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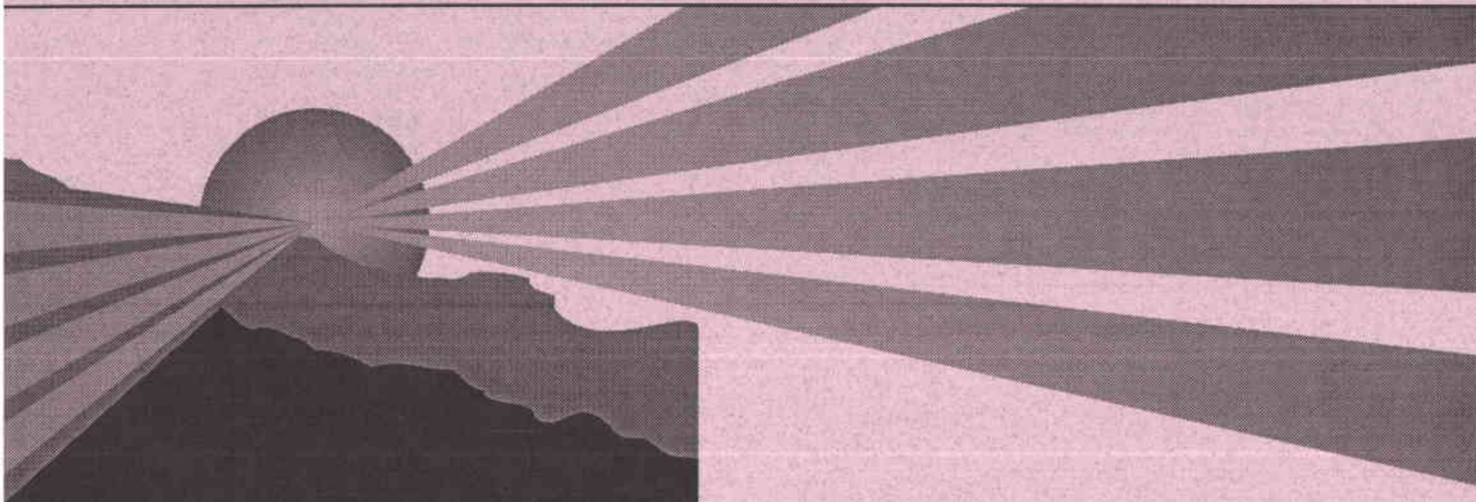

CONCENTRATING SOLAR POWER PROGRAM

Annual Summary 1998

U.S. Department of Energy

CONCENTRATING • SOLAR • POWER

Sun•Lab

Sandia National Laboratories, Albuquerque, NM
National Renewable Energy Laboratory, Golden, CO

Operated for the United States Department of Energy

January 1999

SUMMARY OF ACCOMPLISHMENTS: 1998

Significant progress toward program goals and objectives was made during the year. Following are selected highlights. Details can be found in the body of the report.

Power Tower Activities

- The Solar Two plant exceeded its long-term DOE performance measure of 1,500 MWh of power production in a 30-day period by producing 1,633 MWh.
- We successfully generated grid-connected electricity (100% solar) around the clock for one week continuously (153 hours).
- The record for net generation in a 24-hour period was broken repeatedly, ultimately reaching 105 MWh.
- The Solar Two receiver efficiency was 88%, and the goal for thermal-to-electric conversion efficiency was achieved. We successfully demonstrated that the receiver could be filled reliably in a serpentine fashion.
- We successfully completed more than 42 hours of steady-state, high-flux, on-sun testing up to 1,600 kW/m^2 and 619 thermal cycles of the Boeing/Rocketdyne advanced panel at the NSTTF.
- We completed the optical evaluation of the SAIC heliostat at the NSTTF.
- A long-shafted molten-salt pump was fabricated by Nagle Pumps, Inc. to demonstrate durability of salt-lubricated bearings.

Dish/Engine Activities

- We successfully demonstrated a fourth-generation felt-wick heat pipe on a bench scale, addressing the structural and corrosion issues seen in earlier versions.
- We demonstrated long-term operation on a number of capsule heat pipes, showing long-term materials compatibility and stability.
- We successfully demonstrated a bench-scale hybrid heat-pipe receiver based on a full-scale conceptual design and continued the full-scale design process based on these results.
- We demonstrated the performance advantages of the heat-pipe receiver on an STM Corp. Stirling engine, generating 26.4-kW gross peak power at 29.9% gross conversion efficiency.
- SAIC and STM achieved the first operation of a solar dish/Stirling system on both natural gas and solar energy on April 24, 1998.
- We installed and operated a hybrid dish/Stirling system at the Pentagon in Washington, D.C.

Trough Development Activities

- We completed a roadmap for parabolic trough technology.
- Sunray produced and installed 2,500 low-cost replacement HCEs.
- We placed an ISCCS design optimization contract with Bechtel.

Reliability Activities

- We developed a low-cost HCE.
- We developed an optimized high-wind operating strategy.
- KJCOC installed a radio network that allows technicians working in the field to remotely enter field data.
- Under the O&M Improvement Program, we installed water instrumentation and performed a study to assess water use at KJCOC.
- After resolving several startup problems, we significantly improved the reliability of Solar Two in late 1998.

Cross-Cutting Technology

- We completed and published DOE/EPRI dish/engine, power tower, and parabolic trough technology characterizations.
- We held dish/engine and power tower roadmapping workshops.
- We completed dish/engine market studies for international and U.S. distributed utility applications.
- We developed DNI maps for North Africa.
- SAIC implemented manufacturing line improvements that resulted in a semi-automated, two-facet per day per shift capability. At three shifts per day, more than 2,000 facets could be produced in a year, or the equivalent of almost 100 heliostats and more than 6 MW_t of central receiver capacity.
- We installed four SAIC prototype heliostats: one in Golden, one in Albuquerque, and two at Solar Two.
- Cermak, Peterka, Peterson Inc. completed an interim report on wind load analysis at SAIC's SolMaT heliostat located in Golden.
- We performed a trough analysis for U.S. power markets.

- In an extension of a CRADA with ELI, Sun•Lab provided continued consultation and evaluation of the current manufacturing processes and methods used to produce its new absorber material.
- Related to the ELI CRADA, a matrix of samples was prepared, with varying nickel thickness on stainless steel, to continue accelerated aging testing of ELI's advanced absorber material for mid-temperature applications.
- Surface Optics Corporation completed and provided a report documenting a limited analytical study to design solar-selective absorber coatings using pigment systems for high-temperature applications, such as central receivers.
- In support of industry commercialization efforts, we conducted an investigation of weld-bond corrosion of stainless steel membrane materials.
- In developing a promising advanced reflector material under a Sun•Lab subcontract, SAIC completed the design and fabrication of a cooled stage that will be used to allow high deposition rates (needed to achieve low costs) without damaging heat-sensitive substrate materials.
- We initiated evaluation of a number of new candidate solar-reflector materials and documented the development of two new reflector materials with low cost and extended lifetime potential.
- We applied a service lifetime prediction methodology to two solar mirror materials.
- An eighth outdoor exposure test site was activated in Almería, Spain.
- We relocated and reactivated laboratory facilities at NREL.
- We removed 200,000 pounds of molten salt from the NSTTF.
- We completed the Boeing/Rocketdyne panel tests.
- We passed independent ES&H and New Mexico environmental audits.
- We started fabrication of the long-shafted pump.
- We continued supporting the University of Chicago project.
- We obtained a new customer (Nichols Research) through the Work-for-Others Program.
- CFIC completed the design of a 2-kW solar thermoacoustic engine.
- Edtek fabricated GaSb and silicon photovoltaic cells for its test system. Edtek also fabricated a filter for the GaSb cells, but the filter's transmittance was too low. Cornell University made new stencils by e-beam lithography, and they will be used directly to create a better filter for the on-sun test system.
- NREL fabricated a device that allows the potential difference between the hot and cold ends of a column of high-temperature organic electrolytes for thermoelectric conversion to be measured. We tested two candidate electrolytes with encouraging results.
- We completed environmental testing of structural facets with aluminum honeycomb core at NREL. Except for exposed edges, results indicated minimal change after exposure to 100 cycles between –20° and 150°F at 80% relative humidity. Daggett Leasing Corporation installed the 52-inch by 61-inch trough structural facet with 1/2-inch aluminum honeycomb at SEGS II for evaluation.
- With the assistance of a researcher from the DLR in Germany, we completed experiments at NREL's High-Flux Solar Furnace to evaluate two Lambertian transmitter materials: flame-sprayed alumina on glass and thin (0.2-mm) alumina sheet.

Cross-Cutting Support

- We developed an exhibit for Soltech illustrating the history of the Concentrating Solar Power Program.
- We revised relevant materials to reflect the name change of the program from the Solar Thermal Electric Program to the Concentrating Solar Power Program.
- We developed a financial summary sheet for the Sun•Lab internal web pages.
- We produced displays on the Solar Two and dish/Stirling projects.
- We produced a fact sheet on the NSTTF and snapshots on an overview of the Concentrating Solar Power Program, Sun•Lab, markets for CSP, solar trough systems, Solar Two, SolMaT, Sun•Lab test facilities, solar dish/engine systems, and solar power towers.

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INTRODUCTION

Concentrating solar power (CSP) technologies—parabolic troughs, power towers, and dish/engine systems—convert sunlight into electricity efficiently and with minimum effect on the environment. These technologies generate high temperatures by using mirrors to concentrate the sun's energy up to 5000 times its normal intensity. This heat is then used to generate electricity for a variety of market applications, ranging from remote power needs as small as a few kilowatts up to grid-connected applications of 200 MW or more. CSP technologies can begin providing energy, as well as economic and environmental security, for us today. In the long term, these technologies will compete broadly in U.S. and international markets for electric power production.

Concentrating solar power is the least costly solar electricity for grid-connected applications available today, and it has the potential for further, significant cost reductions. While not currently competitive for utility applications in the United States, the cost of electricity from CSP technologies can be competitive in international and domestic niche applications, where the price of energy is higher. Our goal for advanced CSP technologies is costs below 5¢/kWh. At these costs, our vision for the future, 20 GW of installed CSP capacity by the year 2020, is achievable.

OUR VISION

Our vision for success of the Concentrating Solar Power Program is world leadership by U.S. industry in supplying 20 GW of concentrating solar power by 2020.

OUR MISSION

Our mission within the Department of Energy's (DOE's) Concentrating Solar Power Program is to help provide for the energy, economic, and environmental security of the United States. We will fulfill our mission through research, development, demonstration, technical support, and economic and policy analyses to help U.S. industry deploy concentrating solar power technologies in global, renewable energy markets.

OUR OBJECTIVES

Our objectives for the Concentrating Solar Power Program are to

- Help industry bring CSP technologies to near-term markets, and
- Provide the technical advances needed by industry for expansion into future markets.

OUR STRATEGIES

Our strategies for achieving these objectives, listed in descending order of importance, are to

- Support the next commercial opportunities for CSP technologies,
- Demonstrate improved performance and reliability of CSP components and systems,
- Reduce CSP energy costs,
- Develop advanced CSP systems and applications, and
- Address nontechnical barriers and champion CSP power.

POWER TOWER ACTIVITIES

Molten-salt power tower technology can provide dispatchable electricity from solar energy for peaking and intermediate electric power markets. Research, development, and demonstration are needed to bring this technology to a position of low technical risk and cost-effectiveness.

Rationale

The purpose of the Power Tower Technology Development Project is to support industry and utilities by enhancing performance and mitigating the risks of power tower technologies through research and development. The rationale for these activities is that there are demands for new bulk generating capacity in both domestic and foreign markets; these demands can partly be met by solar thermal power tower technology. Within the power tower activities, Sun♦Lab supports the Solar Two Project, a 10-MW project to validate molten-salt power tower technology. The program's expertise in analytical and experimental work will be used to optimize and refine system operations and procedures and to ensure the technical success of the Solar Two Project.

We also validate new prototype hardware used in power towers. The objectives of the tasks are to test and characterize prototype heliostats and molten-salt hardware proposed by industry for the first commercial plant. The proposed hardware represents developments or improved designs that can potentially reduce operation and maintenance (O&M), improve reliability or performance, or reduce manufacturing costs. In addition to supporting Solar Two and developing prototype hardware, we conduct studies on hybrid power towers. The potential advantages of hybrid power towers include enhanced modularity, lower financial risks, reduced technical risks, and lower energy costs.

1998 Accomplishments

Solar Two Testing

In February, the Solar Two plant was turned over to the O&M contractor, Energy Services, Inc., for operation. The plant exceeded its long-term DOE performance measure of 1,500 MWh of power production in a 30-day period by producing 1,633 MWh between June 14 and July 13. We completed the dispatchability test to demonstrate electricity production after sunset. We successfully generated grid-connected electricity (100% solar) around the clock for one week continuously between July 1 and July 7 (153 hours). The record for net generation in a 24-hour period was broken repeatedly, ultimately reaching 105 MWh. Figure 1 shows Solar Two in operation.

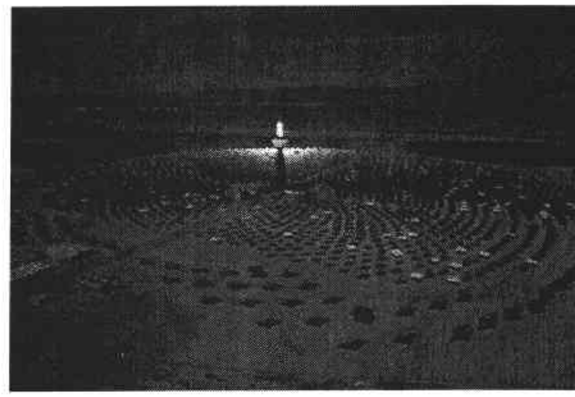


Figure 1. Solar Two in operation.

Steam generator system characterization testing was also completed this past year. Test results indicated that the preheater had become less effective in transferring heat. In late July, the head of the preheater was removed and the tubes were hydroblasted to remove fouling on the water side. After this maintenance, the turbine produced a record gross output of 11.6 MW. The receiver efficiency has been measured at 88% (as designed), and the goal for thermal-to-electric conversion efficiency has been achieved.

