SOLAR THERMAL ELECTRIC

Program Overview Fiscal Years 1993-1994

Message from the Director

Randy Montoya, Sandia National Laboratories

GARY D. BURCH, DIRECTOR OF THE U.S. DEPARTMENT OF ENERGY'S SOLAR THERMAL ELECTRIC PROGRAM, INSPECTS HELIOSTATS UNDERGOING PERFORMANCE TESTING AT SANDIA NATIONAL LABORATORIES IN ALBUQUERQUE, NEW MEXICO. SANDIA AND THE NATIONAL RENEWABLE ENERGY LABORATORY COOPERATIVELY MANAGE THE PROGRAM'S RESEARCH AND DEVELOPMENT ACTIVITIES.

After years of research and development, solar thermal power technologies are coming to fruition. Two of them, power towers and solar dish generators, are on the verge of commercialization. The goal now is to help industry introduce these technologies more quickly.

Joint venture projects, directed by industry, are our principal tools for developing these solar thermal power technologies, enabling the scientific expertise at our national laboratories to be combined with the manufacturing and marketing expertise of our partners.

The U.S. Department of Energy and the solar thermal power industry are making an investment worth more than \$150 million because these technologies have the capability of producing electricity that is cost effective and has little impact on the environment. These technologies will create thousands of high-quality jobs, benefitting regional economies and the nation as a whole. This will position U.S. industry to take advantage of what we predict within the next decade will be a multibillion dollar worldwide market for solar thermal power technologies.

Gary D. Burch
U.S. Department of Energy

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Summary of Program Accomplishments for Fiscal Years 1993-1994

- **Launched five joint venture projects** with U.S. industrial partners valued at more than \$150 million. The Department of Energy (DOE) shares 50% of the cost of the joint ventures, thus effectively leveraging its funding. All the joint-venture partners are committed to the introduction of commercial solar thermal power systems to the market.

Began construction of Solar Two, the world's first prototype power tower system with a molten-salt thermal storage. The molten-salt storage will allow the power plant to operate for 3 hours after the sun sets to provide electricity during peak demand periods. Southern California Edison Company (SCE) of Rosemead, California, leads the joint venture along with a consortium of other utilities and industrial companies. By the end of FY 1994, the Solar Two design was complete, and construction was under way; testing will begin in FY 1995.

Built prototype solar dish generators for the remote and small-power market with Cummins Power Generation (Cummins) of Columbus, Indiana. In 1993, Cummins and Sandia National Laboratories of Albuquerque, New Mexico, received the coveted R&D 100 Award, recognizing the prototype as one of the most important scientific achievements of the year. In July 1994, a Cummins solar dish generator provided power to a utility for the first time in history using a free-piston Stirling engine.

Signed contracts to develop solar dish generators for utility applications with Cummins and Science Applications International Corporation (SAIC) of Golden, Colorado. The two partners committed to develop and operate, along with U.S. utilities, more than 1 MW of prototype systems before the end of the decade.

Substantially reduced costs of operating and maintaining trough power plants operated by the KJC Operating Company of Boron, California.

- **Established the Solar Manufacturing Technology (SolMaT) initiative** in July 1994 by releasing the first solicitation aimed at reducing the cost of heliostats (reflectors), one of the key components of power towers. The purpose of SolMaT is to develop the manufacturing technology and processes that permit cost-effective deployment of solar power systems.
- **Introduced a new reflective material on the market.** The material, a silvered polymer called ECP-305+, was developed as a collaboration between the National Renewable Energy Laboratory (NREL) of Golden, Colorado, and the 3M Company of St. Paul, Minnesota.
- **Tested solarized versions of two existing engines.** The engines, originally developed for cogeneration applications, were modified to operate with input from solar energy instead of heat energy from a burning fuel.

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Solar Meets Many Needs

Solar thermal systems generate electricity while producing virtually no emissions. The fuel is free and inexhaustible. Local communities benefit economically from the jobs at the plants.

Solar thermal power plants have proven themselves in the field. Nine solar plants with a combined rated capacity of 354 MW have operated successfully in California for more than a decade. Their availability to produce power when the sun shines is greater than 92%, a statistic that rivals utility-scale power plants of any type. In addition, the plants bring environmental benefits to California and economic benefits to both the region and the nation.

“THE JOINT VENTURES COMBINE THE SCIENTIFIC EXPERTISE OF THE NATIONAL LABORATORIES WITH THE MANUFACTURING AND MARKETING EXPERTISE OF PRIVATE INDUSTRY.”

As a result, both the solar thermal industry and a number of utilities look forward to the large-scale adoption of solar thermal power during the next decade. At that time, the market for U.S.-designed and U.S.-manufactured technology worldwide could amount to billions of dollars.

The Solar Thermal Electric Program supports this vision through a coordinated program consisting of:

- Joint-venture projects with the goal of commercialization
- Technology development projects with the goal of developing efficient and reliable systems
- Industrial development projects to expand the manufacturing base of the solar thermal power industry
- Market conditioning projects that will increase acceptance of solar electric technologies by utilities and other users.

This document highlights the progress of DOE's Solar Thermal Electric Program during FY 1993 and FY 1994. This document is organized according to the coordinated approach to commercialize the three types of solar thermal electric technologies.

