Solar Thermal R&D Subprogram Overview

Frank (Tex) Wilkins, Team Leader, Solar Thermal R&D

The Solar Thermal Subprogram comprises two activities: Concentrating Solar Power (CSP) and Solar Heating and Lighting (SH&L). CSP technologies use mirrors to concentrate the sun's energy up to 10,000 times sunlight to power conventional turbines, heat engines, or other converters to generate electricity. Energy from CSP systems is high-value renewable power, because energy storage and hybrid designs allow it to be provided when most needed. This is particularly important to utilities that need to increase the amount of power available to them during periods of peak demand. The SH&L research activity develops solar technologies that provide hot water for residential and commercial buildings as well as hybrid solar lighting for commercial buildings. Reducing the cost of these two technologies is important to the goal of a reasonably priced zero energy building. R&D sponsored by the Solar Thermal Subprogram is done in collaboration with industry and university partners.

Goals and Objectives

Concentrating Solar Power
CSP systems currently offer solar electricity at about 12¢–14¢/kWh with systems ranging in size from kilowatt-scale to multi-megawatt power plants. A study by the Western Governors' Association Solar Task Force projected that large CSP systems will be able to produce power at about 5.5¢/kWh with continued R&D and the deployment of 4,000 MW. Our 2012 goal is to reduce the cost of energy from CSP technology to 9¢–11¢/kWh. The 2020 goal is 5¢–7¢/kWh with up to 12 hours of thermal storage. This will be done through R&D carried out by the national laboratories and industry combined with the establishment of CSP plants deployed by utilities and their industry partners. The primary objectives for FY 2006 were to (1) assist industry in lowering the cost and improving the performance of trough and dish technologies and (2) encourage southwestern utilities to consider CSP as a way of fulfilling their renewable portfolio standard requirements by using the region's most abundant renewable resource: solar energy.

Solar Heating and Lighting
SH&L research emphasizes the development of low-cost, polymer-based solar water heaters, which have the potential to cut the cost of today's solar water heating (8¢/kWh) to 4.5¢/kWh. The objectives for FY 2006 were to (1) complete the evaluation of prototype units placed at locations throughout the nonfreezing regions of the country and (2) begin work on the design of solar water heaters applicable to freezing climates. Budget issues, however, precluded the completion of the first objective and led to the postponement of the second. The primary objectives of hybrid solar lighting development were to (1) improve the design of the system and (2) install prototypes at selected commercial locations and evaluate their performance.

Results and Accomplishments

Concentrating Solar Power
The most significant CSP events during FY 2006 were the initial operation of Arizona Public Service's 1-MW trough plant and the beginning of construction of a 64-MW trough plant in Nevada. The Nevada project, called Nevada Solar One, is expected to become operational in 2007. These are the first commercial CSP plants built in the United States since 1991. Both are Solargenix projects and both used a solar collector developed collaboratively with the DOE Solar Program. The Solar Program also assisted industry in making existing projects more efficient. Methods were developed to evaluate the alignment of mirrors on collectors and assess the performance of thermal receivers in a solar trough field. NREL, working with FPL Energy, identified that a loss in efficiency of trough receivers was caused by hydrogen emanating from the heat transfer fluid and migrating through the receiver pipe into the glass jacket. Hydrogen in the

glass jacket was found to increase the thermal losses by a factor of four. Work is now under way to solve the problem.

During FY 2005, Stirling Energy Systems (SES) built, entirely with its own funding, a six-dish 150-kW power plant at the National Solar Thermal Test Facility at Sandia National Laboratories (SNL). SES also moved a sizable portion of its technical staff to Albuquerque to make the best use of the facilities and engineers at SNL. This dish system has become a valuable tool for improving the collector and the Stirling engine. A major redesign of the structure led to a reduction in weight of 4,000 pounds while increasing its ability to withstand wind loads. A redesign of the valves that control the gas management system has led to improved operation of the engine. This dish/engine effort is particularly important because SES has power purchase agreements with Southern California Edison and San Diego Gas & Electric, which could lead to projects totaling 800 to 1,750 MW.

The Energy Policy Act of 2005 directed DOE to assess the potential impact of CSP. In response, the DOE Solar Program issued a report entitled *Assessment of Potential Impact of Concentrating Solar Power for Electricity Generation*. The report summarized the various evaluations of CSP over the last several years (e.g., assessments by Sargent & Lundy and the National Academy) and concluded that the cost of CSP can be reduced to 5¢–7¢/kWh through the combination of R&D and deployment. Whereas R&D was largely a DOE responsibility, deployment was being driven primarily by the renewable portfolio standards established by the southwestern states. The 64-MW project in Nevada was the first example of that happening. A team made up of representatives from industry, SNL, NREL, and the Solar Program met with the governors' offices of several southwestern states during the year to alert them to the benefits of CSP. We found the states were particularly interested in the creation of jobs that would accompany the establishment of CSP manufacturing and projects. After discussions with the California Governor's Office indicated an interest in knowing about CSP, the Solar Program had Black & Veatch write the report, *Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California*. The team also met with several utilities during the year to discuss solar resources in their area and CSP cost scenarios. Utility representatives verified that they had become very interested in CSP because of the capability of CSP technologies to store energy. This is leading us to increase our focus on thermal storage in FY 2007.

Solar Heating and Lighting
Funding for SHL in FY 2006 was significantly lower than in FY 2005 and presaged DOE's recommendation to Congress that SHL be terminated in FY 2007. This limited the activities in the subprogram. On the other hand, the establishment of a tax credit for solar water heaters created optimism among the industry that sales would increase. The legislation that established the tax credit also required qualifying solar water heating systems to be certified. This has placed increased importance on the Solar Rating and Certification Corporation (SRCC). SRCC thus continued to receive funding from the Solar Program to help them process the increased number of systems for which industry was requesting certification. Both industrial partners continued working on the development of a low-cost solar water heater, albeit with less support from DOE. Both partners made design improvements to their water heaters and tested prototypes in preparation for introduction to the market, possibly in FY 2007.

Several design improvements were made to the hybrid solar lighting (HSL) system. By the end of the year, 13 prototype systems had been installed throughout the country. Most of these, unfortunately, developed problems that have identified the need for a redesign of the system. A contract that was initiated in FY 2005 to estimate the market potential of HSL was expected to be completed in FY 2006. However, the lack of funding required this to be postponed.

New Directions

In 2000 and again in 2002, the National Academy stated that CSP systems were too large and too expensive to ever be built. In 2006, however, projects in Spain resulting from a Royal Decree, along with the projects being established in the United States that were fostered by renewable portfolio standards, have proven that large CSP projects can be built. The investment tax credit established by EPAct 2005 reduced the cost of renewable power, making it easier for utilities to select CSP projects. These State and Federal policies have created an optimistic outlook for CSP, and the industry is growing. The Solar Program will respond by continuing to offer industry technical support and to begin development of the next generation of systems. An additional focus in FY 2007 will be planning for a more robust thermal storage activity. The Solar Program will also become more involved with issues surrounding transmission and the location of CSP plants (e.g., solar resource monitoring).

By the end of FY 2006, it was apparent that SHL would receive funding in FY 2007. However, the message was clear that it had to change if it was to gain support. A major focus of FY 2007 will be to develop a new vision for SHL. Part of this may include non-technical activities that help industry expand the market for the technology. In the technical areas, analysis from NREL and our industrial partners shows the polymer water heaters will meet the 4.5¢/kWh goal. The next step is to assist our two industrial partners in the last technical changes prior to their commercialization of the products. The problems associated with the hybrid solar lighting systems installed during FY 2006 will result in a better design in FY 2007, and the field demonstration systems will be made operable.

Concentrating Solar Power

Concentrating solar power (CSP) systems use the heat generated by concentrating and absorbing the sun's energy to drive a conventional turbine or heat engine/generator and produce electric power. Three types of CSP systems—trough, dish/engine, and power tower—are all capable of producing power using the sun's energy.

Trough systems, the most commercially mature of the three systems, use linear parabolic concentrators to focus sunlight along the focal lines of the collectors. Dish/engine systems comprise a parabolic dish concentrator, thermal receiver, and heat engine/generator located at the focus of the dish to generate power. In a variation of the dish/engine system, concentrating photovoltaics (CPV), an array of high-efficiency photovoltaic cells replaces the thermal receiver and heat engine. In a power tower system, a field of two-axis tracking mirrors, called heliostats, reflects the solar energy onto a receiver that is mounted on top of a centrally located tower.

With the advent of renewables-friendly policies within the United States and abroad, there is a renewed interest in CSP technologies based on their potential for low cost and ease of large-scale implementation. The Western Governors' Association (WGA) established a Solar Task Force to determine the potential of solar energy in the West and identify the incentives required to establish projects. The National Renewable Energy Laboratory (NREL) provided much of the analysis required by the WGA. In the U.S. southwestern states, CSP projects are under way in Nevada and Arizona; New Mexico and California are investigating the possibilities of developing CSP plants. R&D priorities of the CSP Subprogram are determined, in part, by projects being developed under the state programs.

The accomplishments of the DOE Solar Program's CSP activity in FY 2006 include:

Dish/Engine System R&D

- Operated and maintained six-dish model power plant at Sandia National Laboratories, cataloging more than 80 development areas.
- Completed design for manufacturing and assembly of dish structure, reducing weight by 4,000 pounds.

Parabolic Trough R&D

- Started initial commercial operation of the first new parabolic trough plant to be developed in nearly 15 years. Arizona Public Service owns the plant, which was developed by Solargenix Energy. The plant uses parabolic trough collector technology developed by Solargenix under a cost-shared R&D contract with DOE/NREL.
- Solargenix began construction of a 64-MW parabolic trough plant in Nevada. The plant uses a new second-generation parabolic trough collector design developed under the company's USA Trough Initiative R&D contract.

Advanced Optical Reflector R&D

- Continued to perform durability testing of optical materials and published results of durability testing of several mirror types.
- Provided significant industry support about reflectors to the concentrating CSP and CPV industries.

CSP Systems Analysis

- Continued analysis in support of the WGA Solar Task Force, with an emphasis on analysis in support of a proposed southwest utility consortium.
- Developed initial version of CSP Jobs and Economic Development Impact model.

Dish/Engine System R&D

Performing Organization: Sandia National Laboratories (SNL)

Key Technical Contact: Charles Andraka, 505-844-8573, ceandra@sandia.gov

DOE HQ Technology Manager: Thomas Rueckert, 202-586-0942, thomas.rueckert@ee.doe.gov

FY 2006 Budget: $1,550K

Objectives

- Improve the reliability and reduce the cost of dish/engine components and systems.
- Support industry in the commercialization of the technology.
- Perform R&D on dish/engine system components and systems.
- Test, evaluate, and improve the performance of dish/engine components and systems.

Accomplishments

- Operated and maintained six-dish model power plant, cataloging more than 80 development areas.
- Tested extensively to qualify valve vendors for gas management system.
- Completed design for manufacturing and assembly (DFMA) of dish structure, reducing weight by 4,000 pounds.
- Developed systems model of field operation with shading and verified with data.
- Supported hiring and training (mentoring) of Stirling Energy Systems (SES) staff.

Future Directions

Primary activities in FY 2007 will support SES's efforts toward commercialization by:

- Continuing to evaluate the reliability of the six-dish mini power plant.
- Identifying and resolving operational and reliability issues.
- Supporting SES as it starts to deploy a 1-MW power plant.
- Testing components to support manufacturable designs; assisting with other design elements.

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1. Introduction

The DOE dish-Stirling program works closely with SES to improve system performance and reliability and to support deployment by industry in the near term, both of which are explicit goals of the *DOE Solar Program Multi-Year Program Plan*, section 4.2.5.3. This year, our primary goal was to test, baseline the performance (reliability, availability, and efficiency) of six SES 25-kW dish-Stirling systems operating as a plant, and begin to solve reliability issues.

The system is derived from the successful McDonnell Douglas Corporation (MDC) system, but was redesigned to improve cost. SES's objective is to put this system into production within a few years, with a target market of bulk power production in the southwestern United States. Preproduction prototypes will begin deployment in the next year, based on lessons learned at SNL.

SES is pursuing an aggressive deployment of 25-kW dish-Stirling systems for bulk power generation. SES hardware is based on the tried-and-true MDC design, with refinements for reducing manufacturing costs. SES is working closely with an SNL engineering team to maximize the possibility of success.

This year, SNL and SES continued operation of the six-dish Model Power Plant (MPP) at SNL. The purposes of this plant are Reliability Improvement, Component Development, and Stakeholder Demonstrations. These purposes often conflict, and Sandia/DOE must defer to SES priorities because SES owns the hardware.

The success of the MPP has, in part, led to SES signing agreements with Southern California

Edison for up to 850 MW of power and San Diego Gas and Electric for up to 900 MW of power. Operation and improvement of the MPP is critical in the design process for these deployments. SES has made significant progress in developing site plans for these plants. The successes in partnering with these utilities and with companies developing the site plans were enabled by the operational plant at SNL.

2. Technical Approach

SES plans to achieve cost reduction by rapidly moving to high production rates in support of bulk power production. This approach, when compared to smaller prototype installations spread out at many locations, has the advantage of lower cost through production automation early in the product design cycle and lower operations and maintenance (O&M) cost through consolidation of O&M resources.

SNL has provided office, test lab, field, and infrastructure facilities to SES at the SNL National Solar Thermal Test Facility, which provides direct access to technology transfer and expertise and allows the engineers daily hands-on access to the dish systems. This is critical to accelerating the development and deployment path and rapidly training new solar engineers.

Last year, we installed and began operating the six-dish system at SNL. Significant portions of the installation were performed by SES industry partners using SNL-developed procedures, which allowed evaluation of the field installation processes. This fiscal year, SNL worked with SES to continue cataloging reliability issues and developing an understanding of root causes, implementing solutions in a limited set of issues. In addition, we performed data development and collection in support of due diligence efforts. All of the dish system hardware is funded through SES investor financing, while SNL, through the DOE Concentrating Solar Power Subprogram, provides in-kind engineering support, technology transfer, training, and facilities.

3. Results and Accomplishments

The power conversion units (PCUs) included engines under various stages of development, from fully Kockums-built PCUs to SES-built PCUs. The Kockums engines are fully refurbished by SNL and SES. All of the systems were converted this year to the newer SNL-designed packages, featuring commercial-off-the-shelf (COTS) radiators, a robust cavity, and better access to the engine for maintenance. This package design has improved the maintainability and therefore the availability of the systems. All of the systems were operational for each of the stakeholder visits during the year, despite being taken offline at times for experimental upgrades to resolve or diagnose long-term issues. The systems have continued to operate a high level of efficiency, with peak net efficiencies in the range of 27%–29%.

SNL engineers substantially supported SES in a major redesign of the dish structure, necessary to address assembly issues noted at SNL during the MPP installation. The new structure features a one-piece main beam, with high-rate assembly processes engineered into the design to support the needed deployment rates. SNL guided development of a suite of tools that combined Computational Fluid Dynamics wind load analysis, Finite Element structural analysis, and CIRCE2 Optical analysis. This suite of tools allowed detailed evaluation of structural changes, and through an iterative process resulted in a weight reduction of about 4,000 pounds while providing a stiffer support structure. This weight reduction, as well as the manufacturability, is critical in reducing costs to meet SES deployment goals. The modeling suite was validated with structural measurements as well as optical measurement on the MPP dish systems.

Continued operation of the systems has demonstrated that the valve redesign performed last year on the compressor valve has resulted in elimination of a critical failure mode. SNL has continued to lead the investigation of the entire gas management system (GMS), with the intent of understanding the design specifications for each valve and then qualifying vendor-supplied modern valves at each location. This work has been successful, identifying (and rejecting) several vendors with quality control issues and down-selecting to a vendor with good quality and excellent costs. We are continuing to test the vendor's valves and other GMS components, and next year will consolidate the selected components into an integrated GMS with dramatically reduced potential leak points.

SNL has been heavily involved in mentoring and expertise development as SES began hiring aggressively this year, particularly in the controls area. Gary Thomas, the lead controls engineer, passed away at the beginning of the year. We

have developed a list of controls-related issues and a plan to address those issue in the short term (MPP and 1-MW builds) and in production. SES also hired an additional reliability engineer, an excellent VP of engineering, and a systems engineer. These key areas are critical to moving the development process forward.

The systems have accumulated 8,025 dish-hours of operation so far (December 31, 2006). With the added engineering horsepower at SES, and a renewed emphasis on the reliability improvement aspect, we expect to dramatically increase operational hours in the next fiscal year. This added horsepower will better leverage SNL's expertise into product improvement. The systems have performed well, with indicated efficiencies similar to the record of 29.4% net. Several SNL-proposed changes to the engine package have further reduced weight, as well as slightly increasing system performance by improving aperture intercept of reflected light.

SNL has worked closely with SES to develop improved data, information, and control handling and systems. We are embarking on a program to update the Supervisory Control and Data Acquisition system to provide graphical interfaces, historical online data, and efficient field communications. This system is database-driven and will provide views suitable for operators (simple), managers (summary), and engineers (highly detailed). In addition, SNL has continued to develop procedures and tools for capturing human interactions (electronic logbook) and documenting safe operational procedures. The larger number of systems requires diligent efforts to capture and catalog issue areas that will lead to product improvement. SNL has helped deploy a COTS Failure Reporting, Analysis, and Corrective Action System to formalize the process for reliability improvement and root cause analysis.

SNL has developed a field performance model that incorporates dish shading into the loss calculations. This model has led to further understanding of operational limitations due to shading observed in the MPP, and has led to very minor adjustments in the field spacing proposed for the next-generation systems. The model also includes revenue stream calculations, so that optimizations can be influenced by enhanced summer revenues.

SNL has updated its gas-fired test capabilities to support long-term cyclic and continuous testing of the SES engines. This capability will be critical for controls development, allowing full power operation with extensive instrumentation to characterize controls operations. This capability is also important for accelerating tests of seals and other wear components, so that enhanced versions can be developed and deployed.

4. Planned FY 2007 Activities

SNL and SES have successfully installed and continued operating a six-dish MPP to demonstrate the technology, develop new components and methods, and improve reliability in preparation for larger deployments. SES has developed agreements with California utilities for up to nearly 2 GW of installed capacity. The systems have brought unprecedented publicity to both the CSP Subprogram and SES.

SNL will continue to support SES in its aggressive schedule for product improvement and deployment. The company will next install a 1-MW (40-dish) system, followed by high-rate production. The involvement of high-production suppliers and the national laboratories in the deployment of the MPP and the 1-MW plant is key to transitioning to production.

The systems are performing at expected efficiency and power production levels, which helps firm up predictions for large plant production. Initial reliability has been impacted by several known problems. SNL and SES have applied engineering resources to these problems, implemented short-term fixes to the MPP, and outlined development paths for the production version.