To mitigate a receiver tube freeze-up issue at startup, we changed from a flood-fill to a serpentine-fill procedure. Although this did not resolve the freeze-up issue, we successfully demonstrated that the receiver could be filled reliably in a serpentine fashion. We have explored other solutions, such as adding heat trace to cold areas on the receiver, to reduce tube freeze-ups. These improvements will be validated next year.

We began to optimize the trace heater set points to increase the net electric output of the plant. Tests include the reduction of set points of molten-salt electric-trace heater elements, turning off unnecessary lighting, and using small pumps to serve reduced cooling loads at night. In a test conducted on September 23, daily consumption from electric heaters was reduced by 50% over the previous conservative practice. In another test, a 100-horsepower pump that was previously used to cool components when the plant was offline was replaced with a 3/4-horsepower pump. The latter change saves almost 2 MWh of parasitic electricity during an offline day.

Validation of Prototype Power Tower Hardware

We successfully completed all testing of the Boeing/Rocketdyne advanced panel (Figure 2). More than 42 hours of high-flux, on-sun testing (up to 1,600 kW/m^2) and 619 thermal cycles were completed. The panel thermal efficiency was 0.928 at an inlet salt temperature of 550°F and an incident flux of 1,550 kW/m^2. There were no indications of degradation in the absorber paint or backside insulation.

Nagle Pumps, Inc. fabricated and shipped a long-shafted molten-salt pump. It consists of a centrifugal pump attached to a long shaft with five sets of bearings. The bearings are lubricated with molten salt. The advantage of this pump over cantilever pumps—whose lengths are limited—is that once the bearings are proven, a pump can be built that fits directly into the hot storage tank without the need for a pump sump. Demonstrating this long-shafted hot pump will allow a much simpler, less expensive, more reliable thermal storage system to be designed.

The pump underwent intensive testing with water at the manufacturer's facility to select candidate sets of bearing materials. We completed fabricating the support structure, insulating the sump that will contain the pump, and preparations for mounting the pump. We also developed a control system that allows the pump to run unattended.

The Science Applications International Corporation (SAIC) heliostat, built under the Solar Manufacturing Technology (SolMaT) program, has been evaluated at the National Solar Thermal Test Facility (NSTTF). In late spring, a lightning storm caused the heliostat control board to fail and the heliostat has been inoperable. Enough data were collected to characterize its performance. A report on the optical performance is being written. Because of concerns that the heliostat drive might fracture during high winds, causing the heliostat to fall to the ground, the SAIC heliostat was disassembled.

Figure 2. Boeing/Rocketdyne advanced panel undergoing high-flux testing at the NSTTF.

Hybrid Molten-Salt Power Towers

We evaluated hybrid power tower concepts by comparing the benefits of the various hybrid concepts. A paper was presented at the 9th International Symposium of SolarPACES in Odeillo, France, on the markets for hybrid power towers. We assessed hybrid options for power towers to compare their technical attributes, and the results were presented at the Power Tower Roadmapping meeting in Santa Fe, New Mexico.

FY99 Task Description

Solar Two

The objective of this task is to provide technical and financial support to the Solar Two demonstration project to ensure that the project successfully demonstrates and validates molten-salt power tower technology on a pilot scale. We will use information derived from Solar Two to guide future technology development efforts and to plan, evaluate, and design future power tower projects.

We will coordinate all test and evaluation (T&E) and other Sun•Lab support with plant operations. This coordination will also include on-site project engineering, T&E leadership, and interactions with plant personnel and management to coordinate all effort. Engineering issues will be addressed in a timely fashion. Through this activity, Sun•Lab activities will be managed with O&M and project management so that all T&E can be completed and the project can meet planned objectives.

Sun•Lab staff will be able to complete all planned T&E activities in cooperation with plant operations. These activities will be documented and the plant will be characterized sufficiently to implement optimization strategies.

Sun•Lab will provide heliostat maintenance and salt system support to improve operational availability and reliability. The goal is to produce 75% of SOLERGY predictions on selected days and improve the overall plant availability.

Sun•Lab will consult with the project on salt-chemistry-specific issues. We will complete stress corrosion cracking studies, reprocess spilled salt, and analyze salt samples. Through this task, we will resolve metallurgical issues, reduce cleanup cost, and demonstrate spilled-salt recycling.

Power Towers

The objective of this task is to support power tower research and development. We will test a long-shafted molten-salt hot pump and document the conceptual design basis for the next molten-salt power plant.

In this task, we will complete testing of an advanced hot-salt pump. The majority of testing will be conducted in an automated sequence. Demonstrating this long-shafted hot pump will allow a much simpler, less expensive, more reliable thermal storage system to be designed.

Bechtel Corporation, the architect and engineer for Solar Two, will develop a conceptual design basis document for the next molten-salt power plant (150-MW hybrid) incorporating lessons learned from Solar Two. The conceptual design will be documented, taking advantage of experience gained from Solar Two.

DISH/ENGINE ACTIVITIES

The objective of this task is to support the CSP industry in developing dish/engine power generation systems for remote power and utility-scale markets. The near-term objective is to build, field, and operate prototype dish/engine systems to establish performance, reliability, and cost databases.

Rationale

While both Stirling-cycle and Brayton-cycle converters have advanced in the commercial realm for nonsolar applications, the solarization of these technologies remains important. The best commercial-quality concentrators provide a non-uniform, high-level thermal flux to the receiver. The integration of the engine with the receiver requires significant changes to the engine layout and requires careful integration with attention to fluxes, temperatures, and materials. The additional requirements for uninterrupted power add the complexity of heat input from a gaseous or liquid fuel in addition to the solar input.

Stirling dish-electric systems have been identified as having potential to meet industry's long-term energy-cost goals. Dish-electric systems based on Stirling engine technology have been successfully demonstrated by Advanco Corporation, McDonnell Douglas Corporation, and others and operated at high efficiency. To reach the ultimate potential for dish-electric systems, a high-efficiency, low-maintenance, and low-cost integrated receiver is required. Sun•Lab has identified the reflux receiver as the best alternative to provide the heat to the engine efficiently with the flexibility needed to absorb the nonuniform flux and incorporate hybrid heat sources without negatively impacting the performance of the engine. While some current industry technology has been applied to these systems, there is a need to develop receivers that improve longevity and reduce O&M costs, as well as improve performance. The integration of the receiver with the engine is also a critical and largely unaddressed issue.

Alternate technologies, such as the Brayton-cycle engine, show some promise of simpler integration with the solar and hybrid input. However, it must be demonstrated that these simplifications outweigh the reduced performance when compared to Stirling systems and result in a competitive product. Small Brayton-cycle machines lack a viable long-term solar receiver approach. Development in this area needs to emphasize thermal stress and air-corrosion issues.

Concentrating solar power systems based on parabolic dishes and focal-point-mounted engine/generators have the potential to be economically competitive in remote export markets by the end of the decade and in the long term could provide base-load power to utilities. Through cost-sharing and technical support, the DOE program offers industry the opportunity to develop the technology and enter these markets more quickly by reducing early technical and financial risks.

1998 Accomplishments

SAIC USJVP

The SAIC/STM Corp. Utility-Scale Joint Venture Project (USJVP) started in November 1993. At the completion of Phase 1 in July 1995, components were designed and assembled into an operating dish/Stirling system, which has demonstrated more than 100 hours of on-sun operation. The operation of the Phase 1 system revealed a number of design changes that included increasing the area of the dish, upgrading the dish and engine control systems, and changing the mechanical connection between the engine and the generator. In addition, as a direct result of input from Arizona Public Service Company (a partner in the development of the system as well as a potential customer), SAIC and STM determined to make the second-generation dish/Stirling system capable of hybrid operation. That is, the system would be able to operate on solar energy or use natural gas at night and at times when solar energy is not available.

SAIC and STM achieved the first operation of a solar dish/Stirling system on both natural gas and solar energy on April 24, 1998.

We also installed and operated a hybrid dish/Stirling system at the Pentagon in Washington, D.C. (Figure 3). The system operated 921 hours during a successful five-month test campaign before removal for reinstallation in Phoenix in February. The system operated for 575 hours on solar energy, 346 hours on natural gas, and delivered 440 kWh of electric power to the grid.

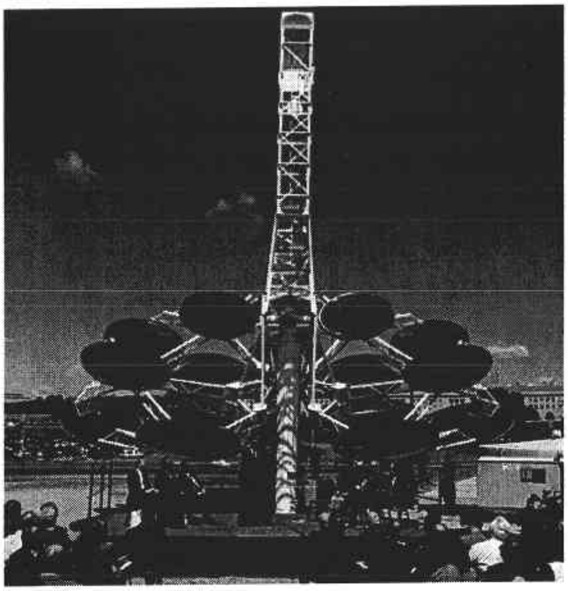


Figure 3. Dedication of the dish/Stirling system at the Pentagon in Washington, D.C.

We achieved cumulative operation for a total of 1,172 hours (801 hours on sun and 371 hours on natural gas) on these two dish/Stirling systems.

We continued to keep SAIC and STM abreast of developments in heat-pipe receiver technology. We involved STM in the integration aspects of our heat-pipe test and returned valuable controls information learned during the testing phase.

Dish/Engine Critical Components

The objective of the Dish/Engine Critical Components (DECC) Project is to develop alternative components for the "solar critical" parts of a dish/engine system to provide technology options and diversify the applications that can be served by U.S. industry. The current projects in this area include cost-shared development of solar dish systems using Brayton- and Stirling-cycle heat engines. Early work will solarize and test these engines, with follow-on activities aimed at integrating the engines into complete systems. We will develop additional, similar contracts under the DECC Project in the future.

The objective of the AlliedSignal DECC project is to solarize a Brayton power generation system that is currently under development by AlliedSignal's Power Systems Inc. (PSI) Division as a gas-fired distributed generator. The plan was to develop a volumetric receiver and test the power conversion system in solar operation at Sun♦Lab's NSTTF.

In July 1998, AlliedSignal's Aerospace Equipment Systems (AES) Division, which had the Sandia contract, was reorganized under new management that determined to refocus the division on its core competencies. With this new direction, the AES Division decided not to continue with the project. However, the PSI Division, which was providing the engine for the project, expressed an interest in developing a solar-Brayton system based on its 75-kW generator design once it is in distribution later in 1999.

We completed the detailed review of AlliedSignal's receiver design. We performed a preliminary evaluation of the German Aerospace Research Establishment's (DLR's) VOBREC receiver and the Weizmann Institute's Directly Irradiated Absorbing Pressurized Receiver. We assembled and tested an engine at AlliedSignal test facilities; the engine performed well but the startup torque was too high, and a problem with the power control unit was identified. We continued to support the AlliedSignal Brayton receiver design effort with design and analysis assistance. However, AlliedSignal has temporarily put further development on hold as it transfers the solar work to a different division.

The ultimate objective of the Boeing North American DECC Program is to commercialize the Boeing dish/Stirling technology. It is essentially a continuation of a solar energy program started by McDonnell Douglas (now Boeing) and United Stirling of Sweden (now Kockums) in the mid-1980s. Like the USJVP, it is a system-level effort led by industry. The objective of Phase 1 is to demonstrate performance and reliability of the critical power conversion unit (PCU). Phase 2 calls for the testing of a complete system, and Phase 3 involves demonstration of multiple systems. The key objective of the DECC Program is to develop alternative components for the "critical" PCU to provide technology options and diversify the applications that can be served by U.S. industry. The Boeing DECC project involves cost-shared development of solar dish systems using the Kockums 4-95 kinematic Stirling-cycle engine. The Kockums 4-95 is among the most proven Stirling engines in the world and was part of the "world record" Advanco system and the McDonnell Douglas dish/Stirling commercialization efforts of the mid-1980s. Boeing is modernizing the dish/Stirling system that was developed by McDonnell Douglas in the 1980s.

We placed a contract with Boeing/Stirling Energy Systems in April 1998. Figure 4 shows a photo of the dish/Stirling system.

We initiated on-sun testing of a dish/Stirling system at Boeing's Huntington Beach, California, test facility in July 1998, accumulating a total of 1,164.1 hours of on-sun power generation time and a total of 15,031 kWh at 95% availability through December 1998.

We initiated gas-fired testing of a 4-95 Stirling engine at Kockums' Malmo, Sweden, facility in October, accumulating 131.5 bench-test hours through December 1998. Figure 5 shows a schematic of the Kockums 4-95 solar PCU.

We began support of the Boeing/Stirling Energy Systems system integration and testing. We performed infrared thermography to verify proper receiver operation and provided technical support in locating leaks and troubleshooting control-valve problems. We also participated in design discussions.

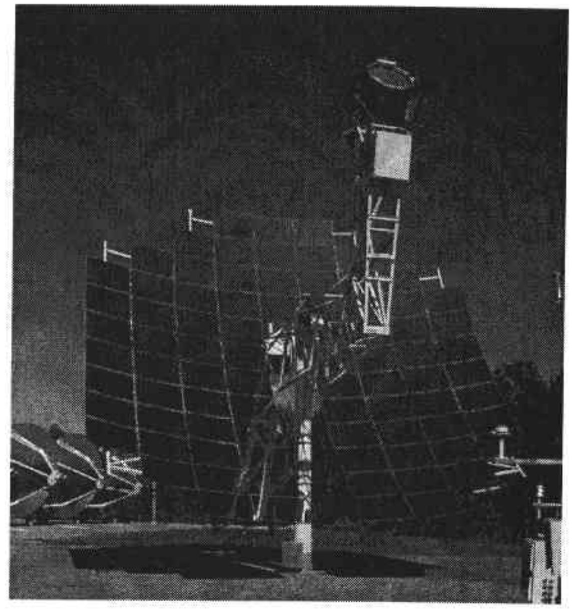


Figure 4. Boeing/Stirling Energy Systems dish/Stirling system.