Three Solar Thermal Electric Technologies

Solar thermal electric technologies convert the energy of sunlight into electricity. To do so, sunlight is concentrated using reflectors, or concentrators, to focus on a receiver. During operation, the receiver transfers the heat to a conventional engine-generator, such as a steam turbine, that generates the electricity. Thus, there are three basic components of a solar thermal electric system: a concentrator, a receiver, and an electric generator.

Power Towers

Solar Dish Generators

Trough Systems

The Solar Thermal Electric Program is supporting the development of three power conversion technologies. Each one uses different types of concentrators, receivers, and electric generators. Each comes in a different size and has different operating characteristics. Each has distinct advantages. The three technologies are:

- ❑ **Power towers** (also called central receivers) use heliostats—highly reflective, nearly flat mirrors that track the sun to concentrate sunlight on a receiver atop a tower. The sun heats a fluid flowing through the receiver to temperatures as high as 565°C (1050°F), and is used to generate electricity in a conventional steam turbine. Or the hot fluid can be stored for a short time in a storage tank for generation at a time that matches the user's need for power.
- ❑ **Solar dish generators** use reflectors formed in the shape of a parabolic dish to focus the sun's rays on a receiver mounted at the focal point of the dish. Because the parabolic shape of the dish and the small size of the receiver are efficient for collecting solar energy, the receivers reach temperatures as high as 800°C (1500°F). The receiver is connected to an engine generator mounted on the dish for power production.

Solar dish generators are much smaller electric generating systems than power towers, with capacities ranging from 5 kW to 50 kW. At this size, solar dish generators are used for stand-alone systems to supply power to small towns or villages in developing countries, or collected in groups for a small-scale power plant connected to a utility.

- ❑ **Trough systems** use reflectors in the shape of a parabolic trough to concentrate sunlight as much as 100 times onto a tube receiver at the focal line of the trough. The fluid flowing through the tube receiver reaches temperatures as high as 400°C (750°F), and is used to generate electricity in a conventional steam turbine.

There are nine existing trough power plants operating in California with a combined capacity of 354 MW.

The Benefits of Solar Thermal Power

Solar thermal power plants offer environmental and economic benefits for utilities, their customers, and the local communities in which they operate. For instance, they operate best during daylight hours, roughly the time utilities most need power. They also bring skilled jobs to local communities where they are manufactured and deployed.

Environmental Benefits

Solar thermal power plants produce electricity with little impact on the environment. They produce virtually no emissions and consume no fuel. The energy supply from the sun is inexhaustible. Land use is the most visible environmental impact.

However, the land use is not excessive. These plants operate best in sunny, semiarid climates in which land is available at a relatively low cost. Today's commercial solar thermal power plants occupy about 5 acres of land per MW of capacity. These land requirements are roughly equivalent to those of conventional coal-fired power plants when the land use of mining is included.

Because of their minimal environmental impact, solar thermal power plants improve a utility's overall environmental performance. They also protect a utility from the effects of future changes in environmental regulations; solar plants can meet any environmental regulations envisioned.

Economic Benefits for Utilities

Solar thermal power plants provide economic benefits to utilities by reducing overall financial risks and providing capacity during peak periods.

Solar thermal power plants are currently in the pilot stage of development and are therefore more expensive than conventional power plants. However, the costs of electricity from solar thermal power plants are predictable. Once the plant is built, operating costs are low, because the fuel is free. On the other hand, conventional power plants have escalating operating costs due to the cost of fuel.

Solar thermal plants reduce the utility's risk that the cost of fuel will change. By including solar in its "portfolio" of energy resources, a utility effectively diversifies this energy mix. Just as diversifying an investment portfolio reduces the financial risk to an investor caused by the change in the price of one stock, diversifying its resource portfolio reduces the risk to a utility and its customers caused by a change in the price of any of its (fuel) resources.

Furthermore, solar thermal power plants produce power during peak demand periods. The hot, sunny days when many utilities experience their peak demand for air-conditioning loads are also days when these power plants generate the most electricity. When combined with energy storage (see Solar Two, p.5) or gas generation, these power plants provide reliable capacity for a utility's peak power needs.

Economic Benefits to Local Communities

In California, 240 people are employed in the operation and maintenance (O&M) of 354 MW of solar thermal power plants. This is roughly two and one half times as many jobs as those in conventional power plants of the same size that generate electricity with fossil fuels.

Sandia National Laboratories

○ Solar thermal power plants create two and one half times as many skilled, high-paying jobs for the communities in which they operate as do conventional power plants that use fossil fuels.

Furthermore, solar thermal power plants yield twice as much tax revenue for state, local, and national government agencies as conventional, gas-fired power plants do. Tax expenses are important to the financial success of building and operating any type of power plant.

To examine the tax expenses paid by operators of different types of power plants and the equitable taxation of solar plants, the Solar Thermal Electric Program initiated a cooperative study with the California Energy Commission (CEC) in FY 1994 to compare the tax revenue generated by a gas-fired power plant and a solar thermal power plant. In the study, both plants were operated similarly and generated the same number of kWh per year.

