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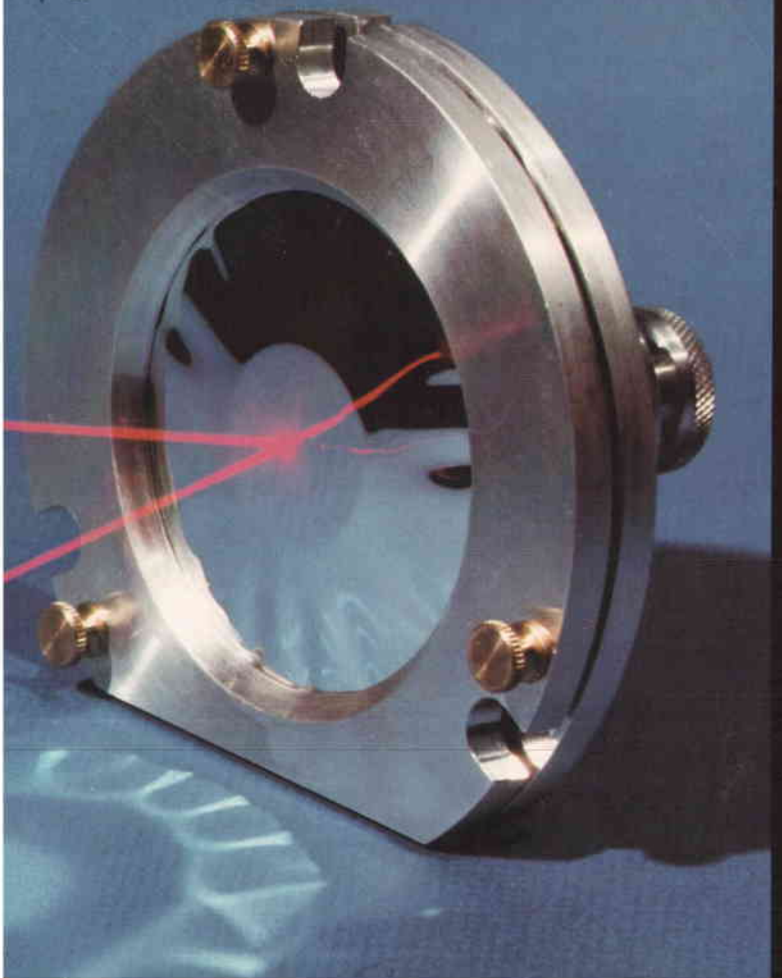

U.S. Departme

Programs in
Renewable
Energy

Solar Thermal Program Summary

Volume I: Overview

Fiscal Year 19

On the cover: ECP 300 film under evaluation for its specular reflectance.

This publication is one of a series of documents on the renewable energy program sponsored by the U.S. Department of Energy. Companion overview and research summaries include the following:

FY 1988 Program Summaries:

- Energy Storage and Distribution
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Solar Thermal Energy Program Summary

Volume I: Overview
Fiscal Year 1988

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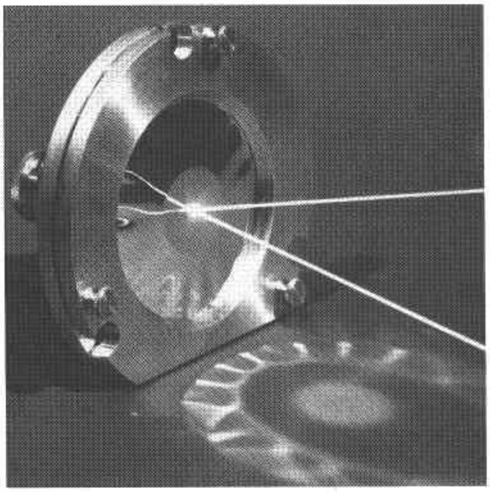
Introduction



ECP 300 film under evaluation for its specular reflectance.

The nation faces many difficult challenges in energy supply and use. The many vital issues include energy security, energy cost, international balance-of-trade, international competitiveness, and environmental quality. Energy security requires maintaining assured access to sufficient energy resources. Growing pervasive problems with atmospheric pollution, water resources, acid rain, and the greenhouse effect may ultimately limit the burning of fossil fuels. Most experts agree that a mixture of energy alternatives will have to be developed for the future.

Solar thermal technology has a number of attractive attributes that make it a very desirable energy supply option: it is a strategically secure energy source; it has low environmental impact; it has short construction times and can be built in small modules to respond to demand growth. As part of a balanced national energy strategy, the widespread implementation of solar thermal energy systems has the potential to increase domestic energy supplies, reduce dependence on imported oil, and help U.S. industry respond to increasing international competition for domestic and overseas markets for solar energy systems.

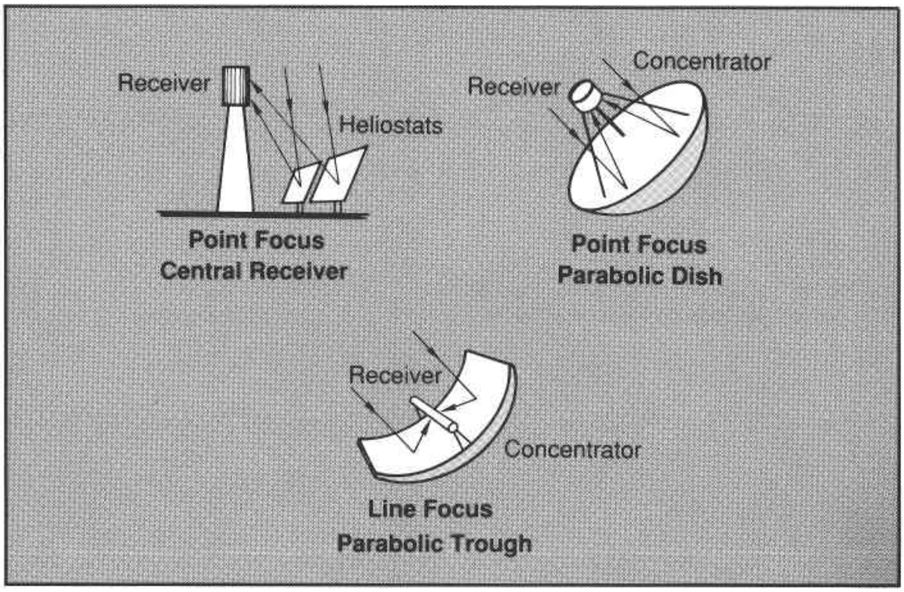
Concentrated sunlight is a very versatile and high-quality form of energy. Solar thermal technology has a broad spectrum of applications, which include industrial and commercial uses of process heat, electrical power generation, hazardous waste destruction, and a variety of other advanced applications that take advantage of the unique attributes of highly concentrated sunlight. Solar thermal energy systems concentrate the sun's radiation to generate electricity, produce high temperature heat, and focus solar photons for use in various chemical reactions including materials processing and the production of transportable fuels.