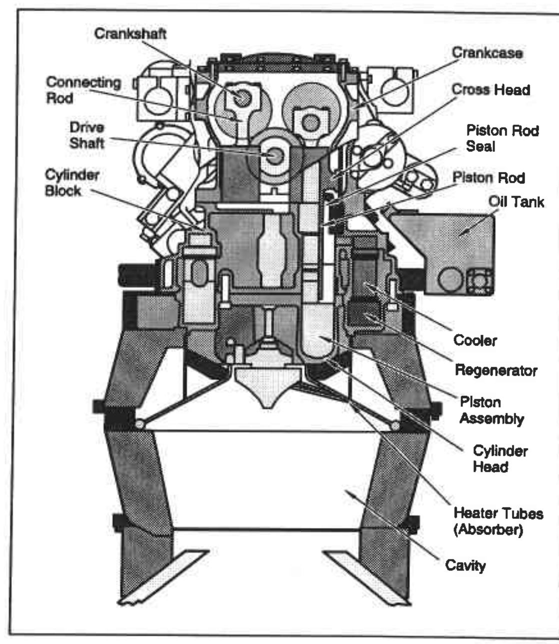


Figure 5. A schematic of the Kockums 4-95 solar PCU.

Remote Power Project

The Remote Power Project was initiated early in the last quarter of 1998. The project objective is to fabricate, demonstrate, and field a fully integrated, stand-alone 10-kW dish/Stirling solar power generation system for use at a remote, off-grid site on a Native American or other remote site in the United States. The project consists of three phases: Phase 1 (FY99) involves developing and testing an integrated, grid-connected, dish/Stirling system at the NSTTF. In Phase 2 (FY00), this system will be converted to stand-alone (off-grid) operation and tested under representative loads. Phase 3 (FY01 and FY02) will be devoted to installation and operation of the system at a selected user site.

We completed the preparation of the preliminary structural design, system specifications, long-lead-item specifications, and detailed project plans, which culminated in a design review on November 4, 1998. We then developed detailed project plans including project objectives and charter, work breakdown structure, and a logic network.

We initiated fabrication of the glass mirror panels for the concentrator with Paneltec Corp. of Lafayette, Colorado. We selected a suitable site at the NSTTF for installation of the remote power system for test.

Validation of Prototype Dish/Engine Hardware

In 1998, several bench-scale devices successfully demonstrated feasible approaches applicable to full-scale designs. We demonstrated 2,700 hours of operation on the latest felt-wick structure, which will be incorporated into a receiver next year. We completed 90 hours of testing on a hybrid bench device, which also will lead to full-scale implementation next year.

We continued to support near-term development of systems by several commercial partners, assisting in design and test support of small (10 kW) and large (25 kW) dish systems. We demonstrated outstanding performance of the STM engine when it is linked to a heat-pipe receiver.

STM Stirling/Heat-Pipe Integrated Test

STM Corp. provided a third-generation Stirling engine to Sun♦Lab at no cost for integration and testing with a heat-pipe solar receiver. The third-generation engine has significant improvements, including an atmospheric-pressure crankcase, lower moving mass, and an electric swashplate actuator. STM also re-engineered our heat-pipe heater heads. We integrated the power conversion system with a Thermacore, Inc. nickel-wick heat-pipe receiver, based on the design used in the prior Cummins program.

The system performed well, producing 26.4-kW gross power at the peak, and came close to the world record with 29.9% gross conversion efficiency. Many details learned during this project are applicable to the SAIC/STM system with a direct-illumination receiver. During the potential record run, the grid connection dropped and the swashplate failed to return to zero-stroke, resulting in an overspeed that damaged the engine and receiver. The feasibility of rebuilding the system is being evaluated at STM and Sun♦Lab.

Felt-Wick Heat-Pipe Receivers

In FY94, Sandia engineers identified a felt metal—supplied by Bekaert Fibre Technologies and applied by Porous Metal Products—as a promising advanced-wick candidate. The felt is more uniform in appearance and has finer wires that other felts previously considered and rejected did not have.

Early prototype tests, both bench-scale and full-scale, have demonstrated the superior operating qualities of the felt-wick structure. However, several long-term issues were identified that drove development efforts in 1998. The wick crushes over time simply from the weight of the column of sodium supported by capillary forces. Many early samples revealed rapid corrosion and concentration of contamination. Some samples have inflated bubbles and ruptures after relatively short operating times.

We continued to test materials and cleaning method combinations in our capsule test array, which allows unattended testing of 12 samples. Twenty-two capsules have been tested to date, with two exceeding 13,000 hours of operation. Several others have been removed from service with 10,000 hours for destructive evaluation. These capsule tests have led to cleaning methods applicable to full-scale testing and have screened potential wick arrangements.

We terminated a long-term durability bench test of a prior promising felt-wick structure because crushing and bubbles were noted in X rays despite improvements in structural rigidity. This failure delayed fabrication of a full-scale receiver.

We began testing a promising new wick arrangement that incorporates a rigid "exoskeleton" over the soft felt wick in a long-term durability device. This device, also operating unattended, more closely simulates conditions seen in a full-scale receiver, but is more difficult and costly to operate than the capsule tests. The current device has operated for 2,700 hours, with a goal of 5,000 hours before disassembly. The operation continues without incident. We have performed X-ray analysis at regular intervals during the testing, and it appears the exoskeleton has resolved the crushing and bubbling structural concerns. Dissection at the completion of the test will verify these results.

Based on the preliminary success of the bench device, we are fabricating a full-scale receiver using the new exoskeleton approach. All receiver components have been ordered, and we are performing small experiments to optimize the wick fabrication technique. These small experiments include various sintering parameters combined with pull tests to determine optimum bonding properties. We expect to test the receiver on sun in early 1999.

We also continued to pursue alternative wicks that have the potential to compete with felt-wick performance without the limitations. We worked on a plasma-sprayed wick and discussed early ideas and results with the DLR, which is considering a similar approach. We also pursued a knitted-fiber approach to provide better structure. We expect to test samples of these approaches in 1999.

Hybrid Heat-Pipe Receivers

Hybrid receivers provide the capability to burn natural gas (initially) and other fuels (long term) to supplement or replace the solar input during nonsolar periods for dispatchability. Several utility and remote customers have indicated that hybrid operation is critical to the acceptance of solar power generation.

The Sun•Lab approach generally favors providing a reliable design that minimizes the capital cost, as prior embodiments have been prohibitively expensive. We previously developed a conceptual design and built a bench-scale simulation to prove critical components of the design.

We continued modifications and testing of a bench-scale hybrid receiver that simulates our full-scale conceptual design. We improved the distribution plenum and investigated a preignition problem. We also continued to investigate alternative burner materials to improve performance and lower cost. We completed 90 hours of testing, making progress toward a 100-hour nonmaintenance goal.

We also continued the detailed design of a full-scale receiver based on this concept. Particular areas of concern in the design have been the seals, the primary heat-transfer section, and the recuperator. We have contracted with a vendor to supply the heat-transfer section at a reasonable cost. We have also contracted with a vendor to provide the design and fabrication of an integrated recuperator assembly. We have continued numerical modeling of the gas process and have compared results to the operating bench device in many operating regimes. We have ordered long-lead items and will have a final design review in early 1999.

We completed the conceptual design of a full-scale hybrid heat-pipe receiver. The design was analytically evaluated for power throughput and efficiency performance. Vendor samples demonstrated fabrication techniques that minimize the cost and complexity of the receiver. Hot-zone gas seals were developed through extensive laboratory testing.

On-Sun Demonstrations

We continued to support efforts at Ft. Huachuca to operate the Cummins 460 concentrator with a SOLO V-161 kinematic Stirling engine. We provided analysis and solutions to a critical controls problem that was causing aperture melting during cloud transients. We also provided hands-on support to repair tripod leg damage. We helped evaluate damage that a controls problem caused to the receiver and suggested implementation of a safety override to ensure the problem does not recur. All of these modifications are applicable to Sun•Lab's new remote power system, which uses the same engine package.

We continued to support Thermacore in the design and fabrication of a heat-pipe receiver integrated with the SOLO engine. Technical difficulties and a change in project personnel at Thermacore delayed the progress. However, an acceptable design is in fabrication, and delivery is expected in early 1999. We currently anticipate testing the combination on Sun•Lab's new remote dish in late 1999.

Technology Transfer

We continued collaboration with several former Soviet laboratories. We negotiated a statement of work with the Institute for Physics and Power Engineering (IPPE) and the Kiev Polytechnic Institute to address the dimensional stability of the felt-metal wicks, and to consider other advanced wick methods. The contract also partners with Thermacore, Inc. of Lancaster, Pennsylvania.

Previous work with Dr. Alexander Shimkevich of the IPPE led to his laboratory processing a Sun•Lab wick using proprietary processes to minimize contaminants in the system. The most significant hurdles included passing customs in both directions, as we still await the return of the filled capsules.

FY99 Task Description

In FY99, we will deploy three dish/Stirling systems, two at Arizona Public Service Company's Solar Thermal Advanced Research Test Facility in Tempe, Arizona, and one at another location yet to be determined. The objective in FY99 is to operate the three systems and start the development of a performance, operational, and maintenance database.

Working with AlliedSignal's AES Division, Sun•Lab will develop a plan to close the DECC contract in January or February 1999. AES will prepare a final report documenting its progress including the reliability model and commercialization plan. We will also maintain contact with AlliedSignal's PSI Division, which has relocated to Albuquerque, New Mexico, to determine how we might proceed with solarizing a 75-kW Brayton PCU.

In its DECC Phase 1, Boeing plans to continue operating the dish/Stirling system in Huntington Beach. In addition, Boeing intends to prepare a second concentrator for on-sun testing of a second Kockums 4-95 Stirling engine. Kockums plans to complete automation of the operation of the bench-test unit early in 1999, thereby allowing around-the-clock operation of the engine. Boeing's goal is to accumulate more than 2,000 on-sun hours and more than 3,000 bench-test hours in Phase 1.

Phase 2 of the Boeing DECC is scheduled to begin in July 1999. Phase 2 will last 24 months and will involve testing of multiple gas-fired and solar 4-95 Stirling engines. Boeing expects to have at least three dish/Stirling systems in operation by the end of 1999. Key Phase 2 activities will be the modernization of the system design (including the concentrator, controls, and Stirling engine) and the manufacture of new 4-95 Stirling engines under license to Kockums.

WG Associates will complete Phase 2 (detailed design of concentrator structure, mirror panels, and control system) and Phase 3 (fabrication, installation, and acceptance testing of the complete system) of its remote power systems contract. At the conclusion of Phase 3, scheduled for August 1999, the integrated remote power system will be ready to commence operational on-sun, grid-connected testing at the NSTTF. WG Associates will also initiate work on Phase 4 of its contract for the redesign of the concentrator and controls and development of a power management system for remote application of the dish/Stirling system. We will begin on-sun operational testing of the fully integrated remote power system in grid-connected mode at the NSTTF in September 1999.

In FY99, we will continue to develop heat-pipe receivers for application to long-term low-cost dish/Stirling systems. The primary objectives are continued refinement of advanced heat-pipe receivers at the 75- to 100-kW$_t$ level, development and design of advanced hybrid receivers, durability testing and lifetime improvements of receiver and wick materials, demonstration of full-scale designs with reasonable life, transfer of technology to industry, and integration support. We will also pursue advanced-wick technologies that show a performance or lifetime improvement potential over current technologies.

We will continue felt-wick heat-pipe development. We will concentrate our efforts on resolving long-term issues, such as corrosion and wick compaction and demonstrating the resolution of these problem areas. We will do this through continued multiple bench-scale and capsule tests, and we will apply the exoskeleton approach to a full-scale receiver. We will develop tools to evaluate new felt-wick approaches. We will continue our efforts with the laboratories of the former Soviet Union to shed more light on these effects and to leverage our efforts. We will incorporate the most promising wick technology into a full-scale receiver.

We will continue to develop advanced hybrid heat-pipe receivers. Our approach is to incorporate low-cost, high-performance features in the initial designs rather than simply demonstrating any working system. We will use the information from the bench test to complete the design and fabrication of a full-scale, nominally 75-kW$_t$, hybrid heat-pipe receiver. The design effort will include any subscale tests necessary to improve confidence in the design.

We will continue to explore alternative wicks that have promise to improve durability without compromising performance. We have identified several potential areas to pursue, including specialized nickel powders, alternative felt materials, and knitted felt structures. Other candidates will be screened for suitability and then tested in capsules, if appropriate. We will work closely with vendors and have them produce the test coupons where appropriate to minimize technology transfer delays later.

We will continue supporting the test of the SOLO V-161 engine on Ft. Huachuca's Cummins concentrator. The results of this demonstration project are critical to the success of the Sun•Lab remote power dish system using the same engine package. We will test a Thermacore heat-pipe receiver on either the Ft. Huachuca or the Sun•Lab remote dish system.

We will evaluate the damage to the STM Generation III Stirling power conversion system and determine if further testing is warranted. If so, we will fabricate a replacement receiver using the latest wick technology and reintegrate it with the STM package. We will keep STM informed of progress and results and will share lessons learned with Boeing team members.

We will continue our successful support of the Joint Venture Partners, addressing issues of immediate concern in which we have appropriate expertise. We have demonstrated quick and appropriate responses to problems such as receiver modeling, dish/receiver integration, receiver design, prototype test instrumentation, and support and engine problem modeling. We will continue to coordinate closely, especially in light of our ongoing integrated testing.

TROUGH DEVELOPMENT ACTIVITIES

With nine plants and 354 MW of operating capacity, parabolic troughs are the most commercially proven CSP technology, and they continue to offer the lowest cost solar power option available for power markets today. The existing plants offer a unique opportunity to learn from and support future trough and other CSP plants.