The CEC reported that solar power plants generate about twice the tax revenue that gas-fired plants do because they are capital-intensive projects. Gas-fired plants, on the other hand, are expense-intensive because of fuel costs. In FY 1995, the Solar Thermal Electric Program will investigate whether solar plants generate as much additional tax revenue in other states, such as Nevada, as they do in California. By providing jobs to local economies and additional tax revenue, solar plants help communities establish a firm tax base and thus promote local economic development.

Utility Consortium Develops Power Towers

Led by Southern California Edison Company, a utility consortium in a joint venture with the Department of Energy demonstrates that power towers provide reliable power during utility peak demand periods. A pilot power tower—Solar Two—is under construction.

After years of testing components of power towers, the solar industry, DOE, and a number of utilities believe they are ready for commercialization. In FY 1993, a utility consortium began design of the second power tower pilot plant, Solar Two. This plant will demonstrate the technical feasibility and cost potential of power towers using advanced molten-salt technology for energy storage.

The first power tower pilot plant, Solar One, operated for 6 years in the Mojave Desert near Barstow, California, during the 1980s. Rated at 10 MW, it proved the technical feasibility of power towers. It also proved that power towers have little impact on the environment and are accepted by the public.

○ Solar One proved that power towers work. Solar Two will prove that power towers with energy storage provide cost-effective power to utilities during peak demand periods.

Solar Two

Solar Two will include an important technological improvement that substantially increases the value of power towers to utilities' energy storage. Solar Two includes a system for storing heat energy in tanks of molten salts. The tanks contain enough thermal energy to continue generating electricity for 3 hours after sunset.

The energy-storage system is valuable because it allows the operators to shift electricity production into SCE's peak demand periods. (Solar Two will be connected to SCE's grid.) These peak periods take place on hot summer evenings when people turn on their air conditioners. If peak energy is not required that evening, the operator can run the plant for maximum power output during the day. In other words, storage makes the plant dispatchable and is thus consistent with utility requirements.

The total cost of building and operating the pilot plant for 3 years is \$48.5 million. DOE is providing 50% of the funds for the joint venture; DOE's partners are providing the other 50%.

In addition to DOE and SCE, other members of the joint venture include:

- ❑ Arizona Public Service Company of Tempe, Arizona
- ❑ Bechtel Corporation of San Francisco, California
- ❑ California Energy Commission of Sacramento, California
- ❑ Electric Power Research Institute of Palo Alto, California
- ❑ Idaho Power Company of Boise, Idaho
- ❑ Nevada Power Company of Las Vegas, Nevada
- ❑ PacifiCorp of Portland, Oregon
- ❑ Rockwell International Corporation of Kenoga Park, California
- ❑ Sacramento Municipal Utility District of Sacramento, California
- ❑ Salt River Project of Phoenix, Arizona
- ❑ South Coast Air Quality Management District of San Diego, California.

Bechtel is the general contractor for the project and is contributing \$2 million of its own funds to the venture. Sandia provides technical support to the project by participating on the project design team with Bechtel and SCE and by chairing the project's technical advisory committee.

In FY 1993, Bechtel began the engineering design of the plant and also started demolition of the Solar One thermal storage system. Bechtel was able to recycle 98% of the materials from the demolition.

In FY 1995, start-up and plant check-out will begin, when all the plant's subsystems will be tested individually. Once the checkout is complete, the consortium will operate the plant for 3 years, beginning in FY 1996.

Joe Flores, Southern California Edison Company

"POWER TOWERS HOLD TREMENDOUS PROMISE FOR SOUTHERN CALIFORNIA EDISON," SAYS SCE'S MARK SKOWRONSKI. SKOWRONSKI HEADS A CONSORTIUM OF UTILITIES BUILDING AND OPERATING SOLAR TWO. "THROUGH SOLAR TWO, WE'RE DEVELOPING A CLEAN, VIRTUALLY UNLIMITED ENERGY SUPPLY THAT WILL BE COMMERCIALY VIABLE WITHIN A DECADE. SCE IS INVOLVED BECAUSE IT'S WHAT OUR CUSTOMERS AND REGULATORS WANT US TO DO."

Components from Solar One

The consortium will use most of the components from Solar One, including the 90-m (300-ft) tower, the turbine-generator, and the field of heliostats.

Of all the components, the field of 1800 heliostats is perhaps the most important. When the project began, Bechtel was not sure whether the field, which had been idle for almost a decade, would be salvageable. Although the majority of the heliostats remained in satisfactory condition, Bechtel is repairing some and building a computerized controller for them. In addition, Bechtel is adding an additional 100 heliostats to the field.

New Receiver and Thermal Storage

The receiver and energy storage system for Solar Two are new. The receiver is designed to accumulate energy reflected from the field of heliostats into tubes containing molten salts. The receiver used in Solar One was designed to produce steam to be fed directly into the steam turbine.

During operation, the molten (liquid) salt will be heated to temperatures as high as 565°C (1050°F) in the receiver and will then be pumped to the thermal storage system next to the tower. The thermal storage system consists of two tanks of molten salts and all of the piping and equipment necessary to move the molten salts from the receiver to the power generator.

Designing and building a molten-salt system of this size represents an engineering challenge. No such system has ever been built before, although each of the components has operated successfully.

