination

The National Climatic Center is responsible for archiving and disseminating data from the National Weather Service 38-station network and for disseminating the historical data bases.

During FY 1980, NCC continued to archive data from the new 38-station network and to disseminate the SOLMET, ERSATZ, and SOLDAY data bases. SERI, as noted, generated and began dissemination of the INSOL data base.

4.5.2.4 Solar Energy Resource Atlas

The IRAP initiated the production of the Solar Energy Resource Atlas to assess the availability of solar radiation across the United States and to disseminate that information to the public, interested businesses, research groups, and government agencies. The Atlas was made possible by the completion of the SOLMET/ERSATZ historical data bases. It will contain extensive computer-generated contour maps of monthly (mean daily) and annual (mean daily) solar thermal global, direct, and diffuse insolation. The Atlas is scheduled to be completed during FY 1981.

4.5.2.5 Insolation Models and Algorithm Research

During FY 1980, the SERI Renewable Resource Assessment Branch completed a fairly extensive review and evaluation of models used to predict both direct and global horizontal insolation for clear-sky conditions. For background information, a similar effort was completed during FY 1979 for direct solar thermal insolation models only. Several models were addressed, including the Hoyt model used to rehabilitate the historical insolation data (26 SOLMET sites). The Hoyt model was used to predict global horizontal insolation at true solar noon on clear days. This value was then used to correct the historical measurements.

During FY 1980, SERI contracted with the Aerospace Corp. to produce and deliver a "user friendly" version of the algorithm that was used to convert the historical global horizontal insolation to direct solar beam insolation. This algorithm is a critical element of the SOLMET/ERSATZ data base. The effort was completed with the installation of the Aerospace algorithm on the SERI computer.

4.5.2.6 Education and Training

As part of the eight university Solar Energy Meteorological Research and Training Site projects that are part of the Insolation Resource and Assessment Program, regional centers for training in making insolation and meteorological measurements and in data handling related to solar thermal energy were provided. The individual universities have successfully conducted several training and education courses designed to ensure quality data and analyses for solar applications. This included workshops for local and regional National Weather Service meteorologists directly involved in operating the 38-station network.

4.5.2.7 Insolation Research Data Collection and Analyses

A portion of the Insolation Resource and Assessment Program consists of a significant effort to collect and analyze insolation research data at several sites throughout the United States. These sites consist of the eight university Solar Energy Meteorological Research and Training Sites and the Insolation Research Lab at SERI. The research data is extensive, consisting of readings taken each minute of direct, global, diffuse, and circumsolar insolation, along with various meteorological parameters. The National Weather Service Stations provide only hourly data. Circumsolar radiation data were collected by the Lawrence Berkeley Labs at Albuquerque, Georgia Tech, and the LBL facility in California. The actual data collection at Albuquerque was performed by SNLA. JPL collected data at the Edwards Air Force Base test facility.

During FY 1980, the SERI and university sites were fully operational and collecting quality data. All such data will be sent to SERI for final archiving. SERI will then produce an Insolation Research Data Base and subsequently disseminate it to the solar community.

These applications will be pursued during FY 1981, when the first data sets become available.

4.5.2.8 Development of Improved Instrumentation

To improve insolation data collection and to meet the specific needs of the solar community, the Insolation Research and Assessment Program conducts various efforts to develop insolation monitoring and recording instrumentation.

During FY 1980 the major effort was devoted to the development of an advanced solar spectroradiometer for characterizing the spectral distribution of direct, diffuse, and global insolation. Such an instrument is required because of a lack of data on the spectral distribution of solar radiation. The new SERI Spectroradiometer is shown in Fig. 4-30.