The partnership between SNL and SES is a new way of doing business that maximizes the benefit to SES while continuing to leverage the expertise developed at the national laboratories. During FY 2007, we will:

- Continue to operate the six-dish MPP, evaluate performance, and identify reliability issues.
- Continue to resolve known issues with field validation and design assistance feeding the DFMA process.
- Support SES as it starts to deploy a 1-MW power plant.
- Actively participate in the DFMA.
- Develop assembly plant and field-deployable alignment tools to support rapid deployment
- Develop rapid deployment component designs including foundation, dish structures, etc., and test prototypes at SNL.

Parabolic Trough R&D

Performing Organizations: National Renewable Energy Laboratory (NREL)
Sandia National Laboratory (SNL)

Key Technical Contacts: Henry Price (NREL, Primary Contact), 303-384-7437, henry_price@nrel.gov
Doug Brosseau (SNL), 505-844-5218, dabross@sandia.gov

DOE HQ Technology Manager: Thomas Rueckert, 202-586-0942, thomas.rueckert@ee.doe.gov

FY 2006 Budgets: $2,310K (NREL), $500K (SNL)

Objectives

- Support development of near-term parabolic trough technology for central station power generation.
- Support development of advanced technologies for next-generation parabolic trough solar fields, thermal energy storage, and power plant technologies to meet long-term goals of the *DOE Solar Program Multi-Year Technical Plan (MYTP)*.
- Support the expansion of U.S. industry to supply parabolic trough technology.
- Support continued SunLab[1] collaboration on parabolic trough technology development and testing.

Accomplishments

- During FY 2006, initial commercial operation began at the first new parabolic trough plant in nearly 15 years. The plant is owned by Arizona Public Service (APS) and was developed by Solargenix Energy of Raleigh, NC. It is a 1-MWe solar power plant using an organic Rankine power cycle provided by Ormat Technologies of Sparks, NV. The plant uses parabolic trough collector technology developed by Solargenix under a cost-shared R&D contract with DOE/NREL.
- Solargenix began construction of a 64-MW parabolic trough plant in Eldorado Valley, near Boulder City, NV. The plant uses a new second-generation parabolic trough collector design developed under the company's USA Trough Initiative R&D contract during FY 2006. The new collector design provides a number of advantages over the earlier design: it's cheaper, easier to erect, and does not require any alignment of mirrors during assembly. Many of the collectors also use a new improved receiver from Schott Glass. The plant is expected to begin operation in the spring of 2007.
- Industrial Solar Technology (IST) completed phase I of its FY 2004 USA Trough Initiative contract for the development of an advanced low-cost parabolic trough concentrator. The decision was made to proceed to phase II. The contract for phase II was placed at the end of FY 2006.
- SNL has developed and tested a prototype theoretical overlay photographic alignment system for evaluating the alignment of mirrors and receivers on parabolic trough collectors installed in a solar field.
- Latent Structures developed a non-intrusive device to measure gas composition and pressure in a parabolic trough receiver. The system was field-tested and detected hydrogen in a number of receivers installed in the solar field.
- NREL developed a new laboratory test stand for measuring the thermal losses from parabolic trough receivers. The test stand was used to test eight receivers provided by FPL Energy. Four of the eight had shown high glass temperatures in the solar field. Receiver testing found that the receivers that were hot in the solar field had hydrogen present, which caused thermal losses to increase by a factor of four.

[1] SunLab is a collaboration between Sandia National Laboratory and the National Renewable Energy Laboratory in support of the U.S. Department of Energy's R&D activities on concentrating solar power technologies.

- NREL continued development of a new selective coating that appears to meet the long-term selective property goals for parabolic trough receivers. NREL modified its vacuum deposition system to allow codeposition of the materials required to make the coating. Initial samples were deposited with promising results.
- The Video Scanning Hartmann Optical Test (VSHOT) instrument was used to evaluate the accuracy of the new Solargenix SGX-1 concentrator and the improved IST PT-1 concentrator. VSHOT testing was also conducted on Luz LS-2 and LS-3 collectors to provide a baseline for comparison to the new collectors from Solargenix and IST.
- NREL has continued to improve the speed of infrared (IR) imaging of receivers for assessing the thermal performance of receivers in the solar field. NREL imaged the 9,600 receivers in two days at SEGS VI to help FPL Energy categorize receiver performance in advance of a major receiver upgrade program.
- SNL began initial evaluation of alternative molten salt formulations for use as the heat transfer fluid in trough solar fields and thermal storage systems. SNL also developed models and plans to support laboratory testing of freeze protection and recovery approaches in solar fields based on impedance heating concepts.
- Nexant completed work on several tasks to look at the optimum size of parabolic trough plants, the benefit of building plants in a power park, and the impact of dry cooling on cost and performance.

Future Directions

- Continue development of advanced receiver and concentrator technologies to meet long-term *DOE Solar Program MYTP* goals.
- Support development of advanced thermal energy storage technologies.
- Continue building laboratory capability to support trough testing and analysis.

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1. Introduction

Parabolic trough technology is starting to be reintroduced into the marketplace. During FY 2006, the first parabolic trough power plant to be built in 15 years began commercial operation. The 1-MWe Arizona Public Service (APS) Saguaro parabolic trough solar power plant first produced electricity in December 2005 (Fig. 1). Solargenix Energy began construction of a 64-MWe parabolic trough solar power plant in February 2006 that is expected to be completed and start operation in the spring of 2007. Both plants use Solargenix parabolic trough collector designs developed under cost-shared DOE R&D contracts.

In addition, several Spanish parabolic trough projects reached financial closure during FY 2006. These projects will use thermal energy storage technology that was developed by the U.S. Concentrating Solar power Program.

Fig. 1. New APS solar power plant using Solargenix parabolic trough concentrator and Schott receiver

The focus of the DOE parabolic trough R&D program has been to:

- Advance technologies that have an opportunity to be deployed in early projects.
- Encourage the development of advanced technologies that will improve the competitiveness of future parabolic trough plants.

- Encourage expanded U.S. supply in these early plants.
- Develop improved tools, testing capabilities, and the knowledge base necessary to support the needs of a growing U.S. parabolic trough industry.

2. Technical Approach

The parabolic trough R&D effort is broken into four areas in the *DOE Solar Program MYTP*: (1) USA Trough Initiative, (2) solar field technology, (3) thermal energy storage technology, and (4) systems integration.

2.1 USA Trough Initiative
The USA Trough Initiative includes a number of competitive solicitations designed to encourage U.S. industry to develop new technology and services that advance the state of the art of parabolic trough technology. During FY 2006, activities focused on:

- Completion of phase I activities and decisions to progress to phase II for two contracts awarded in FY 2005 to Solargenix Energy and IST for the FY 2004 near-term component manufacturing solicitation.
- Awarding a new contract to PPG for the FY 2005 near-term component manufacturing solicitation.
- Technical support by SunLab to Solargenix and IST.

2.2 Solar Field Technology
The solar field technology agreement focuses on SunLab development of new parabolic trough solar technology and tools for evaluation of trough technology. During FY 2006, SunLab activities focused on:

- Development of an IR camera system for rapid field assessment of receiver performance.
- Developing a new field alignment system for assessing alignment of mirrors and receivers on parabolic trough concentrators.
- Development of a new receiver test stand to accurately test the thermal losses in a laboratory-controlled environment.
- Continued development of advanced selective coating technologies for receivers, with the focus on developing coatings with improved thermo/optic properties and that are thermally stable in air up to 500°C.
- Development of a system to nondestructively test the vacuum on receiver tubes.
- Development of an approach for in-situ injection of an inert gas in receiver tubes.

2.3 Thermal Energy Storage (TES) Technology
The SunLab TES program is responsible for the development of the indirect 2-tank molten-salt TES system that will be used in several parabolic trough solar plants under development in southern Spain. Unfortunately, this TES technology is still more expensive than the U.S. power market will tolerate (about $35–$40/kWht). The objective of the TES R&D effort is to develop next-generation TES technology, which will cost substantially less ($15–$20/kWht). To achieve this goal, the DOE R&D effort focuses on:

- Developing single-tank (thermocline) TES systems.
- Applying TES systems that use inorganic molten salt directly in the solar field.
- Developing advanced new heat-transfer fluids that will lower the cost of the TES system.
- Developing a heat-transfer, fluid-testing program at the SEGS plants and developing the laboratory tests to evaluate the hydrogen concentration in the fluid.

2.4 Systems Integration
This activity focuses on the development of systems-integration tools for evaluation of trough technologies and assessment of program activities. Specific FY 2006 activities included:

- The VSHOT was used to measure the optical accuracy of the Solargenix SGX-1 concentrator, the IST concentrator, and the Luz LS-2 and LS-3 concentrators.
- Nexant completed an analysis of the optimum-size parabolic trough power plant, the cost advantage of building trough plants in a power park, and the performance and cost impact of moving to dry cooling.
- NREL began updating the TroughNet Web site.
- Quarterly milestone reports were generated in support of the CSP FY 2006 Joule milestone.

Budget allocations by task are provided below.

Task Title	FY 2006 /CO* Budget ($K)
USA Trough Initiative	300/0
Solar Field Technology	1,690/150
Thermal Storage Technology	440/100
Trough Systems Integration	380/0

*Carryover from FY 2005

3. Results and Accomplishments

3.1 USA Trough Initiative

During FY2006, Solargenix Energy developed a new second-generation parabolic trough concentrator design that is currently being used in its new 64-MWe parabolic trough plant under construction in Eldorado Valley, near Boulder City, NV. The new Solargenix collector (the SGX-1) is a clear advancement over the company's first-generation collector (DS-1) used at the 1-MWe APS parabolic trough plant completed in 2005. The new collector design has the following improvements:

- The collector uses a new low-cost organic hub design developed by Gossamer.
- The spaceframe has 50% fewer parts than the DS-1, and about 80% fewer fasteners.
- The spaceframe is 30% lighter.
- Field assembly requires one-third of the time.
- The design uses low-cost extruded parts.
- No field alignment of mirrors is required during assembly.
- Simple drilling jigs are used to obtain high tolerances.

These features, combined with the new drive, ball joint assemblies, and the control system developed from earlier contracts, as well as the new improved Schott receiver, mean that the Solargenix collector is now potentially the most advanced and cost-effective parabolic trough collector design for high-temperature commercial solar power plant applications. Figures 2 and 3 highlight the new structure and Gossamer organic hub design.

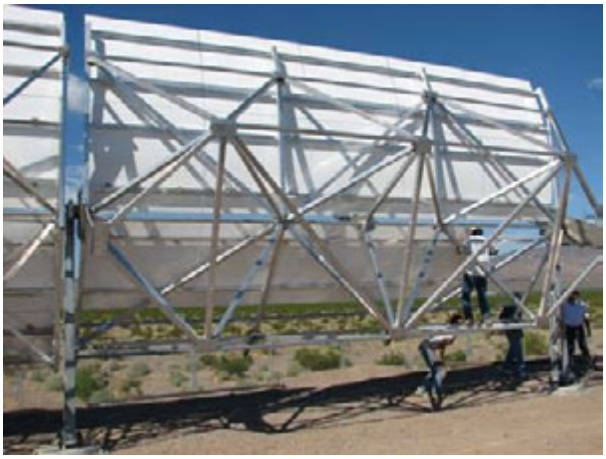

Fig. 2. New Solargenix SGX-1 concentrator with Gossamer organic hubs

Fig. 3. Gossamer organic hubs

Work has been completed on the Solargenix FY 2005 USA Trough Initiative request for letters of interest (LOI) phase I contract. Solargenix has identified the detailed statement of work for phase II of the contract. During FY 2006, the Solargenix Nevada collector test loop was damaged by high winds and Solargenix needed to remove the collectors. A significant amount of the remaining funds on earlier contracts were for adding a thermal loop to the collector test loop. NREL and Solargenix have decided to redirect the money for the thermal loop to pay for the phase II efforts. The phase II work will focus on developing a larger space frame that holds up to four receivers and possibly a wider aperture. This work will also look at reducing the cost of the drive.

IST completed phase I of its USA Trough contract. This effort developed a new design for a parabolic trough collector that rotates around the receiver, potentially eliminating the need for conventional flex hoses or ball joint assemblies. The new design would use a low-cost structure similar to the IST process-heat parabolic trough (PT-1) collector. Part of the effort included developing detailed structural design models (Fig. 4). The models were validated by building several new PT-1 collector models and testing them to failure. Based on these results, the PT-1 design was modified to improve its structural integrity. The structural models were then used to develop a new fixed focal point trough (FFPT) collector that would double the length and aperture of each module. Preliminary designs were developed for the drive and bearing to allow the concentrator to rotate around the receiver. An alternative design was also developed in which the receiver rotated with the collector and required some form of swivel or ball joint at the end of the collector. The SunLab

contract review team decided to move forward with phase II of the IST development. IST negotiated the phase II work effort and will begin work, in the early part of FY 2007, on developing two new full-scale prototypes, one of the FFPTs, and a scaled-up version of the IST PT-1 design.

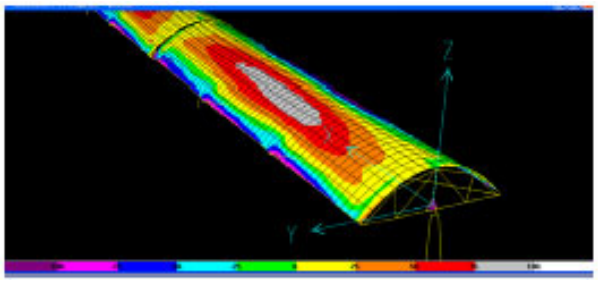

Fig. 4. Finite-element analysis of new IST focal point power trough collector showing predicted stresses in the reflector.

One contract was selected for award from the FY 2005 LOI. Contract selection went to PPG, a large U.S. glass supplier, for development of a new parabolic trough mirror. During contract negotiations, PPG decided not to move forward with the proposed statement of work based on a reprioritization of its internal R&D funds.

FY 2006 Milestones:

- Go/no go decision on Solargenix USA Trough Phase II LOI work. Statement of work and contract extension in place. (6/06)
- Go/no go decision on IST USA Trough LOI Phase II work. Statement of work and contract extension in place. (9/06)

3.2 Solar Field Technology

During FY 2006, SNL conducted field tests of a new prototype system for conducting field alignment checks on parabolic trough collectors. The system, called the theoretical overlay photographic (TOP) alignment system, can be used to check for misalignment of mirrors and receivers. The system concept, shown in Fig. 5, uses a modification of the distant observer approach to assess alignments. In a true distant observer approach, the collector is viewed from a long distance away and the image of the receiver completely fills the image in the mirrors. The TOP system is a variation that observes the collector from a closer distance such that the receiver only fills a portion of the image seen in the mirrors. The TOP system compares where the receiver image actually appears compared to where it should appear if the collector were perfectly aligned. Based on the relative position of the receiver location in the mirror, one can determine any misalignment of mirrors or receivers.

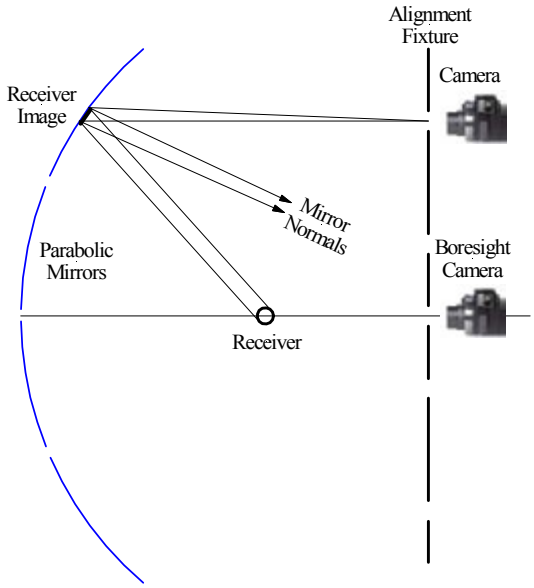

Fig. 5. Theoretical overlay photographic (TOP) alignment conceptual schematic. Accurately positioned cameras on an alignment fixture measure the position of the receiver image in the mirror. The boresight camera is used to align the fixture receiver and mirror module. The mirror is aligned to superimpose the receiver image onto the theoretically calculated image position.

A major advantage of this alignment-system approach is the ability to rapidly take images of trough modules between existing rows of commercial trough collectors. The TOP system, shown in Fig. 6, will allow rapid measurement and characterization of large commercial solar fields.

Fig. 6. Prototype TOP alignment system under test at the APS Saguaro parabolic trough plant.

Work continues on development of a new selective coating that appears to meet the long-term selective property goals for parabolic trough receivers ($\alpha \geq 0.96$ and $\varepsilon \leq 0.07$ @ 400°C). During FY 2005, a first prototype of the coating was deposited using a single-component deposition process. During FY 2006, NREL adapted its vacuum deposition system to allow deposition of two materials at the same time. This allows deposition of two constituent compounds. During FY 2006, new prototype coatings were deposited. The new coating improved the absorptance, but the lack of good layer thickness control resulted in a higher emittance than desired. Work has continued on improving the deposition thickness control.

During FY 2005, NREL developed a technique for evaluating receiver thermal performance in operating solar fields using an IR camera. FPL Energy, the operator of seven of the SEGS plants, found the system to be useful in understanding solar field performance and indicated that it would be a useful tool for periodic monitoring of receiver performance. During FY 2006, an effort was undertaken to improve the speed of field measurements and data analysis to allow a more rapid field survey of receiver condition. Upgrades to the IR system allowed all 9,600 receivers in the SEGS VI solar field to be imaged during a 2-day period. Although, the new system was able to image the field rapidly, the data analysis still took too much time. Additional upgrades are planned for FY 2007 to enable much quicker data assessment.

Latent Structures and NREL developed a new non-destructive device to measure vacuum on receivers while installed in the solar field. The system works because confined gases under low pressure emit characteristic spectra when a high-voltage discharge is allowed to pass through the gases. The characteristic emission wavelengths provide the identity of the gas (qualitative analysis); and the intensity of the emissions are proportional to the amount of gas (quantitative analysis). Field-testing with the device demonstrated that the hot glass failure being observed on many of the receivers at the SEGS plants was due to the presence of hydrogen in the receivers. Figure 7 shows the device and a plasma arc of hydrogen during calibration of the device.

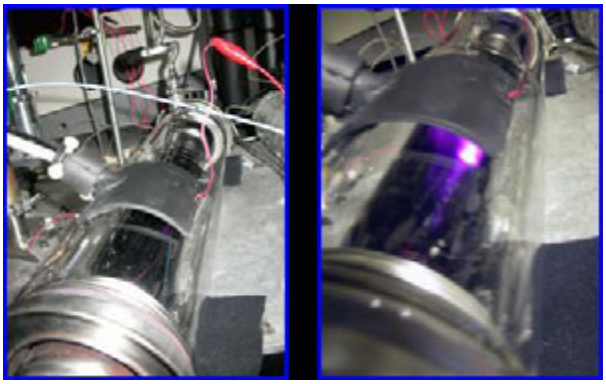

Fig. 7. Device for in-situ field measurement of receiver vacuum (Latent Structures)

During FY 2006, NREL developed a new receiver thermal loss test platform to help accurately evaluate thermal losses from parabolic trough receivers. The test bed is based on approaches used by both Schott and The German Aerospace Center (DLR). The test bed uses electric resistance heaters to heat a receiver up to a simulated steady state temperature. The power required to keep the receiver at a steady state temperature is equal to the thermal losses from the receiver. Figure 8 shows the new thermal test bed.