Technology and Program Review

Technology Overview

The three primary solar thermal technology optical concepts are central receivers (CR), point-focus parabolic dishes, and line-focus parabolic troughs. Groups of point-focus parabolic dishes and line-focus parabolic troughs where each reflector module has its own receiver are called distributed receiver (DR) systems. All three concepts employ the same principle of concentrating sunlight and are distinguished by the various mirror geometries and receivers utilized.

- CR systems use fields of two-axis tracking mirrors called heliostats to reflect the sunlight onto a single tower-mounted receiver. Heliostats have been built in sizes up to 200 m^2. Systems generating 10 MW_e and containing more than 1800 heliostats with surface areas of 40 m^2 each have been constructed and successfully operated.
- Parabolic dishes use a two-axis tracking concept and focus the sunlight onto receivers/engines located at the focal surface of each dish. Dish modules can be used in stand-alone or large multi-module systems. Systems containing over 700 dish modules and generating approximately 4.9 MW_e have been constructed and successfully operated.
- Parabolic troughs usually use single-axis tracking collectors that concentrate sunlight onto a receiver tube positioned at the focal line of each trough. Individual trough modules can be combined in rows to meet large capacity needs. Parabolic trough systems collectively generating 134 MW_e are currently in operation in the United States. These systems use trough technology developed under the Solar Thermal Technology Program.



Solar thermal technology concepts.

Program Overview

The goal of the solar thermal program is to improve overall solar thermal systems performance and provide cost-effective energy options that are strategically secure and environmentally benign. Major research activities include energy collection technology, energy conversion technology, and systems and applications technology for both CR and DR systems. This research is being conducted through research laboratories in close coordination with the solar thermal industry, utility companies, and universities. The Solar Thermal Technology Program is pursuing the development of critical components and subsystems for improved energy collection and conversion devices. This development follows two basic paths:

- for CR systems, critical components include stretched membrane heliostats, direct absorption receivers (DARs), and transport subsystems for molten salt heat transfer fluids. These components offer the potential for a significant reduction in system costs; and,
- for DR systems, critical components include stretched membrane dishes, reflux receivers, and Stirling engines. These components will significantly increase system reliability and efficiency, which will reduce costs.

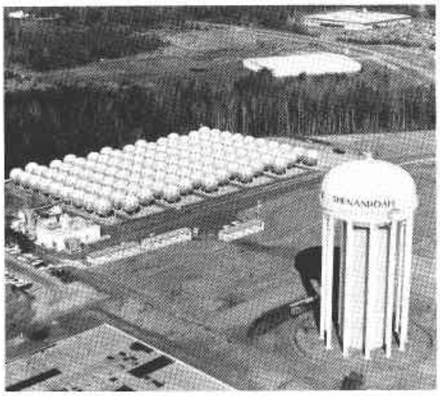
The major thrust of the program is to provide electric power. However, there is an increasing interest in the use of concentrated solar energy for applications such as detoxifying hazardous wastes and developing high-value transportable fuels. These potential uses of highly concentrated solar energy still require additional experiments to prove concept feasibility. The program goal of economically competitive energy production from solar thermal systems is being cooperatively addressed by industry and government.

Program History, Progress, and Status

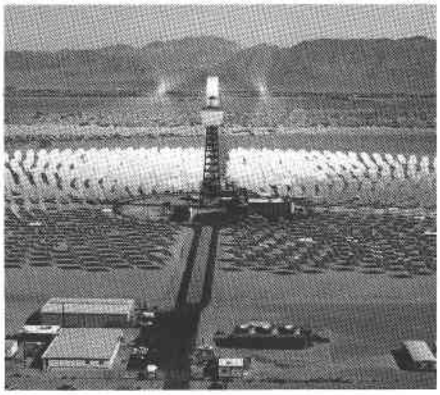
Program History. Significant progress has been made toward achieving economically viable solar thermal energy generation for electrical and industrial heat applications. Vigorous research and development (R&D) efforts in the past decade have improved the performance and reliability of solar thermal systems and contributed toward reductions in the cost of delivered energy. Successful operation and data collection from major solar thermal experiments, such as the 10-MW_e Central Receiver Pilot Plant (Solar One) in Daggett, California, and the Solar Total Energy Project (STEP) in Shenandoah, Georgia, are diminishing the uncertainties and risks associated with system performance, operation, and maintenance. Furthermore, increased involvement by industry and the utility sector, such as the LaJet SOLARPLANT 1 and the Luz Solar Electric Generating Stations (SEGS), have capitalized on federally sponsored R&D accomplishments in solar thermal technology. The success of experiments sponsored by DOE, combined with private industry efforts, has resulted in commercial readiness of parabolic trough technology. However, further cost reductions appear necessary for continued penetration of electric and process heat markets.

Luz SEGS Project.

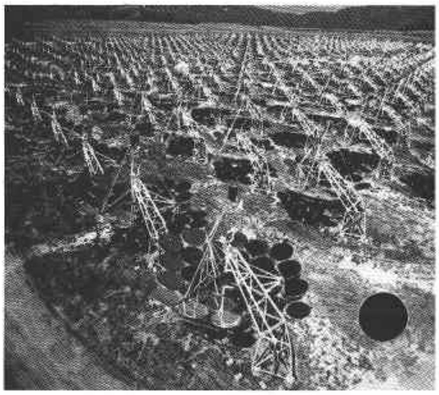
Major solar thermal technology experiments.



Shenandoah Dish Project.

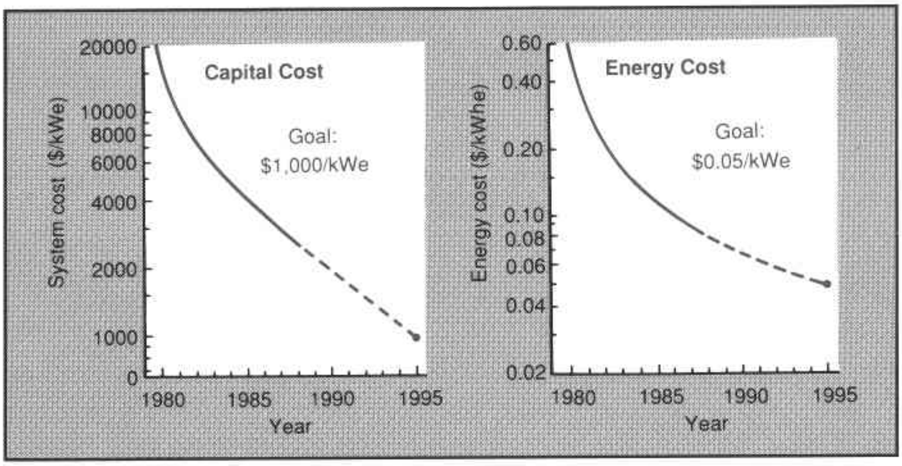


Barstow Solar One Project.



LaJet SOLARPLANT 1.