4.5.3 Ranking and Evaluation of Solar Thermal Systems for Electric and Thermal Applications

Since 1978, SERI has evaluated and ranked solar thermal systems for various applications and transmitted the results to the DOE Division of Solar Thermal Energy Systems. The objective of these evaluations is to determine those solar thermal systems that have the greatest perfor-

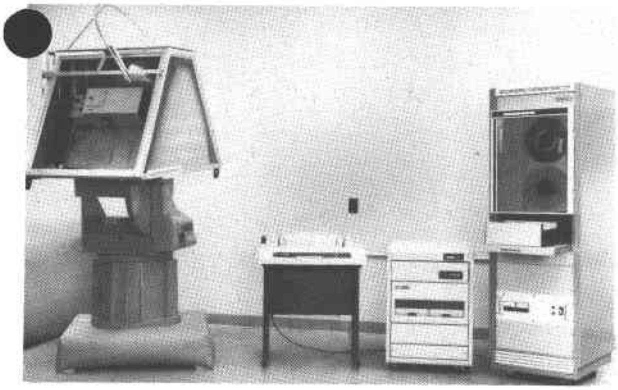

Figure 4-30. SERI Spectroradiometer

mance potential at the lowest cost for the mid-1990s and beyond. Detailed simulations of performance for different sites and operating strategies illuminate the strengths and weaknesses of each system and allow assessment of the risks involved in attaining certain cost and peformance levels.

In FY 1979-80, systems designed specifically for electric power generation by industry and small utilities were evaluated. Because of Department of Energy interest in small systems, plants of 0.1- to 10-MW_e capacity were considered, with a variety of capacity factors ranging from no storage to 0.8.

Systems designed specifically for supplying thermal energy (process heat) over a wide range of temperatures to industrial users will be evaluated and ranked during FY 1980. Again, the major result will be to pinpoint the strengths and weaknesses of each system so that the most promising concepts receive appropriate funding.

4.5.3.1 The Comparative Evaluation of 0.1-10 MW_e Electric Generating Systems [16]

Systems with capacity ranges of 1-10 MW_e were examined for use in small utility applications. Capacity factors ranged from approximately 0.25 (no-storage case) as high as 0.7, considering both electric and thermal storage, depending on the system under consideration. These systems were assumed to operate as an integral part of a grid.

Smaller systems of 0.1-1 MW_e capacity were considered for industrial, military, and small community use. These systems, which included storage capability, were designed as primary power sources, using the grid as backup.

4.5.3.2 1-10 MW_e Systems for Utility Applications

Table 4-3 presents a comparative ranking, based upon technical, economic, social, and commercial criteria derived from the utility and R&D communities.

The systems are listed in order of preference within each group in Table 4-3. Two system types (Group I) rank significantly higher than the rest and are the most appropriate options for development. The point-focus central receiver system with Rankine-cycle power conversion (PFCR/R) represents a technology with some development history and superior performance at high capacity factors. A close second to the PFCR/R system is the point-focus distributed receiver system using dish-mounted Stirling engine generators (PFDR/S) which offers comparable capital and energy costs to the central receiver and ranks higher than the central receiver at low power ratings and capacity factors. Because it has received less development than the central receiver, the PFDR/S system involves greater risk, although it has excellent potential.

Five systems (Group II) achieve acceptable rankings over a wide range of capacities and capacity factors. Parabolic dish technology is represented twice, once with central Rankine power conversion (PFDR/CR) and once with dish-mounted Brayton engines (PFDR/B), indicating the continued viability of that collector technology. In particular, the PFDR/CR sys-

Table 4-3. Final Overall Ranking of 1-10 MW_e Systems for Utility Applications

Group	Rank	System
I	1	Point-focus central receiver with Rankine-cycle power conversion (PFCR/R)
	2	Parabolic dish collectors with distributed Stirling engines (PFDR/S)
II	3	Parabolic dish collectors with central Rankine power conversion (PFDR/CR)
	4	Parabolic dish collectors with distributed Brayton engines (PFDR/B)
	5	Point-focus central receiver with Brayton power conversion (PFCR/B)
	6	Parabolic trough system with central Rankine power conversion (LFDR-TC)
	7	Low concentration, nontracking CPC system (LCNT)
III	8	Line-focus central receiver system (LFCR)
	9	Fixed-mirror, distributed-focus bowl system (FMDF)
	10	Segmented trough with tracking receiver system and central Rankine power conversion (LFDR-TR)
	11	Shallow solar pond system (SSP)

tem shows costs and performance approaching Group I systems at capacity factors just under 0.7. Two Brayton-cycle systems (PFDR/B and PFCR/B) show potential, but consistently rank lower than Rankine-cycle or Stirling-cycle conversion options with identical collector technologies. Finally, the line-focus distributed receiver with tracking collector (LFDR-TC) or parabolic trough, and the low-concentration nontracking system (LCNT), or compound parabolic concentrator, which operate at lower temperatures, show potential for small power system applications but generally do not rank high. Both LFDR-TC and LCNT systems are strong contenders in other market applications such as process heat. In fact, the relative commercial and environmental advantages of the LCNT system were so strong that it was the only concept to be significantly affected by those qualitative criteria in this ranking.