Fig. 8. New parabolic trough receiver thermal loss test bed

During FY 2006, the plan was to test several new and used receivers on the test bed. However in early FY 2006, FPL Energy requested that NREL test eight Solel UVAC receivers that they had

removed from the solar field. Four of the receivers had exhibited the hot glass failure during operation in the solar field and four were in good condition. All eight receivers were tested. The four hot receivers also exhibited the hot glass temperatures under test and had thermal losses four to five times that of the cool receivers. Figure 9 shows the glass temperature and thermal losses from one good (cold) and one bad (hot) receiver. The vacuum gas measurement system showed that the rapid temperature increase on the hot tube corresponded to the release of hydrogen from the getters in the receiver vacuum annulus.

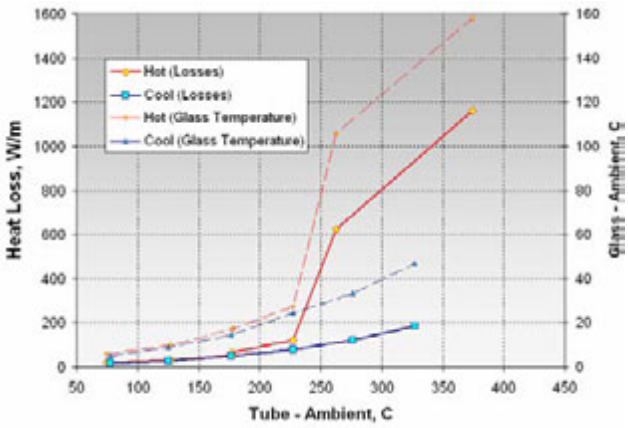

Fig. 9. Parabolic trough receiver thermal loss test bed results

One approach for reducing thermal losses from hydrogen and other gases in the receiver vacuum annulus is to inject a small amount of a thermally inert gas to disrupt the hydrogen heat transfer. SNL has proposed an approach for field repairs of receivers experiencing hydrogen build-up. A gas-filled volume with the correct amount of inert gas is placed on a heat collection element. A laser is used to form the volume to the receiver glass. The laser is then focused to drill a hole through the receiver and the side of the gas-filled volume attached to the receiver, allowing the inert gas to enter the receiver. The laser is then defocused to close the drilled hole. The next step is to prototype the concept.

FY 2006 Milestones:

- Field test of new IR camera system for receiver field performance assessment. (8/06)
- Complete second prototype of advanced selective coating for higher temperatures, improved selective properties, and improved manufacturability. (10/06)
- Report on test results from new receiver test bed. Include comparison of new and old receivers. (delayed to 07/07)
- Field test of device for non-destructive in-situ evaluation of receiver vacuum gas composition. (11/05)
- Field test validation of new alignment jig using modified distant observer approach to evaluate the alignment of mirrors and receivers on a parabolic trough collector module. (10/06)
- Assessment of distant observer technique for evaluation of collector field alignment. (cancelled)

3.3 Thermal Energy Storage Technology

A SunLab and industry team has developed a thermal energy storage development plan for parabolic trough technology. The plan envisions a move to inorganic molten salts, as the heat transfer fluid in the solar field, as the most promising opportunity for cost reduction and improving the overall economics of parabolic trough plants in the future. A trip to visit the Italian National Agency for New Technologies, Energy and the Environment (ENEA) parabolic trough molten-salt test facility is planned for early in FY 2007. The storage team will also meet with DLR to get an update on its concrete and phase-change-material thermal storage activities. The update of the thermal energy storage plan was postponed until after the visits to ENEA and DLR. Due to delays in the start-up of the APS 1-MWe trough plant and changes in the rules for the Arizona renewable energy standard, only limited discussions with APS took place during FY 2006 on initiating the thermocline storage test.

The advanced heat transfer fluid development efforts are looking for new organic fluids that have sub-atmospheric vapor pressures at operating temperatures, low freeze point, and higher (greater than 400°C) upper temperature operating limits. Although a number of potentially attractive organic fluids have been identified, it is the thermal stability at temperatures around 400°C that limits use of most fluids. During FY 2006, the advanced fluid work focused on understanding the thermal decomposition mechanisms for Therminol VP-1. The decomposition of the heat transfer fluid is important, not only because of replacement cost of the fluid, but also because decomposition of the fluid results in hydrogen being present in the fluid, which is an issue for maintaining the vacuum in the receiver. A number of possible degradation mechanisms have been identified. Based on this

knowledge, several new polyphenyl compounds are being evaluated for use. Unfortunately, the polyphenyl compounds tend to have a high freeze point, so work is progressing on evaluating eutectic mixtures to determine if the freeze point can be reduced to an acceptable level.

Another option for advanced heat transfer fluids is the identification and development of alternative inorganic molten salt formulations. Current formulations, while offering many advantages over the therminol oil currently used in the SEGS plants, have distinct disadvantages. Primary among these are high freezing temperatures, higher cost, and potential unidentified material interaction issues. Testing completed at SNL during FY 2002 through FY 2004 identified both the potential benefits associated with improved molten salt formulations as well as some of the key issues related to their use in parabolic trough solar fields. Planning in FY 2005 and efforts in FY 2006 were focused on investigating a large suite of potential nitrate and nitrite salt constituents that might be combined to yield favorable heat transfer fluid properties at reasonable cost. Detailed plans were written to continue a phased development program during FY 2007. At the same time, freeze protection and recovery from freeze events in solar fields will remain a key issue even with improved salt formulations that exhibit lower freeze points. As such, simple modeling of likely freeze events was completed in solar fields that will contain heat collection elements with widely variable conditions and heat loss characteristics. This modeling identified the need for a comprehensive testing program involving freeze protection and recovery methods based on impedance heating designs. This testing will occur during FYs 2007 and 2008.

FY 2006 Milestones:

- Advanced heat transfer fluid R&D progress review and development plan. (9/06)
- Updated molten-salt TES plan. (12/06)

3.4 Systems Integration

SunLab is working to develop a better understanding of the cost and performance of the original Luz parabolic trough concentrators in an effort to establish a clear baseline cost and performance for comparison to new collector designs. In FY 2006, FPL Energy allowed NREL to VSHOT test the LS-2 and LS-3 collectors at two of its sites. The LS-2 and LS-3 concentrators demonstrated slope errors of 2.8 to 3.0 mrads. Figure 10 shows the VSHOT testing at SEGS IX.

Fig. 10. Optical testing of LS-3 concentrator at SEGS IX with VSHOT

Nexant, Inc., completed an analysis of the optimum size parabolic trough power plant, the cost advantage of building trough plants in a power park, and the performance and cost impact of moving to dry cooling. The optimum size for a parabolic trough plant appears to be on the order of 200 to 250 MWe with current technology, depending on whether thermal energy storage is included. The study found that building four 250 MWe plants together could reduce the cost of energy by about 10% to 12%. Switching to dry cooling increased the cost of energy by about 7% to 10%, depending on climate and other factors. All three task reports can be downloaded from NREL's publication database.

During FY 2006, NREL began an update of the TroughNet Web site. A major effort is being pursued to get all subcontractor technical reports updated and placed on the Web. The technical content is being updated to reflect the current status of parabolic trough technology. TroughNet will be moved from the EERE to the NREL Web site. TroughNet is currently scheduled to be updated by the second quarter of FY 2007.

Quarterly milestone reports were generated in support of the Concentrating Solar Power (CSP) FY 2006 Joule Milestone. The Joule metric had both cost of energy and annual solar to electric efficiency metrics. The parabolic trough technologies being installed in the 64-MWe Nevada Solar One power plant, Solargenix SGX-1 parabolic trough collector, and Schott PTR70 parabolic trough receiver are used to evaluate progress toward the milestones listed above. The table below shows the current cost and performance milestone goals as well as the current status of commercial parabolic trough technology.

The table shows that the current commercial parabolic trough technology exceeds both the Joule cost metric and DOE annual solar-to-electric performance milestones. This is in large part due to the aggressive efforts by industry to implement improved technology in their commercial products. The Solar Energy Technologies Program R&D efforts in recent years have played an important role in achieving these results. The cost of electricity is also very sensitive to the debt interest rate. With recent interest rate increases, we felt that the levelized cost of energy (LCOE) calculation should also reflect a more current debt interest rate. The following table shows that the technology meets the milestone metric goals even with today's higher interest rates.

FY 2006 CSP Joule Metric

Milestones	Goal	Commercial Technology	
Debt Cost %	6%	6%	8%
Real LCOE (2004$)	12-14 ¢/kWh	10.8 ¢/kWh	12.1 ¢/kWh
Annual Solar-to-Electric Efficiency	11.9%	14.0%	

FY 2006 Milestones:

- Initial revision of updated TroughNet Web site implemented on nrel.gov server. (delayed until FY 2007)
- Draft report of trough baseline data and modeling assumptions. (9/06)

4. Planned FY 2007 Activities

Key activities planned for FY 2007 include:

- Phase II of USA Trough Initiative near-term component manufacturing contracts with IST and Solargenix will build prototypes of new concentrators.
- VSHOT testing of new concentrators developed under USA Trough Initiative. (9/07)
- Modify VSHOT to perform three-dimensional mapping of mirrors. (03/07)
- Field demonstration of new TOP concentrator optical alignment tool. (09/07)
- Complete receiver testing of new and used receivers with new receiver thermal loss test rig. (07/07)
- Continue implementation and optimization of co-deposition prototype samples of new high-temperature selective coating. (09/07)
- Initiate program to test thermocline storage system at APS 1-MWe plant.
- Evaluation and development of inorganic salt compositions for use as direct thermal energy storage fluid.
- Initiate testing of receivers with molten salt to evaluate their freeze/thaw behavior.
- Evaluate polyphenyl compounds for use as lower pressure and higher temperature heat transfer fluids.

5. Major FY 2006 Publications

Canada, S.; Brosseau, D.A.; Price, H. (2006). "Design and Construction of the APS 1-MWe Parabolic Trough Power Plant." Paper No. ISEC2006-99139. Morehouse, J.H. and Krarti, M., eds. *Solar Engineering 2006: Proceedings of the ASME 2006 International Solar Energy Conference* (ISEC2006), 9–13 July 2006, Denver, Colorado.

Hurt, R.; Yim, W.; Boehm, R.; Hale, M.J.; Gee, R. (2006). "Advanced Parabolic Trough Field Testing—Real Time Data Collection, Archiving, and Analysis for the Solargenix Advanced Parabolic Trough." Paper No. ISEC2006-99078. Morehouse, J.H. and Krarti, M., eds. *Solar Engineering 2006: Proceedings of the ASME 2006 International Solar Energy Conference* (ISEC2006), 9–13 July 2006, Denver, Colorado.

Marcotte, P.; May, K.; Forristall, R. (2006). "Development of the Focal Point Power Trough (FPPT): An Advanced Parabolic Trough Concentrator for Electricity Generation." Campbell-Howe, R., ed. *Proceedings of the Solar 2006 Conference,* 9–13 July 2006, Denver, Colorado (CD-ROM).

Kelly, B. (2006*). Nexant Parabolic Trough Solar Power Plant Systems Analysis; Task 1: Preferred Plant Size,* 20 January 2005–31 December 2005. 59 pp.; NREL Report No. SR-550-40162.

Kelly, B.; Kearney, D. (2006). *Parabolic Trough Solar System Piping Model: Final Report,* 13 May 2002–31 December 2004. 23 pp.; NREL Report No. SR-550-40165.

Kelly, B. (2006). *Nexant Parabolic Trough Solar Power Plant Systems Analysis; Task 3: Multiple Plants at a Common Location,* 20 January 2005–31 December 2005. 32 pp.; NREL Report No. SR-550-40164.

Kelly, B. (2006). *Nexant Parabolic Trough Solar Power Plant Systems Analysis; Task 2: Comparison of Wet and Dry Rankine Cycle Heat Rejection,* 20 January 2005–31 December 2005. 27 pp.; NREL Report No. SR-550-40163.

Kolb, G.J.; Hassani, V. (2006). "Performance Analysis of Thermocline Energy Storage Proposed for the 1 MW Saguaro Solar Trough Plant." Paper no. ISEC2006-99005. Morehouse, J.H. and Krarti, M., eds. *Solar Engineering 2006: Proceedings of the ASME 2006 International Solar Energy Conference* (ISEC2006), 9–13 July 2006, Denver, Colorado.

Parabolic Trough Solar Thermal Electric Power Plants. (2006). 2 pp.; NREL Report No. FS-550-40211; DOE/GO-102006-2339.

Prabhu, E. (2006). *Solar Trough Organic Rankine Electricity System (STORES) Stage 1: Power Plant Optimization and Economics*, November 2000–May 2005. 67 pp.; NREL Report No. SR-550-39433.

Price, H.; Forristall, R.; Wendelin, T.; Lewandowski, A.; Moss, T.; Gummo, C. (2006). "Field Survey of Parabolic Trough Receiver Thermal Performance." Paper No. ISEC2006-99167. Morehouse, J.H. and Krarti, M., eds. *Solar Engineering 2006: Proceedings of the ASME 2006 International Solar Energy Conference* (ISEC2006), 9–13 July 2006, Denver, Colorado.

Wendelin, T.; May, K.; Gee, R. (2006). "Video Scanning Hartmann Optical Testing of State-of-the-Art Parabolic Trough Concentrators." Paper No. ISEC2006-99172. Morehouse, J.H. and Krarti, M., eds. *Solar Engineering 2006: Proceedings of the ASME 2006 International Solar Energy Conference* (ISEC2006), 9–13 July 2006, Denver, Colorado.

Diver, R., Moss, T (2006). "Practical Field Alignment of Parabolic Trough Solar Concentrators," Paper No. ISEC2006-99146. Morehouse, J.H. and Krarti, M., eds. *Solar Engineering 2006: Proceedings of the ASME 2006 International Solar Energy Conference* (ISEC2006), 9–13 July 2006, Denver, Colorado.

6. University and Industry Partners

The following organizations partnered in the project's research activities during FY 2006.

Organization/ Principal Investigator	Location/e-mail	Description/Title of Research Activity	FY 2006 ($K)	Cost Share
Solargenix Energy Nicholas Potrovitza	Raleigh, NC randycgee@comcast.net	USA Trough: Near-Term Component/ Subsystem Development – Advanced Parabolic Trough Concentrator Components and Subsystems, Phase II	(299)*	20%
Industrial Solar Technology Ken May	Golden, CO industrialsolar@qwest.net	USA Trough: Near-Term Component/ Subsystem Development – Advanced Parabolic Trough Concentrator, Phase II	220	55K
Nexant Bruce Kelly	San Francisco, CA bdkelly@nexant.com	Dry cooling analysis, power plant size optimization study, APS thermocline TES engineering design and cost	100	0
Latent Structures, LLC Dr. Robert Meglen	Boulder, CO bmeglen@comcast.net	Development of field instrument non-intrusive measurement of hydrogen in trough receiver annulus	30	0
Arizona Public Service Scott Canada	Phoenix, AZ scott.canada@aps.com	Planned for use in thermocline storage test to begin in FY 2007.	350	20%

* Funded with redirected funds from prior year (FY 2004–2005) contracts from CSP ($243K) and Nevada Renewable Earmark ($56K).

Advanced Optical Reflector R&D

Performing Organizations: National Renewable Energy Laboratory (NREL)

Key Technical Contact: Cheryl Kennedy, 303-384-6272, cheryl_kennedy@nrel.gov

DOE HQ Technology Manager: Thomas Rueckert, 202-586-0942, thomas.rueckert@ee.doe.gov

FY 2006 Budget: $130K

Objectives

- The cost of the solar collector technologies needs to be reduced by half to achieve the long-term goals of developing parabolic-trough power plants, power towers, and dish-Stirling systems capable of competing on a cost competitive basis with conventional fossil power technologies as dispatchable intermediate power generation in the wholesale power market (levelized energy cost [LEC] $0.04 to $0.06/kWh). For mirrors, this is accomplished through technology advances by moving from heavy glass mirror reflectors to lightweight front-surface reflectors that include surface coatings to reduce soiling.
- Develop advanced reflector materials that are low in cost (less that $1/ft^2 or $10.76/m^2) and maintain high specular reflectance (90%–95% into a 4-mrad cone angle) for long lifetimes (10 to 30 years) under severe outdoor environments.
- Test the durability of optical materials to determine lifetime of solar reflector materials.

Accomplishments

- Continued to perform durability testing of optical materials and published results of durability testing of several mirror types.
- Provided significant industry support about reflectors to the concentrating solar power (CSP) and concentrating photovoltaic (CPV) industries.

Future Directions

- Continue durability testing of optical materials to determine lifetime of solar reflector materials.
- Analyze and publish results of testing of thin-glass mirrors applied to CSP technologies.
- Analyze and publish status of reflector materials.

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1. Introduction

Commercialization of concentrating solar power (CSP) technologies requires the development of advanced reflector materials that are low in cost and maintain high specular reflectance for lifetimes of 10 to 30 years under severe outdoor environments. The *DOE Solar Program Multi-Year Technical Plan* targets cost reductions of up to 50% for the solar concentrator. These goals should be achieved through technology advances such as lightweight front-surface reflectors that include anti-soiling coatings. The objective of this research is to identify new, cost-effective advanced reflector materials that are durable with weathering.

2. Technical Approach

Candidate reflector materials are identified based on their potential for low cost and high optical performance and durability. All candidate materials are optically characterized prior to exposure testing and as a function of exposure time to assess optical durability. These mirrors are subjected to accelerated or outdoor weathering at a variety of geographically diverse exposure sites.

3. Results and Accomplishments

- Provided status of test results of candidate solar mirror samples and identified promising candidates. (11/06)
- Provided significant industry support about reflectors to CSP and concentrating photovoltaics (CPV) industry.

3.1 Glass Mirrors

Glass mirrors have excellent durability in terms of reflective layer corrosion, are readily available, have the confidence of the solar manufacturing industry, and are commercially deployed. However, they are heavy, fragile, and require expensive slumped glass for curved shapes.

Trough mirrors (used in commercial solar plants) manufactured by Flabeg have been very durable; they use silvered thick, slumped low-iron glass that is protected with a proprietary multilayer paint system designed for outdoor exposure (see Fig. 1). Flabeg reported to NREL they converted their mirror line to 4- or 5-mm glass and a new low-lead paint system in FY 2003, in which the lead was reduced to the point that durability remained equivalent. The base paint of the three-layer paint system contains 2.5% lead, the intermediate paint contains 1% lead, and the white top coat is acrylic based with high UV stability. Side-by-side exposure testing of the original and new construction began in the second quarter FY 2004. After 2 years of accelerated Weather-Ometer (WOM) and outdoor exposure in Colorado, the new mirrors with the reduced lead paint system are performing similarly to the original mirrors. [The Atlas Ci65a WOM uses a xenon-arc light source with filters designed to closely match the terrestrial air-mass 1.5 solar spectrum and operates continuously at 60°C and 60% relative humidity (RH), with light levels about equal to outdoor exposure. A single day of testing (24 hours) is roughly equivalent to three times the outdoor exposure in terms of light intensity.