During the 1980s, both the capital and energy costs of solar thermal systems have been reduced by 80%. Current system designs generating electricity have an annual efficiency of about 15% (process heat efficiency of greater than 50%) and a capital cost of about $3000/kW_e$ for CRs, and 30% and $3000/kW_e$ (peak) for DRs. In addition, further cost reductions are required to make solar thermal energy cost-competitive with energy generated by fossil fuels. Prime opportunities for solar thermal electricity generation include peaking and intermediate load generation for CRs, and peaking, intermediate, and remote applications for DRs. Long-term electricity generation goals call for system capital cost of $1000/kW_e$ and system energy costs of 5¢/kWh_e. To reach these goals, researchers are developing components and systems with higher efficiency, performance, and reliability, as well as lower cost.

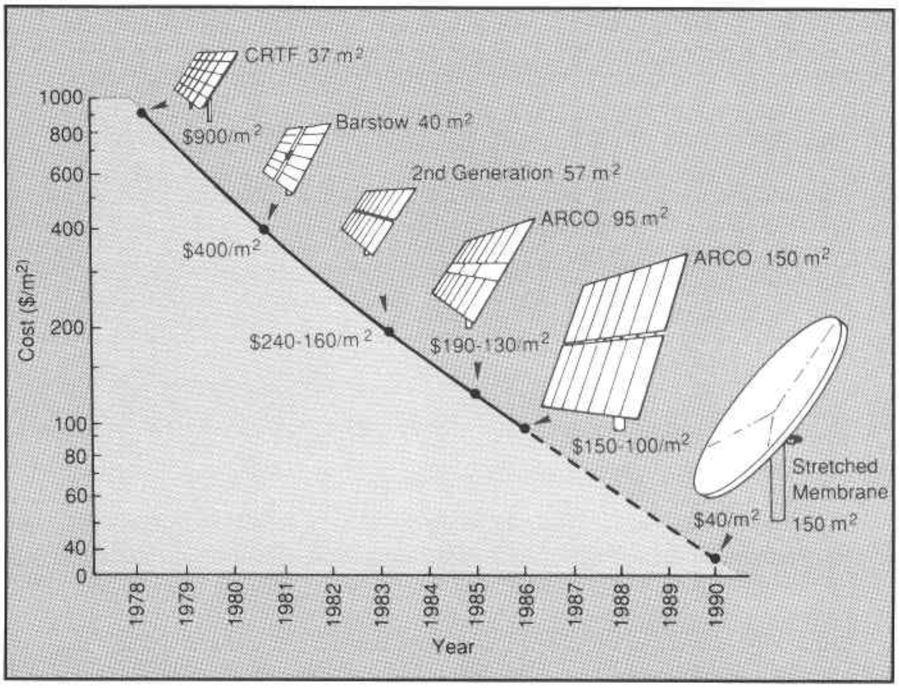


Solar thermal electricity cost trends.

Central Receiver Technology Progress

Solar thermal electricity cost trends. Central receiver R&D efforts include the development of designs, the analysis of system parameters, and the experimental testing of components or groups of components. Solar One has demonstrated the concept of electric power production and has provided valuable operation and maintenance experience to the utility plant operators through a three-year power production phase (August 1984 to August 1987). Solar One was operated in a semi-commercial mode by the utility owner until August 1988 and has provided additional data on revenue optimization from a solar thermal CR plant. In Albuquerque, New Mexico, the Central Receiver Molten Salt Experiment established the technical and economic feasibility of using molten salt as a heat transfer fluid by testing specific critical components such as pumps, valves, and the receiver. In addition, a group of southwestern utilities is studying the best possible approach to the next generation of central receiver technologies in utility applications. The group has selected conceptual designs for a 100 MW_e plant using molten salt receivers and stretched membrane heliostats.

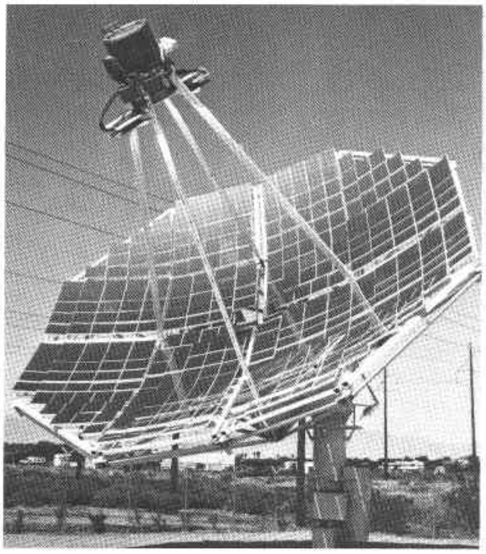
In recent years, R&D on central receiver components and systems has resulted in significant cost reductions based upon improved designs and operational experience. Individual heliostat costs have decreased from more than $\$1000/m^2$ to than $\$150/m^2$, while the reflectivity of mirror surfaces has increased from 70% for early systems to over 90% today. Major developments in heliostat technology have proceeded along two primary fronts; large area glass/metal mirrors and stretched membrane heliostats. Stretched membrane concepts show significant potential for further cost reductions. In the last year, testing of two large area glass/metal heliostats was conducted, and the results have verified the predicted performance and optical quality specifications. Also, two stretched membrane prototype heliostats were designed, fabricated, and evaluated during FY 1988.



Heliostat R&D progress.

Research has also shown that improved system performance and lower costs can be achieved with heat transfer fluids such as molten salts that have better heat transfer characteristics than water and can also be used for thermal energy storage. In this area, substantial progress is being made through design and testing of molten salt subsystems and components in the molten salt experiments mentioned above. CR technology will also benefit greatly from the higher temperatures, solar flux levels, system efficiencies, and lower costs than those achieved with DARs. The DAR takes full advantage of molten salt by eliminating the need of thousands of tube welds and absorbs the sun's energy directly in the salt. Recent progress in development of this technology has included the design of a 3-MW_t Solar Panel Research Experiment to allow flow testing with molten nitrate salt and provide a test bed for DAR testing with actual solar heating. The system is capable of operating at flow conditions similar to a commercialized DAR and is being designed for easy replacement of panels and manifolds to allow testing of different configurations. In addition, research is continuing to characterize flow conditions of molten salt DAR and investigate alternative blackeners for use in DAR systems.

Parabolic Dish Technology Progress



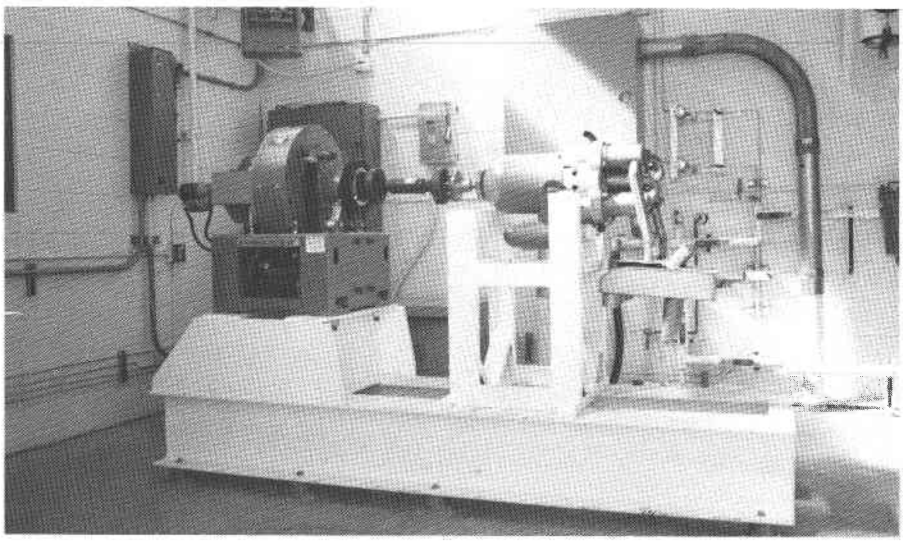
Vanguard Project.