The four remaining systems (Group III) are inappropriate for small electric power applications. Although other market applications may be suitable for certain systems such as low-temperature IPH from shallow solar ponds, the systems in Group III fared poorly on important cost and performance criteria, when considered for electric applications.

The two top-ranked systems, PFCR/R and PFDR/S, can yield busbar energy costs that are competitive with expected costs of electrical energy from conventional alternatives in the 1990s. Both the PFDR/S (capacity factor 0.4) and the PFCR/R (capacity factor 0.7) systems show predicted levelized busbar energy costs as low as 93 mills/kWh.

Sensitivity studies indicate that if concentrator costs are reduced and engine efficiency increased to the levels believed possible by advocates of the PFDR/S system, busbar energy costs as low as 75 mills/kWh could be achieved. These concentrator and engine developments are beyond those considered likely by 1990 and would require vigorous component and system development. If government ince ives such as highly leveraged low-interest 6%) financing were initiated, busbar energy costs might be further reduced to as low as 50 mills/kWh.

4.5.3.3 0.1-1 MW$_e$ Systems for Industrial Applications

Table 4-4 presents the ranking of ten generic systems considered for industrial applications, which do not wholly correspond to the systems considered for utility applications. The study of the 1-10 MW$_e$ systems indicated that some systems could not provide electric power in the capacity ranges that are economically competitive with other solar systems. The shallow solar pond (SSP), the line-focus central receiver (LFCR), and the line-focus trough with tracking receiver (LFDR-TR) were eliminated from the 0.1-1 MW$_e$ ranking.

At the beginning of the 0.1-1 MW$_e$ phase of this study, newly available data indicated that two systems that were not considered in the earlier 1-10 MW$_e$ study could be potentially competitive with other systems that were evaluated previously. These two systems, the point-focus central receiver with a tower-mounted Stirling engine (PFCR/S) and the point-focus distributed receiver with a Rankine engine and generator mounted at the focal point (PFDR/R), have been included in the ranking of systems for industrial applications.

The relative ranking of 0.1-1 MW$_e$ systems presented in Table 4-4 is based on mid-1990 cost and performance predictions as well as the preferences of 14 industrial and small-community decision makers.

The systems are ranked and divided into significant groups. Group I contains only the PFDR/S system, which leads over non-dish systems because of the high efficiency of the Stirling engine at small sizes, the use of a dish with a larger diameter and a correspondingly larger, more efficient engine than was used in the 1-10 MW$_e$ study, the high optical efficiency of the parabolic dish/ receiver combination, and the user's preference for lower capacity factors.

Central receiver systems ranking third, fourth, and fifth suffer primarily from low

Table 4-4. Final Overall Ranking of 0.1-1 MW$_e$ Systems Industrial Applications

Group	Rank	System
I	1	Parabolic dish collectors with distributed Stirling engines (PFDR/S)
II	2	Parabolic dish collectors with distributed Brayton engines (PFDRB/B)
	3	Point-focus central receiver with central Stirling power conversion (PFCR/S)
	4	Point-focus central receiver with Brayton power conversion (PFCR/B)
	5	Point-focus central receiver with Rankine power conversion (PRCR/R)
	6	Parabolic dish collectors with distributed Rankine engines (PFDR/R)
	7	Parabolic dish collectors with central Rankine power conversion (PFDR/CR)
III	8	Parabolic trough system with central Rankin power conversion (LFDR-TC)
	9	Fixed-mirror, distributed-focus bowl system (FMDF)
	10	Low concentration, nontracking CPC system (LCNT)

conversion efficiency. The highest ranked of the point-focus central receiver systems uses central Stirling or Brayton engine generators, which retain high efficiency at smaller capacities. The central Rankine conversion system drops in efficiency at small sizes, particularly at 0.1 and 0.3 MW_e.