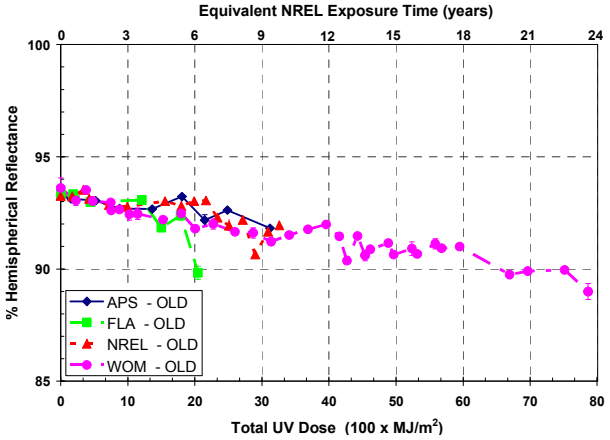

Fig. 1. Loss of solar-weighted reflectance of original Flabeg thick-glass mirrors as function of accelerated WOM and outdoor exposure at Phoenix, AZ (APS), Miami, FL (FLA), and Golden, CO (NREL), in total UV dosage.

Two significant changes in mirror manufacturing have recently occurred in the classical wet-chemistry process because of environmental concerns. The first is the method of forming a copper-free reflective mirror, and the second is the use of lead-free paints. The copper-free process requires stringent quality control, and the lead-free paints were developed for interior applications. Consequentially, the basic mirror composition of commercially available mirrors is radically different from historically durable solar mirrors, and alternatives are limited because the glass, chemical silvering, and mirror paint industries have consolidated.

Testing of samples of Pilkington (4-mm copper-free) mirrors and "Spanish" (Cristaleria Espanola S.A; i.e., Saint Gobain) glass mirrors (3 mm, copper-free, and lead-free paint), bonded to steel with four different candidate adhesives, was initiated in FY 2001 for possible use at Solar Tres. Neither Pilkington nor Spanish mirrors exposed outdoors for 72 months show degradation up to this point (see Fig. 2). Pilkington mirrors exhibit better optical durability than the Spanish mirrors in accelerated WOM exposure testing. Spanish mirrors degraded 19.0%, whereas Pilkington mirrors degraded 2.8% after 53 months of accelerated WOM exposure. Adhesive-related degradation is more prevalent with Spanish glass mirrors. Depending on the adhesive used to bond the mirror, Spanish mirrors degraded 4.7% to 12.0%, whereas Pilkington mirrors degraded 1.7% to 2.9% after 50 months of accelerated WOM exposure.

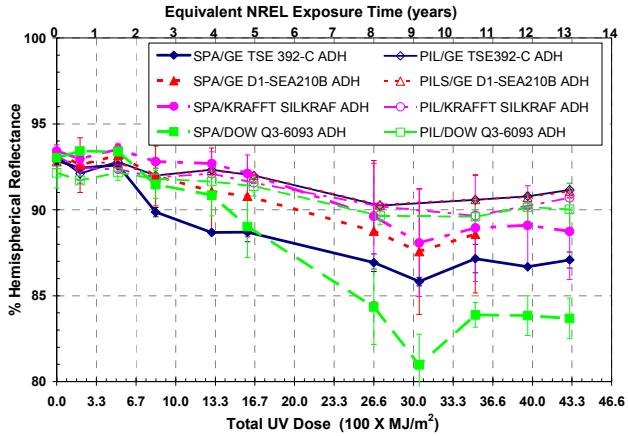

Fig. 2. Loss of solar-weighted reflectance of thick Pilkington and Spanish reflectors with copper-free back layer, Pb-free paint, and four adhesives as a function of WOM exposure.

Thin-glass mirrors also use traditional wet-silvered processes on thin (<1 mm), relatively lightweight glass. The choice of adhesive has been observed to affect the performance of weathered thin-glass mirrors, and corrosion has been observed in deployed mirrors, including mirrors using the new copper-free protective layer and lead-free paints. In addition, some thin-glass silvered copper-free, lead-free mirrors sold for outdoor applications have not passed the minimum ASTM standards (i.e., 120-h CASS, 480-h salt spray, and damp heat) to qualify for indoor applications.

A matrix of sample constructions was prepared to identify the most promising combinations of paints and adhesives for use with solar reflectors. After more than three years of exposure in the WOM and in damp heat, data indicate that the mirror performance strongly depends on the back protection. (The BlueM damp-heat chamber operates continuously at 80°C and 80% RH, and the samples are not exposed to the light. The BlueM does not have the same known acceleration factor as the WOM, but from experiments the acceleration factor may be as high as roughly 10X WOM.) For the copper-free constructions, the addition of epoxy and polyurethane back protection appears to be a poor choice because when these constructions failed, they typically failed catastrophically by silver/paint delamination. Between the mirrors incorporating the new copper-free process, the Glaverbel mirror (Belgium) tended to outperform the Naugatuck mirror (U.S.) in the mirror matrix experiment. However, this could be because, at the time the mirrors were acquired, Glaverbel had more experience than Naugatuck in manufacturing mirrors with the copper-free technique.

CPV manufacturers have expressed significant concern regarding the durability of thin-glass mirrors made with copper-free and lead-free paint systems. Naugatuck Glass responded to the mirror degradation issue in FY 2006 and provided copper-free mirror samples for testing with a two-coat, lead-free paint system plus moisture and adhesive-resistant back protection, instead of the one-coat paint system previously used in its manufacturing line. Preliminary exposure testing results appear encouraging and testing is ongoing (see Fig. 3).

Although glass mirrors with copper back layers and heavily leaded paints have been considered robust for outdoor use, the new copper-free, back layer and lead-free paint systems were designed for interior mirror applications, and their outdoor durability must be determined.

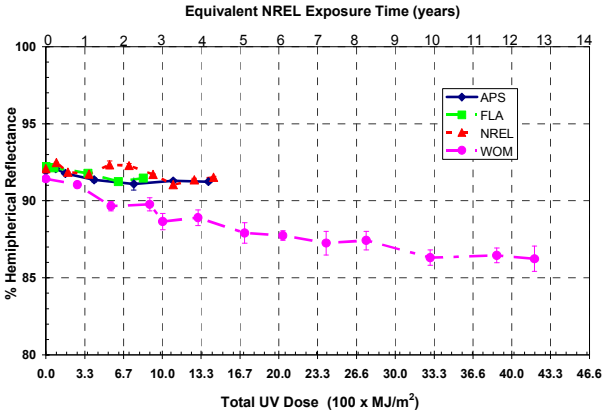

Fig. 3. Loss of solar-weighted reflectance of Naugatuck thin-glass mirrors with Cu back layer and Pb-free paint as a function of APS, FLA, NREL, and WOM exposure.

3.2 Aluminized Mirrors

Aluminized reflectors use a polished aluminum substrate, an enhanced aluminum reflective layer, and a protective oxidized topcoat. The major concern has been poor durability of such materials in urban and industrialized (polluted) locations. An improved anodized aluminum mirror incorporated a protective polymeric overcoat onto aluminized aluminum. However, the specularity degraded with outdoor exposure at Arizona, Florida, and Colorado (NREL) and with accelerated exposure in the WOM. Alanod stopped selling this material in FY 2004 for outdoor use because of problems associated with the delamination of the overcoat. Alanod worked to improve the reflector durability and its in-house testing capability. The fluoropolymer overcoat was replaced with a nanocomposite oxide protective layer. New samples received in FY 2005 are undergoing testing. Alanod reintroduced the product for sale as Miro-Sun in early FY 2006, and the material is commercially available from Alanod in Germany for ≈$2.50/ft^2. The initial solar-weighted hemispherical reflectance is ≈91.8%; initial specular reflectance at 25 mrads is ≈83.7% and at 7 mrads is ≈63.9%. Preliminary exposure testing results appear encouraging and testing is ongoing (see Fig. 4). Alanod is now working to develop a silvered solar reflector likely to be called Miro-Silver.

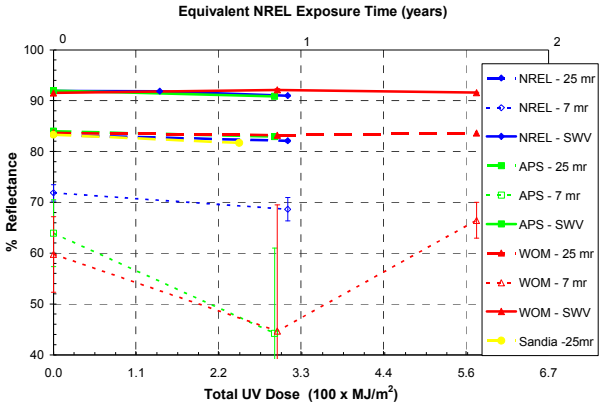

Fig. 4. Loss of solar-weighted reflectance, 25- and 7-mradian specular reflectance at 660 nm of Alanod Miro-Sun aluminized reflectors as a function of APS, NREL, and Sandia outdoor exposure and accelerated WOM exposure.

3.3 Silvered Polymer Reflectors

A polymeric solar reflector was developed through collaborative research with ReflecTech. In FY 2001, a small pilot run demonstrated that production could be achieved using standard commercial film converter equipment. This initial pilot-run material shows minimal loss in solar-weighted reflectance after 5 years of real-time outdoor exposure in Golden, CO. In addition, there was no significant loss in solar-weighted reflectance for samples after the equivalent of 10 years of accelerated outdoor exposure in ACUVEX (natural sunlight in Phoenix, AZ, concentrated seven to eight times with a Fresnel-reflector while samples are cooled with a fan to near-ambient conditions and sprayed with deionized water 8 minutes per natural sun hour). However, WOM results showed significant reflectance loss earlier than anticipated. Prototype materials to test modifications to the baseline construction were produced. These tests were successful in identifying changes to the baseline construction that dramatically improved the WOM durability of the reflective film. Some of these improvements were then incorporated into a new pilot plant production run delivered late FY 2004; initial hemispherical and specular reflectivity were low due to a vacuum problem during the manufacturing process. ReflecTech produced and delivered samples from its most recent pilot-plant production run (ReflecTech [06-48,06-60]) with improved hemispherical and specular reflectivity in the second quarter of FY 2006; the durability testing is ongoing (see Fig. 5). The ReflecTech material is being field-tested at SEGS and SolarGenix Power Roof system and has been installed in 685 mirror modules on a JX Crystals 100-kW CPV project in China. Other solar manufacturers have expressed an interest.

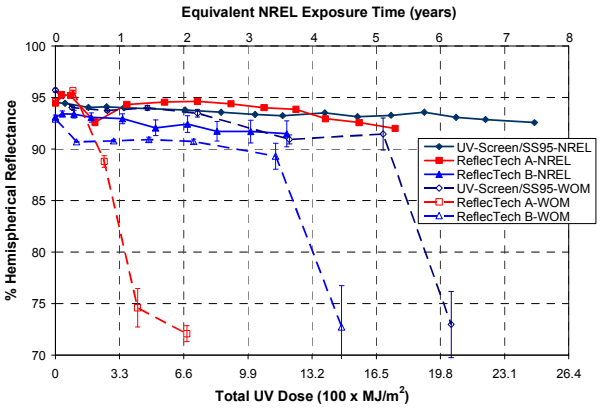

Fig. 5. Loss of solar-weighted reflectance of ReflecTech prototype, initial pilot run, and most-promising variation to baseline construction as a function of outdoor exposure in Colorado and accelerated WOM exposure.

Progress has been made on advanced solar reflector research, but development work has been severely limited based on a lack of funding. Durability testing of reflectors supplied by industry is ongoing. Glass, ReflecTech, and Alanod mirrors are commercially available and, based on accelerated exposure testing, should meet the 10-year lifetime goals. However, predicting an outdoor lifetime based on accelerated exposure testing is risky. Recently, the construction of all of the solar reflectors has significantly changed. Because of this, all of the solar reflectors commercially available have been in outdoor real-time exposure testing for less than 3 years.

4. Planned FY 2007 Activities

Continue optical characterization of advanced reflector materials, accelerated and outdoor testing of commercial and experimental reflector materials, and industry support.

- Memo report on testing of thin-glass mirrors applied to CSP technologies (03/31/07)
- Summary report of status of reflector materials. (08/31/07)

5. Major FY 2006 Publications

Kennedy, C.E.; Terwilliger, K.; and Warrick, A., 2006, "Summary of Status of Most Promising Candidate Advanced Solar Mirrors," *CSP FY 2006 Milestone Report*.

CSP Systems Analysis

Performing Organizations: National Renewable Energy Laboratory (NREL)
Sandia National Laboratories (SNL)

Key Technical Contacts: Mark Mehos (NREL), 303-384-7458, mark_mehos@nrel.gov
Tom Mancini (SNL), 505-844-8643, trmanci@sandia.gov

DOE HQ Technology Manager: Thomas Rueckert, 202-586-0942, thomas.rueckert@ee.doe.gov

FY 2006 Budgets: $520K (NREL), $255K (SNL)

Objectives

- Provide support for the Concentrating Solar Power (CSP) Subprogram analysis efforts related to implementation of 1000 MW of concentrating solar power in the Southwestern United States through the Western Governors' Association (WGA).
- Support CSP-specific analysis related to implementation of the Systems-Driven Approach within the DOE Solar Program.
- Support DOE and Energy Information Administration analysis requests on as-needed basis.

Accomplishments

- Continued analysis in support of the WGA Solar Task Force, with an emphasis on analysis in support of a proposed southwest utility consortium.
- Developed geographical information system (GIS)-based tools designed to support requests for siting analyzes from public and private institutions.
- Developed initial version of CSP Jobs and Economic Development Impact model.
- Completed development of Concentrating Solar Deployment System market penetration model.

Future Directions

The primary activity for the systems analysis task in FY 2007 will be to continue support implementation of concentrating solar power in the Southwest. Specific directions will include:

- Providing continued analytical support to WGA Solar Task Force.
- Continuing interactions in the West with Arizona, New Mexico, Nevada, Texas, and Colorado in support of developing further CSP opportunities in those states.
- Continuing development of tools (GIS, market analysis, economic impact analysis) for use in supporting the activities described above.

---

1. Introduction

The 1000 MW CSP project was initiated in FY 2002 based on a Congressional request to DOE to investigate the "feasibility of 1000 MW of concentrating solar power in the Southwest by 2006." The original charge has grown and now involves a number of activities including: outreach to the Southwestern states; support of state-level activities in New Mexico, California, and Colorado, and analysis in support of the Western Governors' Association (WGA) 30 GW Clean Energy Initiative.

The focus of the 1000 MW CSP Initiative is to accelerate the commercialization of concentrating solar power generation technologies. Analysis shows that cost reductions needed for the technologies to be competitive in central power generation markets will result from a combination of R&D advances, system scale-up, and learning/deployment. The 1000 MW CSP Initiative addresses cost reductions resulting from deployment.

This project links directly to the DOE Energy Efficiency and Renewable Energy (EERE) and Solar Program missions to "bring clean, reliable, and affordable energy technologies to the marketplace" and to "increase the viability and deployment of renewable energy technologies." Cost reductions due to learning and deployment, the primary outcome of this project, directly

support the Solar Program's long-term goal of achieving wholesale, central power generation from solar energy at costs of $0.05–$0.08/kWhr.

2. Technical Approach

The report on the potential of 1000 MW of CSP power in the West was completed and submitted to Congress in August of 2002. During the preparation of this report, DOE formed the 1000 MW Team with the purpose of educating energy offices and professionals on the potential of CSP power in the Southwestern states. This "road show" sought to provide information on the characteristics of CSP technologies, the potential in each of the states, and the benefits that would accrue from its implementation. In April of 2004 at the North American Energy Summit in Albuquerque, New Mexico, the Western Governors' Association resolved to evaluate diversification of Western energy resources. The mechanism for doing this is the 30 GW Clean Energy Initiative for the West, which includes a declaration to "establish a stakeholder working group to develop options for consideration by the governors in furtherance of the 1,000 MW Initiative." The April 2004 resolution rolled up the 1000 MW Initiative under the umbrella of the 30 GW WGA Study. In FY 2005, we provided significant support to the WGA analysis efforts, through a combination of in-house and subcontracted technical, policy, and market analyses. This effort continued in FY 2006 by working with the WGA Solar Task Force to produce a final draft of the task force report (June 2006 deliverable), to continue analysis in support of task force efforts, and to represent this analysis to Southwest stakeholders, with a particular emphasis on Arizona where a consortium of Southwest utilities, with Arizona Public Service (APS) leading the effort, are considering collaborating on the development of a large-scale (up to 250 MW) CSP project.

Budget allocations by task are provided below.

Task Title	FY 2006 Budget ($K)
1000 MW Initiative Support - NREL	$520K
1000 MW Initiative Support - SNL	$255K

3. Results and Accomplishments

The technical work plan for FY 2006 focused on:
(1) Continued support to the WGA Solar Task Force
(2) Analytical support for Southwest stakeholders
(3) Development of analytical tools to support these efforts.

3.1 Continued Support to WGA Solar Task Force

- Supported completion of a final draft of the WGA Solar Task Force report. (see: http://www.westgov.org/wga/initiatives/cdeac/Solar-full.pdf)
- Met with state stakeholders, primarily Arizona, to provide overview of key WGA Task Force findings.

3.2 Analytical Support to Southwest Stakeholders

- Provided technical support to APS development of a Request for Information to industry for interest in developing a regional Concentrating Solar Power Project.
- Provided analytical support to APS and participating consortium utilities on the impact of project size, incentives, and financing options on the cost of CSP

3.3 Development of Analytical Tools to Support These Efforts

- Completed development of initial phase of Concentrating Solar Deployment System (CSDS) Model, with emphasis on analyzing parabolic systems with thermal storage. The model was used to investigate the impact of policy scenarios on the penetration of CSP in U.S. markets (see Fig. 1).
- Continued development of in-house GIS-based siting tools designed to support public (state and local stakeholders) and private industry requests for siting analysis (see Fig. 2).
- Developed initial draft of Jobs and Economic Development Impact (JEDI) Model.

Fig. 1. CSP capacity deployment by region in 2030 based on output from the Concentrating Solar Deployment System Model.

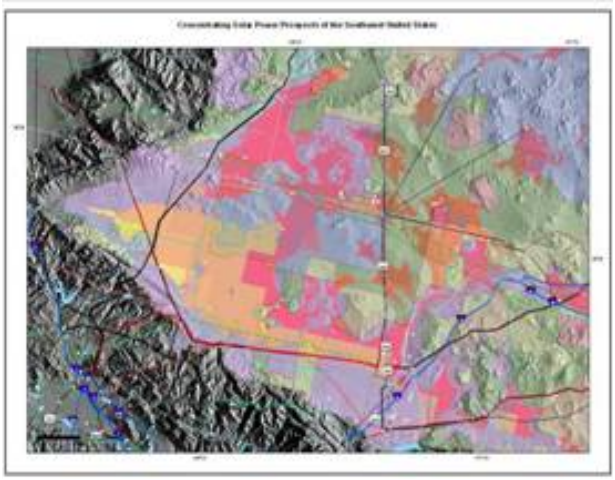

Fig. 2. GIS siting analysis based on utility request for support

4. Planned FY 2007 Activities

The activities of this task have resulted in an increased awareness of the technologies by energy decision makers in the Southwestern United States. In FY 2007, we will continue to provide analysis in support of stakeholders interested in deploying significant levels of CSP in the Southwest.