Electric power production from parabolic dish systems has been evaluated for lower temperature (less than 600 °C) Rankine-cycle systems using water/steam or organic working fluids. For example, the 3-MW_t system at Shenandoah, Georgia, operational since 1982, uses parabolic dish modules to heat a silicone-based fluid to provide process heat, air conditioning, and electric power.

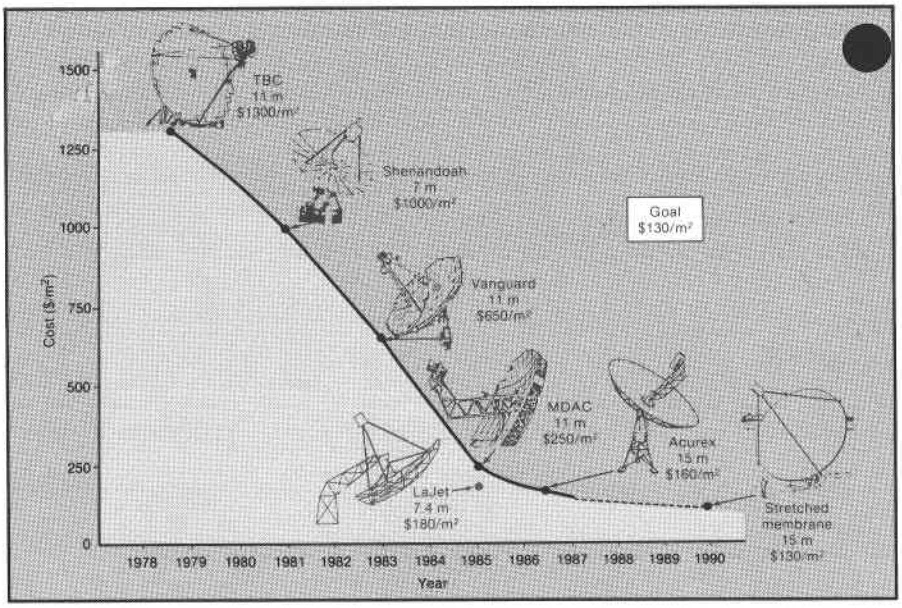
Current parabolic dish designs are evolving toward higher operating temperatures (up to 1370 °C) to take advantage of higher engine efficiencies. Parabolic dishes are able to provide these higher temperatures because of their high solar flux concentration capability. The most notable progress for parabolic dish systems with heat engines at the focal surface has been the achievement of higher receiver operating temperatures for electric conversion processes, resulting in increased overall system efficiency. A record of 31% gross (29% net) energy conversion of sunlight into electricity was achieved using a focal-mounted Stirling-cycle engine in an advanced dish module.

Work continues on advanced power conversion cycles with recent advances in Stirling engine R&D. The reflux receiver concept has been identified as a potential receiver option for Stirling engines. The reflux concept promises simple, low-cost, reliable, and efficient receivers and readily permits fossil fuel hybridization.

Similar to CR technology, dish systems will also benefit from recent advances in stretched membrane and other low-cost concentrator technologies. Research has identified major structural/optical response parameters indicating that high quality optical membrane surfaces are feasible from a structural perspective, and that a vacuum can be used to stabilize the membrane into the desired shape. A 2-m diameter membrane dish was completed in FY 1987. The surface quality and overall shape of the membrane were comparable to the optical surfaces on the heavier, more expensive earlier dishes.



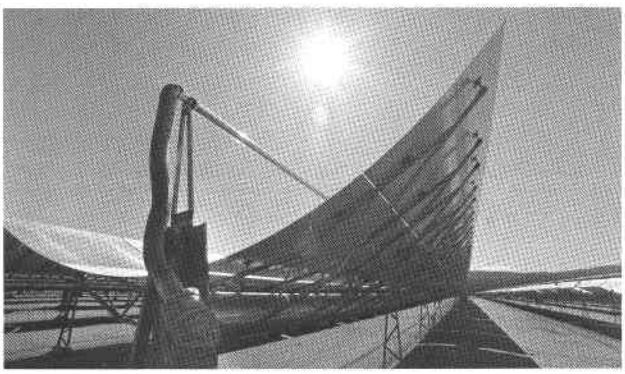
Kinematic Stirling engine (STM 4-120) at the Engine Test Facility.



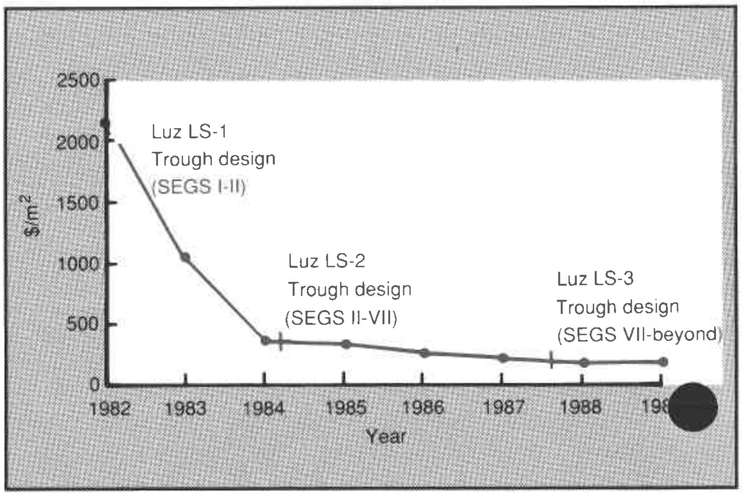
Parabolic dish R&D progress.

Parabolic Trough Technology Progress

The parabolic trough technology is the most developed of the three major solar thermal technologies. It has a well-defined range of industrial process heat/steam applications at temperatures below 400°C. Numerous field test installations have been built and operated successfully, and analysis of their performance has provided valuable operation and maintenance (O&M) information and guidance. Parabolic trough systems also have shown significant cost reductions and performance improvements. Today's collectors have raised the peak performance standards to 60% peak efficiency by increasing concentrator accuracy and incorporating silvered glass reflector technology. Costs for these systems are currently less than $400/m² of installed collector aperture, which is consistent with Luz being able to deliver electricity to the Southern California utility grid at a cost of less than 12¢/kWh. Luz International Ltd. has been successful in applying trough technology, using concepts developed under the Solar Thermal Technology Program, to a large-scale commercial application in their Solar Electric Generating Station (SEGS I-VII) projects.