Parabolic dish systems with either distributed (PFDR/R) or central (PFDR/CR) Rankine power conversion fall into the lower end of Group II. The PFDR/R system suffers from the low efficiency of Rankine engines in the 75- to 100-kW_e range. The PFDR/CR system has high thermal-transport losses as well as poor engine performance.

Group III contains three systems that operate in medium-temperature ranges (285° C) with central Rankine engines. Poor engine efficiency largely results from lower turbine inlet temperatures and the effect of small sizes. Also, these systems do not rate as high in optical efficiency as the other systems.

The top-ranked systems, Group I and the upper half of Group II, can possibly yield electrical energy for industrial use for less than 100 mills/kWh, a cost that is competitive with the rate that users in small industries often pay now; i.e., 60-90 mills/kWh.

4.5.3.4 The Comparative Ranking of 5-MW_t Systems for Thermal Applications

During FY 1980, an evaluation of solar thermal systems for thermal applications was performed. As in the previous study, systems were evaluated on their mid-1990 cost and performance potential. Also, the preferences of potential industrial users were considered.

Table 4-5 identifies those systems being considered. Each system is conceptually designed to supply thermal energy at four process temperatures. Table 4-6 outlines the process temperatures and describes the choice of transport and storage media used at each temperature. While both no-storage and storage cases are being considered, all systems are assumed to have conventional fuel backup to supply energy when the solar system is unavailable.

A thermal capacity of 5 MW_t has been selected for the baseline plant size.

Analysis shows that, while plants may require as much as 1500 MW_t, the largest share of thermal energy is used by plants of 1- to 10-MW_t capacity.

Fresno, California, a growing industrial area with good potential, was selected as

Table 4-5. Collector Systems Considered in Thermal Applications Evaluation

Concentrated Parabolic Collectors
Evacuated Tube
Fixed-Mirror Distributed Focus
Flat Plate
Fresnel Lens
Line-Focus Central Receiver
Line-Focus Distributed Receiver—Tracking Collector
Line-Focus Distributed Receiver—Tracking Receiver
Point-Focus Central Receiver
Point-Focus Distributed Receiver
Salt-Gradient Solar Pond
Shallow Solar Pond

Table 4-6. Transport and Storage Media Selection for Thermal Applications

Process Temperature	Transport Media	Storage Media
66°C (150°F)	Water	Water
177°C (350°F)	Oil	Oil/Rock
288°C (550°F)	Oil	Oil/Rock
538°C (1000°F)	Salts	Salts

the plant location. Typical Meteorological Year (TMY) insolation data are available for Fresno. Economic factors representative of the Fresno area are being developed.

Systems are designed and costs projected using the methodology developed for the 0.1-10 MW_e study. The BALDR simulation code is being modified to incorporate various control strategies for supplying thermal energy. Results will be tested to check the sensitivity of the ranking to variations in system cost and performance.

The evaluation was completed in FY 1980 and results will be published in FY 1981.

4.5.4 Quality Assurance and Standards

The FY 1979 study of quality assurance and standards development for solar thermal technology consisted of a preliminary review. The initial task placed upon SERI for FY 1980 was to "Develop a Plan for Quality Assurance and Standards Development." Accordingly, SERI instituted the process of developing matrices to define the functions of components, subsystems, and systems and to determine the standards used, needed, or modifiable to suit solar thermal plant requirements. The working approach has been to canvas the industry (principally DOE contractors and field centers) for input, to give indus y the opportunity to say what is wanted ather than to dictate standards.

4.5.4.1 Standards Plan Update

Status. The current status of the solar thermal quality assurance and standards development plan is that a cross section of industry associated with solar thermal technology has been canvassed to nominate standards development priorities, and their preliminary input is being processed. Over 1000 applicable, modifiable, or acceptable standards have been identified. Simultaneously, the National Bureau of Standards data bank on standards has been reviewed and the vigor and degree of activity within the various standards-writing bodies assessed.