Sandia National Laboratories

○ Receivers and other components for power towers undergo testing at the National Solar Thermal Test Facility at Sandia National Laboratories.

The pumps, piping, and valves are large and must operate reliably at high temperatures. Some industries use similar components in chemical production plants. But chemical plants typically operate 24 hours a day, whereas a power tower will turn on and off every day. This cycling results in larger stresses on components; they must be designed to withstand such cycling.

Engineers will also evaluate the maintenance required to prevent the molten salts from corroding the components before the end of their expected lifetime. In FY 1993, Sandia engineers completed 7000 hours of corrosion tests on components exposed to molten nitrate salts.

Technology Development

Program engineers continued in FY 1993 and FY 1994 to develop technology to be applied to future power towers. For example, engineers at Sandia are currently developing a new receiver, called the volumetric receiver, for power towers. Program engineers at NREL are evaluating the feasibility of combined-cycle power towers.

Sandia engineers are working in a cooperative project with engineers from Bechtel and the Spanish energy agency to design and test a volumetric receiver for use on power towers. A volumetric receiver absorbs the energy reflected from the heliostats onto a wire-mesh receiver instead of, for example, on the surface of the tubes in the receiver used for Solar Two. Air is heated as it is pulled through the mesh, which, in turn, provides energy to the steam turbine generator. The surface will not get as hot as that of the receiver used on Solar Two. Therefore, the receiver will not undergo as much heat loss from the surface and will operate more efficiently.

In FY 1993 and FY 1994, a design was developed, and a pilot receiver was fabricated. In FY 1995, testing will begin at the Plataforma Solar de Almeria test station in Almeria, Spain.

In addition to solar-only power towers, engineers at NREL are working with several utilities to examine the feasibility of building hybrid power towers that run on both solar energy and natural gas. They could run continuously (with a high-capacity factor), like other gas-fired power plants.

○ Engineers from Sandia National Laboratories have tested components for power towers, such as these heliostats, for years.

Sandia National Laboratories

Hybrid power towers would provide several advantages to utilities. The towers would have a smaller solar component, be easier to finance and build than an all-solar power tower, and could use a combined cycle gas turbine instead of a conventional steam turbine to achieve higher efficiency.

"FOR US, HYBRID POWER TOWERS ARE WELL-SUITED TO UTILITY NEEDS," SAYS BUD BEEBE OF THE SACRAMENTO MUNICIPAL UTILITY DISTRICT. "OUR CALCULATIONS SHOW THEY CAN BE COST EFFECTIVE IN TODAY'S POWER MARKETS."

As a result, several utilities have shown interest in developing the hybrid power tower. Bud Beebe, Project Leader for the Sacramento Municipal Utility District (SMUD), says, "For us, hybrid power towers are well-suited to utility needs." In FY 1995, the Program will work with SMUD and other utilities to investigate the feasibility of building a commercial hybrid power tower.

Joint Ventures Commercialize Solar Dish Generators

The Program's joint-venture partners direct the research and development of solar dish generators on projects that speed commercialization.

In the near future, solar dish generators will be competitive in markets for stand-alone and utility applications. Stand-alone systems will be economically competitive in remote locations where a connection with the utility power grid is unavailable or expensive.

Utilities could use solar dish generators in groups to support the voltage at the ends of their distribution system. Used in this way, solar dish generators would preclude the utility upgrading distribution equipment such as substations and power lines. Or the systems could be grouped together in a multi-megawatt power plant.

Different solar dish generators will be required for remote power or utility applications. Remote or overseas applications require sturdy solar dish generators with little required maintenance, they must run unattended in harsh environments for long periods at a time, and they must be easy to ship and construct without access to specialized equipment. Generally, remote power systems are smaller in size than utility scale systems.

○ Solar dish generators such as this one undergoing performance testing at Sandia National Laboratories, can generate electricity from sunlight with high efficiency.

SOLAR DISH GENERATORS PRESENT AN ATTRACTIVE ALTERNATIVE TO DIESEL ENGINES FOR POWER GENERATION IN REMOTE LOCATIONS.

Sandia National Laboratories

Utility applications require low-cost maintenance and the lowest possible energy cost. Unlike engines for remote power applications, these solar dish generators will operate in a utility environment with a dedicated maintenance crew. They must be larger to produce energy more cost effectively.

To meet these differing requirements, DOE launched joint-venture projects in FY 1992 and FY 1994 to develop two different solar dish generators. The joint-venture projects will continue at least 5 years and will cost more than \$90 million between DOE and the joint-venture partners.

Warren Gretz, National Renewable Energy Laboratory

"WE SELL \$1 BILLION OF POWER GENERATION EQUIPMENT RATED LESS THAN 1500 kW," SAYS JEROME DAVIS, PRESIDENT OF CUMMINS POWER GENERATION. DAVIS INSPECTS CUMMINS' PROTOTYPE SOLAR DISH GENERATOR AT THE TEST FACILITY IN ABILENE, TEXAS. "OUR JOINT VENTURE WITH DOE WILL HELP US MEET THE CHANGING NEEDS OF OUR CUSTOMERS IN A WORLD WHERE SOLAR ENERGY WILL INEVITABLY PLAY A LARGER ROLE."