Luz SEGS troughs



Parabolic trough R&D progress.

Technology, Industry, and Marketplace Status

Efforts to bring solar thermal systems to the marketplace are already showing measurable results. Building on the wealth of system experience developed in the DOE program, several companies have made commercial sales of parabolic trough industrial process heat systems; these systems are operating well. The present low price of oil and natural gas has limited the penetration of this technology into the process heat market. However, Luz International has installed 134 MW_e of power generation using parabolic trough technology to date and will add another 60 MW_e in December 1988. Luz has also scheduled an additional 400 MW_e of power generating stations in the United States during the next decade. Today, these parabolic trough systems generate electricity for 10¢-12¢/kWh and have the potential for even lower cost. The LaJet Energy Company has also installed a 5-MW, investor-owned power plant, SOLARPLANT 1, that uses 700 parabolic dishes to generate steam for a centrally located turbine-generator.

An assessment of the developmental status of the various solar thermal technologies, coupled with an examination of the business plans and projections of industry and users, leads to the conclusion that significant marketplace opportunities exist in both the near- and long-term. Two applications with high early market potential are electric power generation and hazardous waste destruction. The potential market size for electric power generation in the southwestern United States alone, projected to be 35,000 MW in the next decade, is huge compared to a sustainable production volume for the U.S. solar thermal industry. Development of export markets for solar thermal systems can also contribute significantly to the market base.

Applications judged to have the highest potential for bringing additional solar thermal technology to the domestic and export marketplace within a five-year timeframe are:*

- trough and dish systems for electric power generation in plants similar to Luz's SEGS plants and LaJet's SOLARPLANT 1 with centrally located engine/generators; and,
- use of concentrated solar energy for destruction of hazardous wastes through the combination of high-temperature and photo-enhanced chemical reactions.

In five to seven years, solar thermal systems based on advanced components with higher performance and lower cost should find substantially expanded domestic and export market opportunities. Examples of these potential applications are:

- CR electric power plants using low-cost glass/metal or stretched membrane heliostats and an advanced molten-salt receiver; and,
- dish-electric systems, which use low-cost membrane concentrators and advanced focal-mounted engines, for remote and grid-connected markets.

Advanced applications based on the unique properties of the concentrated solar spectrum, such as fuel and chemical production and materials treatment, are likely to be important additional markets within ten years.

The DOE's strategy for bringing results of solar thermal research to the marketplace is centered on the development of improved cost effectiveness and reliability of solar thermal components and the development of additional early markets with high strategic or economic value by U.S. industry. This balanced, two-part approach of R&D coupled with market development will introduce essential technological improvements while allowing industry to acquire the production experience base to further lower the cost.

* *Bringing Solar Thermal Technology to the Marketplace - A Report to the U.S. Congress, August 1988.*

Global warming, acid rain, polluted water, air and soil, and fouled public beaches have received increased national attention during FY 1988. The airing of these environmental problems coincided with exploratory research on the use of concentrated solar energy to destroy hazardous chemicals. During the year, experiments were conducted using the solar furnace at the White Sands Missle Range to evaluate how solar flux can attack one of the most dangerous chemicals to the environment: dioxin. The experiments were to determine the possibility of a beam of concentrated solar energy destroying dioxin to the level required by the Environmental Protection Agency (EPA). The tests indicated that the combination of thermal and photolytic effects inherent in the intense solar beam resulted in a more complete destruction of the dioxin at lower temperatures than could be obtained through the more conventional incineration process.

The Solar Thermal Program

Program Goals and Research Thrusts

To develop the balanced, flexible source of affordable and abundant energy mandated by the National Energy Policy Plan, the Solar Thermal Technology Program supports research and development to improve cost and performance and broaden the areas of applicability of solar thermal systems. This ongoing research complements existing private industry efforts and will provide technically proven options for eventual incorporation into the nation's energy supply.

The Solar Thermal Technology Program goals are to:

- develop high-performance, reliable solar thermal systems and components that will be competitive for electric and process heat applications;
- develop technology for new applications using concentrated solar energy; and,
- enhance technology exchange between the national laboratories, universities, and the private sector.

Research efforts in the DOE Solar Thermal Technology Program are developing the foundations necessary for a viable solar thermal technology. The research efforts during FY 1988 were focused on concepts, processes, and materials for a broad range of applications and on the identification and proof-of-concept of advanced applications for highly concentrated solar energy, as follows:

- research on optical materials and advanced optical techniques for high-performance, lower cost solar concentrators:
- research on high-temperature materials and concepts for receivers that efficiently handle high solar flux for electric power generation;
- research on materials, processes, and components related to the generation of concentrated solar energy for the destruction of hazardous wastes; and,
- research to apply the unique attributes of concentrated solar thermal flux to fuel and chemical production and materials processing.

Key Program Elements

Technology development efforts translate research results into essential components that enable industry to approach a broad range of market opportunities with proven, high-quality, cost-effective, and reliable systems. DOE/industry cost-sharing of the development of key components to reduce risk, enhance U.S. industry competitiveness, and verify performance, manufacturability, and reliability is sought as a means of leveraging research funds. Efforts during FY 1988 were on innovative approaches for reducing cost and improving performance of key solar components including:

- development of low-cost, lightweight stretched membrane heliostats and parabolic dish collectors;
- development and testing of advanced molten-salt receivers and transport components for CR plants;
- development of advanced sodium-reflux receivers for dish systems;
- development of reliable, high-performance, low maintenance focal-mounted engines for dish-electric systems; and,
- development and testing of DARs for CR plants.

Ongoing research efforts are exploring the possibilities of using concentrated solar energy for unique applications including:

- development of a concentrator that uses innovative optics for very high concentration ratios;
- exploration of concentrated solar energy for altering chemical reactions, destroying hazardous chemicals, and synthesizing fuel additives; and,
- exploration of concentrated solar energy for enhancing material properties of carbon fibers and metals.

Summary of FY 1988 Program Activity

The solar thermal program structure, shown here, includes a list of major program elements and responsible organizations. The following summary is a detailed narrative for each program activity conducted during FY 1988.