Specific activities identified in the FY 2007 Annual Operating Plan include:

- Support for analysis of transmission issues impacting implementation of CSP in the Southwestern United States.
- Continued development and subsequent use of the CSDS model for investigating the impact of policy and cost-reduction scenarios on penetration of CSP in the Southwestern United States.
- Continued discussions and analysis in support of implementing CSP within "Solar Development Zones."
- Continued development of a mapping tools for identifying candidate locations for CSP plants.
- Continued development of a JEDI model to support analysis of the economic impact of CSP for specific locations in the Southwestern United States.
- Siting of weather ground stations for key direct normal incident resource sites in the Southwestern United States.

5. Major FY 2006 Publications

Final Report of the Western Governors' Solar Task Force, January 2006.

Black and Veatch, "Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California," Final Report, April 2006, NREL Report No. SR-550-39291.

N. Blair, M. Mehos, W. Short, and D. Heimiller, "Concentrating Solar Deployment System (CSDS) –A New Model for Estimating U.S. Concentrating Solar Power (CSP) Market Potential," July 2006, NREL Report No. CP-620-40525.

M. Mehos and D. Kearney, "Tackling Climate Change in the U.S.: Potential Carbon Emissions Reductions from Concentrating Solar Power by 2030," presentation at ASES Solar 2007, draft report.

6. University and Industry Partners

The following organizations partnered in the project's research activities during FY 2006 (no cost share).

Organization/ Principal Investigator	Location/e-mail	Description/Title of Research Activity	FY 2006 ($K)
Morse Associates, Inc. Fred Morse	Washington, D.C. fredmorse@morseassociatesinc.com	Consulting for government and utilities on CSP applications and marketing policy	150
MRG and Associates Marshall Goldbert	Nevada City, CA mrgassociates@earthlink.net	Development of CSP JEDI model	8.4

Solar Heating and Lighting

The Solar Heating and Lighting (SH&L) effort consists of research and technology development programs for solar water heaters and hybrid solar lighting systems. The program works with industry, the national laboratories, and others to develop and demonstrate systems and components that will improve the reliability and reduce the cost of these solar systems. The Technical Assistance Program aids builders, manufacturers, and others in designing and installing solar water heating systems. To ensure that safe and reliable systems are installed, the program supports the testing and certification activities of the Solar Rating and Certification Corporation.

Although solar water heaters have been manufactured and used for some time, there are still barriers to their widespread use, which the DOE Solar Program is working to overcome. The primary issues are the cost, reliability of systems, and the unfamiliarity of related but very necessary trades such as builders, architects, plumbers, roofers and other mechanical contractors.

SH&L research emphasizes the development of low-cost, polymer-based solar water heaters, with the goal of reducing the levelized cost of energy for these systems by at least 50%. The DOE program works with two industrial teams to develop a new generation of low-cost polymer water heaters that could reduce the cost of solar water heaters because of less expensive materials and simplified manufacturing, assembling, and installation.

The Hybrid Solar Lighting Project is developing an entirely new application of solar power in buildings through the use of fiber optic systems that bring sunlight into interior rooms of commercial buildings. This technology can improve the quality of indoor lighting with its associated benefits in worker productivity, student performance, and shoppers' buying behavior.

Following are highlights of SH&L achievements in FY 2006.

Low-Cost Polymers

- The Davis Energy Group/SunEarth team resolved leak issues for its integral collector storage system and developed pilot projects.
- The FAFCO team developed and tested system prototypes and field-tested second-generation units.

Materials Durability

- The ultraviolet stability of a number of new candidate polymeric glazing constructions was tested.
- Mechanical creep was measured as a function of temperature and applied stress for two candidate absorber materials.

Industry Manufacturing Assistance

- Deployed a "freeze-protected" roof-integrated collector on a Building America home.
- Published a SAND report that documented the multi-year development of the roof-integrated thermosiphon.

Hybrid Solar Lighting

- Developed real-time, remote monitoring system to record energy use, tracker performance, and video data from 13 hybrid solar lighting (HSL) beta sites across the United States.
- Produced a high-quality, long-lasting, 48"-diameter acrylic mirror for use with HSL and concentrating photovoltaics applications.

Low-Cost Polymers

Performing Organization: National Renewable Energy Laboratory (NREL)

Key Technical Contacts: Jay Burch (NREL), 303-384-7508, jay_burch@nrel.gov

DOE HQ Technology Manager: Glenn Strahs, 202-586-2305, glenn.strahs@ee.doe.gov

FY 2006 Budget: $357K (NREL)

Objectives

- Collaborate with industry teams to reduce the levelized cost of saved energy (LCOE) for solar water heaters (SWHs) suitable for mild climates by at least 50%, from ~10¢/kWh$_{th}$ to less than ~5¢/kWh$_{th}$ in new homes.
- Develop low-cost system concepts that can lower the LCOE for SWH suitable for cold climates by at least 50%, from ~12¢/kWh$_{th}$ to less than ~6¢/kWh$_{th}$ in new homes.

Accomplishments

- Davis Energy Group/SunEarth team: glazed/unglazed polymer integral collector storage (ICS) that can achieve 6¢/kWh$_{th}$:
  - Resolved leak issues for the Davis Energy Group/SunEarth SunCache ICS.
  - Developed pilot projects.
- FAFCO team: unglazed drainback that can achieve 5¢/kWh$_{th}$:
  - Developed and tested system prototypes.
  - Carried out field-testing of second-generation units.
- Demonstrated lowered scale rates in candidate polymers.
- Cold-climate systems:
  - New models and test methods for thermosiphons
  - Cold climate thermosiphon system concept development.

Future Directions

- Continue minor support to industry teams for wider field-testing and product refinement.
- Issue request for proposal (RFP) for conceptual development of low-cost SWH for cold climates (if funding available).
- Define most promising solar thermal pathways to attain cost-neutral zero energy homes.

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1. Introduction

Domestic hot water is a major residential end use in the United States, totaling about 2.7 quads/yr and averaging about 13% of total residential usage nationwide. The LCOE for SWHs is currently ~10¢–25¢/kWh$_{th}$, which ranges based on varying solar resource and system cost. System cost depends sensitively on the market scenario: for retrofits, the cost is 50% to 100% higher than for new construction (specific costs quoted herein refer to new construction, with LCOE 1.5 to 2 times that for new construction). LCOE is to be compared with an effective gas water heating cost of ~3¢/kWh$_{th}$ and electricity cost at ~6¢–25¢/kWh$_{th}$ *Significant* reduction in LCOE is needed for SWH to capture significant market share through good economics. As detailed further in the *DOE Solar Technologies Program Multi-Year Technical Plan* (MYTP) and other studies, high first cost is the key barrier to U.S. SWH markets. The Solar Heating and Lighting (SH&L) Subprogram set a goal in 1998 of *reducing LCOE for SWH by at least 50%.* This work started in 1999 and was focused on passive systems for mild climates to limit work scope, given sustained low funding levels. In response to an RFP, five teams were initially funded for concept development. After down-selection in 2001, two teams were "stage-gated" through engineering development to field trials and manufacturing development in FYs 2005–2006. The two teams are: Davis Energy Group/SunEarth (DEG/SE) and FAFCO, Inc. The systems that have resulted from this partnership are shown in current form in Figs. 1–4. Each team intends to market several variations of its system, including glazed and unglazed versions.

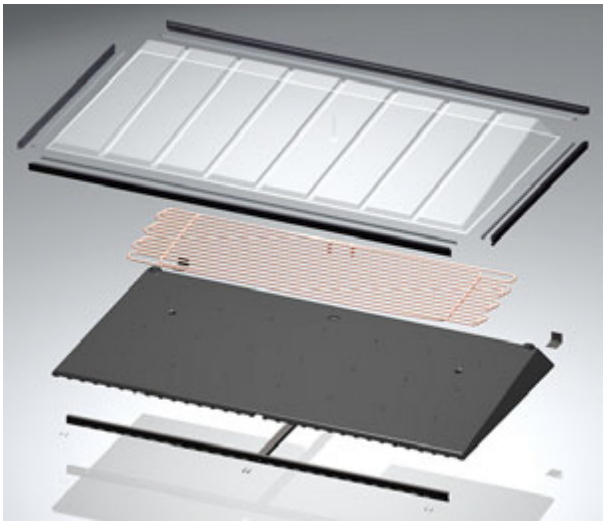

Fig. 1. Schematic of DEG/SE glazed ICS. An immersed heat exchanger carries pressurized potable water.

Fig. 2. DEG/SE glazed ICS on field test in Sacramento, CA.

Fig. 3. DEG/SE unglazed unit. The unit is easily carried by one person.

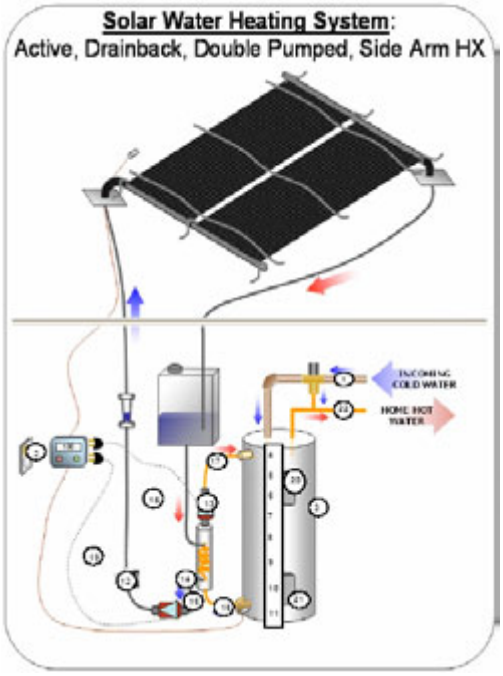

Fig. 4. Schematic of an unglazed drainback

Support at NREL for the industry teams involved public domain work common to the teams, including: materials durability testing, modeling and testing, pipe freeze protection, overheat protection, immersed heat exchangers (modeling, testing, polymer tubing durability, and scaling).

2. Technical Approach

The technical strategy to achieve low costs includes: (1) use low-cost polymer materials and manufacturing technology; (2) simplify system designs and installation, exploiting the light weight and formability of polymers. The management approach is to contract with solar industry teams in public-private partnerships that leverage private industry innovation and manufacturing abilities with national laboratory and university expertise in modeling, testing, and materials.

The project's meager resources and limited solar industry resources are severe handicaps to developing successful low-cost polymer systems. The average budget for low-cost SWH at NREL has been about one-tenth of what DuPont allocated for its polymer collector work. With the hope of attracting polymer processors with added resources for product development, an effort was made to publicize the potential of polymer solar systems to the broad polymer industry through publications at national conferences and in trade journals.

With the polymer strategy comes new opportunities but new problems. A key problem is polymeric materials durability, given harsh environmental stresses and the occasional high system temperatures during stagnation events under no-load conditions. Accelerated testing is needed to identify workable materials in a timely fashion, and this has been done at NREL and at the University of Minnesota. NREL concentrated on identifying and testing candidates for glazings and absorbers. Materials work is described more fully in the SH&L project description *Materials Durability*. The University of Minnesota has focused on heat exchangers, including modeling/testing, and lifetime and scaling issues in polymer tubing suitable for polymer heat exchangers.

The 2006 MYTP called for initiating development of low-cost, cold-climate SWHs in FY 2007. Freeze-protected thermosiphons as in Fig. 5, with their inherent cost and reliability advantages, could reach LCOE of 4¢/kWh$_{th}$. However, risk of freeze damage and catastrophic burst of supply/return piping has been a showstopper. To encourage industry to consider such designs, NREL has been working for several years to establish freeze protection methods for the supply/return piping, including both primary and fail-safe backup protection. Another barrier to low-cost, unpressurized cold-climate thermosiphons is that modeling is generally unavailable for most configurations, making design and optimization difficult and dictating the need for costly system tests to develop "effective" rating models at Solar Rating and Certification Corporation (SRCC).

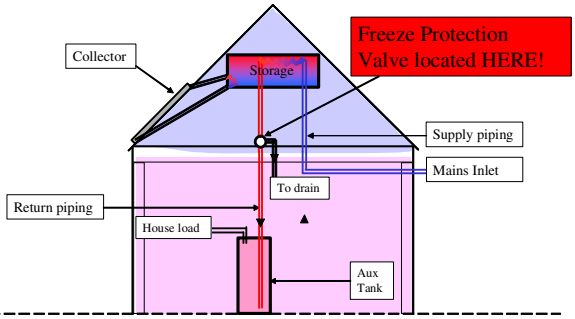

Fig. 5. An indirect thermosiphon system is shown, with a freeze-protection valve for primary freeze protection.

Modeling/design of heat exchangers has been subcontracted to the University of Minnesota, which has supported the teams in their heat exchanger designs and tested prototypes. Compared to copper heat exchangers, polymer heat exchangers have the potential to lower costs and weight. Use of lower-strength commodity plastics for heat exchangers drives the design to small diameters (reducing hoop stress). However, oxidation and subsequent polymer degradation becomes a more serious issue with thin walls. Antioxidant life must be at least 10 years. Scale buildup is also a concern, and these issues are also being addressed through testing and modeling.

3. Results and Accomplishments

Both industry teams plan to bring their low-cost SWH designs to market in 2007. The DEG/SE team refined its design and developed pilot installations and detailed marketing and manufacturing approaches. DEG/SE redesigned its unglazed collector mounting to eliminate leaks developing with that mounting. DEG/SE has been developing pilot projects with the Sacramento Utility District, migrant housing authorities in California, and Building America.

In FYs 2005–2006, the FAFCO team found 100% leakage failures in its previous direct system with a glazed polymer collector. In FY 2006, FAFCO changed its system type from a glazed, pressurized system (which NREL strongly recommended not pursuing in FY 2004) to an unpressurized drainback system with an unglazed polymer flat-plate collector. FAFCO developed full-scale prototypes, held successful field trials, and made plans to formally introduce the system in February 2007 at the National Association of Home Builders show. To attract potential development from polymer processors, four papers on polymer solar thermal systems (two from NREL) were presented at the annual technical conference of the Society of Plastics Engineers (ANTEC2006).

To allay cold-climate thermosiphon freeze concerns and potentially extend indirect thermosiphons to the entire United States, PEX supply/return potable water piping can serve as a fail-safe backup to any primary pipe freeze protection. To see if unsubstantiated claims of freeze tolerance are true, four brands of PEX piping were subjected to freeze-thaw cycling. *Two of the four brands proved to be resilient against freeze-thaw beyond 450 cycles*, as long as configurations promoting non-uniform freezing were avoided. Pipe freeze tolerance was confirmed by complementary stress-strain data at 0°C, as in Fig. 6.

Another barrier to cold-climate thermosiphons has been the lack of models for innovative systems, inhibiting design optimization and forcing more costly ratings. New thermosiphon models for TRNSYS (TRaNsient SYstem Simulation Program) based on a general routine for inference of convection loop mass flow rate have been developed, although oscillations at reasonable time-steps need to be resolved before industry and SRCC use. Standard TRNSYS types for collectors and tanks with immersed heat exchangers are used, enabling efficient development of system models. To determine accuracy of models based on component testing only, component and system tests were performed for three innovative thermosiphon systems, and normal operation data over 6 weeks were taken for validation. The results demonstrate that when only components are tested, the resulting TRNSYS system models predicted measured normal-operation performance within 5%, even when the flow rate was not accurately predicted. This insensitivity of performance to flow rates (well-known in active systems) was corroborated by simulations, in which the flow was varied up to a factor of 10 from the base case, with variation less than 4%.

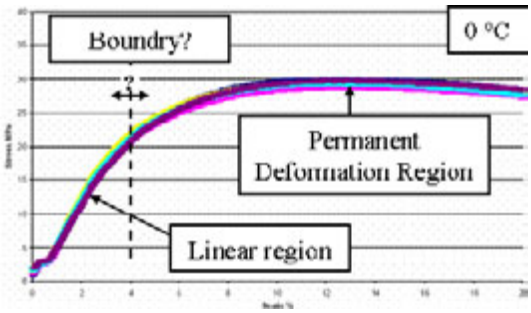

Fig 6. Stress versus strain for five samples of a silane-based PEX. A quasi-linear region without significant permanent deformation exists for the hoop strain from uniform freeze.

Progress has been made on the issues with potential polymer heat exchangers. The University of Minnesota has developed and validated a model for antioxidant depletion. It predicts antioxidant concentrations over time based primarily on molecular diffusion data. Scaling in the small-diameter heat exchanger tubing can choke off flow in scale-prone waters. Data on scale rates at high, but realistic, supersaturation have shown that polymer tubing initially scales less rapidly than copper tubes, as in Fig. 7.

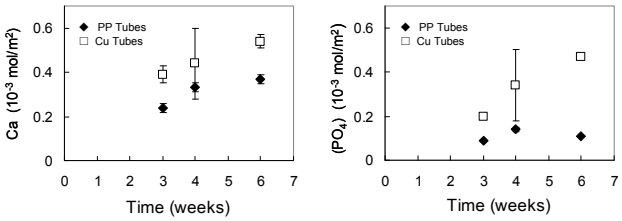

Fig. 7. Calcium carbonate and calcium phosphate scale rates on copper (open symbols) and polymer tubes (filled symbols).

4. Planned FY 2007 Activities

4.1 Industry Teams

DEG/SE will continue to monitor field installations and seek other low-volume opportunities for pilot projects. Design refinement will continue, including a simpler heat exchanger design and a more impact-resistant acrylic glazing. FAFCO will continue to monitor field-test results and refine its drainback models, with a glazed version under development.

4.2 Polymer Industry Outreach

A session on polymers in solar thermal is being organized for ANTEC2007. NREL will present a paper on materials testing, along with University of Minnesota papers. NREL has been asked to produce an article in 2007 on the potential market for polymers in solar thermal in the industry journal *Modern Plastics*, widely read by polymer industry executives.

4.3 Solar Thermal for Zero Energy Home

The SH&L Subprogram mission has shifted from supporting the development of low-cost solar water heaters to supporting the development of "cost-neutral" solar thermal pathways to zero energy homes, in collaboration with the DOE Building America Program. (Cost neutral means the system cost savings just offsets the extra mortgage cost). Homes on the path from code minimum to zero energy improve shell and HVAC first, and then look to install solar water heaters at about the 50% savings level. Although it makes great sense to develop lower-cost systems suitable for cold climates, a previously planned RFP for development of cold-climate systems will not be issued unless DOE specifically provides funds for this initiative from FY 2007 funds. For aggressively approaching zero energy, solar thermal systems that provide water heating, space heating, and space cooling (triple play) deserve close consideration, to determine if the extra collector/storage can be cost neutral. Annual

storage schemes, that can produce high solar fractions for triple-play systems will be investigated. A concept for a unity-solar-fraction solar thermal system based on liquid desiccants will also be analyzed for its potential feasibility.