Solar Dish Generator for Remote Applications

The first project is to develop a small, sturdy solar dish generator for remote power applications. The system will have a rated capacity of 7 kW, large enough to pump water or supply power to a small village in the developing world.

DOE selected Cummins as its partner for the project. Cummins is a subsidiary of Cummins Engine Company, one of the largest manufacturers and distributors of diesel engines in the world. At the end of the project, Cummins intends to add solar dish generators to its catalogue of engines for distribution in sunny, semiarid climates worldwide.

From the beginning of the venture, Cummins has maintained a leadership role. The company's principal goal is to design a solar dish generator that can be manufactured inexpensively. To accomplish this, Cummins is applying its system of "total quality management," a system that examines the design of every component for manufacturability.

Before the project is completed, Cummins will build and test 13 preproduction solar dish generators. Cummins will build the units in FY 1995 and FY 1996, using a fully designed preproduction manufacturing line. The company will test the units at utility-interconnected and remote locations throughout the Southwest.

In FY 1993, Cummins designed, built, and successfully tested its first prototype solar dish generator. The prototypes were immediately recognized in the scientific world as a major accomplishment.

In FY 1994, Cummins installed prototypes at four test sites—Lancaster, Pennsylvania, run by Thermacore Inc. (the receiver manufacturer) and partially funded by the Pennsylvania Energy Office; California State Polytechnic University of Pomona, California; Texas Utilities' Solar Park in Dallas, Texas; and the Cummins test site in Abilene, Texas. In FY 1994, the prototype at Cummins's Abilene test site became the first solar dish generator in history to be successfully connected to a utility grid using a free-piston Stirling engine.

Sandia National Laboratories

○ This solar dish generator system built by Cummins Power Generation in collaboration with Sandia National Laboratories, won *R&D* magazine's prestigious R&D 100 Award in FY 1993, recognizing the system as one of the most important scientific accomplishments of the year.

Solar Dish Generators for Utility Applications

In FY 1994, DOE initiated two additional joint ventures to develop solar dish generators for utility applications. DOE selected Cummins and SAIC as its partners. Before the two joint ventures are completed, the partners will build and place in operation solar dish generators with a combined capacity of more than 1 MW.

At 25 kW, the utility-scale solar dish generators will be larger than those for remote applications and use different components. Each company is using receivers with new designs and different engines.

Receivers

Receivers function as the interface between the collectors and the engine; their job is to provide heat energy uniformly to the heater-head of the engine. One of the receivers under development uses liquid sodium as the heat-transfer medium because sodium boils at the working temperature of the solar dish generator. The other uses tubes directly illuminated by the concentrated sunlight.

IN JULY 1994, A SOLAR DISH GENERATOR BUILT BY CUMMINS POWER GENERATION SUPPLIED POWER TO A UTILITY GRID FOR THE FIRST TIME IN HISTORY USING A FREE-PISTON STIRLING ENGINE.

Receiver

The receiver collects the concentrated solar energy and provides a uniform heat flux to the engine. It is the interface between the solar collector system and the electricity-generating part of the solar dish generator.

Cummins is using a sodium-based receiver with a wick made of a porous metal or metal felt. During operation, the felt "wicks" the hot sodium away from the lower surface to the illuminated, hot surface of the receiver. This type of heat exchanger is called a "heat pipe." The heat pipe receiver uses less sodium, and therefore takes less time to warm up after starting the system.

In FY 1994, Sandia engineers successfully tested a prototype heat-pipe receiver developed by Cummins' partner, Thermacore Inc. of Lancaster, Pennsylvania. By the end of FY 1994, Thermacore engineers had accumulated more than 2500 hours of test data on their design in Pennsylvania. In addition, Cummins tested the receiver outdoors for more than 2000 hours at the company's test site in Texas.

SAIC is using a directly illuminated receiver in its prototype. Because of concerns about the receiver's lifetime in the harsh operating environments, SAIC is also investigating another receiver that is empty except for a pool of liquid sodium. For this reason, it is called a "pool boiler" receiver. Sandia engineers successfully tested pool boiler receivers outdoors in FY 1993 and FY 1994. In FY 1995, they will collaborate with SAIC engineers to design a receiver to work in SAIC's larger, 25-kW solar dish generator.

Solarized Engines

Sandia and DOE's joint-venture partners are developing "solarized" versions of conventional engines originally developed for cogeneration applications. Currently, there are two candidate engines to use in solar dish generators: the Stirling engine and the Brayton engine, also known as a gas turbine. The Stirling engine, designed to operate on an external source of energy (such as solar), is a good match for solar operating conditions. The (free-piston) Stirling engine has only two moving parts—both pistons—and requires no oil and little maintenance. The gas turbine is produced commercially worldwide for a variety of applications.

Warren Gretz, National Renewable Energy Laboratory

Sandia during FY 1993 and FY 1994. In FY 1994, NREC successfully tested a gas-fired version of its engine. Near the end of FY 1994, NREC engineers began designing a full-scale engine that they will test in prototype solar dish generators in FY 1995. The NREC engine is a backup for the Stirling engine in the Cummins solar dish generator.