Status of Standards Development. The American Society for Testing and Materials (ASTM) Committee E-44 on Solar Energy has 44 documents in the process of being drafted (at the committee stage). The approximate lifetime of these committees so far is 2-3 years. To date, three standards that could be defined as applicable to solar thermal are in final draft form to be issued for comment. Future standards production rates estimated by ASTM authorities are 3 or 4 per year. The only other major activity is the updating of ASHRAE 93.77. Code-writing subcommittees under the auspices of ASME are also developing requirements for receiver storage vessels and heat exchangers, but the first draft documents are not expected until 1981-82.

The majority of components used in solar thermal systems are not unique to solar thermal. They are in use in other technologies and are therefore covered by existing standards. In such cases it is necessary only to ensure that such items, where necessary, are declared applicable to solar thermal, and that the standards are not too costly or conservative for the commercial program or can be accepted by the issuing and jurisdictional bodies for amendment to solar thermal use.

Those components or materials applications listed below are unique to the solar thermal technologies and will require special development:

- design envelopes (strain-time-load curves) for receiver materials,
- characterization of ceramics,
- metrology of reflective surfaces properties,
- rules for fabrication and use of liquid metals and fused salts,
- collector rating methods,
- solar components and systems operation and maintenance,
- procedures for monitoring coatings tenacity and performance, and
- standard procedures for measuring efficiency and cost-effectiveness of solar thermal components.

4.5.4.2 Performance and Reliability

Standards play the traditional roles of providing interchangeability, reliability, and safety. However, in the solar thermal program there is also the need to confirm to insurers, institutional lenders, and tax concessions analysts in this preproduction era that an item is as defined by a standard, or has been built to standard requirements. This information is also essential to the establishment of a repairs and maintenance program.

4.5.4.3 Standards Development System and Implementation

The organizational procedure originally proposed for establishing standards will be supplemented by one additional step—the use of an "overview" committee. It is believed that such a body should include representatives from the associated solar thermal programs so that it will receive input from each project and issue appropriate directives to all.

The customary purposes of a standard are agreements on its use between two contracting parties, approval by institutional authorities like insurance inspection boards for its use in a particular application, and use of it as a mandatory standard by state or local authorities, where necessary.

4.5.5 Environmental Control

The University of California, Los Angeles, Laboratory of Biomedical and Environmental Sciences (LBES) was designated a "lead laboratory" in studying environmental effects of solar thermal power systems in FY 1979. The scope of the project was summarized in the FY 1979 Annual Technical Progress Report. Several of the studies undertaken are of a continuing nature. Their current status is reported below. In FY 1980, the (LBES) Solar Project received approximately equal funding from both the DOE Office of Conservation and Solar Energy and the Office of Environment.

4.5.5.1 Toxicological and Health Implications of Solar Thermal Process Fluids

This study is a continuation of "Worker Health and Safety in Solar Thermal Power Systems" Vol. 1-6, issued in October

79. Findings were issued as Vol. 7 of the series in October 1980. The study consists of the following tasks:

- identify various candidate fluids useful in high-temperature solar total energy system applications;
- identify physical and chemical characteristics;
- screen identified fluids for toxic potential;
- conduct detailed analysis of toxicological and health implications of selected fluids; and
- compare toxicological and health implications in solar total energy systems with those in industries using the same or similar fluids at high temperatures.

4.5.5.2 Assessment of Potential Effects of Chemical Contamination of Soils by Salts and Fluids Released from Solar Thermal Power Systems

The general objective of this program is to study the environmental hazards of some of the fluids that might be used, or are in use, in prototype solar thermal energy systems. Specific experiments determine the rate of degradation and persistence of these materials in different soils, the rate of their movement or transport in soils, and the threshold levels of toxicity of these materials (or their degradation products) to plants.

The general order of toxicity of fluids applied to the three mineral soils was ethylene glycol, Dow Corning Fluid No. 200, Caloria HT43, and Therminol 66. The order of toxicity among the fluids applied to the organic soil, Egbert muck, was ethylene glycol, Caloria HT43, Dow Corning Fluid No. 200, and Therminol 66. A relatively large amount of Therminol 66 was tolerated by barley seedlings. Depending on the soil, the amount of Therminol 66 tolerated by the seedlings was about 36-fold greater by weight than that of ethylene glycol.