5. FY 2006 Special Recognitions, Awards, and Patents

The NREL article on polymer-based solar thermal systems was highlighted in the January edition of the *SPE Highlights*. The DEG/SunEarth SunCache system is being submitted for an R&D 100 Award in FY 2007.

6. Major FY 2006 Publications

Burch, J., Shoukas, G., Brandemuhl, M., and Krarti, M., "Modeling and Test-and-Rate Methods for Innovative Thermosiphon Solar Water Heaters," *Proc. ASES 2006*.

Burch, J., Heater, M., Brandemuhl, M., and Krarti, M., "Northward Market Extension for Passive Solar Water Heaters by Using Pipe Freeze Protection with Freeze-Tolerant Piping," *Proc. ASES 2006.*

Burch, J., Heater, M., Brandemuhl, M., and Krarti, M., "Pipe Freeze Prevention for Passive Solar Water Heaters Using a Room-Air Natural Convection Loop," *Proc. ASES 2006.*

Burch, J., "Polymer-based Solar Thermal Systems: Past, Present, and Potential Products," *Annual Technical Conference of the Society of Plastic Engineers, ANTEC2006.*

Burch, J., "High Temperature Issues for Polymer-based Solar Thermal Systems," *Annual Technical Conference of the Society of Plastic Engineers, ANTEC2006.*

7. University and Industry Partners

The following organizations partnered in the project's research activities during FY 2006.

Organization/ Principal Investigator	Location/e-mail	Description/Title of Research Activity	FY 2006 ($K)	Cost Share ($K)
Davis Energy Group/SunEarth Dick Bourne	Davis, CA dbourne@davisenergy.com	Field monitoring of 10 systems, codes, leak elimination	75[1]	45
FAFCO, Inc Mike Rubio	Chico, CA mrubio@fafco.com	Refine new designs, test prototypes	0	300[2]
University of Minnesota Jane Davidson	Minneapolis, MN jhd@me.umn.edu	Stratification, pipe materials testing, and scaling rates	50[1]	400[3]
Thermal Energy System Specialists, Inc. Jeff Thornton	Madison, WI thornton@tess-inc.com	Develop TRNSYS and TRNSED models in support of industry teams	50[4]	0
SRCC Jim Huggins	Cocoa, FL huggins@fsec.ucf.edu	Rating and certification of solar thermal collectors and systems	318[5]	0

Notes:
1. Funded with prior year funds.
2. All work has been funded internally at FAFCO.
3. High degree of co-funding through university and state grants devoted to solar thermal.
4. Open contract through FY 2007, funds allocated in 2005.
5. Funded through the Golden Field Office from SH&L funds.

Materials Durability

Performing Organization: National Renewable Energy Laboratory (NREL)

Key Technical Contact: Gary Jorgensen, 303-384-6113, gary_jorgensen@nrel.gov

DOE HQ Program Manager: Glenn Strahs, 202-586-2305, glenn.strahs@ee.doe.gov

FY 2006 Budget: $150K

Objectives

- Identify alternative polymeric glazing and absorber materials/constructions that will allow design trade-offs that can help reduce the costs associated with solar domestic hot water systems.
- Perform materials testing to demonstrate whether such candidate polymers will meet the durability requirements for real systems.

Accomplishments

- The ultraviolet (UV) stability of a number of new candidate polymeric glazing constructions was tested.
- The impact strength of several candidate glazing materials has been measured as a function of UV exposure time.
- Mechanical creep was measured as a function of temperature and applied stress for two candidate absorber materials.

Future Directions

- Provide support for industry partners, including investigation of thin-film glazings.
- Provide support for standards development, including hail testing of evacuated tube collectors.
- Continue long-term testing and evaluation of candidate polymeric glazing and absorber materials.

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1. Introduction

Improved polymeric glazing and absorber materials are required to increase the reliability of cost-effective solar collectors. As discussed in the *DOE Solar Program Multi-Year Technical Plan*, a major impediment to development of low-cost solar water heating systems is the uncertainty in durability of polymeric components.

Both passive solar water heating and active cold-climate solar water heating technologies require polymeric glazings and absorbers to survive in harsh operating environments. The objectives of this research are to: (1) identify alternative polymeric materials/constructions that will allow design trade-offs that can help reduce the costs associated with solar water heating (SWH) systems and (2) perform materials testing to demonstrate whether such candidate polymers will meet the durability requirements for real systems. This task complements and supports the Low-Cost Systems Development/Low-Cost Polymers activities. Materials are evaluated and recommended to private-sector partners for use with their prototype systems. We also test materials that are of interest to the project's subcontractors.

2. Technical Approach

The primary property of interest for candidate polymeric materials is the ability to avoid optical and mechanical degradation (yellowing and embrittlement) during exposure to elevated temperatures and UV light. A number of candidate glazing constructions have been subjected to photothermal weathering using three complementary forms of exposure. These include outdoors, in laboratory-controlled accelerated weathering chambers, and at NREL's unique UV-concentrator facility. Optical transmittance and mechanical impact strength are measured as a function of exposure time and conditions.

To assess the mechanical stability of candidate polymeric absorber materials, creep is measured as a function of temperature and applied stress.

3. Results and Accomplishments

The major results and accomplishments of the project during FY 2006 include the following:

- The optical and mechanical durability of a number of candidate glazing materials was quantified. (09/06)
- A creep-compliance master curve was generated for two candidate polymeric absorbers of interest to a private sector company planning to manufacture collector systems using these materials. (09/06)

3.1 Glazing Materials

Based on accelerated screening tests, we have found that fluoropolymers and acrylic are UV weatherable, and all other polymeric glazing materials tested lose transmittance and yellow. However, fluoropolymers are relatively expensive and realistically would be limited to use as thin-film glazings. Acrylic tends to be too brittle and exhibits thermal sag, which is a concern for a glazing candidate for solar collector applications. We have also found that polycarbonate (PC) laminated to an acrylic UV-screening film (Korad®, a product of Polymer Extruded Products) can also be UV weatherable. The most promising construction uses a UV-screening film that is adhesively laminated to a PC sheet. Without the additional UV-screening layer, PC products exhibit 3%–5% loss in solar-weighted hemispherical transmittance after about 2–3 years' equivalent exposure. In addition, severe visual yellowing (an aesthetic concern) occurs in the same timeframe. With the addition of a UV-screening film, significant loss in hemispherical transmittance does not begin until between 10–15 years' equivalent outdoor exposure at elevated operating temperatures.

Interactions were held with material suppliers to identify several new types of polymeric glazing materials. A company that is a major supplier of PC sheet is interacting with Polymer Extruded Products to provide thermally bonded UV-screening film/PC samples. The UV screening layer is thicker than previously used (0.08–0.15 mm thick, rather than 0.05 mm thick), and enhanced screening films (that provide twice as much UV absorption as previously tested) are incorporated into their laminate samples. Two major polymer manufacturers have supplied samples in which UV-absorbing organic clear coats are applied to PC sheet. Such constructions are used in automotive headlamp applications. If a UV screening film cannot be thermally bonded to PC sheet as it is extruded, and/or cannot avoid severe adverse thinning during thermoforming, then clear coats could be applied to thermoformed PC to avoid such damaging effects to the screening agent.

Prospective solar manufacturers are also considering non-PC glazing materials, including impact-modified acrylic (IMA) and fiberglass-reinforced polyester. Solar-weighted transmittances for some of these more recent samples are shown in Fig. 1. Most of these materials are maintaining optical performance after a cumulative UV dose equivalent to about 5 years outdoor exposure in Miami, FL.

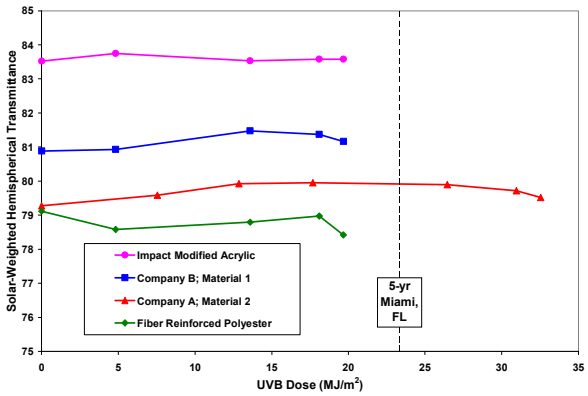

Fig. 1. Solar transmittance as a function of UVB dose for candidate glazing polymeric materials exposed at NREL's UV concentrator at 70°C.

Impact strength of several candidate glazing materials has also been measured as a function of exposure time in our XR-260 weatherometer. Figure 2 shows a loss in transmittance for unscreened PC as the samples yellow. Impact strength also degrades. However, the impact strength of PC was substantially greater than for IMA. The initial impact strength for 2.3-mm-thick PC was 32.1 ± 0.25 J, whereas the unweathered value for 2.2-mm-thick IMA was 0.17 ± 0.03 J. Furthermore, IMA lost ~25% impact strength in less than 1 year equivalent outdoor exposure. The behavior upon impact of these two glazing materials was also quite different. The PC generally failed by cracking around the perimeter of permanently deformed dimples, whereas the IMA typically cracked or shattered at the impact site without any plastic yield.

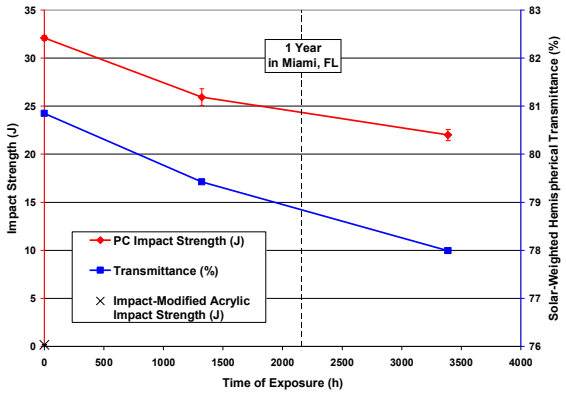

Fig. 2. Effect of UV exposure on impact strength and transmittance of 2.3-mm-thick polycarbonate glazing.

3.2 Absorber Materials

Industry partners have identified two absorber materials that we have tested, namely, polypropylene (PP), including PP random copolymer (PPR), and metallocene-based multi-density polyethylene (MBMDPE). Creep is an important concern for absorber materials. Severe deformations can result in elevated stress concentrations that can result in cracking. If absorber bulges reach the glazing, then thermal performance is catastrophically compromised. Creep has been measured for both MBMDPE and PPR. Results for MBMDPE were previously reported. For PPR, samples of two materials (A and B) were tested at 82°C/2.3 MPa (the reference conditions), 100°C/2.3 MPa, 100°C/3.4 MPa, 75°C/3.4 MPa, and 110°C/2.8 MPa. The data sets were then used to derive transformation equations to allow extrapolation to extended times at the reference conditions, as shown in Fig. 3. The resulting strain values after 20 years service are about 2.7% for material A and 3.8% for material B at the design reference conditions. Significant surface oxidation was also visible for material B during the creep measurements.

4. Planned FY 2007 Activities

The most significant activities planned for FY 2007 include:

- Continue testing UV stability of new candidate polymeric glazing constructions including thin films. (09/07)
- Provide support for development of standards for hail testing of evacuated tube collectors. (09/07)
- Continue long-term testing and evaluation of candidate polymeric absorber materials. (09/07)

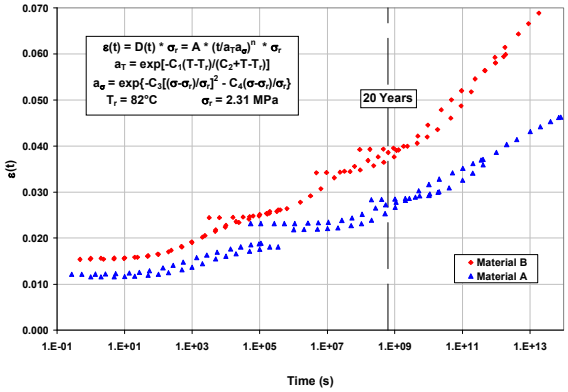

Fig. 3. Strain for PPR obtained from creep compliance master curve for reference conditions of 82°C and 2.3 MPa.

5. FY 2006 Special Recognitions, Awards, and Patents

The World Intellectual Property Organization granted an Australian patent (#2001238405): Gary J. Jorgensen and Allan A. Lewandowski, *Ultra-Accelerated Natural Sunlight Exposure Testing Facilities,* August 28, 2006.

6. Major FY 2006 Publications

G. Jorgensen, K. Terwilliger, C. Bingham, C. Lundquist, and M. Milbourne, "Durability of Polymeric Glazing and Absorber Materials," *DOE Solar Energy Technologies Program Review Meeting*, Denver, CO, November 2005.

M. Köhl, G. Jorgensen, S. Brunold, B. Carlsson, M. Heck, and K. Möller, "Durability of polymeric glazing materials for solar applications," *Solar Energy*, **79**, No. 6, December 2005, pp. 618–623.

G.J. Jorgensen, K.M. Terwilliger, and C.E. Bingham, "Durability of Polymeric Glazing and Absorber Materials," Presented at the *Solar 2006 35th ASES Conference*, Denver, CO, July 8–13, 2006.

Industry Manufacturing Assistance

Performing Organization: Sandia National Laboratories (SNL)

Key Technical Contact: Greg Kolb, 505-844-1887, gjkolb@sandia.gov

DOE HQ Technology Manager: Glen Strahs, 202-586-2305, glenn.strahs@ee.doe.gov

FY 2006 Budget: $90K (FY 2006) + $6.5K (FY 2005 Carryover) = $97K

Objectives

- Help solar thermal manufacturers improve their products.
- Help solar technology users design their systems to achieve maximum cost effectiveness.

Accomplishments

- Deployed a "freeze-protected" roof-integrated collector on a Building America home.
- Helped the manufacturer of a "non-freeze protected" roof-integrated thermosiphon (RITH) solve technical problems and obtain Solar Rating and Certification Corporation (SRCC) certification.
- Published a SAND report that documented the multi-year development of the RITH.
- Helped the University of New Mexico establish a solar energy R&D program.
- Provided technical assistance to the SRCC and several other solar users and manufacturers.

Future Directions

- Continue to work with Building America and Artistic Homes to test a freeze-protected roof-integrated system.
- With NREL, define role of solar hot water systems within zero energy homes.

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1. Introduction

Sandia National Laboratories (SNL) provides technical assistance to the solar thermal industry. Through its Industry Assistance Program, SNL follows a Systems-Driven Approach to help manufacturers improve their products. In addition, the program helps potential technology users design their systems to achieve maximum cost effectiveness. This assistance is often highly leveraged with funding from the U.S. Department of Defense (DoD) and the utility industry.

2. Technical Approach

Solar thermal technology users and manufacturers make a formal request to SNL for technical assistance. Guidelines for making this request are described on the program Web site (www.sandia.gov/Renewable_Energy/solarthermal/Center/index2.htm). Assistance is given on a "first come, first served basis" to government agencies and to the private sector. Proposed project activities must not compete with those offered in private industry.

3. Results and Accomplishments

Budget allocation during FY 2006 was very limited. This allowed us to complete projects begun in FY 2005 and to provide limited technical assistance to manufacturers and users. No new R&D projects were started. The main areas of activity are described below.

3.1 Deployed a Freeze-Protected Roof-Integrated Collector Project

Roof integration is popular with both builders and architects. Roof integration solves many objections for adopting solar hot water systems that have been raised in the past by builders. The advantages of roof integration include much improved aesthetics, a reduction in the number of roof penetrations, and the ability to replace/repair a roof without removing the solar collectors. In FY 2006, SNL worked with the Building Science Corporation to deploy a roof-integrated design that is capable of operating in a freezing climate. The drainback method was selected as the preferred method of achieving freeze protection.

A demonstration system was installed on a Building America high-efficiency home (by Artistic Homes) in Los Lunas, New Mexico. The system was flashed into the roof instead of on top of the roof, which has been the tradition for the past 30 years. SNL engineers designed an energy monitoring system and provided it to Artistic Homes. Data collection began in June 2006.

A system price goal of $2,000 has been set, given a production scenario of several hundred per year. If this price can be achieved, the system will be cost effective for sunny locations in which natural gas is >$1/therm; the system can be included in the home mortgage and be paid off by the resultant energy savings.

If the demonstration is successful and predicted costs are reasonable, Artistic Homes could offer solar hot water as an appliance option to homebuyers.

3.2 Helped RITH Manufacturer Achieve SRCC Certification

The RITH is a "non-freeze-protected" solar hot water system for the new-home market. The collector is the same as installed in the Building America project described above, but the design of the remainder of the system is totally different. Unlike the drainback system, the RITH has no pumps and water is circulated through the collector by natural circulation caused by placing the solar tank inside the attic above the elevation of the collector, i.e., the thermosiphon effect.

In FY 2005, RITH failed its SRCC certification test because of leaks caused by faulty welds. In FY 2006, SNL worked with the RITH manufacturer (Energy Laboratory Incorporated) to solve the technical problems that precluded certification. Welding issues were resolved and the unit was resubmitted to SRCC in early 2006. The unit passed the retest and was certified in August 2006.

The final report that describes the multi-year RITH development effort was published.

3.3 Helped the University of New Mexico Establish a Solar Energy Program

During FY 2006, the University of New Mexico Mechanical Engineering Department (UNM/ME) was awarded a grant from the State of New Mexico to design, build, and operate a solar air-conditioning testbed. SNL was a principal advisor to the UNM/ME team in developing the grant proposal and was instrumental in the design of the plan that was proposed and was funded.

The grant covers the cost of new collectors, a 10-ton absorption chiller, all of the associated balance of system components, and the labor to design and install the testbed. The testbed will be used for graduate and undergraduate studies and will produce chilled water for the UNM/ME building, where the system will be installed.

The UNM/ME faculty will be offering, for the first time in nearly 20 years, solar engineering courses in upcoming semesters, eventually developing solar engineering degree programs at both graduate and undergraduate levels.

3.4 Provided Technical Assistance to the Solar Rating and Certification Corporation

SRCC is the solar hot water industry's certifying organization for systems and collectors. SRCC has only a few paid positions and overhead costs. Historically, DOE has supported SRCC with about one-quarter million dollars per year. However, most of the organizational activities involve volunteer labor, most of it professional, supplied by the industry and supporting organizations. SRCC depends on the involvement of high-quality assistance from the national laboratories to continue to conduct its business in a professional manner.

In FY 2006, SNL supported SRCC by chairing the Standards Committee and serving as technical liaison between the labs and SRCC. The Standards Committee meets monthly via conference call, with appropriate subcommittees meeting more frequently as needed. The chair is an ex-officio member of each subcommittee and often attends these meetings. Typically, the committee considers detailed technical information concerning testing and certifying collectors and systems and often involves technical analysis and supporting information.