SAIC is working with Stirling Thermal Motors (STM) and Detroit Diesel of Ann Arbor, Michigan. STM is providing its design of a Stirling engine to Detroit Diesel, which, in turn, will be responsible for review of the design for mass-production considerations. Detroit Diesel will also be responsible for testing STM's Stirling engine beginning in FY 1995.

"THE SAIC SOLAR DISH GENERATOR IS HIGHLY EFFICIENT AND COST-COMPETITIVE," SAYS KELLY BENINGA, SCIENCE APPLICATION INTERNATIONAL CORPORATION'S ENERGY PROJECTS DIVISION MANAGER. "OUR SOLAR DISH GENERATOR CAN RUN ON FOSSIL FUELS WHEN SOLAR ENERGY IS NOT AVAILABLE. COMMERCIALIZATION OF THIS TECHNOLOGY FOR U.S. AND FOREIGN MARKETS IS A TOP PRIORITY AT SAIC."

Cummins is "solarizing" both engines. In FY 1994, a Cummins subcontractor developed a Stirling engine with unique features, including strap flexures and an engine design that greatly reduces vibration during operation. Testing will continue in FY 1995.

Another program subcontractor, Northern Research and Engineering Corporation (NREC) of Boston, Massachusetts, developed a Brayton-cycle engine while working with

Innovation Reduces Operation and Maintenance Costs

An innovative joint venture with operators of solar power plants in California reduces operation and maintenance costs for the entire industry.

The third type of solar thermal power plant uses trough concentrators and is the most mature technology. During the 1980s, nine power plants with a combined capacity of 354 MW were installed in the Mojave Desert in California. These plants represent more than \$1.2 billion of invested capital, and more than 90% of the world's capacity of utility-scale solar power plants. To date, the plants have generated 4 billion kWh of electricity, enough to supply the needs of a small city.

○ The operators of these trough-type power plants in California face many of the same challenges to lower costs as do the operators of any other type of power plant.

Joint Venture to Reduce O&M Costs

The plants produce energy at a levelized cost of about \$0.12 per kWh, about the cost from peaking power plants. As the utility power markets become increasingly competitive, the plant operators want to reduce costs.

More than 20% of the cost of energy from the trough plants is due to O&M. As a result, reducing maintenance costs is one of the most effective ways of keeping these plants competitive.

Responding to the needs of the industry, DOE established a joint venture with the KJC Operating Company, to reduce O&M costs at the company's power plants. KJC operates five trough-type power plants at Kramer Junction, California. The joint venture is entering its third year; a final report will be issued at the end of FY 1995.

The joint venture will also benefit future operators of power towers. Because power towers have many of the same subsystems as trough plants do, many of the same O&M procedures can be applied. So far, Sandia researchers have analyzed more than 40 plant-years of O&M data and have concluded that more than two-thirds of the recommendations for improving trough plants can be applied to power towers.

Luz International Ltd.

KJC Operating Company

"WE HAVE RECEIVED EXCELLENT RESULTS FROM OUR COST-SHARING ARRANGEMENT," SAYS ROBERT HOLLIS, PRESIDENT OF KJC OPERATING COMPANY. HOLLIS INSPECTS A FIELD OF COLLECTORS AT THE KJC POWER PLANT IN KRAMER JUNCTION, CALIFORNIA. "DOE IS EVALUATING HOW THESE O&M COST-REDUCTION OPPORTUNITIES WOULD ENHANCE THE MARKETABILITY OF PROPOSED SOLAR THERMAL POWER PLANTS. WE ARE CONTINUING TO REDUCE O&M COSTS AND IMPROVE PRODUCTIVITY."

There has also been a substantial increase in KJC workforce productivity because of the project. During FY 1993 and FY 1994, DOE and KJC engineers worked on several types of improvements, including redesigning components, implementing information systems for plant and O&M control, and improving performance of the field of reflectors.

Redesigning Components

One of the most costly events for any power plant is to shut down because of the failure of an ordinary component such as a pump, a valve, or a seal. For example, it cost KJC more than \$250,000 to fix one seal on one pump at its No. 3 power plant.

Usually such failures occur because the component operates in an environment that undergoes more stress (from mechanical loads or from sudden changes in temperature, as in the case of the seal) than it was designed to

handle. In FY 1994, KJC engineers designed a new seal that better withstands the mechanical loads it experiences in operation.

Computerized Controls and O&M

In FY 1994, Sandia and KJC engineers upgraded controls and introduced an advanced computerized information system to the KJC power plants. The advantage of the new, computerized system is that one crew can maintain several KJC power plants at once, thus substantially increasing crew productivity. KJC management estimates the new controls and information system will reduce overall O&M costs by 20%.

The new control system uses computer software on a personal computer (PC) and is more efficient than the system it replaced. Thus, it takes advantage of similar control programs developed for utilities to run other types of power plants. Because it is based on a PC, the system easily accepts new hardware and control software as they become available.

KJC and Sandia also developed an advanced information system for the power plants made up of a fiber-optics network that links all five of the KJC plants. The network links all of the control rooms, the maintenance facilities, and the administration complex at the 800-acre facility. Using the new system, KJC schedules repairs or routine maintenance to optimize power output and plant revenues.