The Solar Thermal Technology Program Structure

Collection Technology Research	Conversion Technology Research	Systems & Applications Technology
Optical Materials Silver ultralight polymer reflectors (SUPR) (SERI) Structural membrane composite materials research (SERI) Soiling and cleaning of solar reflectors (SERI) Thin foil stainless steel reflectors (Sandia)	**Heat Engines** Stirling engine cycles (Sandia) Regenerative thermoelectrochemical conversion (RTEC) heat engine research (SERI) Heat engine analysis (Sandia)	**Innovative Concepts & Applications/Small Business Innovation Research** (SERI) New ideas/innovative concept development at universities Small business innovation research
Concentrators Central receiver concentrator R&D (Sandia) Distributed receiver concentrator R&D (Sandia) Advanced concentrator research (SERI)	**Direct Conversion** (SERI) Direct conversion of solar thermal energy Solar induced surface transformations of materials	**Balance of Plant** (Sandia) Automated control systems **Central Receiver (CR) Systems** (Sandia) Systems applications studies CR Test Facility
Receivers Central receiver R&D (Sandia) Distributed receiver R&D (Sandia) Advanced receiver research (SERI)		**Distributed Receiver (DR) Systems** (Sandia) Systems engineering, evaluation & analysis DR Test Facility **System Experiments** (Sandia) Solar One Barstow project Small Community Solar Experiments

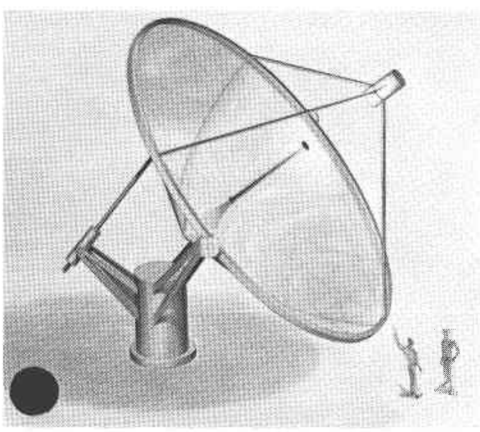
Membrane heliostat.

Collection Technology Research. During FY 1988, support continued for research on silvered polymer and front-surfaced silver steel reflectors. Outdoor weathering tests for 3M's silvered polymer film, ECP 300, continued to show encouraging results. ECP 300 samples have maintained reflectance greater than 90% for over two years outdoors in Golden, Colorado, and Miami, Florida, and are only slightly below 90% in Phoenix, Arizona. These results are close to achieving the five-year lifetime goal for this material, which will be critical for successful application in membrane concentrators.

Research also continued on stretched membrane heliostats and stretched membrane dish concentrators. During FY 1988, successful optical testing and evaluation was conducted on a first generation prototype stretched membrane heliostat developed by Solar Kinetics, Inc. (SKI). Results show very favorable performance compared with conventional glass/metal heliostats; the former perform at least as well as the latter. Reflectivity is above 90% and windy day performance meets specifications. In addition, durability after over one year in the field is good. Also during the year, both SKI and Science Applications International Corporation (SAIC) completed design and fabrication of improved second generation prototype stretched membrane heliostats. The SAIC prototype has been installed at the Central Receiver Test Facility (CRTF). Initial tests show that the beam quality is as good as SKI's first generation heliostat and that the focus control system in windy conditions seems better. Progress also continued in the development of stretched membrane dish concentrators. SKI was awarded a contract to continue developing their front membrane dish collector design with the goal of fabricating a full-scale, solar collector capable of producing 100 kW of thermal power for a receiver operating at 800°C.

A significant breakthrough in solar concentration occurred during FY 1988. Through research in optics at the University of Chicago, a technique was developed in which the solar beam could be concentrated to 60,000 times the normal intensity of the sun striking the earth. The previous record was less than 20,000 suns. This now provides an energy source that approaches the intensity of the energy at the sun's surface. The concept opens an exciting new area of solar research. It provides a tool that will make it possible to learn more about the effect of the sun's energy on materials and chemicals. It also provides an energy threshold from which it is possible to use a solar beam to power a laser.

Research continued throughout the year on advanced central and dish receivers. Work on the DAR concept for central receivers is continuing at both SERI and Sandia. Experimental work at SERI continued to investigate nitrate salts and blackeners, which will be used in DAR applications, to determine their behavior under high-temperature/high-flux conditions. Results show good behavior of the salt films at temperatures and flux levels representative of DAR working conditions. SERI researchers have also conducted experiments with a long salt-film apparatus to study the behavior of clear and doped salts at flow conditions approaching those of a working DAR. At Sandia, experimental work continued on a large-scale water flow apparatus needed to examine flow properties of full-scale receiver components, and on a 3-MW_e solar DAR panel. Testing on the large-scale water flow apparatus is designed to examine techniques for reducing wave formation and droplet ejection from falling liquid films. The 3-MW_e panel research experimental apparatus is under construction at the CRTF with completion expected during the first quarter of next fiscal year. During FY 1988, Foster Wheeler Solar Development Corporation conducted preliminary design studies of a surround field/external cylinder DAR in a commercial-scale central receiver power plant. These studies examined receiver-specific aspects of a 320-MW DAR, emphasizing differences between previous salt-in-tube receiver designs and a DAR design. This DAR design will be 40% lighter and 30% less expensive than



Dish concentrator.

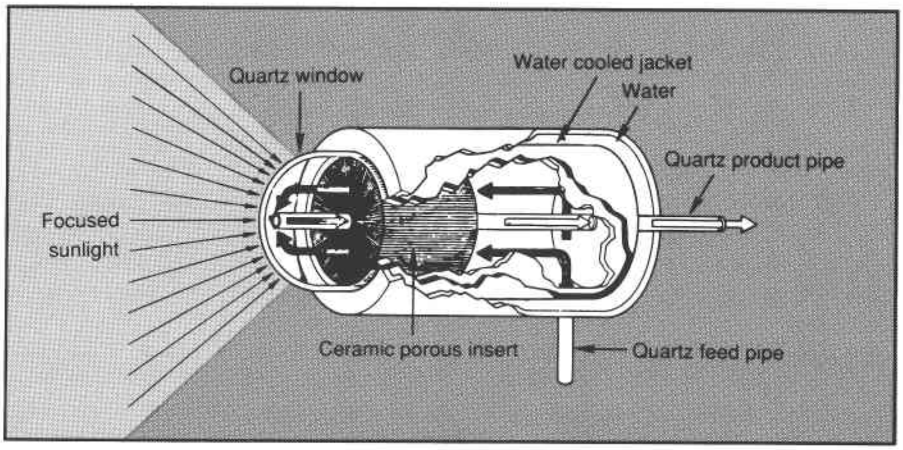
comparably sized salt-in-tube receivers. The benefits of this commercial DAR design give it the potential to reduce the levelized energy cost of the central receiver system by 15%.

In the dish receiver development program, a variety of activities related to reflux receiver development were conducted. This receiver concept uses a boiling metal such as sodium as an intermediate heat transfer fluid and is based on a heat pipe concept for heat transfer from the absorbing surface to the working fluid of the energy conversion device. Several different receiver designs were investigated, including a pool boiling design and a wicked absorber design. The latter is being pursued by Stirling Thermal Motors in conjunction with their development of a variable swashplate kinematic Stirling engine. This heat pipe receiver uses a stainless mesh wick and an absorber made of two Inconel plates separated by a coarse stainless mesh. A final detailed design will be completed early in FY 1989; testing will begin shortly thereafter.