In addition, SNL provides critical guidance in the development of a strategic marketing plan for SRCC as a whole.

3.5 Other Industry Assistance Activities

We provided solar thermal assistance to several organizations that contacted us through our Web site. The major organizations and the help provided are included in the table below.

4. Planned FY 2006 Activities

- Continue to work with Building America and Artistic Homes to test a freeze-protected roof-integrated system.
- With NREL, define role of solar hot water systems within zero energy homes.

5. Major FY 2006 Publications

Menicucci, D. F, T. A. Moss and G. E. Palomino, *The Development of a Roof Integrated Solar Hot Water System,* SAND2006-5529, Sandia National Laboratories, Albuquerque, NM, September 2006.
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6. University and Industry Partners

The following are the major organizations that received assistance during FY 2006.

Organization/ Principal Investigator	Location/e-mail or Phone	Description/Title of Research Activity
Building Science Corporation Mark Sevier	Westford, MA mark@buildingscience.com	Install freeze-protected roof-integrated solar hot water project for Building America.
University of New Mexico Andrea Mammoli	Albuquerque, NM mammoli@me.unm.edu	Help develop solar R&D program.
Energy Laboratory Inc. Mike Newman	Jacksonville, FL mike.newman@solarenergy.com	Resolve welding issues.
SRCC Jim Huggins	Cocoa, FL huggins@fsec.ucf.edu	Aid the standards committee.
City of Tucson Vinnie Hunt	Tucson, AZ vajra@vecat-inc.com	Develop a solar HVAC monitoring strategy.
U.S. Air Force Patrick Pfaltzgraff	Washington, DC ppfaltzgra@law.gwu.edu	Perform research study to estimate potential of solar on military bases.
Concurrent Designs Jim Smith	Austin, TX 512-869-0904	Provide info on 2-axis solar drives.
Shell Oil Aina Abayomi	Houston, TX Aina.Abayomi@shell.com	Help with study for trough application in Bakersfield, CA.
Quest Energy Group Jeremy Rivera	Durango, CO 970-247-3120	Provide info for solar swimming pool heat project.
David Erickson Sonoma County	Sonoma County, CA jdavidерickson@comcast.net	Discuss feasibily/economics of possible district heating system.
SENTECH Douglas Hinrichs	Bethesda, MD DHINRICHS@sentech.org	Review solar HVAC report.
Puget Sound Energy Stephen Emmert	Seattle, WA Stephen.emmert@pse.com	Advise on solar tower applications.

Hybrid Solar Lighting

Performing Organization: Oak Ridge National Laboratory (ORNL)

Key Technical Contact: Melissa Lapsa, 865-576-8620, lapsamv@ornl.gov

DOE HQ Technology Manager: Glenn Strahs, 202-586-2305, glenn.strahs@ee.doe.gov

FY 2006 Budget: $220K

Objectives

- Deploy two beta-test units in Texas and California.
- Deploy two beta-test units at ORNL for R&D and continued test and evaluation.
- Develop real-time monitoring hardware for Sunlight Inside Initiative beta sites.
- Report on benefits associated with 2005 Sunlight Inside Initiative describing energy savings and user feedback.

Accomplishments

- Developed real-time, remote monitoring system to record energy use, tracker performance, and video data from 13 hybrid solar lighting (HSL) beta sites across the United States.
- Began evaluation of beta-testing data to be fully reported in FY 2007. Early data show nearly 70% peak energy savings at beta sites.
- Produced a high-quality, long-lasting, 48”-diameter acrylic mirror for use with HSL and concentrating photovoltaics (CPV) applications.
- Fully deployed one HSL beta-unit (HSL3100) at the Sacramento Utility District (SMUD) headquarters in Sacramento, CA.
- Partially installed one HSL beta unit at WalMart’s experimental store in McKinney, TX (completion expected by end of February 2007).
- ORNL researchers were recognized in 2006 with an R&D 100 Award for the HSL system. These awards are presented annually by *R&D Magazine* in recognition of the year's most significant technological innovations.

Future Directions

- R&D on larger 64”-diameter primary mirror
- Reporting on benefits associated with “Sunlight Inside Initiative” beta sites.
- Integration of PV and CPV technology with existing platform.

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1. Introduction

In the United States, artificial lighting represents the single largest component of electricity use in commercial buildings, costing building owners nearly $17 billion a year. Despite this high consumption of energy and the continued demand by occupants for more natural lighting, natural lighting from conventional options, such as skylights and windows, illuminates only a tiny fraction of the available commercial space. This limited use of natural lighting is a result of the architectural limitations of skylights and windows and the uncontrollable nature of the sunlight itself (e.g., it fluctuates in intensity and can be highly directional, producing glare and unwanted heating). A significant market exists for a natural lighting product that can offer the benefits of natural lighting with all of the conveniences and control of an artificial lighting system.

Hybrid solar lighting (HSL) technology meets this previously unmet need and has the potential to provide a product with an economic payback of three to four years for commercial buildings in the Sunbelt regions of the world. In the U.S. Sunbelt alone, there exists 20 billion square feet of commercial space that meets the requirements for implementation of an HSL system. Each year, this amount of applicable space grows by 600 million square feet of new construction.

Commercialization of HSL technology will initially focus on a small subset of retailers representing jewelry, furniture, and apparel markets. This niche market of early adopters is expected to increase sales volumes of HSL technology, permitting cost reductions through economies of scale. With system price reductions, greater market penetration into this niche market and the larger commercial building market (including office buildings) is anticipated. Full-spectrum solar energy systems, such as HSL, provide a new and realistic opportunity for wide-ranging energy, environmental, and economic benefits. Their development is directly in line with the mission of the DOE Solar Program to improve America's security, environmental quality, and economic prosperity through public-private partnerships that bring reliable and affordable solar energy technologies to the marketplace.

Advantages of HSL include:

- Small and minimal roof penetrations, reducing the potential for leaks.
- Infrared and ultraviolet energy in sunlight is separated from the visible light, rather than being transmitted into buildings. Heating, ventilation, and air-conditioning (HVAC) loads are thus reduced by 5% to 10% compared to electric lighting systems.
- Ready adaptability to commercial buildings with multiple stories, relatively low ceiling heights, and interior walls. A single system can distribute enough sunlight to co-illuminate several rooms in a typical office building.
- No need for large portions of precious plenum space—the area between the roof and drop ceiling—so there is little competition with other building services, such as HVAC ducts, sprinkler systems, and electrical conduits.
- Versatility of use for both direct, ambient lighting (as in skylights) and for indirect, task, and accent lighting applications.
- Easily incorporated into existing building designs (for retrofit markets), and the optical fibers can be rerouted to different locations as lighting needs change. By intentionally misaligning the solar collector from the sun, occupants can even dim or curtail distributed sunlight.

2. Technical Approach

Research in HSL technology for FY 2006 was aimed at field-testing the developed technology while also conducting R&D to increase system performance and flexibility. Beta-testing at various sites across the United States—such as in hot, cold, wet, or dry climates—was expected to reveal flaws and limitations in the solar collector design that would be evaluated and remedied. Two ORNL-supervised beta sites at WalMart (in McKinney, TX) and SMUD Headquarters (in Sacramento, CA) were planned to educate the public about the technology and to evaluate installation challenges associated with the technology. A real-time, remote monitoring system was to be developed to monitor energy data from these two site, two prototyping units at ORNL, and 10 additional sites throughout the United States to provide a good survey of the current design year-round performance.

In addition to beta-testing, a third-party market potential analysis was planned to gauge the commercial market size and characteristics for the technology. The benefits of the HSL activity were prioritized as (1) light quality, (2) reduction of waste heat compared to other lighting systems, and (3) fossil energy conserved by using solar energy for lighting applications. Unfortunately, due to budget limitations, this analysis was begun by Antares, Inc., but was discontinued pending additional funding.

3. Results and Accomplishments

In June 2006, the first HSL beta-site installation was completed at San Diego State University. Through the rest of 2006, an additional eight sites were installed by ORNL's commercialization partner, Sunlight Direct. Additional units were jointly installed by ORNL and Sunlight Direct at SMUD Headquarters in Sacramento, CA, and an experimental Walmart store in McKinney, TX (expected to be completed in early 2007).

In addition to the beta sites, two prototype HSL units were installed at ORNL. One has been used for HSL testing and demonstration while another is being configured for CPV applications.

All beta-testing and prototyping units were equipped with a custom-designed monitoring system that allows the energy savings associated with the units to be remotely monitored. A cellular connection allows a high-bandwidth connection to each site and provides energy data, tracker control and diagnostics, and video feedback to be transferred back to ORNL.

Early assessments of the beta-testing data show that the tracker platforms are performing very

reliably with only two known instances of tracker interruption (which were corrected remotely by Sunlight Direct within 24 hours). In addition, energy-savings data appears as expected, although additional data evaluation and reporting will be required before issuing a final assessment of the technologies energy-savings potential. Figure 1 shows actual energy data from San Diego State University's beta site, demonstrating the potential of the technology to deliver significant energy savings during the peak daylight hours.

Technical design flaws in the current HSL solar collector were identified early in the beta-testing effort and were corrected on later models that went into beta-testing. These flaws included:
(1) Zenith bearing seal deficiencies
(2) Tracker axle coupling slippage under high wind loading
(3) Fiber heating due to contaminants.

These issues were all corrected in the field and addressed in the production of later beta installations. Initial response to the technology has been positive and the technology has been featured in a number of popular publications in 2006.

In addition to the beta-testing effort, ORNL has been working to further increase the functionality and performance of the HSL technology and components. Significant efforts went into continuing the development of a high-quality 48"-diameter, thermoformed acrylic mirror for the HSL technology. In 2006, the quality of the mirror continued to improve and is close to rivaling glass alternatives. ORNL continues to push the state of the art in accurate acrylic thermoforming for solar imaging applications.

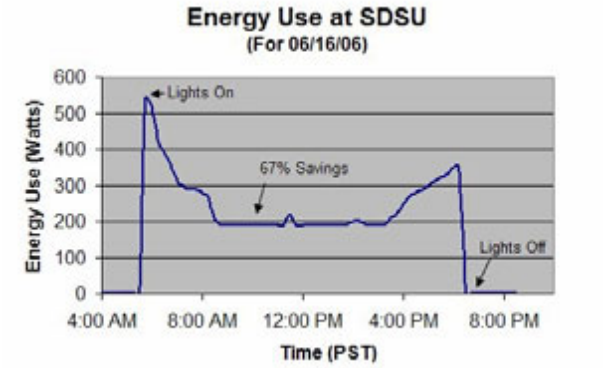

Fig. 1. Actual data from 2006 Sunlight Inside Beta-Testing Initiative

Accomplishments:
- Developed real-time, remote monitoring system to record energy use, tracker performance, and video data from 13 HSL beta sites across the United States.
- Began evaluation of beta-testing data to be fully reported in FY 2007. Early data show nearly 70% peak energy savings at beta sites.
- Produced a high-quality, long-lasting, 48"-diameter acrylic mirror for use with HSL and CPV applications.
- Fully deployed one HSL beta-unit (HSL3100) at SMUD headquarters in Sacramento, CA.
- Partially installed one HSL beta unit at WalMart's experimental store in McKinney, TX (completion expected by end of February 2007).

Fig. 2. One of 13 installed HSL beta units

4. Planned FY 2007 Activities

The greatest technical challenges/barriers remaining for the HSL project are:
(1) Reliability of the 2-axis tracking mechanism
(2) Sustained performance of the collection optics and optical fibers
(3) System cost
(4) System integration for other solar applications.

Great progress has been made in improving the reliability of the HSL tracking mechanism and control electronics in recent years. However, smarter controls that use feedback sensors and self-learning algorithms and improved mechanical designs combined with extensive testing of the HSL tracker are needed to further improve the system's reliability and lifetime. Tracker improvements that provide improved survivability and stability at high wind speeds, an improved tracking resolution of 0.05° in both axes, a self-calibrating controller, and a tracker with an

integrated Web server to allow remote monitoring and servicing are key improvements that have been identified.

Significant advances have already been made in the quality and cost of the plastic optical components used with the HSL technology. Despite these technical advances, the optical performance of the acrylic mirror is still not as high as desired. Variations in the shape of the mirror result in a large focal spot that has limited the collection efficiency of the HSL system and contributed to heating in the optical fibers. In FY 2007, we will improve the optical quality of the 48" mirror by implementing a real-time 2D temperature control system to more uniformly heat the thermoformed plastic. Doing so is expected to consistently produce a plastic mirror that rivals the performance of early glass mirrors and has a focal spot of less than 1.0 cm. In addition, we will scale up this fabrication process and the associated molds to accommodate a larger 64"-diameter mirror that can collect twice as much light as the current design. The larger mirror design will increase the illumination area of a system from 1,000 to 2,000 sq. ft., thereby reducing the cost per square foot by nearly 40%. With the development of a new, larger, primary mirror that will allow the current HSL system to increase its illumination area from 1,000 to 2,000 sq. ft. will also come the need to extend the optical fiber length (to allow full coverage of the 2,000-sq. ft. area). The goal of the FY 2007 effort will be to develop a 1.5"-diameter optical fiber bundle with 65% transmission after 65 ft. costing less than $1,000. Research will continue toward improving the performance of the plastic optical fibers by studying the microscopic optical loss mechanisms present in commercially available PMMA optical fibers. R&D efforts will be conducted with an emphasis on investigating available post-processing techniques that could improve fiber performance.

To address the above technical issues and to conduct our market assessment, a budget of $2M is requested for FY 2007.

FY 2007 Milestones:

- Complete design and implementation of improved tracker controller and fiber receiver module.
- Work with commercialization partner to reduce COGS (cost of goods sold) by 50% per square foot over FY 2006 levels.
- Report on benefits associated with 2006 Sunlight Inside Initiative describing energy savings and user feedback.
- Complete 3rd Party Market Assessment of Hybrid Solar Lighting.
- Technical report/paper on long-term improvements and applications of the base HSL platform.

5. Major FY 2006 Publications

Melissa Lapsa, "Hybrid Solar Lighting," oral presentation, U.S. Green Buildings Council Middle Tennessee Chapter Meeting, Nashville, TN, July 27, 2007.

Christina Ward, "Innovative Hybrid Solar Lighting Reduces Waste Heat and Improves Lighting Quality," oral presentation and paper, *Solar 2006 Conference,* July 11, 2007.

Steve Allison, "Hybrid Solar Lighting Provides Energy Savings and Reduces Waste Heat," oral presentation and paper, *World Energy Engineering Congress,* September 13, 2006, Washington, D.C. (part of a Federal Energy Management Session titled "Leading by Example: Examining New Energy Efficient Technologies for Federal Buildings").

Press Coverage:

- "Hybrid Solar Lighting Technology... Soon to shine on the commercial scene!" *Electrical Line Magazine,* September/October 2006, Volume 12, Number 5.
- "Vote Solar Initiative: How to Break Down Barriers to Solar, New Solar Hybrid Lighting Hits Select Retail Stores For Testing," *Renewable Energy Access*, Aug. 31, 2006.
- "ORNL Spin-Off Beta Tests Hybrid Solar Lighting, *EE Times*, Portland, OR, Aug. 21, 2006.
- "Hybrid Solar Lighting Gaining Momentum around Nation," Renewable Energy Assess, Aug. 15, 2006.
- "ORNL Hybrid Lighting Technology Gaining Momentum around Nation," *The Oak Ridger,* Oak Ridge, TN, August 7, 2006.

6. FY 2006 Special Recognitions, Awards, and Patents

ORNL researchers received an *R&D Magazine* R&D 100 Award for the HSL system. The system uses a roof-mounted solar collector and small fiber optics to transfer sunlight to hybrid fixtures with

electric lamps. A control system enables sunlight to power the light and illuminate about 1,000 square feet during sunny daylight hours while clouds and darkness allow the system to revert to providing regular electrical light.

HSL reduces energy usage not only for lighting, but also for cooling due to the system's ability to block ultraviolet and infrared heat. The technology could be particularly valuable in areas where there is an abundance of sunshine. The Hybrid Lighting Team is composed of David Beshears, Melissa Lapsa, Art Clemons, Dennis Earl, John Jordan, Randall Lind, Curt Maxey, Jeff Muhs, Christina Ward, and Wes Wysor. The late Larry Dickens was ORNL's commercialization manager on the project. John Morris of Sunlight Direct is also a member of the team.

7. University and Industry Partners

The following organizations partnered in the project's research activities during FY 2006 (no cost share).

Organization/ Principal Investigator	Location/e-mail	Description/Title of Research Activity	FY 2006 ($K)
University of Tennessee Rao V. Arimilli	Knoxville, TN arimilli@utk.edu	Wind loading modeling conducted by a graduate student and professor on acrylic mirror design	27
Antares Christian Demeter	Landover, MD cdemet@antaresgroupinc.com	Market assessment	10
Bennett Mirrors Alastair Bennett	Tauranga, New Zealand alastair@bennettmirror.com	Produced prototype acrylic mirrors	5

Systems Integration and Coordination

The National Center for Photovoltaics (NCPV), headquartered at the National Renewable Energy Laboratory (NREL) in Golden, Colorado, provides overall coordination of the PV Subprogram at the request of DOE. NREL and Sandia National Laboratories (SNL) in Albuquerque, New Mexico, are partners in the NCPV, and provide the management oversight for the respective projects in their laboratories, as well as management support for the NCPV. The Concentrating Solar Power (CSP) Subprogram is managed collaboratively between SNL and NREL in the virtual entity referred to as Sun♦Lab. NREL, SNL, and Oak Ridge National Laboratory (ORNL) in Oak Ridge, Tennessee, jointly participate in managing the Solar Heating and Lighting Subprogram.

Management activities include analysis, administration, budget control, reporting, and integration of programs, including oversight of staff, equipment, and facilities at NREL, SNL, and ORNL. The management team develops inputs for new program initiatives, conducts review meetings at the request of DOE, and provides oversight for communications, outreach, and cross-cutting analysis activities. The team also provides leadership and support for various Solar Program activities, such as development of the *DOE Solar Program Multi-Year Program Plan* (MYPP) and the Systems-Driven Approach to program management.

Some significant accomplishments in FY 2006 are listed below.

Systems-Driven Approach

- Provided analytical support to the Solar America Initiative, including writing a number of internal white papers, preparing presentation materials, drafting documents related to the Technology Pathway Partnership Federal Opportunity Announcement.
- Analyzed the potential for very large-scale solar PV deployment in the United States.

Communications and Outreach

- Completed five annual core documents for the Solar Energy Technologies Program.
- Managed key components of, and staffed the, 2005 Solar Decathlon; participated in critical lessons learned, selection, and planning activities for the 2007 Solar Decathlon.

International Activities

- Published the *Solar International Activities: Strategic Plan* and adopted relevant elements of plan as SAI Market Transformation activities.
- Supported participation in both International Energy Agency (IEA) Task 9, “Coordination of Renewable Energy Training and Certification Activities,” and IEA Task 10, “Urban Scale PV Applications."