Rationale

In recent years, Sun•Lab has supported parabolic trough technology through collaboration with KJC Operating Company on its O&M Cost Reduction Study and by providing some level of technical support to many of the existing solar electric generating systems (SEGS) plants. FY98 represents the first year of a new focus that directly supports the commercial deployment of future parabolic trough plants. Because this activity represents a significant change to the DOE Concentrating Solar Power Program, the primary focus of the FY98 activities was to develop a technology roadmap that identifies the key issues and needs that support future deployment of parabolic trough technologies. In addition, Sun•Lab continued to provide technical support and help facilitate O&M technology transfer between the existing SEGS projects in an effort to support the continued operation of all existing projects.

1998 Accomplishments

Parabolic Trough Technology Roadmap

Sun•Lab sponsored the development of a parabolic trough technology roadmap. The roadmapping process began with a workshop meeting held in Boulder, Colorado, January 20 through 22, 1998. The roadmap meeting was attended by an impressive cross section of industry, laboratory, government, and nongovernment organizations. The purpose of the meeting was to determine whether there was a future for trough technology and what needed to be done to maximize potential opportunities. The group concluded that markets do exist for this technology today and that there is significant potential for further cost reduction in the future. The group developed a multifaceted approach for the continued development of parabolic trough technology. The results of the workshop provided the foundation for the parabolic trough technology roadmap subsequently developed.

The roadmap defines a vision for the future development of parabolic trough technologies. The vision builds on the successes of current trough experience and identifies a low-risk approach to advance the state of the technology. This vision relies on a synergy of technology development steps and market expansion through the following defined scenarios. The technology development is foreseen to proceed in a multi-step process with several clear technology advances that correspond to very distinct cost-reduction steps. The table on the next page outlines the basic developments within these steps and shows the simultaneous market and policy deployment steps required for success.

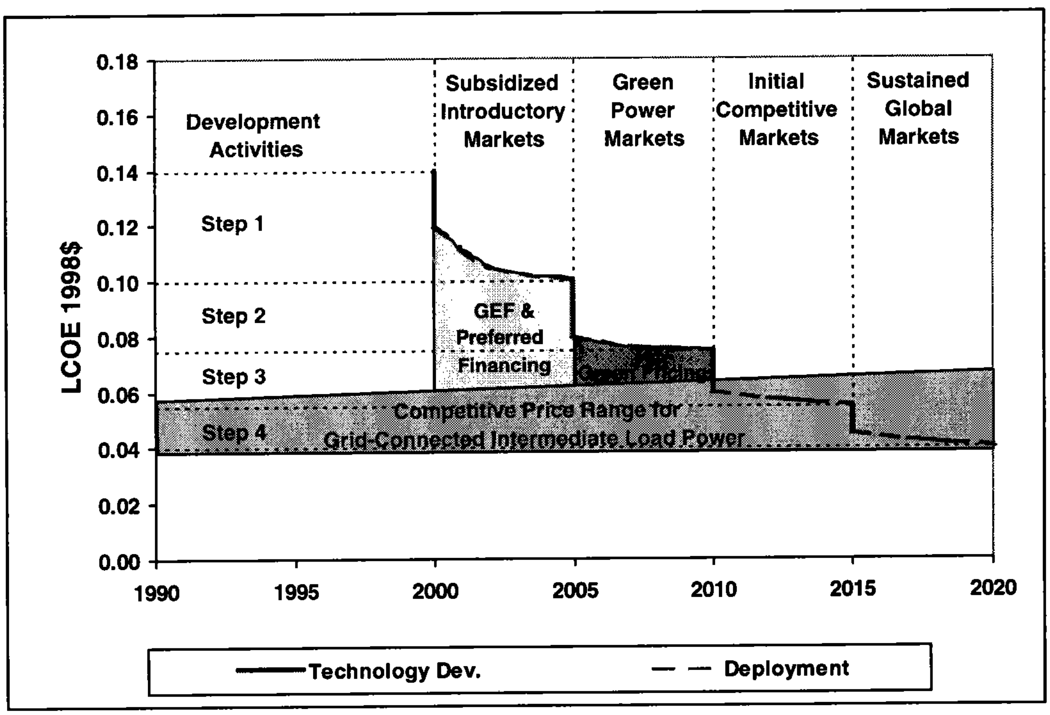
Figure 6 illustrates the steps and timing of this vision, showing the interrelationship of the technology and market development activities along with the expected electricity costs achieved during the process. Each of the technology steps is followed by additional cost reductions resulting from plant deployment. Based on this vision, a sustained market is envisioned for trough technology during the next 20 years.

Initially, the cost of trough power is expected to be in the range of 10¢ to 12¢/kWh, depending on plant configuration. Initial projects will be built using state-of-the-art technologies that take advantage of lessons learned since the last trough projects were built. We expect these markets will be subsidized by Global Environment Facility cost buydown grants or other special green/renewable financing options. The next level of technology development is expected to reduce the cost of trough power to 6¢ to 8¢/kWh. This cost range should allow trough technology to compete in the emerging green markets. To achieve this cost target, a next-generation collector and other cost reductions will be needed. Additional technology development and cost reductions will be necessary to achieve later cost reductions that drop costs below 6¢/kWh. Though market penetration is traditionally very difficult to predict, rough estimates suggest that achievement of up to 1 GW installed capacity by 2005 and 5 GW by 2010 is possible.

The trough roadmap identifies a number of opportunities to improve parabolic trough technology.

Technology Development and Deployment Activities

Step	Technology Development	Deployment
1	State-of-the-art Collector Integrated Solar Combined-Cycle System Design Optimization	Global Environment Facility Market Aggregation Low-Cost Financing and Grants
2	Optimized Steel Collector Improved Heat-Collection Element Lifetime Thermal Storage Process Design Optimization Standardized Designs Specialized O&M Tools and Equipment	Green Market Development Solar Tax Equity Standard Financing Packages Systems Analysis Tools High-Resolution Satellite Insolation Data
3	Advanced Trough Collector Advanced Reflector Advanced O&M	Solar Power Parks Solar Investment Funds
4	Tilted Collector Direct-Steam Generation or Other	



LCOE = levelized cost of energy

Figure 6. Trough technology development steps and cost versus market opportunities.

The specific focus areas include advanced collector components; solar field design; power plant design; O&M; design, manufacturing, and construction; and project development. Although many opportunities were identified, several stand out as the most important to focus on. These are as follows:

- Integrated Solar Combined-Cycle System (ISCCS) – The ISCCS potentially offers significant opportunity for reducing the cost of solar electricity and is likely the most attractive option for near-term trough deployment.

- Trough Collector Development – The trough collector represents the largest single cost in the parabolic trough plant and thus represents a critical opportunity for cost reduction.

- Receiver Tube – The receiver tube has a major influence on the efficiency and reliability of the solar field. Presently, the selective surface and the overall performance design characteristics appear to be excellent; however, reliability and maintainability continue to be unsatisfactory.

- Thermal Storage – An efficient form of thermal storage would be a key enhancement for parabolic trough technology and would open new market opportunities.

- Standardized/Optimized Solar Boiler Designs – Major opportunities for cost reduction in trough plants exist through development of standardized designs, the use of advanced design approaches to minimize part counts, the use of modular or skid-mounted designs, and the simplification of designs.

- Project Development – A number of activities has been proposed to address the critical project development issues facing future trough development.

Two initiatives have been identified to address the opportunity for parabolic troughs.

- Near-Term Trough Development – The United States is uniquely positioned to play a key role in the future development of trough technologies because of the experience and expertise gained at the current SEGS plants. This initiative could expand U.S. industry involvement in worldwide trough activities and advance the state of the technology.

- Strategic Alliances and Market Awareness – This initiative would address many of the market-related issues and barriers that are hindering the deployment of parabolic troughs and other CSP technologies.

Sunray Low-Cost HCE

Sunray Energy, Inc. (the operator of SEGS I and II) and Sun•Lab have developed a low-cost retrofit heat-collection element (HCE) to improve the performance of existing SEGS facilities. Sunray has produced the low-cost replacement HCEs using its new on-site manufacturing capability. More than 2,500 low-cost HCEs have been fabricated and installed at both SEGS I and II. The low-cost HCE concept uses used stainless steel HCEs (optical coating degraded) with the glass envelope removed, i.e., previously broken; a very thin (to minimize the thermal emittance) coating of Pyromark® black paint; and a new glass envelope. The installed cost of the low-cost HCE is less than $170 each. One significant cost-reducing approach embraced by Sunray was the purchase of glass tubing in lengths that are one-half the total length of the HCE. Using a glass lathe, also purchased by Sunray, site personnel are joining the tubing together into the useful single length. The Sun•Lab team trained Sunray personnel in glass-joining techniques using its in-house glass manufacturing expertise. Additional low-cost HCE installations are planned for next year at both SEGS I and II using on-site manufacturing capability. Sunray has ordered additional glass tubing for this purpose.

HTF Degradation at SEGS I

The Sun•Lab team continued work to help Sunray develop a solution to the oil-coking problem at the SEGS I plant. The main objectives of the effort are to eliminate the cause of the coking problem, clean the existing oil, and help Sunray monitor and assess the economic impacts of the oil-coking problem. This effort could potentially save millions of dollars for Sunray over the next few years. The degradation is being investigated under a contract with Yves Parent of Chemical Consultants, Inc. (formerly of NREL). This study addresses the coking of the paraffin-based oil because of over-temperature conditions in the solar field during summer months. Current results indicate that a combination of adsorption and filtration is needed to "clean" the heat-transfer fluid (HTF) to acceptable particulate levels. The particulate formed during coking is slowly deposited onto the heat exchanger tube walls of the steam generator and gradually reduces the solar-to-electric generation performance of the plant. Currently, the HTF-to-steam heat exchangers must be cleaned annually to recover the resulting "lost" thermal performance.

In a related effort, Sun•Lab is collaborating with Sunray and the University of Stuttgart to help mentor a graduate engineering student at the Daggett, California, site. The student's efforts are directed toward a better understanding of the current flow conditions in the SEGS I field and assessing the performance and economic impacts of various operational strategies. The first phase of this work has been completed and the results were presented to the Industry Assistance/Sun•Lab team. The results from this work will be used to assist in formalizing a procedure to flow-balance the solar field to minimize excessive oil temperatures.

Prototype Replacement Mirror Test

Sun•Lab provided Sunray with a prototype honeycomb trough mirror facet for testing at its SEGS II facility. Strong interest has been expressed in creating a cost-shared program with Sun•Lab and all of the SEGS plant operators to work with Paneltec Corp. to further develop this facet design with the goal of providing a commercial low-cost replacement facet. This program would enable the combination and use of Sun•Lab's expertise in honeycomb construction, bonding materials, and optical testing. Development of this mirror facet is currently in progress as an FY99 Sun•Lab development activity with involvement and cost share from all the operating companies of the SEGS facilities.

Bechtel ISCCS Merchant Plant Design

The ISCCS is a hybrid concept that integrates a parabolic trough solar plant with a combined-cycle plant. Historically, the ISCCS design oversizes the steam turbine so that the solar energy can be used in the combined cycle's Rankine steam bottoming cycle. This approach effectively reduces the cost of the conventional portion of the plant. The primary concern with this ISCCS approach is that the gas-mode efficiency of the combined cycle is reduced when solar energy is not available. Bechtel Corporation, under contract to NREL, has developed a number of new ISCCS designs that do not have a negative impact on the combined cycle's gas-mode-only conversion efficiency. These designs are based on integrating a trough plant into a "merchant" combined-cycle plant. In the merchant plant, a relatively small trough plant about the same size as SEGS I (50,000 to 75,000 m^2) is integrated with a large combined-cycle plant (approximately 300 MW). The plant is designed for solar output to offset the normal drop in plant power output as ambient temperatures rise. The design solar contribution is approximately 5% of the total plant output. Because "merchant plants" are already designed to use duct burners to increase the power output of the steam turbine during high ambient temperature conditions, no significant changes to the combined-cycle power plant are required. In addition, because adding solar steam improves the use of waste heat from the gas turbine, the apparent solar-to-electric conversion efficiency of solar steam is increased from about 34% (net) in a conventional SEGS plant to more than 45% in at least one of the proposed ISCCS configurations. Other integration approaches, such as generation of high-pressure steam to inject into the gas turbine, have also been evaluated and can be used to help increase the solar contribution in the ISCCS plant. Bechtel is considering these ISCCS options for project opportunities in Mexico, the United States, and other locations.

SolWin Development

Sun•Lab and DLR, the German Aerospace Research Establishment, have continued development efforts on the SolWin software. SolWin is being developed as a user-friendly model that can be used to evaluate the electric and financial performance of CSP technologies as well as other renewable and conventional power technologies. Sun•Lab has completed a parabolic trough solar field model that will be included in the SolWin model.

Parabolic Trough Power for Competitive U.S. Power Markets

A study shows that parabolic trough technology is relatively close to being competitive in the deregulated U.S. power market. The study shows that a 30% capacity factor solar plant would need to produce power for about 5.5¢/kWh to be competitive with a state-of-the-art combined-cycle plant. Opportunities were identified for reducing the cost of parabolic trough power. These opportunities included the development of large SEGS-type trough plants in a solar power park environment, reducing tax inequity on the "solar fuel," and identifying potential incentives to offset the remaining noneconomic portion of the cost of power. Developing trough power in a solar power park environment would allow power to be produced for about 8¢/kWh (blended cost of 85% solar and 15% fossil). Treating the solar field as a fuel from a taxation standpoint (no sales or property tax) and converting solar from a 10% investment tax credit to a 1.5¢/kWh production tax credit similar to wind would drop the cost of power below 7¢/kWh. The remaining noneconomic portion of the cost could be offset by any of the following: a 2¢/kWh green pricing premium, 25% investment tax credit, $200/ton carbon tax, or access to low-cost debt (6% for the project or 4% on solar equipment). It is important to note that the key reason that solar power is still not economical is because the solar fuel must be purchased up front with high-cost capital. If the fuel from a combined-cycle plant were purchased in the same manner (at the beginning of the project with high-cost capital), the cost of power would jump from 5.5¢/kWh to more than 11¢/kWh. On the other hand, if the tax incentives that existed in 1985 were available today, it would be possible to structure a competitive trough solar power park project in California today.