In the field, two experiments are in progress. The first entails the determination of the rate of downward movement of three different fluids (Therminol 66, Caloria HT43, and Dow Corning Fluid No. 200) in the profile of a bare soil plot contaminated on the surface. The results obtained from the bare soil plot contaminated with Therminol 66 on October 17, 1979 showed about 15 cm downward movement of the fluid as of July 22, 1980. The second experiment determined the effect of the fluids on native plants. Larrea tridentata and Ambrosia dumosa were contaminated by sprinkling the fluids on them on October 16, 1979. This was done by sprinkling two gal (7.58) of fluids on 1-m^2 areas, each containing a single plant. Larrea plants were lush green when the fluids were applied, whereas Ambrosia plants were dormant (without leaves). Each of the fluids applied turned the leaves of the Larrea plants brown and apparently killed them. As of May 20, 1980, the contaminated Larrea plants did not show any signs of recovery. The Ambrosia plants contaminated with Caloria HT43 or Dow Corning Fluid No. 200 appeared dead, but those contaminated with Therminol 66 leafed out almost completely and were in full bloom. This suggests that Therminol 66 was the least toxic of the fluids used.

4.5.5.3 Vegetation Management and Recovery at Sites Disturbed for Solar Thermal Development

This is a continuing study initiated in FY 1979 to address the difficult problem of revegetating disturbed arid land, and to provide a basis for developing a soil surface management strategy within heliostat arrays using plants. Shrub transplant experiments on disturbed Mojave Desert land have been established to determine needs for supplemental water, nutrients, and protection from grazing rabbits. Results to date show that these three factors are limiting conditions which must be satisfied in order to achieve successful restoration of shrubs on disturbed sites.

New transplants must be irrigated with 3- to 5-gal of water at 3- to 4-week intervals during the first year, from the time of transplanting until the onset of late fall and winter rainfall. It would appear that, for restoration of large disturbed areas, early fall transplanting would be the most economical procedure to follow. Transplants have responded favorably to supplemental nitrogen fertilizer supplied in both organic and inorganic form. We observed some initial adverse effects on growth when commercial manure supplements were used. These were overcome after six months, and enhanced growth followed. We have established field-trial tests on disturbed land near the 10-MW$_e$ pilot plant site at Daggett, and at Frenchman Flat, Jackass Flat, and Yucca Flat on the Nevada Test Site.

Transplanting shrubs for restoration of vegetation around the 10-MW$_e$ solar site visitors' center was started during the third quarter. Both native shrubs and ornamental horticulture plants are being used. A small botanical garden consisting of various Mojave Desert shrubs will be established as part of this effort.

4.5.5.4 Environmental Monitoring of the 10-MW$_e$ Pilot Site and Surroundings

This is a continuing study initiated in FY 1978. Baseline environmental measurements at the Barstow 10-MW$_e$ pilot plant site begun in 1978 were concluded in the summer of 1979. A report, "Ecological Base Line Studies at the Site of the Barstow 10-MW$_e$ Solar Thermal Power System," was issued in November 1979. Work at the site then entered a new phase—that of examining possible environmental consequences of construction activities.

Construction of the pilot plant began in the fall of 1979. Environmental monitoring in the environs of the developing facility continued, with emphasis on possible disturbances associated with construction activities. Measurements were made from 100 to 150 m east of the downwind side of the heliostat field, where potential effects would be most conspicuously expressed, and farther to the east at distances beyond likely influences of construction activities. The heliostat field was cleared and graded in the early fall of 1979. The major impact of this work was movement of windblown sand into areas downwind of the field. Fluxes of blown sand between ground level and 36 cm were measured at six sites. Between October 13, 1979 and March 1, 1980, we estimated that about 160 metric tons of sand were removed by wind and deposited in an arc along the downwind margin of the field. Observations during the spring of 1980 indicated that, in some areas, new sand deposits inhibited germination of annual plants and reduced density and diversity. These effects were erratically expressed and restricted to areas 100-150 m downwind of the mirror field.