Improving the Collector Field

Keeping the collector field operating at optimal level is perhaps the most important challenge for KJC. The field is large and must track and concentrate the sun precisely for maximum power output. (All together, there are about 2.5 km² [1 mi²] of collector surface area required to supply 354 MW of power from all of the trough plants, including KJC's.) There are two operational challenges for KJC: (1) keeping the mirrors clean so reflectance is high, and (2) keeping them aligned so they reflect the sun accurately.

In FY 1994, Sandia engineers developed a new tool for measuring reflectivity to allow KJC maintenance personnel to quickly test whether the collectors need cleaning. The new hand-held device, called a reflectometer, has a data connection with the computerized O&M scheduler. KJC management estimates this new device will reduce the time it takes them to measure and analyze collector reflectivity by a factor of five.

The collector mirrors must track the sun accurately throughout the day to operate at maximum efficiency. In FY 1994, Sandia engineers developed a quick method to determine which collectors had lost alignment. The new method involves analyzing photographs taken from a helicopter. The method is fast and effective because one person checks the entire field in less than a day instead of several people taking days of measurements to check collector alignment.

Luz International, Ltd.

○ One of the biggest challenges facing KJC Operating Company is keeping the field of collectors in optimum condition.

Science Produces Low-Cost Reflectors

Low-cost materials recently introduced to the market underscore the potential for producing competitive power from solar thermal systems.

Warren Gretz, National Renewable Energy Laboratory

○ Samples of new optical materials undergo performance and durability testing at the Outdoor Test Facility established in FY 1994 at the National Renewable Energy Laboratory in Golden, Colorado.

Most of the existing solar thermal electric power systems use mirrors to concentrate sunlight for power generation. Although glass mirrors are excellent reflectors and producing them uses well-established technology, their cost amounts to a significant portion of the total cost of power. For example, from one-half to one-third of the first commercial power tower costs will be for heliostats with glass mirrors.

Most of the high cost is due to the large amount of mirror surface required. Solar Two, for example, will use 80,000 m² (0.09 km²) of reflective surface on the heliostats. The mirrors are made of thin glass with a layer of silver coated on the back. The amount of glass needed is substantial. The glass requires careful shipping and handling. The costs of producing, handling, and providing structural support for this quantity of glass adds to the cost of solar thermal electricity.

Substantial savings in materials and costs can be obtained by developing new reflectors made from lightweight optical materials produced at low costs in large quantities. Heliostats made with these materials also require less structural support than do glass mirrors.

The Solar Thermal Electric Program supports development of several candidate materials. In FY 1993 and FY 1994, the program successfully engaged some of the largest companies in the United States with expertise in vacuum coating and polymer film development. The companies are introducing new reflective materials, such as polymer films, to the market.

"WE THINK THE NEW REFLECTIVE FILM WE DEVELOPED WITH NREL IS READY FOR INTRODUCTION TO THE MARKET," SAYS DICK DAHLEN, TECHNICAL MANAGER FOR 3M COMPANY. "WE'RE EXCITED ABOUT ITS POTENTIAL FOR SOLAR APPLICATIONS."

These films have excellent optical and wear-resistant properties and are produced at a fraction of the cost of glass mirrors. Candidate materials include acrylic silver films and all-polymer reflectors. The projects under development are:

- 3M Company
St. Paul, Minnesota
ECP-305+ (silvered polymethylmethacrylate or PMMA)

- Cummins Power Generation
Columbus, Indiana
Aluminized polymeric film
- Industrial Solar Technologies
Golden, Colorado
Silvered Teflon™
- Dow Chemical Company
Midland, Michigan
Polymeric (nonmetallic) reflectors

In the past, silvered polymeric films have separated from their substrates in the field when exposed to rain, thus losing reflectivity. They have also lost reflectivity from exposure to abrasive wind-born substances such as sand or hail.

In FY 1994, 3M Company introduced a new silvered polymeric film on the market for solar applications. The film, called ECP-305+, represents years of cooperative research between 3M and NREL. It has a specular reflectance of more than 95%. And it has excellent durability, projected at more than 5 years in most outdoor environments. In FY 1995, Cummins will test this film outdoors on its pilot solar dish generator in Abilene, Texas.

○ The 3M Company installed the first commercial application of its new reflective film for solar applications, ECP-305+, in July 1994 at this industrial facility in Brighton, Colorado.

Warren Gretz, National Renewable Energy Laboratory

Initiatives Support Industry

Initiatives introduced in FY 1994 help manufacturers to assure near-term markets for their products.

In FY 1994, the Solar Thermal Electric Program introduced two initiatives—SolMaT and a Solar Enterprise Zone—to help industry strengthen its infrastructure and secure its markets. Throughout FY 1993 and FY 1994, the program continued to provide design assistance to the solar thermal power industry.

Solar Manufacturing Technology Initiative

The Program launched the SolMaT initiative in FY 1994. Under SolMaT, the Program will work with companies that manufacture components of solar thermal power systems to develop and put into place the technology

and manufacturing processes that can eventually take advantage of economies of large-scale production.

Most component manufacturers are confident of achieving low costs at high production volumes through economies of scale in purchasing, tooling, and use of capital equipment. At current low production volumes (mostly for pilot plants), low-cost production is difficult to achieve.