Conversion Technology Research. Energy conversion research during FY 1988 had two principal thrusts: heat engine development and direct conversion research. A major program is under way to develop a free-piston Stirling engine (FPSE) for use in dish electric systems. During FY 1987, two contractor teams, headed by Mechanical Technology, Inc. (MTI) and Stirling Thermal Company (STC), developed conceptual designs for free-piston Stirling engines that show promise for meeting program cost and performance goals. During FY 1988, a request for proposal (RFP) for Phase II of this program was released. Phase II will consist of preliminary design of a 25-kW_e FPSE, based upon the Phase I conceptual designs. An announcement of the results of this competition is expected during the first quarter of FY 1989.

Another heat engine development initiative receiving attention during FY 1988 was the regenerative thermo-electrochemical converter (RTEC) jointly developed by Hughes Aircraft Company and SERI. During the first quarter of FY 1988, a cost-shared subcontract was placed with Hughes. SERI work over the past year has focused on the regenerator. Much work has been conducted to determine thermophysical properties of the working fluid and to identify containment materials that are not subject to high rates of corrosion. Current research at SERI includes troubleshooting a prototype, lab-scale flow regenerator. Successful shakedown of this regenerator design will be a demonstration of the availability of materials to contain the corrosive working fluid at high temperatures as well as the successful design of a metered expansion device for inclusion in a 10-W, closed-loop RTEC prototype experiment scheduled for FY 1989. Hughes has been focusing on the electrochemical portions of the system and completed fabrication of the electrochemical cell test loop during FY 1988. This apparatus will be used to experiment with two kinds of membrane/electrodes, both kinds using the solid polymer electrolyte (SPE) electrode.

Direct conversion research has focused on the development of concentrated photon energy processed for the destruction of hazardous chemicals, the production of high value fuels and chemicals, and the development of high value materials properties. During the year, experiments were conducted using the solar furnace at the White Sands Missile Range to determine if it was possible for a beam of concentrated solar energy to destroy dioxin to the level required by the EPA. Solar tests, run at nearly one-thousand concentrations of the sun's energy, produced destruction efficiencies of greater than 99.9999%, a level that would meet or exceed EPA requirements. A solar detoxification reactor, placed at the focus of a solar beam, was able to accomplish this destruction efficiency because of two complementary effects: photolytic effect from ultra-violet and visible portion of the solar spectrum, and thermal effect from the infrared portion of the spectrum. The tests indicated that the combination of both effects caused a more complete destruction of the dioxin at lower temperatures than could be obtained through the more conventional incineration process. In addition, a number of successful proof-of-concept experiments were conducted involving the direct illumination of catalyst surfaces by concentrated solar flux as a means of photocatalytic destruction of hazardous wastes.



Solar detoxification reactor at the White Sands Missile Range solar furnace.

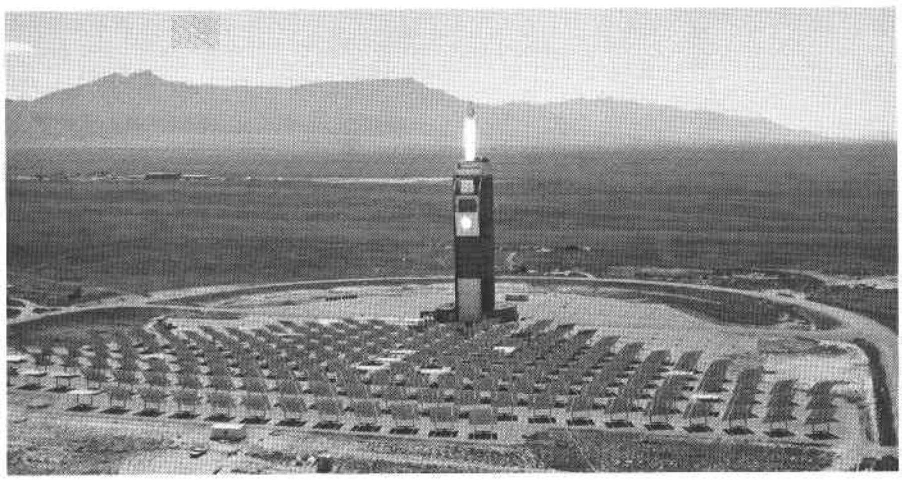
Researchers at the University of Houston are investigating the use of high flux solar radiation to initiate and sustain endothermic reactions. Reactions with high commercial potential that are being investigated include hydrocarbon reforming and cracking reactions for the production of fuel additives and the upgrading of low value hydrocarbons. For instance, over the past two years, researchers have shown a photoenhancement of fiftyfold for the conversion of propanol to propylene compared to the thermal reaction alone. During the past year, photoenhancement has also been shown for hexane to benzene. Researchers at the University of Houston are searching for high value chemical reactions that can be photoenhanced and lead to beneficial use of concentrated solar flux.

Two major efforts were under way last year to examine the beneficial effects of high levels of solar flux on materials. SERI is conducting experiments at the solar furnace at the CRTF that are examining approaches to depositing surface coatings on various materials and inducing surface transformations in a variety of materials. Processes that have been examined include phase transformation hardening (pulsed heating), carburizing and boriding of steels, and cladding of steels. At the Georgia Technology Research Institute (GTRI), work is under way to identify beneficial solar effects on carbon fibers and carbon/carbon composites as well as to investigate solar-induced chemical vapor deposition (CVD) of high quality ceramic powders and coatings. During FY 1988, GTRI continued experiments that show improved moduli and high temperature oxidation resistance of carbon fibers exposed to high levels of solar flux. These properties are highly desirable in this material, which is being widely used in a variety of critical defense and aerospace applications. In other experiments, researchers have produced ceramic whiskers of hafnium carbide, hafnium oxide, and carbon using the solar CVD process. These whiskers have been produced in size ranges equal to or larger than commercially produced silicon carbide whiskers and have the potential to withstand higher temperatures.

Systems and Applications Technology. During the year, work continued on investigating systems level issues and identifying next generation system concepts for CR systems. During FY 1988, DOE and the Electric Power Research Institute (EPRI) provided partial funding for semi-commercial operation of Solar

One, the world's largest central receiver electricity generating station. The plant was operated by Southern California Edison Company on a five-day-per-week schedule with a minimal operations and maintenance crew. During the one-year semi-commercial power production phase, availability of the plant was 96%, exceeding both the previous high of 83% and the design value of 90%. The plant operated for 247 days, delivering 9245 MWh (net) to the grid. Extrapolating these data for full-year (365 days) operation results in an estimated 13,959 MWh, significantly better than any previous year, and only 9.3% below the annual energy goal set for the plant.

Work by two southwestern utility companies also continued in FY 1988 in order to define a viable path to eventual commercialization of solar central receiver technology. During FY 1987, the two teams developed conceptual configurations of a next generation utility-scale central receiver system. During FY 1988, the two utility teams consolidated into a single team to focus on the R&D path necessary to reduce technical and financial risks associated with future CR systems. This work was completed in FY 1988, and recommendations will be presented early in the first quarter of FY 1989. Also, work continued on the testing of large-scale components (receivers, pumps, and valves) for advanced molten salt CR systems at the CRTF, Albuquerque, New Mexico.



Central Receiver Test Facility in Albuquerque, New Mexico.