Investigations of possible effects of construction activities will continue through the fall of 1981, at which time the pilot plant is expected to begin a preoperational testing phase.

4.5.5.5 Ecological and Microclimatic Effects within Heliostat Arrays

This study was in place at the time LBES was given responsibility for its management and is being implemented through a subcontract to Arizona State University. A series of plywood panels simulates the shading effects of heliostats. Monitoring has included weekly biotic and abiotic data collection over the last two years characterized by measuring air temperatures and humidity, soil moisture, precipitation, accumulated air flow, incoming short-wave radiation, net all-wave radiation, gross plant productivity for two dominant shrubs, germination and distribution of annual plants, and identification and quantification of arthropods and reptiles.

Field activities were completed in June 1980. A final report of findings is scheduled to be released in October 1980. The results of this study will be combined with findings of the revegetation studies being conducted by LBES at Barstow and used to develop a soil surface stabilization strategy to test within the heliostat array at Barstow in FY 1982.

4.5.5.6 Guidelines for Community Utilization of Small-Scale Solar Thermal Energy Systems

This project is studying the problems of community utilization of small-scale solar thermal energy systems. The principal barriers to the commercialization of current solar conservation technologies are institutional rather than technical. Similar barriers are likely to inhibit the commercialization of small-scale solar total energy systems. Many of these problems can be reduced or eliminated with minimal social impact.

An ongoing literature search has indicated that a comprehensive community impact and utilization study for small-scale STES has not been accomplished. Most of the related studies offer only a piecemeal approach or address themselves to the larger central receiver systems which will most likely be managed by utilities. It is assumed that small-scale STES will not require centralized management and control. Significant community and utility impacts could result from the possible diversification and decentralization of electrical production and distribution. Information on these problems and impacts is noticeably lacking.

This project will generate information on the needs, barriers, and impacts to the utilization of small-scale STES. Project studies include: (1) the value to communities of small-scale STES and barriers to their use, (2) elimination of those barriers, (3) community effects (environmental, urban design, social, and institutional), (4) comparison of effects of small-scale STES with those of traditional central power facilities, (5) the interface of these systems with utilities and energy industries, (6) study of the best uses for these systems, and (7) formation of a plan for community utilization.

4.5.5.7 Project Management

Faculty and graduate students from the UCLA campus are frequently recruited to prepare short authoritative position papers on subjects under consideration for more detailed treatment. Faculty and students from the graduate program in Environmental Science and Engineering used this subject as a theme for summer course work under LBES sponsorship: Siting a Hybrid Solar Thermal Power System in the Eastern Mojave Desert of California: A Test Case.

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ACRONYMS AND ABBREVIATIONS

ACRES	Advanced Component Research Facility
ACTF	Advanced Component Test Facility (Georgia Institute of Technology)
ADVS	Analog Design Verification System
AGT	Advanced Garrett Turbine
ALO	Albuquerque Operations Office (Department of Energy)
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
BCS	Beam Characterization System
BuRec	Bureau of Reclamation (Department of Interior)
CMTF	Collector Module Test Facility (Sandia National Laboratories, Albuquerque)
CR	Central Receiver
CRS	Central Receiver System
CRTF	Central Receiver Test Facility
CST	Central Solar Technology (Department of Energy)
DCS	Distributed Collector System
DGAP	Data Gathering and Processing
DNB	Departure from Nucleate Boiling
DOD	Department of Defense
DOE	Department of Energy
EPRI	Electric Power Research Institute
ERDA	Energy Research and Development Administration
ESG	Energy Systems Group, Rockwell International
ETS	Edwards Test Station (Jet Propulsion Laboratory)
FACC	Ford Aerospace and Communications Corporation
FMDF	Fixed Mirror, Distributed Focus
FWDC	Foster Wheeler Development Corporation
FY	Fiscal Year
GA	General Atomic
GE-AED	General Electric Company Advanced Energy Department
GE-SCD	General Electric Company Simulation and Controls Department
GIT	Georgia Institute of Technology
GRP	Glass Reinforced Plastic
HMO	Heat Medium Oil
HVAC	Heating, Ventilating, Air Conditioning
IEA	International Energy Agency
INSOL	Insolation Data Base
IPH	Industrial Process Heat
IRAP	Insolation Resource Assessment Program
JPL	Jet Propulsion Laboratory (California Institute of Technology, National Aeronautics and Space Administration)