FY99 Task Description

During FY99, Sun•Lab will follow the recommendations of the parabolic trough technology roadmap through the introduction of the USA Trough Initiative and through continued industry assistance of existing SEGS facilities. The USA Trough Initiative is a competitive request for proposal to address near-term technology development needs. The industry assistance activity will focus on the development of low-cost split-glass replacement HCEs, low-cost mirrors, and HTF filtration.

RELIABILITY ACTIVITIES

CSP technologies must demonstrate a high degree of reliability before power producers will use them. As currently being demonstrated at the Kramer Junction, California, SEGS plants, a high degree of reliability can be achieved through the proper design, operation, and maintenance of the solar facility. The purpose of this task is to improve the reliability of current and future CSP technologies. We will accomplish this task by developing advanced components, O&M methods, and analysis tools, as well as learning from the success at the Kramer Junction SEGS plants.

Rationale

Improved reliability in CSP technologies will be accomplished by completing the O&M Improvement Program at the Kramer Junction SEGS plants, documenting the results, and transferring this information to the CSP industry. In addition, we will monitor and analyze the reliability of the Solar Two power tower during its first post-startup operating year and develop a plan for reliability improvement.

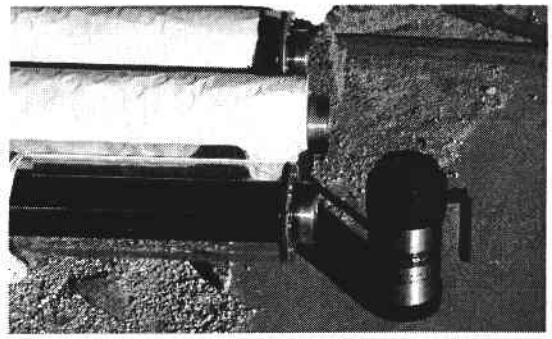


Figure 7. Vacuumless HCE.

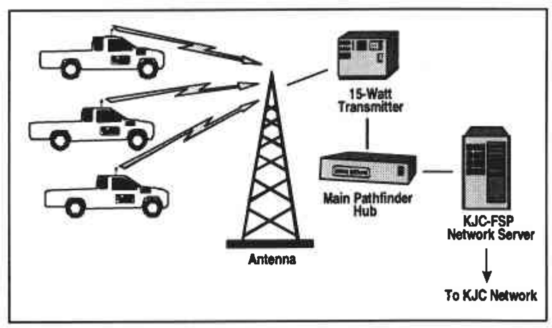


Figure 8. Maintenance data are entered from the solar field via radio transmitters.

1998 Accomplishments

Improve System Reliability

The four accomplishments listed below were achieved within the KJC Operating Company/Sun•Lab O&M Improvement Program (O&MIP).

- We developed a low-cost HCE (see Figure 7). The cost is lower because the current design does not employ the complex manufacturing step of establishing a vacuum within the surrounding glass annulus. While an initial evaluation of the performance of the HCE looks promising, long-term performance is uncertain. Thus, the next plants will likely employ an evacuated HCE.

- KJC Operating Company installed a radio network that allows technicians working in the field to remotely enter field reliability data; the user interface is a computer screen that is attached to the windshield visors of the solar-field trucks (see Figure 8). The radio-data-entry feature is recommended for projects with very large solar fields, such as those at Kramer Junction.

- We developed an optimized high-wind operating strategy after thoroughly understanding the wind loads on the collectors. Special load-cell instrumentation was applied to a collector in the windward area of the solar field and a series of experiments evaluated 10 different wind-protection schemes. The scheme that appeared to work best was to stow every fourth row of collectors. However, because of several uncertainties regarding wind forces and wind patterns, the chosen strategy must continue to be conservative.

- Because water is scarce in desert environments, it is a relatively expensive commodity. To reduce consumption, the O&MIP installed water instrumentation and performed a study to assess water use at KJC Operating Company. Results of the study indicated only 1.4% of the total is used for mirror washing and more than 90% is associated with operation of the Rankine power-cycle equipment. The assessment of water quality suggested that blowdown of the Rankine-cycle equipment was occurring too frequently, leading to higher-than-needed water use. This greatly improved understanding of water use and quality led to water-conservation measures that resulted in a 33% reduction in water use per megawatt-hour of electricity produced.

Research and Development at Solar Two

After a rocky startup phase in which several design and quality-control problems were identified, the reliability of the Solar Two power tower dramatically improved during 1998. The resolution of the startup problems and the reliability improvements achieved during 1998 are described below.

Startup Problems – Four major problems occurred during startup of the plant that delayed the project for more than 1½ years. During this time, the plant was, for the most part, nonoperational. These problems and their solutions are described below:

1. Soon after plant dedication in June 1996, it was discovered that most heat-trace circuits were not installed properly largely because of a lack of quality-control inspections. This improper installation led to unacceptable corrosion and high thermal stresses in certain areas of the salt-piping system. The plant was shut down for approximately four months to reinstall heat trace. The heat-trace system has worked well since being corrected.

2. A tube ruptured in the steam generator in November 1996. The design of the steam generator was found to be flawed because issues related to startup of the system were not completely analyzed during the design phase. The plant was shut down until the summer of 1997 to replace the evaporator tube bundle and to correct several design deficiencies. The steam generation system has worked well since being fixed.

3. Stress-corrosion cracking (SCC) was identified in the receiver in late summer 1997. The plant was shut down for a few months to determine the severity of the problem. The problem was not pervasive. The short-term solution was to remove moisture inside the receiver tubes by blowing dry air through the receiver during overnight shutdown. Outages caused by SCC have not been a significant problem since the air dryer was installed. This problem had not been seen in smaller receiver tests at Sandia before Solar Two became operational because Sandia tested a cavity-type receiver that was not exposed to the night sky and therefore not subject to dew formation. The long-term solution is to use materials that are not susceptible to SCC; an advanced receiver panel made of such a material has worked well since being installed in December 1997.

4. Upon restart of the plant in the fall of 1997, several valves in the receiver were leaking. The plant was shut down to replace the ball-type valves with gate valves. The gate valves have worked well. The Solar Two project has determined that ball valves are not suitable for molten-salt service. Gate valves were also tested extensively at Sandia before Solar Two became operational and were found to be acceptable.

Reliability Progress in 1998 – After resolution of the four problems, the plant began running on a regular basis starting in early November 1997. Plant turnover from the construction crew to the O&M crew occurred in February 1998, and the O&M crew—working with the Test and Evaluation team—began to optimize plant operation; many tests were performed and several relatively minor reliability issues were solved. Significant progress toward achieving the 88% availability goal* was made in the latter part of 1998; plant availability was 71% during September and October 1998. The causes of the outages in each of these months is shown in Figure 9.

The pie charts in Figure 9 indicate that most of the plant outages are related to the receiver. Elimination of some of the outages should occur naturally given additional operating time. For example, outages caused by test preparation will be eliminated after the test program is completed, and outages caused by operator decisions and weather will be reduced as the operators become more comfortable operating the plant—especially during partly cloudy and windy weather. However, other outages will require corrective action to fix the root cause of the problem. For example, outages caused by tube freeze-up during startup of the receiver require a design modification that will be implemented in 1999.

* It should be noted that much of the balance of plant equipment at Solar Two is more than 15 years old and equipment redundancy is not at the standard set for a commercial plant. The goal for plant availability at Solar Two is therefore below the commercial plant goal (88% vs. 91%).

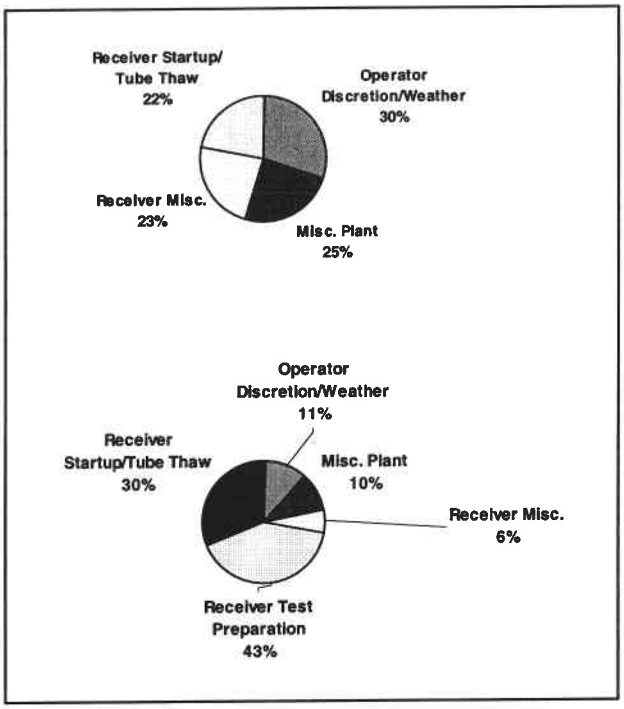


Figure 9. Causes for outages at Solar Two during September (top) and October (bottom) 1998.

FY99 Task Description

We will complete and publish the final report of the O&M Improvement Program at Kramer Junction, which summarizes this six-year program. No new O&M cost reduction activities will be initiated. Reliability improvement activities at Solar Two will also be documented in a Sun•Lab report.

During FY99, most of Sun•Lab's new research and development will focus on improving the reliability of the dish/Stirling system.

CROSS-CUTTING TECHNOLOGY

Cross-cutting technologies provide advancements that can be applied to power towers, dish/engine systems, and trough plants. Activities included in this section are systems analysis, manufacturing, concentrator technology development, materials identification and development, facilities operation and maintenance, and long-term research and development.

Rationale

Systems analysis is necessary to develop an improved understanding of CSP technologies and their applications, support the analysis of advanced concepts, and identify ways to reduce capital and O&M costs while increasing performance. Specific activities help to evaluate the status of research and development efforts and to identify promising new directions for technology development. Efforts this year will support development of the technology roadmaps, updating the technology characterizations as necessary, and performing various topical analyses as appropriate.

In the advanced materials task, we will identify and develop reflectors and absorbers for CSP applications that meet industry's goals of cost, performance, and durability. We will accomplish this task by performing testing, characterization, and evaluation of candidate advanced materials, by collaborating with the solar and materials industries to develop and test advanced materials of near- and long-term interest, and by conducting long-term research and analysis to better understand the fundamental properties that influence advanced materials performance. Cross-cutting support is provided for the CSP five-year goals associated with advanced systems, power towers, dish/engine systems, cost reduction, reliability and O&M costs, and industry needs. The success of near-term goals (Solar Two, USJVP, and so forth) hinges on durability issues because such systems must survive and operate reliably for extended lifetimes. The long-term success of CSP systems depends upon their economic viability because dramatic cost reductions, as may be achieved by new advanced materials, are needed.

The objectives of the Solar Manufacturing Technology (SolMaT) activity are to develop manufacturing technology and processes that will (1) permit cost-effective deployments of concentrating solar power systems in low-volume, early commercial applications; (2) reduce uncertainty in the cost and reliability of key solar components to improve financing of early commercial systems and reduce the risk of performance warranties; (3) promote the development of system-level business plans and industrial partnerships linking manufacturing scenarios to commercial sales prospects; and (4) establish the manufacturing basis for achieving the substantial cost reductions possible through higher volume production. SolMaT is aimed at reducing the cost of concentrating solar power technologies in an environment of uncertain future sales and modest initial production volumes. In this way, SolMaT will fill a critical need for allowing manufacturers to produce cost-effective products even before market demand will support high-volume production.

The objective of concentrator technology development is to bring heliostat and parabolic dish solar concentrators to commercial readiness for use in CSP systems. Heliostats and parabolic dishes provide the "fuel" for CSP systems. These two types of solar concentrators comprise similar parts and use similar manufacturing processes; for example, both have an optical surface (typically glass), an optical element support structure, a two-axis drive, and a tracking/control system. Power tower and dish/engine design studies show that the cost of the solar concentrator is 40% to 50% of the cost of these two types of solar systems. The challenge that continues to face us is to reduce the cost of the concentrator while continuing to maintain the high levels of performance that are demonstrated by many of the current designs.

Facilities support is needed to operate and maintain Sandia's NSTTF (see Figure 10) in support of testing and evaluation for Concentrating Solar Power Program objectives. Operating tasks include maintaining site test equipment so it is available for testing; maintaining environment, safety, and health (ES&H) requirements for the site; providing site technical support; purchasing material and equipment for testing; calibrating test equipment; inventorying equipment; waste management; shipping and receiving; reapplying equipment and materials; and removing obsolete test equipment.

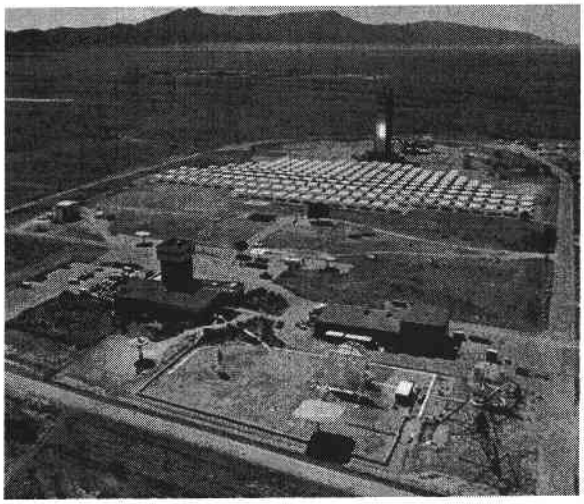


Figure 10. An aerial view of the NSTTF.

Long-term research and development (R&D) is intended to provide the basis for new concentrating solar power technologies. Through solicitations within and outside Sun•Lab, the project seeks the best ideas and supports proof-of-concept analyses or testing. Projects for which the concept can be proven are moved forward to field testing at Sun•Lab facilities and are expected to become mainstream R&D activities within the program.

1998 Accomplishments

Systems Analysis

The CSP technology characterizations were submitted to the DOE and the Electric Power Research Institute (EPRI). The final DOE/EPRI review of the technology characterizations was held during the first quarter of FY98, and final versions of the technology and summary sections were completed based on feedback from the review. Published versions of the technology characterizations are available in document form or electronically on the U.S. DOE Office of Utility Technologies web site.