Efforts continued during FY 1988 to examine systems level issues for DR systems. Perhaps the largest single set of activities was related to the Small Community Solar Experiments (SCSE). During the year, the LaJet Innovative Point-Focus Solar Concentrator, planned for use in the SCSE #1 module, was installed for testing at the Distributed Receiver Test Facility (DRTF). Unfortunately, wind damage to the concentrator forced delays in the test program while repairs were made. Barber-Nichols engine (SCSE #1) verification tests of the organic Rankine cycle engine (ORCE) were conducted during FY 1988. The engine was operated, with electric heaters supplying the thermal input, with only minor problems. By the end of the fiscal year, the ORCE had operated over 640 hours. In addition, that engine, operating with electric heaters, and the JPL-Ford prototype ORCE, operating with solar input from a test bed concentrator, were successfully operated in parallel to simulate the operation of two engines into one inverter. The Power Kinetics, Inc. (SCSE #2) module verification tests were completed during June 1988. Concentrator operation during May and June had been essentially without problems. Operation appears to be functionally adequate, although performance appears to be below expectations. However, repeated design and component problems, low system efficiency, and energy economics resulted in the termination of both Small Community Solar Experiments at the end of FY 1988.

International Activity. International activities were conducted during FY 1988 through the collaborative R&D agreements of the International Energy Agency (IEA) and bilateral agreements with Israel. Involvement in these projects provided the opportunity to leverage research funds, to gain access to experience and expertise in other countries, and to conduct projects and experiments that could not be funded by the United States alone. The labs, universities, and private sector organizations were also participants in the international R&D projects, and program managers were responsible for managing and giving policy direction to U.S. participation. The international projects are supportive of and integrated into the Solar Thermal Technology Program.

International Activities in Solar Thermal Technology - FY 1988

IEA Small Solar Power System (SSPS) Agreement

IEA Task	Program Area
High-Temperature Receiver Technology (Task #3)	Collection Technology Research
High-Temperature Thermal Storage (Task #4)	Central Receiver Systems
Solar Fuels, Chemical and Energy Transport (Task #5)	Conversion Technology Research
Long-Term Fuels and Chemicals (Task #6)	Conversion Technology Research

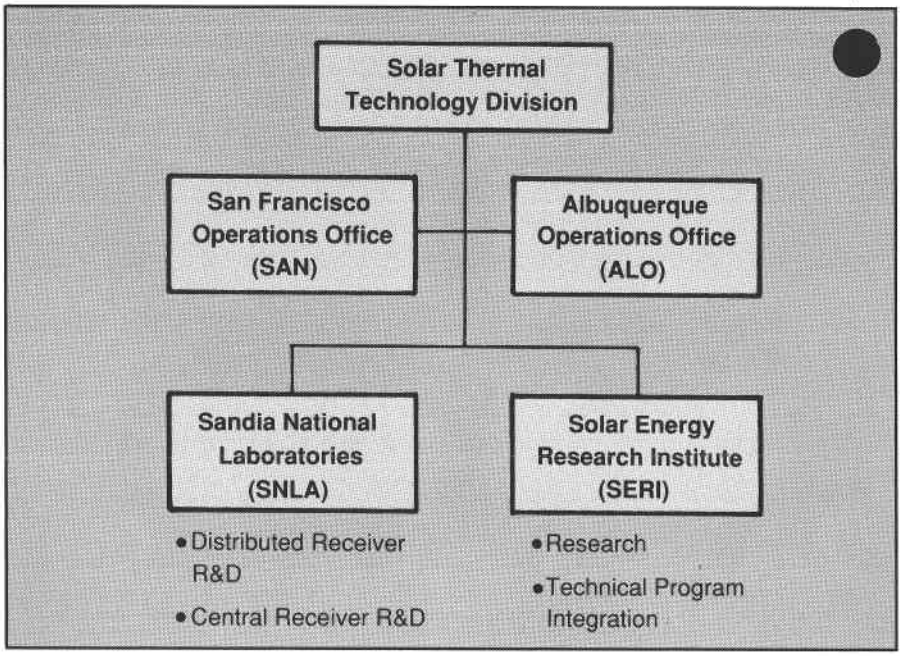
U.S./Israel Bilateral Agreement

Activity	Program Area
Testing of U.S. ceramic receiver in test facility in Israel	Collection Technology Research
Hardware testing and other experiments to advance the understanding of solar-driven thermochemical processes	Conversion Technology Research

Program Management

Within the Department of Energy, the Solar Thermal Technology Program is the responsibility of the Division of Solar Thermal Technology, which reports to the Office of Solar Heat Technologies.

Policy formulation, planning, and program evaluation activities are performed by DOE Headquarters with implementation of each element delegated by a field organization. Management control over the program is maintained through a schedule of periodic reporting and reviews to ensure that the program is proceeding as described in the field Annual Operating Plans (AOPs) approved at the start of the fiscal year. Program control is exercised through approved field AOPs. Any significant changes in work plans from those submitted and approved at the start of the fiscal year require approval by DOE Headquarters.



Solar thermal program organization structure.

Summary of FY 1988 Funding

The FY 1988 Solar Thermal Technology Budget Plan includes the field/laboratory organizations responsible for each program area. FY 1988 solar thermal contract descriptions are presented here, along with relevant contract data and funding information in a separate report.

Solar Thermal Technology Budget Plan

(Dollars in Thousands)

	FY 1988			
Program Activity	DOE HQ	SERI	Sandia	Totals
Collection Technology Research	—	3,440	6,520	9,960
Energy Conversion Technology Research	—	1,070	1,450	2,520
Central Receiver Systems Technology Research	555	275	1,890	2,720
Distributed Receiver Systems Technology Research	305	275	1,170	1,750
Capital Equipment	—	44	44	88
Totals	860	5,104	11,075	17,038

Successfully bringing solar thermal technology to the marketplace will depend on strong interaction between R&D efforts and industrial initiatives to identify and develop commercial markets. Industry builds on the technology base through application projects and provides feedback to identify supporting activities essential to initial market penetration. In summary, successful penetration of a variety of early markets for solar thermal technology will ensure the vitality of this important renewable energy option.

Key Contacts

Dr. Robert San Martin
Deputy Assistant Secretary, Renewable Energy
U.S. Department of Energy
(202) 586-9275

Dr. Frederick H. Morse
Director, Office of Solar Heat Technologies
U.S. Department of Energy
(202) 586-1535

Dr. Howard S. Coleman
Director, Solar Thermal Technology Division
U.S. Department of Energy
(202) 586-8121

U.S. Department of Energy
Forrestal Building
1000 Independence Ave. S.W.
Washington, DC 20585

Dr. Lawrence M. Murphy
Acting Director, Solar Heat Research Division
Solar Energy Research Institute
1617 Cole Blvd.
Golden, CO 80401
(303) 231-1050

Dr. Billy W. Marshall
Manager, Energy Conversion and Science Department, #6210
Sandia National Laboratory
P.O. Box 5800
Albuquerque, NM 87185
(505) 844-2964

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