ACRONYMS AND ABBREVIATIONS (Continued)

kW_e	Kilowatts (electric)
kW_t	Kilowatts (thermal)
LASL	Los Alamos Scientific Laboratory
LBNL	Lawrence Berkeley National Laboratory
LCC	Low-Cost Concentrator
LCNT	Low Concentration Non-Tracking System
LeRC	Lewis Research Center (National Aeronautics and Space Administration)
LFDR	Line-Focus Distributed Receiver
LLNL	Lawrence Livermore National Laboratory
LBES	Laboratory of Biomedical and Environmental Sciences (University of California, Los Angeles)
MCS	Master Control System
MDAC	McDonnell Douglas Astronautics Company
MISR	Modular Industrial Solar Retrofit Program
MMC	Martin Marietta Corporation
MMPE	Military Module Power Equipment
MSSTF	Midtemperature Solar System Test Facility (Sandia National Laboratories, Albuquerque)
MTCRF	Medtemperature Collector Research Facility (Solar Energy Research Institute)
MTI	Mechanical Technology, Inc.
MW_e	Megawatts (electric)
MW_t	Megawatts (thermal)
NASA	National Aeronautics and Space Administration
NCC	National Climatic Center
NMSU	New Mexico State University
NOAA	National Oceanic and Atmospheric Administration
NRL	Naval Research Laboratory
NSF	National Science Foundation
O&M	Operations and Maintenance
ORC	Organic Rankine Cycle
PCC	Pittsburgh Corning Corporation
PCM	Phase Change Material
PCU	Power Conversion Unit
PDTS	Parabolic Dish Test Site
PFDR	Point-Focusing Distributed Receiver
PFDRT	Point-Focusing Distributed Receiver Technology
PMMA	Polymethylmethacrylate Acrylics
PNL	Battelle Pacific Northwest Laboratories
PPG	Pittsburgh Plate Glass Industries
PRDA	Program Research & Development Announcement
QAS	Quality Assurance and Standards
RAD	Research and Advanced Development
R&D	Research and Development
RFP	Request for Proposal

ACRONYMS AND ABBREVIATIONS (Concluded)

rms	root mean square
RTV	Room Temperature Vulcanizing
SAN	Department of Energy, San Francisco Operations Office
SCSE	Small Community Solar Thermal Power Experiment
SEIDB	Solar Energy Information Data Bank (Solar Energy Research Institute)
SEOR	Solar Enhanced Oil Recovery
SERAPH	Solar Energy Research and Applications in Process Heat Facility (Solar Energy Research Institute)
SERI	Solar Energy Research Institute
SFDI	Solar Facilities Design Integrator
SHAC	Solar Heating and Cooling
SMSA	Standard Metropolitan Statistical Area
SNET	Southern New England Telephone Company
SNLA	Sandia National Laboratories, Albuquerque
SNLL	Sandia National Laboratories, Livermore
SOLAR/CS	Division of Solar Applications under the Office of the Assistant Secretary for Conservation and Solar Applications
SOLAR/ET	Division of Central Solar Technology and Division of Distributed Solar Technology under the Office of the Assistant Secretary for Energy Technology
SOW	Statement of Work
SPHER	Small Particle Heat-Exchanger Receiver
SPSA	Small Power Systems Applications
SRE	Subsystem Research Experiment (Jet Propulsion Laboratory)
STEP	Solar Total Energy Project
STES	Solar Total Energy Systems
STF	Systems Test Facility
STMPO	Solar Ten-Megawatt Project Office (Department of Energy)
STOR	Energy Storage Systems (Department of Energy)
STTFUA	Solar Thermal Test Facilities Users Association
TBC	Test-Bed Concentrator (Jet Propulsion Laboratory)
TES	Thermal Energy Storage
TMY	Typical Meteorological Year
UCLA	University of California at Los Angeles
WPRS	Water and Power Resources Service (Bureau of Reclamation, Department of Interior)
WSSF	White Sands Solar Furnace

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