Sun•Lab is developing technology roadmaps for distributed and dispatchable concentrating solar power technologies. The parabolic trough technology roadmap was completed during 1998. Roadmap workshops with participants from industry, government/laboratories, and nongovernmental organizations were held for dish/engine and power tower technologies during the year. The formal documentation of the technology roadmaps will be completed during FY99. The following sections highlight the tentative conclusions from the workshops:

- Dish/Engine Roadmap – A number of high-value market opportunities were identified for 25-kW dish/engine technologies. Although remote applications were identified to have the highest value, they also have the highest reliability, availability, and maintainability requirements. As a result, the workshop focused primarily on distributed grid-connected applications where high-value green image or green market opportunities existed. In these markets, the smaller modular size allowed a relatively higher cost dish/engine solar technology to compete. The workshop identified component and system reliability to be the key issue facing the technology. Although cost and performance are also important, they would not be the driving factors in near-term markets. In addition, the dish/engine industry indicated the need for rapid manufacturing scale-up if the technology is to meet the needs of the market and be an attractive product for industry.

- Power Tower Roadmap – Power towers face a difficult development path in the current highly competitive power market environment. Power tower technology is perceived as being too high of a risk to be developed and financed in a competitive market. In addition, the power tower industry is unlikely to continue investing corporate resources in additional R&D activities given the lack of any obvious near-term sales opportunities. The power tower workshop developed a straw man technology roadmap that identified a pathway for development of the next power tower project. The plan includes near-term research, development, and demonstration needs for power tower technology. The near-term R&D focus is to complete the test and evaluation plan at Solar Two and to identify a near-term heliostat for a next power tower project. Extension of the operation of Solar Two would be advantageous to reduce the perceived risk of the technology for future projects. In addition, an industry team needs to start working on developing the next power tower project as an independent power producer project structure in which the project risk can be born by suppliers and potentially a host country interested in the technology. The Global Environment

Facility or other organizations would be needed to help buy down the noneconomic portion of the project.

A Distributed Utility Associates study looked at the market opportunities for distributed generation in the U.S. Southwest. They found that a market of 1,800 MW per year existed for distributed technologies. Market penetration began at 11¢/kWh (corresponding to a dish capital cost of $2,000/kW and an O&M cost of 1¢/kWh). Full competitiveness occurs at 7¢/kWh (dish cost of $1,200/kWh). Hybridization offers capacity credit, approximately $300/kW. For hybrid dish systems, cost is the primary factor and gas-mode efficiency is not very important because gas is only used for peaking.

A market study performed by Peter Lilienthal and Kathleen Campbell at NREL looked at market opportunities for international off-grid applications. They identified three potential applications for dish/engine systems: irrigation/desalination, unelectrified villages, and existing diesel mini-grid systems. The irrigation market is very large but is better suited to systems of about 5 kW or smaller. Because 40% of the world's population is currently without power, the unelectrified village market is huge. However, this is a difficult market and is probably not suitable for a new technology. The final opportunity identified is to install multiple dish/engine systems in existing diesel mini-grid systems of 200 kW to 1,000 kW. In this system, the dish/engine system would operate during the day to reduce diesel operation. Lilienthal and Campbell estimated a market potential for 40,000 to 80,000 25-kW units. Although this represents a significant opportunity, it is not sufficient to generate the mass production volumes required to achieve competitive cost with diesel systems. In all of these applications, high system reliability and available service infrastructure are essential. Hybridization may provide an important capability for the system to minimize cycling of the diesel system.

Sun•Lab participated in a workshop titled "Opportunities for Independent Power Production with Solar Thermal Power Technologies" hosted by the European Commission's Directorate General XVII – Energy in Brussels, Belgium. The workshop pulled together key stakeholders from the world finance community and potential customers of the technology from developing countries to meet with companies interested in supplying solar power technologies. The workshop had presentations on the status of project opportunities, key financing elements, and who could implement projects. In the project section, presentations were given by representatives from Egypt, Jordan, and Morocco to describe the status of opportunities in those countries. Key highlights from the meeting include the following: Egypt announced a target of 4,000 MW of solar capacity installed by 2017, Jordan is considering integrating solar into an existing plant, Bechtel indicated it is planning to offer turnkey parabolic trough plants, and the financial community indicated strong interest in finding good solar projects in which to invest.

NREL Resource Assessment generated solar radiation maps for northern Africa and southern Europe and distributed them to the CSP community. The maps show monthly and annual values of total cloud cover and direct-normal radiation. The methodology uses a database of worldwide, satellite-acquired cloud cover information on 40-km square grids for the years 1985 to 1991 to make estimates of direct, diffuse, and global solar radiation. Calculating direct-normal radiation requires knowledge of the total and opaque cloud cover, aerosol optical depth, precipitable water vapor, atmospheric pressure, and ozone (in order of decreasing importance). The cloud cover maps show monthly average total cloud cover during daylight hours in tenths. The direct-normal maps show monthly average daily totals in kilowatt-hours per square meter per day. Annual maps show annual averages of monthly values. These cartographic-quality maps use a standardized color scheme identical for both cloud cover and solar radiation, with more desirable values (for CSP systems) at the top of the scale.

SolMaT

In Phase 1 of its SolMaT project, SAIC developed a new heliostat design based on its previous dual-module approach (see Figure 11). The new design moved to smaller facets primarily to take advantage of a central facet fabrication facility from which facets would be shipped to the plant site for assembly with the remainder of the structure. The facet size—approximately 3-m diameter—was determined from the maximum size that could be shipped by truck. A 22-facet design, with a face-down stow, yields a total facet reflective area of 170 m^2.

SAIC and its partners, Boeing North American and Bechtel Corporation, made significant strides in their Phase 2 SolMaT project toward our overall goals.

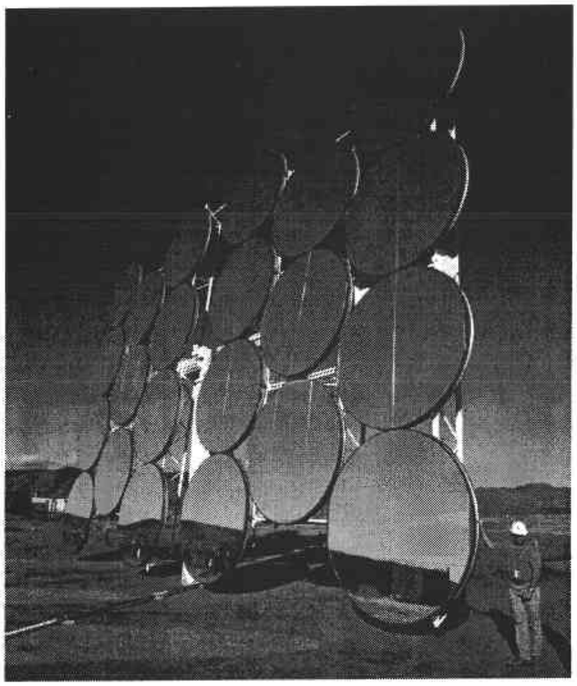


Figure 11. SAIC SolMaT heliostat installed at NREL in Golden, Colorado.

Specifically, they implemented a semi-automated facet production system that greatly increases their production capacity for both the heliostat and dish systems. This semi-automation has reduced the work-hours associated with facet fabrication by more than 70%. Further automation can continue to squeeze labor out of the overall cost. Cost estimates for increased production levels indicate that installed cost has been reduced by 10%, although there remains significant uncertainty concerning the estimating methodology. To demonstrate the new 22-facet design, four heliostats were installed that were designed to provide test beds for longer term operation and performance.

The heliostat in Golden, Colorado, was instrumented with strain gauges to measure wind loads. Along with wind speed and direction instrumentation and a high-speed data acquisition system, data were collected to determine the wind characteristics for the location. Wind load data were beginning to be acquired when, unfortunately, a drive flange on the heliostat failed during a severe windstorm and one-half of the heliostat fell to the ground. Analysis of the failure seems to indicate a fatigue problem. The other three heliostats (one at Sandia in Albuquerque and two at Solar Two) are being dismantled because of a lack of confidence in drive strength and the potential safety hazard.

Concentrator drives are a critical and costly component in a dish or a heliostat. This activity addresses using existing, mass-produced gear drive technologies that may be modified as concentrator drives. The intent is to find hardware that can meet concentrator drive needs without incurring mass production setup costs. In FY97, almost 200 potential suppliers were surveyed. The original intent of the survey was to focus on about 10 of the best candidates to determine in some detail the potential of their gear drives to meet our needs for concentrator drives. Redirected during FY99 planning activities, this effort will now focus on the potential for alternate, small heliostat designs that may use existing drive components.

Concentrators

Researchers used the Sun•Lab/NREL Video Scanning Hartmann Optical Tester (VSHOT) system to support the Dish/Stirling Joint Venture Project. A number of dish/heliostat concentrating mirror facets were tested and results provided to SAIC, the facet manufacturer. This test matrix helped determine the consistency of the facet manufacturing process. SAIC used this data to further refine its facet manufacturing process.

The VSHOT system was also used to test the installed SAIC Phase 2 dish at the Mesa Top test site at NREL. This test further demonstrated VSHOT's capability by extending its use to outdoor in-the-field testing and alignment. Field alignment and focusing is critical to dish/Stirling performance and up until now has been a time- and labor-intensive job. The VSHOT has the potential to do this job quickly and thoroughly.

Researchers used the VSHOT to test several prototype aluminum honeycomb mirror facets as part of Sun•Lab's innovative concentrator technology efforts. After thermal cycling in an environmental chamber and retesting with the VSHOT, these facets exhibited no degradation in performance. This is an encouraging result in Sun•Lab's efforts to develop a robust, low-cost, high-performance mirror facet suitable for all CSP technologies.

Instrumentation for wind load assessment of SAIC's SolMaT heliostat located at NREL's Mesa Top facility was installed and data acquisition was initiated. Measurements include calibrated strain gauges at various points on the torque tube and pedestal and the wind speed and direction. Wind speed and direction are required to be within certain values for data acquisition to occur; therefore, data were collected over the span of many months. Wind speed data were analyzed and the results show that the site can be characterized as nearly an open-field environment. Much of the low-wind-speed test matrix was completed.

Advanced Materials

Energy Laboratories, Inc. (ELI) of Jacksonville, Florida, is continuing development of a new solar-selective coating for both parabolic trough and solar domestic water heating applications. This unique coating is produced by combining two processes, namely, the electro-deposition of a crystallographic metallic alloy and application of a solution-derived glass-like overcoat. Scanning electron micrographs of the coating before and after application of the solution-derived overcoat are shown in Figures 12A and 12B, respectively. This work is being done under a cooperative research and development agreement. Activities during 1998 included accelerated thermal aging of samples prepared on stainless steel substrates to evaluate the thermal stability, in air, at parabolic trough operating temperatures of 350°C to 390°C. Results to date indicate that the stainless steel substrate preparation influences the long-term thermal stability of the coating, with thicker nickel-coated substrates exhibiting better stability. Surface analyses of degraded samples indicate that iron diffusion from the substrate may be a significant factor, and additional analysis is under way to better understand the degradation mechanism(s). Improved substrate preparation(s) are under way to assess the long-term thermal stability issues needed for parabolic trough installation. A matrix of samples has been prepared, with varying nickel thickness on stainless steel, to continue accelerated aging. Other low-cost diffusion barriers may be evaluated if the diffusion issue is not significantly mitigated using the thicker nickel layer. If this coating demonstrates parabolic trough potential, tubing sections will be prepared and installed at Daggett Leasing Corporation (SEGS II) for solar field evaluation.

Surface Optics Corporation (SOC) has completed and provided a report documenting a limited analytical study to design solar-selective absorber coatings using pigment systems for high-temperature applications, such as central receivers. The analysis was performed using the Pigment Computer Aided Design (PigCad) code, a Surface Optics product, which considers distributions of multi-layered spherical pigments in semi-transparent binders. The design goal for these coating systems was for a 0.95 solar averaged absorptance and a thermal emittance (blackbody temperature range of 540°C to 575°C) in the 0.2 to 0.3 range. A limited number of refractory metal-coated spherical pigments in fused silica and alumina matrices were modeled. Preliminary analytical results indicate that a solar-selective absorber coating meeting the optical properties design criteria could be theoretically constructed using the appropriate materials and pigment distributions. Additional design trade-off studies will be needed to optimize the material selections and assess the feasibility of constructing the candidate coating(s).

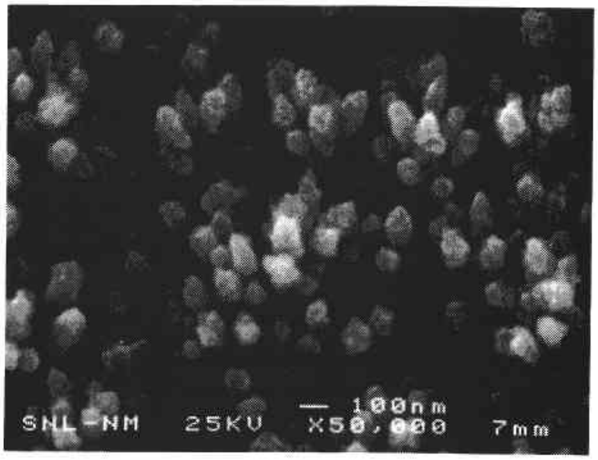


Figure 12A. Black Forest (crystal) as deposited, 50,000 X.

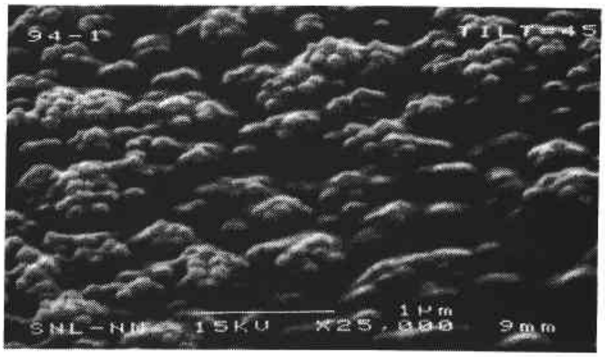


Figure 12B. Black Forest (crystal) with solution-derived glass overcoat, 25,000 X.