SolMaT will establish the bridge between current processes based on low-volume production and the substantial cost reductions possible through higher-volume production. These advances are based on applying improvements to existing manufacturing processes that also apply to future processes based on larger production volumes. SolMaT will also help participating companies develop system-level business plans and industrial relationships, such as those with suppliers, that low-cost production requires. SolMaT will make these relationships possible, eventually linking manufacturing scenarios to commercial sales prospects.

The first SolMaT partnerships will be with manufacturers of heliostats, the largest single cost component for power towers. Several contracts will be awarded in FY 1995. First, heliostat manufacturers will carry out feasibility studies of proposed manufacturing processes; second, they will build the pilot production lines and test the lines by producing a small number of prototype heliostats.

○ Through the Solar Manufacturing Technology initiative, the Department of Energy's industrial partners will establish processes for large-scale production of solar electric components.

Warren Gretz, National Renewable Energy Laboratory

**Average Direct-Normal Solar Radiation
(on a surface always facing the sun)**

Large areas in the Southwest, especially Nevada and Arizona, receive high amounts of direct-normal solar radiation. This area is ideal for solar thermal power plants.

Solar Enterprise Zone

DOE is working with the state of Nevada and the Department of Defense to develop a solar enterprise zone (SEZ) where solar thermal power systems will be built and operated. The SEZ may use land belonging to DOE at the Nevada Test Site formerly used for testing nuclear weapons. The test site, in the Nevada desert, has some of the best solar insolation in the country, ideal for solar power plants.

Congress authorized the formation of the enterprise zone in FY 1993 as part of a defense-conversion bill. In FY 1994, a task force was formed to establish it. A number of organizations joined the task force, including DOE, the state of Nevada, and several Southwest utilities. Power sales from the first few installations may help finance future installations in the enterprise zone.

The task force has plans for more than 650 MW of solar thermal installations phased in during the next 10 years. The capacity will be divided evenly between the three types of technologies: power towers, solar dish generators, and troughs. With installations of this size, a continuing market for solar thermal power technology is sufficient for manufacturers to put their new systems, developed under SolMaT, into place.

Sandia's Solar Thermal Design Assistance Center

The Solar Thermal Design Assistance Center (STDAC) at Sandia helps potential users decide when solar is an appropriate energy source. It provides users with the performance data and approximate cost data needed to decide whether or not to use a solar thermal power system. The STDAC also collaborates with researchers in the solar thermal power industry to develop, test, and evaluate promising new solar thermal technologies. Each year, STDAC engineers respond to about 500 requests for information and technical assistance.

Three examples of STDAC projects show the broad range of its activities. First, STDAC engineers testified before the Federal Energy Regulatory Commission (FERC) in FY 1993 about the reduction of direct solar energy in that year. The reduction occurred because the Mt. Pinatubo eruption in the Philippines the year before released millions of tons of ash into the atmosphere, reducing direct solar radiation around the globe for more than a year.

Sandia National Laboratories

○ Sandia National Laboratories engineers put one of the KJC Operating Company troughs on a rotating test platform in FY 1993 to characterize the trough's performance independently of the rest of the power plant. KJC engineers use this characterization to optimize repair of trough components.

The reduction in solar energy reduced the electricity production at the KJC plants in California. KJC's plants are solar-gas hybrids; they operate partly on natural gas. STDAC testimony about the temporary reduction in the solar resource allowed KJC to successfully petition FERC to burn additional natural gas that year.

Second, the STDAC helped an operating company design new components to withstand earthquakes. On July 2, 1992, an earthquake struck Landers, located about 80 km (50 mi) west of the trough plants operated by the Daggett Leasing Corporation (DLC) of Daggett, California. The magnitude of the earthquake was 7.5 on the Richter scale, thus making it the strongest earthquake to strike Southern California in the last 40 years. During the quake, a number of mirrors and tubes separated from their supports and fell to the ground.

Sandia engineers offered to help DLC engineers reinforce the supports to withstand future earthquakes. They performed a complete engineering study of the trough collectors using finite element computer codes not available at the time the troughs were designed. DLC rebuilt the supports to withstand even stronger earthquakes.

Third, the STDAC helped a small solar company in FY 1994 introduce a product to the market. The product was developed as a partnership between Sandia and Industrial Solar Technology of Denver, Colorado. It consists of an antireflective film for coating glass tubes used in troughs. The film reduces reflection from the surface of the tube and allows it to absorb more energy. It increases the tube's energy collection by 20%. The company shipped its first commercial delivery of tubes containing the film in FY 1994.

The Future for Solar Thermal Power

By the end of FY 1994, DOE's Solar Thermal Electric Program had put into place a series of coordinated initiatives to introduce solar thermal power technologies to the market, support manufacturers in order to reduce costs, and increase the acceptance of these technologies to the market. In FY 1995, data from the prototype systems will be available to industry and utilities. These data will underscore the value of these technologies to industry and the nation.

U.S. Geological Survey

○ The eruption of Mount Pinatubo in the Philippines in 1992 reduced direct solar radiation to the Earth for much of the following year, requiring KJC Operating Company power plants to increase their use of natural gas.