In support of industry commercialization efforts, an investigation of weld-bond corrosion of stainless steel membrane materials was conducted. A number of heliostat facets (developed by SAIC under the SolMaT program) recently deployed at the Solar Two test facility had failed. These facets had been manufactured in Golden, Colorado, and shipped, untarped on open flatbed trucks, to Barstow, California. During shipment, some facets were subjected to salt/chemical spray associated with inclement winter weather conditions. Failures occurred primarily along seams where the stainless steel membrane material was welded to the support ring, and visual corrosion was evident at these weld seams (see Figure 13). Sun•Lab performed X-ray photoelectron spectroscopy (XPS) analysis of corroded regions of failed samples. The elemental composition at the surface (which included carbon, silicon, aluminum, chlorine, sodium, sulfur, and calcium) was consistent with exposure to mixed road salts and dirt spray. XPS analysis into the bulk of corrosion spots found that ionic contaminants persist into the depth of the samples, suggesting an aggressive pitting corrosion. Additional laboratory accelerated exposure testing of unfailed samples demonstrated the susceptibility of the membrane material to salt solutions. Sun•Lab also provided recommendations to SAIC regarding materials selection and welding processes.

During 1998, work continued toward developing a number of new reflector materials with low-cost potential and improved lifetime. Two of these are particularly attractive, namely, a super-thin glass mirror and a reflector constructed by laminating commercial products. The first of these is being developed under a subcontract with SAIC (discussed below). The second was devised, and is being pursued, jointly by staff from Sun•Lab and Industrial Solar Technologies (IST). Both of these materials have low-cost potential, and the accelerated weathering tests for the super-thin glass mirror show promise of a higher lifetime than ECP-305+. We have not yet accumulated sufficient test time on the Sun•Lab/IST material to accurately assess its lifetime, but believe that it will also be greater than the lifetime of ECP-305+. Other promising candidate solar mirrors being tested include additional samples with protective oxide overcoats (both provided by industry and constructed in-house), a commercial product called SolarBrite (that uses an ultraviolet-stabilized polyester film superstrate), and an all-polymeric reflector construction that has recently experienced rejuvenated industrial interest.

Under a Sun•Lab subcontract, SAIC in McLean, Virginia, is developing a promising advanced reflector material. The structure of this ultra-thin glass material is alumina/silver/copper/PET, where PET is a polyester film substrate. A proprietary ion-assisted process is used to allow highly dense coatings of alumina that provide excellent protection of the silver reflective layer and consequent high-optical weatherability. The key to obtaining low cost is the ability to achieve high deposition rates without damaging the heat-sensitive substrate material. To date, the highest deposition rate has been 7 nm/s; deposition rates greater than 30 nm/s (depending upon coating thickness) are projected to lower the cost to $\$1/ft^2$. One way to allow high deposition rates on PET is to use a cooled stage to control substrate temperature during the deposition process. During 1998, SAIC completed fabrication and installation of such a cooled stage (Figure 14). The stage consists of a curved aluminum plate with an electropolished top surface. On the back surface, copper tubing is attached in a serpentine pattern using thermally conducting epoxy. Cooling is achieved by flowing water through the coil during deposition onto substrate materials held in contact with the electropolished surface of the stage.

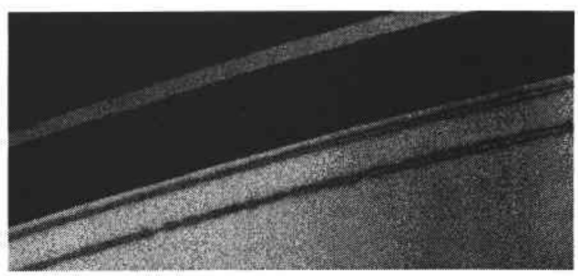


Figure 13. Weld-bond corrosion of stainless steel facets.

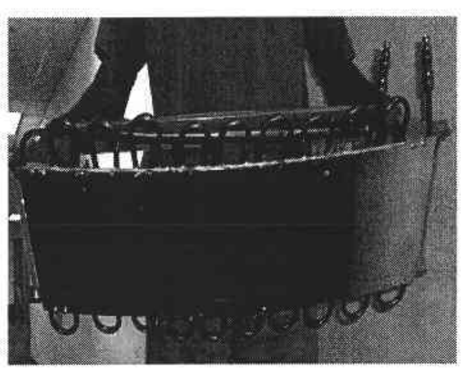
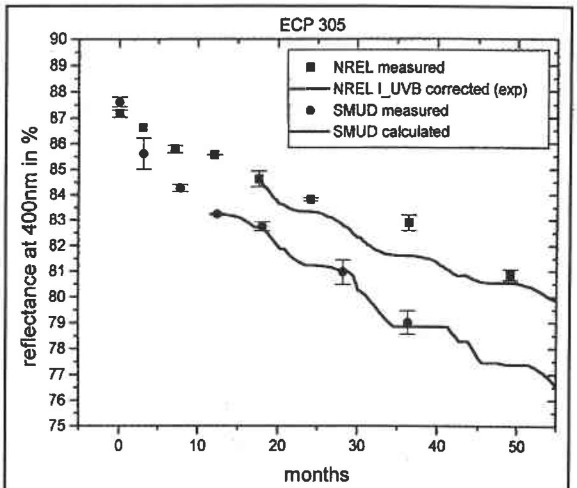


Figure 14. SAIC's cold-shoe substrate for high-speed deposition of solar mirrors.

Efforts were made during 1998 toward predicting, from accelerated test results, the service lifetime of advanced reflector materials in real-world service. Tests were completed on two reflective materials. Results from an accelerated exposure experiment at NREL's High-Flux Solar Furnace were used to develop models that would predict actual weathering experience. The predictions from the models were then compared to long-term weathering data at two outdoor exposure test sites. The model for one of the materials produced highly accurate predictions at both sites evaluated (see Figure 15). Results for the second material were less conclusive, showing the proper trends but with less accuracy than the first material. We believe that the methodology developed is sound and that much of the uncertainty for the second material is explained by some erroneous data that were recorded at the outdoor test sites. We are fixing the data collection problems and expect to refine the service lifetime prediction results during the coming year. Overall, we are encouraged with the progress that has been demonstrated in developing these service lifetime prediction models and feel that they offer significant promise for predicting the lifetime of solar materials in real-world applications.



Use constant, accelerated stress exposure to obtain model coefficients:

$$\Delta P = A\, I\, e^{-[E/T]}\, e^{C \cdot RH}\, \Delta t$$

Use coefficients and outdoor weather data to predict:

$$\Delta P = \Sigma\, A\, I(t)\, e^{-[E/T(t)]}\, e^{C \cdot RH(t)}\, \Delta t$$

Figure 15. Comparison of real-world measured versus predicted performance loss.

Facilities

We completed the installation and testing of the Boeing/Rocketdyne panel on top of the tower and used the renovated Lucker lifting system. The tower and heliostat field are shown in Figure 16.

We continued regular ES&H walkthroughs and documented corrective actions. We passed a Sandia independent ES&H audit and a New Mexico environmental audit of the NSTTF.

We continued to make progress in the repair and upgrade of the NSTTF heliostat field; 211 out of 218 heliostats were operational for the Boeing panel test. The 200,000 pounds of molten salt used for experiments approximately 12 years ago were removed from the NSTTF by an outside contractor and will be reused.

We set up and tested several receivers at the rotating platform. We also started fabricating the long-shafted pump in preparation for improved molten-salt component tests.

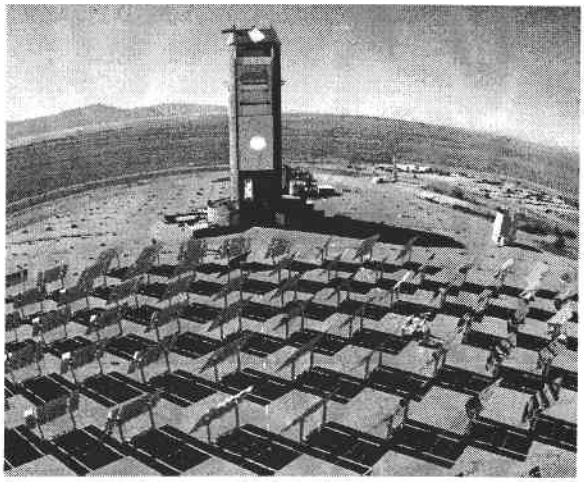


Figure 16. The tower and heliostat field at the NSTTF.

We supported several tests for the University of Chicago where the heliostat field is used to concentrate light energy from space on banks of photon tubes to intensify the image from space.

We obtained a new customer, Nichols Research, through the Work-for-Others Program. Nichols completed testing at the NSTTF in October. Negotiations for tests in 1999 were started.

Long-term Research and Development

In FY98, Solar Thermal Advanced Research (STAR) solicited both within and outside Sun•Lab for additional ideas for CSP technologies. The internal solicitation was open to all concepts. The external solicitation focused on new conversion concepts. This solicitation asked for technologies that differ significantly from our mainline R&D areas but have potential to supply solar thermal electricity at low cost or to open new markets for CSP.

Two subcontracts were awarded as part of the STAR process. The first was to Clever Fellows Innovation Consortium (CFIC) for a novel thermoacoustic engine concept. Sun•Lab is supporting the design and development of a small, 2-kW prototype as part of a larger project supported by the state of New York and other private investors (see Figure 17). The second subcontract was awarded to Edtek, Inc. for a novel thermophotovoltaic converter concept (see Figure 18). Both of these initial subcontracts will continue into FY99, and both expect to yield prototype converter hardware for test at Sun•Lab facilities.

Three internal projects were under way in 1998; two were completed and one was terminated. In an internal STAR project, an NREL investigator proposed a unique thermoelectric concept as an alternate conversion technology. Unfortunately, the investigator left NREL before completing the project.

The two additional internal projects included the continuation of structural facet fabrication techniques using honeycomb core materials and a unique flux measurement tool using Lambertian materials.

FY99 Task Description

We will complete roadmap workshop documentation and develop a roadmap for each technology. We will generate web versions of these documents to go on the Sun•Lab web site. We will continue to support SolarPACES Solar Thermal Analysis, Review and Training missions and Global Environment Facility project development activities. We will also continue to support the technology development areas on an as-needed basis.

No SolMaT tasks were funded for FY99.

In FY99, the concentrator task will focus on some different areas. The development of the structural facet work will continue with the goal of providing trough facets to each of the three SEGS plants as replacements for mirrors damaged by winds. This will further demonstrate (as already demonstrated in thermal cycle testing) the high performance and durability of the aluminum honeycomb structure in real operating environments. It will also provide the end users with another option for their replacement mirrors.

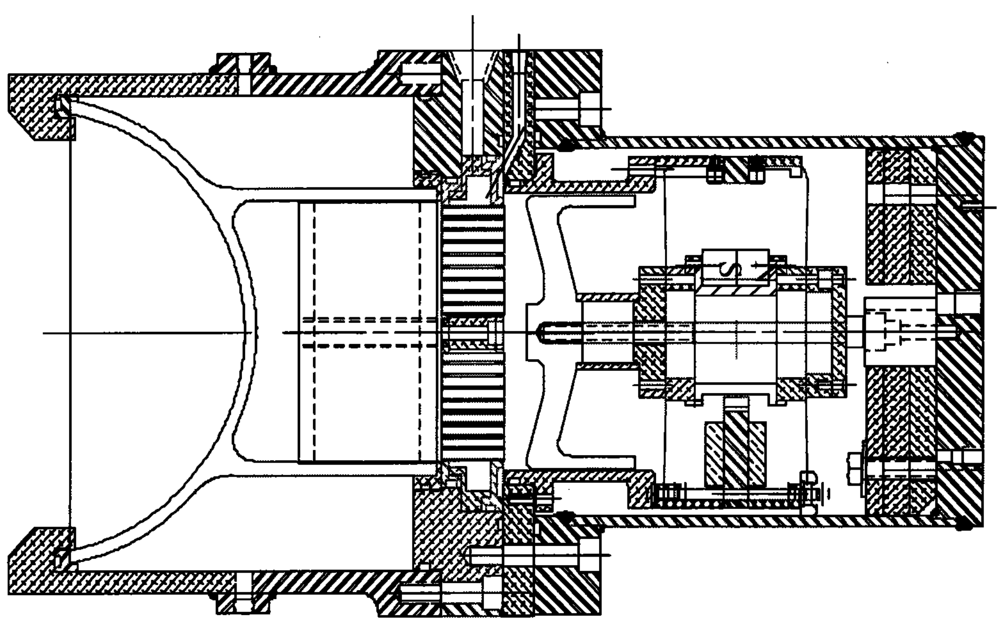


Figure 17. Schematic drawing of CFIC's prototype thermoacoustic engine.

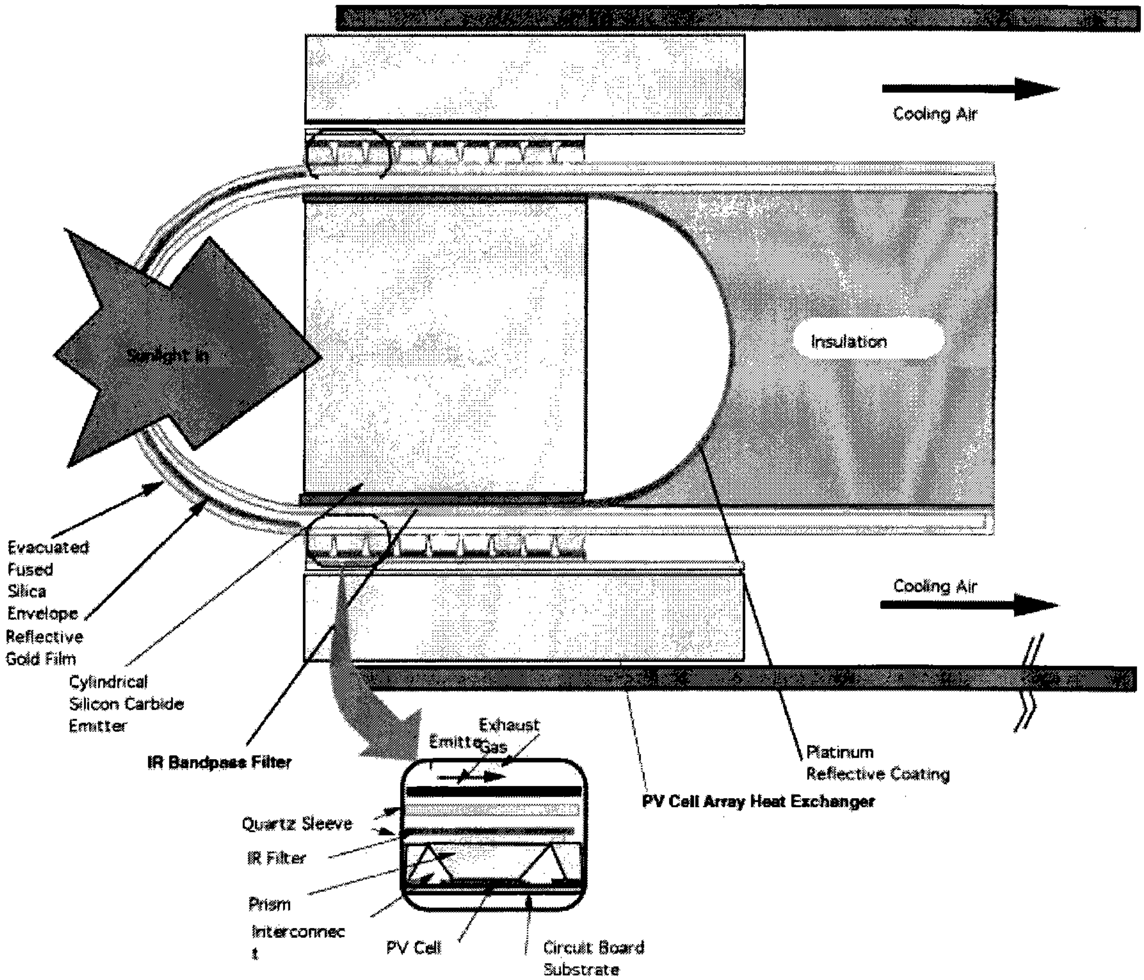


Figure 18. Conceptual drawing of Edtek's thermophotovoltaic converter.

A task was initiated to take a fresh look at heliostat design. With the development of state-of-the-art control systems and manufacturing processes unavailable at the time current heliostat concepts were in the design stages, it is possible that different and smaller heliostat designs could be cost-effective compared to conventional larger heliostat designs. This task will explore these new developments and compare cost and performance of a range of heliostat sizes for several different power tower plant sizes and types.

We will identify and develop candidate advanced reflector materials that meet the solar thermal industry's goals of cost, performance, and durability. Improved reflectors reduce capital and O&M costs and increase delivered energy of CSP systems. A promising subcontracted activity for development of an alumina-overcoated silver mirror will be continued. Prototype solar mirrors will be constructed for further evaluation using a new vacuum deposition system. Interactions with the vacuum coating industry will also continue to allow advances within that industry to be incorporated into development activities and to ensure viable process scale-up of advanced reflector candidates.

We will use a general methodology to establish the durability of advanced materials exposed to outdoor and accelerated test environments. This methodology will allow quantification of O&M and reliability analyses and increase the confidence of prospective solar manufacturers in systems, products, warranties, and life cycle cost projections. This will be conducted by building upon previously developed capabilities that encompass methodology development and validation, sample preparation, performance characterization, outdoor weathering, accelerated exposure testing, analytical techniques allowing failure mechanistic studies, and model development including statistical analysis.

We will continue to support testing for the Concentrating Solar Power Program by providing a quality facility and personnel to perform these tests. We are also pursuing other nonrenewable test and evaluation business opportunities to leverage the facility's O&M costs.

We will develop and evaluate CFIC's optically heated thermoacoustic converter for small, remote-power applications. We will demonstrate and evaluate the on-sun operational performance of a 1-kW thermoacoustic engine. Solar thermoacoustic converters are a new and potentially efficient, cost-effective, and reliable engine option for small-scale (1- to 2-kW) applications.

We will conduct an on-sun demonstration of Edtek's thermophotovoltaic generator. This generator is a potentially efficient and low-cost means of generating CSP electricity without moving parts.

CROSS-CUTTING SUPPORT

Cross-cutting support activities address issues and needs that are common to all CSP technologies. These include activities such as developing an understanding of the power market's requirements and developing the communication tools that will provide access to CSP technical information.

Rationale

Market opportunities for CSP systems are changing rapidly as a result of deregulation in the domestic and international utility power generation markets. It is critical that we understand the potential markets and the requirements that they have for our systems.

The objective of the market opportunities and barriers task is to help us understand what is required to get CSP technologies to the marketplace. More specifically, this initiative is to ensure that the technology development activities of the DOE's Concentrating Solar Power Program have the most current information on the *revolution* taking place in the domestic and international electric power industry.

The quality of our communications products should reflect the technical excellence of Sun•Lab's work. All of our products, be they publications, electronic media, film, or exhibits, should communicate clearly the work Sun•Lab is doing and explain its relevance to the future of solar energy for the nation and the world. It is important that the accomplishments coming from the government laboratories and industries involved be made known as widely as possible.

1998 Accomplishments

Market Opportunities and Barriers/Identify First Customers

We completed a white paper on the market status of concentrating solar power technologies. The study concluded that restructuring of the power-generation industry is changing the providers of power from the traditional utilities to independent power producers. Furthermore, there are external forces at work that could provide new opportunities for the deployment of CSP systems. In the past, we have not actively helped industry pursue the opportunities to deploy a small number of precommercial systems. We need to seek out opportunities to test systems in field environments, to highlight our successes, and to continue to assess market opportunities and requirements and feed this information *back* to technology and project development activities.

Communications

During its second year of existence, the Sun•Lab Communications team developed an exhibit for Soltech illustrating the history of the Concentrating Solar Power Program; developed a financial summary sheet for the Sun•Lab internal web pages; produced displays on the Solar Two project and the dish/Stirling project for publicity purposes at Sandia's Sun•Lab offices and at DOE in Washington; revised relevant materials to reflect the name change from the Solar Thermal Electric Program to the Concentrating Solar Power Program; and produced fact sheets describing Sun•Lab projects.

FY99 Task Description

We will continue to monitor market development at a low level of effort in FY99.

Our primary task in FY99 will be to provide communication products for Sun•Lab management and staff as these needs are identified during the year. We will provide support for Soltech '99; we will provide assistance and publicity for the planned ceremony to mark the closing of Solar Two; we will assist Sandia's Renewable Energy Office with the American Solar Energy Society Conference in Maine in June; we will create new fact sheets for use in publicizing the program and will update our World Wide Web pages to include this information. We will actively seek new opportunities to publicize the activities of the Concentrating Solar Power Program. We will contribute to the annual operating plan, quarterly reports, and annual summary of program activities.

1998 MILESTONE SUMMARY

1998 MAJOR MILESTONES – Listed by completion date				
Activity	**Milestone Description**	**Staff Responsible**	**Expected Completion**	**Actual Completion**
Cross-Cutting Support	Provide input for the *Solar Industry Journal.*	A. Van Arsdall, D. Crawford	Quarterly during FY98	Nov 97 Feb 98 May 98
Cross-Cutting Technology	Complete installation of wind-load instrumentation for the SAIC heliostat.	A. Lewandowski	Nov 97	Nov 97
Power Tower	Complete the 99-hour Solar Two plant acceptance test.	M. Prairie	Dec 97	Jan 98
Dish/Engine	Install first second-generation dish/Stirling system. (SAIC)	M. Mehos	Dec 97	Jan 98
Power Tower	Document results of the Solar Two Test and Evaluation Program for 1997.	M. Prairie	Jan 98	Apr 98
Power Tower	Enter the Power Production Phase of Solar Two.	H. Reilly	Jan 98	Feb 98
Dish/Engine	Begin on-sun testing of STM Generation-III engine with a heat pipe.	S. Rawlinson	Jan 98	Jun 98
Cross-Cutting Support	Create visitor information materials at Solar Two.	A. Van Arsdall, D. Crawford	Feb 98	Apr 98
Dish/Engine	Select solar concentrator design for Phase 2. (AlliedSignal)	T. Mancini	Mar 98 Rescheduled to Dec 98	Cancelled (entire contract cancelled)
Dish/Engine	Place contract or terminate negotiations with Boeing and Stirling Energy Systems. (Sun•Lab)	R. Diver	Mar 98	Apr 98
Power Tower	Complete and document the Solar Two steam generation system characterization test.	J. Pacheco	Apr 98 Delayed (data unavailable)	Dec 98
Dish/Engine	Begin on-sun testing of the Solo 161 engine with a heat pipe.	R. Diver	Apr 98	Cancelled (will become part of the remote power system)
Dish/Engine	Deliver Brayton power conversion system to NSTTF for testing. (AlliedSignal)	T. Mancini, T. Moss	Apr 98 Rescheduled to Nov 98	Cancelled (entire contract cancelled)
Reliability	Complete the KJC Operating Company O&M Improvement Program and document the final results.	G. Kolb	Apr 98 Delayed (data unavailable)	est. Jan 99

1998 MILESTONE SUMMARY

Activity	Milestone Description	Staff Responsible	Expected Completion	Actual Completion
Cross-Cutting Technology	Identify manufacturer for industry assistance.	P. Cordiero	Apr 98	Sep 98
Cross-Cutting Support	Provide exhibit materials and support for Soltech '98.	A. Van Arsdall	Apr 98	Apr 98
Power Tower	Complete testing of the Boeing/Rocketdyne panel.	J. Pacheco	May 98	Jun 98
Dish/Engine	Begin on-sun testing of a next-generation heat-pipe receiver.	C. Andraka	May 98 Delayed (prototype problems)	est. Mar 99
Dish/Engine	Install a dish/Stirling system in the Washington, D.C. area. (SAIC)	T. Mancini	May 98	Apr 98
Cross-Cutting Technology	Complete SAIC Phase 2 Project and document heliostat cost reductions of 25%.	A. Lewandowski	May 98	Jul 98
Power Tower	Complete and document the Solar Two receiver efficiency test.	J. Pacheco	Jun 98 Delayed (equipment breakdown)	est. Apr 99
Power Tower	Present results of the hybrid study at the Roadmapping Workshop.	T. Williams	Jun 98	Jul 98
Dish/Engine	Complete testing of hybrid bench-scale prototype.	M. Mehos	Jun 98	Oct 98
Dish/Engine	Install a dish/Stirling system in Sacramento. (SAIC)	T. Mancini	Jun 98	Cancelled (scope reduced)
Trough Development	Complete parabolic trough roadmap.	H. Price	Jun 98	Jun 98
Trough Development	Document fluid degradation resolution plans.	R. Mahoney	Jun 98	Jun 98
Cross-Cutting Technology	Complete drive design modifications evaluation.	B. Kolb	Jun 98	Cancelled (lack of funding)
Cross-Cutting Technology	Complete technology roadmap for solar power tower.	H. Price	Jun 98 Delayed (staffing changes)	est. Feb 99
Cross-Cutting Technology	Complete technology roadmap for dish/engine systems.	H. Price	Jun 98 Delayed (industry and staffing changes)	est. Mar 99
Cross-Cutting Technology	Complete DNI map for international location.	H. Price	Jun 98	Aug 98

Activity	Milestone Description	Staff Responsible	Expected Completion	Actual Completion
Power Tower	Demonstrate dispatchability: generate electricity with Solar Two for three hours after dark at maximum power output.	H. Reilly	Jul 98	Jul 98
Dish/Engine	Complete 750 hours of operation on a Phase 2 dish/Stirling system. (SAIC)	M. Mehos	Jul 98	Oct 98 (Boeing)
Cross-Cutting Technology	Complete Video SHOT dual laboratory and field system.	S. Jones	Jul 98	Jul 98
Dish/Engine	Complete testing of the Brayton power conversion system. (Sandia and AlliedSignal)	T. Moss	Aug 98 Rescheduled to Mar 99	Cancelled (entire contract cancelled)
Cross-Cutting Technology	Start one new STAR project.	M. Bohn	Aug 98	Cancelled
Power Tower	Complete characterization of SAIC's heliostat at the NSTTF.	J. Grossman	Sep 98	May 98
Power Tower	Document Solar Two power production test results.	M. Hale	Sep 98	Dec 98
Dish/Engine	Complete design of full-scale hybrid heat pipe.	J. Moreno	Sep 98	Jul 98 (preliminary design)
Trough Development	Complete Sun•Lab input to SolWin.	H. Price	Sep 98	Sep 98
Reliability	Monitor reliability at Solar Two and recommend solutions to reliability problems.	G. Kolb, M. Hale	Sep 98	Sep 98
Cross-Cutting Technology	Report on manufacturing assistance.	P. Cordiero	Sep 98	Sep 98
Cross-Cutting Technology	Develop two new reflector materials with low-cost potential and a lifetime (as measured by accelerated weathering tests) greater than ECP-305+.	G. Jorgensen	Sep 98	Sep 98
Cross-Cutting Technology	Apply Service Lifetime Prediction methodology to three solar mirror materials.	G. Jorgensen	Sep 98	Sep 98
Cross-Cutting Technology	Develop a new mid-temperature (approximately 400°C) solar absorber material with low-cost potential and thermal stability extrapolated (from accelerated test results) beyond 5,000 hours.	R. Mahoney	Sep 98 Rescheduled to Apr 99	est. Apr 99
Cross-Cutting Support	Create a video on Solar Two to show its operational capabilities.	D. Crawford	Sep 98	Cancelled
Cross-Cutting Support	Create four new fact sheets about projects within the Concentrating Solar Power Program.	A. Van Arsdall, D. Crawford	Sep 98	3 in late 1997; 1 pending

Activity	Milestone Description	Staff Responsible	Expected Completion	Actual Completion
Cross-Cutting Support	Support one SolarPACES START mission.	G. Kolb	Sep 98	Sep 98
Cross-Cutting Support	Identify and implement three activities to facilitate development of an CSP project.	T. Mancini	Sep 98	Cancelled (no immediate follow-on action identified)

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