Process Integration, Capital Equipment, and Facilities

- At the Science and Technology Facility (NREL): performed project management and engineering development leading to the delivery, acceptance, and operation of an inter-tool transport pod to move samples between tools in a controlled ambient (high vacuum). Achieved successful transfer of samples between the stand-alone tool for transparent conducting oxides and the transport pod.
- At the National Solar Thermal Test Facility (SNL): completed preliminary testing of a theoretical overlay photographic trough alignment approach on the trough rotating platform.

Systems-Driven Approach

Performing Organizations: National Renewable Energy Laboratory (NREL)
Sandia National Laboratories (SNL)

Key Technical Contacts: Joe Tillerson (SNL on detail to DOE, Primary Contact), 202-586-1495, joe.tillerson@ee.doe.gov
Chris Cameron (SNL), Paul Gilman (NREL), Charles Hanley (SNL), Robert Margolis (NREL), Mark Mehos (NREL), David Mooney (NREL)

DOE HQ Technology Manager: Thomas Rueckert, 202-586-0942, thomas.rueckert@ee.doe.gov

FY 2006 Budgets: $990K (NREL), $610K (SNL)

Objectives

- To develop and apply a market-driven, validated, user-friendly, analytical framework for determining research priorities within the DOE Solar Program, including the following:
  - **Analysis** – To improve the analytical basis for understanding the system and policy drivers of solar technologies in various markets.
  - **Benchmarking** – To benchmark current system, component, and subcomponent performance and cost to provide validated input to the Systems-Driven Approach (SDA) model and to validate SDA model output.
  - **Modeling** – To develop a user-friendly solar energy systems model that will allow program managers and others users to investigate the impact of variations in physical, cost, and financial parameters to inform R&D and design decisions.

Accomplishments

- **Analysis**
  - Provided analytical support to the Solar America Initiative (SAI), including writing a number of internal white papers, preparing presentation materials, drafting documents related to the Technology Pathway Partnership (TPP) Federal Opportunity Announcement (FOA).
  - Provided training and assistance to SAI TPP applicants with respect to using the Solar Advisor Model (SAM).
  - Analyzed potential for very large-scale solar PV deployment in the United States.
- **Benchmarking**
  - Established a cost basis for PV systems in the three market sectors of the Solar America Initiative, which was used as a starting point for TPP developments.
  - Defined reference systems and their parameters as input to SDA models and the *DOE Solar Program Multi-Year Program Plan.*
  - Provided data and analytical input to the SETP Posture Plan and a planned update of the Multi-Year Program Plan.
- **Modeling**
  - Developed and released version (June 30, 2006) of Solar Advisor Model for use by SAI bidders and reviewers.
  - Developed documentation for SAM and held SAM workshop (July 25, 2006) for potential SAI bidders.
  - Supported external review/validation of SAM by Strategen.
  - Completed utility-scale, independent power producer (IPP) finance modeling option (upgrade to previously developed model).
  - Added user defined variable capability to allow flexibility in modeling nonstandard variables (variables modeled through linkages with Excel spreadsheets).
  - Enhanced parametric analysis capability to include parameterization of non-numeric variables (e.g., climate, tracking type, financing type, depreciation schedule) and to include parameterization of user-defined variables.

- Continued improvements to model functionality for photovoltaic (PV) and concentrating solar power CSP cost and performance algorithms and interface in response to internal and external users.

Future Directions
In FY07 and beyond, these SDA activities will be more integrated as the Solar Program implements SAI and develops closer cooperation with the industry-led TPPs. Thus, as SDA becomes more intrinsic throughout the Solar Program, activities will focus more on development of needed tools for SAI and industry partners, and less on the establishment of a process for program implementation.

- **Analysis**
  - Continue work on analysis of long-term benefits of solar energy.
  - Continue to carry out policy analysis in support of the Solar Program, in particular, to help provide context for SAI R&D planning.
- **Benchmarking**
  - Work with TPPs and other partners to establish a basis for tracking progress of their technical developments on the basis of levelized cost of energy (LCOE).
  - Develop a means to input future revisions to benchmarks that will facilitate TPP reporting, such as a Web-based database.
- **Modeling**
  - Add capability for modeling Federal, state, and local incentives (performance-based incentives, capacity-based incentives, investment-based incentives, and investment and production tax credits) for residential, commercial, and utility-scale PV and CSP systems.
  - Add additional utility finance options (e.g., investor-owned utility, municipal utility).
  - Add capability of analyzing time-dependent valuation of PV and CSP output.
  - Complete refinement and integration of solar only, solar w/ storage, and solar w/ hybrid parabolic trough performance and cost models.
  - Begin development of dish/Stirling performance model w/ linkage to program-developed cost model.

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1. Introduction

The DOE Solar Program began the formulation of a Systems-Driven Approach (SDA) to R&D portfolio management and prioritization with a workshop held in December 2002. The *DOE Solar Program Multi-Year Program Plan* (MYPP) states that "we have implemented the use of our Systems-Driven Approach to guide us through difficult programmatic options and to make sound decisions considering limited resources." The SDA provides a framework for program planning that supports this objective. Under the tasks described below, data and tools are being developed and applied to support the use of SDA in decision-making by program management. The SDA team works closely with other projects, especially the PV Systems Analysis Project. During FY 2006, the work under this task was focused specifically on supporting the implementation of the Solar America Initiative (SAI).

2. Technical Approach

The SDA is the basis for the multi-step planning process used in the Solar Program for portfolio decision-making. The SDA allows us to assure that all technical targets for R&D on the components and systems funded through the Solar Program are derived from a common market perspective and national goals, and the resultant technologies are tested and validated in the context of established criteria for each market. The key steps in the decision-making process are:

- Identifying technology improvement opportunities and analyzing impact on LCOE
- Assessing research activity contributions to technology improvement
- Developing a multi-year research portfolio
- Assessing progress.

Analysis, benchmarking, and modeling activities are the three primary components of the SDA efforts. In FY 2006, activities focused primarily on new PV modeling capabilities and associated applications directly in support of the SAI.

Task Title	FY 2006 Budget ($K)
Analysis	430
Benchmarking	610
Modeling	560

2.1 Analysis

Analysis is used to establish a sound basis for understanding the system and policy drivers of solar technologies in various markets. Results from analysis activities are linked to the broader SDA process and provide a market context for the benchmarking and modeling efforts.

We are developing long-term, market-penetration projections for solar technologies by examining both system and policy drivers of solar technologies in various markets in both the short and long term, as well as improving the analytical basis for projecting the program's economic and environmental benefits. Existing models, such as MARKAL and the Energy Information Administration (EIA) National Energy Modeling System (NEMS), are used to carry out analysis, and feedback is provided on how to improve the representation of solar technologies in these models. New models, such as the Solar Deployment Systems (SolarDS) model, are also being developed. This model analyzes the market penetration of PV on buildings in the United States under different policies and rate structures.

We are also reviewing the feasibility of achieving the program's technical and economic targets. This task examines proposed research goals given technical, funding, and other constraints. Here, our emphasis is on reviewing the existing literature on cost and performance projections, drawing on experts from both within and outside the solar community to review detailed technology cost models, and grounding the program's targets in real-world experience. In addition, value analyses are completed in which we evaluate policies, as well as other factors, that impact the value of solar energy technologies in various markets.

In carrying out these tasks, we utilize resources at NREL and SNL, as well as subcontracts (as described below in Section 6).

2.2 Benchmarking

With the development and initiation of the Solar America Initiative during this year, much of the benchmarking effort of the SDA was transitioned into supporting this initiative through the provision of underpinning data and analyses. Specific efforts contributed to the achievement of the planned milestones for this task area, including:

- Providing leadership and technical support to the several industry Technical Exchange Meetings that took place during the year, in Chicago, Washington, D.C., and San Francisco, and the compilation of results reports that directly fed the development of the FOAs for SAI.
- Contribution of materials for the Solar Program Posture Plan, to prepare for its release and publication in early FY 2007.
- Provide support and verification of the baseline cases in the Solar Advisor Model, which was released for use in TPP applications.
- Contribute to the development of the Multi-Year Program Plan, and then to revisions, based on sound data collection and analysis.
- Define and communicate the stage-gate process for technical development in the context of Solar America Initiative.
- Contribute to the development of the TPP FOA and additional announcements as part of the SAI Market Transformation activities.

2.3 Modeling

The primary function of the Solar Advisor Model (SAM) is to allow users to investigate the impact of variations in physical, cost, and financial parameters to better understand their impact on key figures of merit. The model is intended for use by DOE and laboratory management and research staff in implementation of the SDA to program planning. The model is also intended to support members of the solar industry to inform internal R&D direction and to estimate systems cost and performance, in particular, as required in the TPP FOA process.

The working model consists of a user interface module for selecting and providing input data on the system configuration and operating environment; a system performance module, which simulates the hour-by-hour output of the selected system for the lifetime of a project; a cost input module for providing simple or detailed cost inputs for system components; and a financial analysis module for calculating system economics. The modules work in concert to generate the physical and financial figures of merit relevant to the particular user.

Subcontracted work, listed in Table 6, includes Paul Gilman (model documentation and training), Steven Janzou (model code development), and the University of Wisconsin (TRNSYS support and model code development).

3. Results and Accomplishments

3.1 Analysis

During FY 2006, a major emphasis of the analysis effort was to provide a wide range of technical and analytical support to help implement the SAI. Two examples include providing support to the SAI Technical Exchange Meeting (TEM), held in Chicago during April 2006, and helping to develop the TPP Funding Opportunity Announcement. With respect to the TEM, tasks included writing white papers, preparing presentation materials, organizing planning and strategy reviews, providing breakout facilitation, and documenting results from the meeting. With respect to developing the TPP FOA, tasks included drafting major technical sections of the FOA and supplemental material, developing evaluation processes and criteria, establishing technical requirements, identifying technical support activities, integrating industry feedback from the TEM, and incorporating review comments.

In addition, improving our understanding of the long-term market potential for solar technologies has been an important part of our analysis task. For example, SolarDS is being developed to examine sensitivity of PV market share to PV capital cost and performance, rate structures, competition with other distributed-generation technologies, tax and environmental policies, storage and load controls, and financing options and consumer choice.

3.2 Benchmarking

As stated above, the results of the integrated SDA activities provided the analytical basis for the Solar America Initiative and several of its related documents. This included further documentation of past efforts. For example, an appendix was prepared for the Multi-Year Program Plan that discussed in detail the system-level analyses portrayed in the document. This appendix was not published, because soon after the release of the MYPP, the program management decided that the document needed extensive revision.

In addition, investigations were conducted to further understand the cost elements for balance-of-system components and installation steps for residential PV systems. These studies involved extensive Web-based investigations and interviews with several PV system suppliers across the United States. This information has been compiled in an Excel workbook, and further review will be done to determine how best to incorporate it into the Solar Advisor Model.

3.3 Modeling

In the SAI's Technology Pathway Partnership's Funding Opportunity Announcement that was released in June, applicants were required to project the impact of their proposed improvements on the PV system's LCOE. While they could use any model of their choosing to calculate LCOE, they were encouraged to use the Solar Advisor Model and were informed that SAM would be used in the review process to verify their LCOE claims. In conjunction with the release of the FOA, SAM was also made available for download in late June from the SAI Web site. Leading up to the due date for applications, which was in October, about 300 people had downloaded SAM. To support this activity, a one-day training workshop was held at NREL in July with about 35 attendees.

Ultimately, 55 applications were accepted for review under the FOA. All 55 applicants had downloaded and utilized SAM in calculating their LCOE baselines and the impacts of their proposed improvements on LCOE.

The first step in the technical review of the application involved the formation of a FOA Technical Committee (FTC). FTC members, who were versed in the use of SAM, looked at each of the 55 applications and input the relevant values from the applications into SAM in order to validate the applicant's LCOE projections. Reports of these validation runs were generated and made available to the FOA Merit Review Committee for its consideration in the overall review of the applications. SAM will continue to be utilized in the technical monitoring of the selected TPPs in order to track progress toward LCOE targets.

In conjunction with, and following release of SAM for use within the SAI framework, the SAM development team continued to refine and improve the SAM functionality. SAM was updated to support enhanced parametric analysis by adding the capability to parameterize non-numeric input variables (e.g., climate, tracking type, finance type). In addition, the development of user-defined variables will provide users with greater analytical flexibility by allowing them to investigate the impact of parameters not predefined in the models graphical user interface.

4. Planned FY 2007 Activities

4.1 Analysis

During FY 2007, the analysis team will continue to support the implementation of the Solar America Initiative. In particular, this work will emphasize improving our understanding of the long-term market potential for solar technologies and continuing to review the program's technical and economic targets, as follows:

- Developing better approaches for evaluating the benefits and costs of achieving the SAI targets (for example, related to employment, energy, and environmental benefits).
- Continue to carry out technology and policy analysis in support of the Solar Program, in particular, to help provide context for SAI R&D planning.
- Continue to assess progress toward meeting the program's long-term goals.

4.2 Benchmarking

As the SAI implementation ramps up with industry-led TPPs, benchmarking will support several activities, including:

- Establishing and verifying baselines regarding PV system cost and performance with the TPPs, to facilitate technical program tracking and stage-gate reviews.
- Continuing to lead the establishment of system-level program metrics to help determine technological program impacts on a broad, industry-wide level.
- Developing a standard, Web-based means of inputting and summarizing such baselines, to allow TPPs and DOE management greater and easier access to technical information.
- Participating in modeling team activities and contributing to the development of new analytical tools, for the benefit of both Solar Program management and the various players in the U.S. PV industry.

In FY 2007 and beyond, these activities will be coordinated throughout the task areas in the Annual Operating Plan and will not be limited to only the SDA task area.

4.3 Modeling

The capability of the SDA model will be expanded and applied, as follows:

- Addition of capability to analyze the impact of incentives (performance- and capacity-based) and tax credits (investment and production) on the cost of energy delivered from PV and CSP systems.
- Addition of time-dependent valuation of generation from PV and CSP systems.
- Inclusion of addition utility-scale project finance models (investor owned and municipal).
- Refinement of parabolic trough system cost and performance models and initial development of a dish/Stirling system performance model.

5. Major FY 2006 Publications

Blair, Nate, Christensen, Craig, Mehos, Mark, Janzou, Steve, (2006), "Cost and Performance Solar Analysis Model for All Solar Technologies," (ISEC2005-76207), *Solar Engineering 2005: Proceedings of the 2005 International Solar Energy Conference* (ISEC2005), 6–12 August 2005, Orlando, Florida. New York: American Society of Mechanical Engineers, pp. 225-228; (NREL TP CP-620-38049).

Denholm, Paul, and Robert M. Margolis, "Very Large-Scale Deployment of Grid-Connected Solar Photovoltaics in the United States: Challenges and Opportunities," paper presented at *Solar 2006*, Denver, CO, July 9–13, 2006.

Denholm, Paul, Ken Zweibel, and Robert M. Margolis, "Tackling Climate Change in the U.S.: The Potential Contribution from Solar Photovoltaics," paper presented at *Solar 2006*, Denver, CO, July 9–13, 2006.

Margolis, Robert M., Richard Mitchell, and Ken Zweibel. "Lessons Learned from the Photovoltaic Manufacturing Technology/PV Manufacturing R&D and Thin-Film PV Partnership Projects. Golden, CO: National Renewable Energy Laboratory, NREL Technical Report (NREL/TP-520-39780), September 2006.

Margolis, M. Robert, and Jarett Zuboy, "Nontechnical Barriers to Solar Energy Use: Review of Recent Literature." Golden, CO: National Renewable Energy Laboratory, NREL Technical Report (NREL/TP-520-40116), September 2006.

Perez, Richard, Robert Margolis, Marek Kmiecik, and Marc Perez, "Update: Effective Load Carrying Capability of Photovoltaics in the United States," paper presented at *Solar 2006*, Denver, CO, July 9–13, 2006.

U.S. Department of Energy, *Solar Energy Technologies Program Multi-Year Program Plan 2007–2011*, DOE Office of Energy Efficiency and Renewable Energy, Washington, D.C., January 2006.

Wiser, Ryan, Mark Bolinger, Peter Clappers, and Robert Margolis, "Letting the Sun Shine on Solar Costs: An Empirical Investigation of Photovoltaic Cost Trends in California," Golden, CO: National Renewable Energy Laboratory, NREL Technical Report (NREL/TP-620-39300), January 2006.

6. University and Industry Partners

The following organizations partnered in the project's research activities during FY 2006 (no cost share).

Organization/ Principal Investigator	Location/e-mail	Description/Title of Research Activity	FY 2006 ($K)
Energy Strategy Associates, LLC. Gerry Braun	Damestown, MD gbraun12@comcast.net	Experience scaling up manufacturing of emerging photovoltaic technologies, Part 2	14
Paul Gilman	Washington, DC paulgilman@earthlink.net	Documentation and training for solar analysis tools	37
Janzou Consulting Steve Janzou	Evergreen, CO steve@janzouconsulting.com	Provide coding support for advisor model development	125
University of Wisconsin Madison Sandy Klein	Madison, WI klein@engr.wisc.edu	CSP parabolic trough plant model, and support for TRNSYS/SAM integration.	64

Communications and Outreach

Performing Organizations:	National Renewable Energy Laboratory (NREL) Sandia National Laboratories (SNL) DOE Golden Field Office (DOE/GO) National Energy Technology Laboratory (NETL)
Key Technical Contacts:	Don Gwinner (NREL), 303-384-6570, don_gwinner@nrel.gov Susannah Pedigo (NREL), 303-384-6624, susannah_pedigo@nrel.gov Terry Wilson (SNL), 505-844-6830, tcwilso@sandia.gov Glenn Doyle (DOE/GO), 303-275-4706, glenn.doyle@go.doe.gov
DOE HQ Technology Managers:	Robert Hassett, 202-586-8163, robert.hassett@ee.doe.gov Thomas Rueckert, 202-586-0942, thomas.rueckert@ee.doe.gov
FY 2006 Budgets:	$570K (NREL), $132K (SNL), $300K (DOE/GO and NETL)
Special Budget Note:	Communications and outreach activities related to the Solar Decathlon (2005 and 2007 events) are discussed in this section of the report, but the funding for those activities is captured in the Building-Integrated Photovoltaics section.

Objectives

- Focus on innovative ways to reach critical audiences and improve business performance—get the right information to the right people at the right time in the right form.
- Unify the outreach efforts of the Solar Program so that communications and knowledge transfer emphasize *all*, rather than *individual* solar technologies, leading to understanding, collaboration, and partnership to advance solar energy technologies.
- Use communications products and activities to inform and persuade audiences, move them to action, and help overcome barriers for particular technologies and applications.

Accomplishments

- Completed five annual core documents for the Solar Energy Technologies Program (SETP).
- Played a key role in the Solar Program Review Meeting.
- Participated in IEA Photovoltaic Power Systems Programme, Task 1.
- Supported efforts for the publication of about 400 technical publications.
- Maintained, expanded, and/or developed 12 Web sites.
- Employed visual display and design expertise, creating products such as 3-D animations, kiosks, posters, and displays for a variety of products.
- Created and/or staffed several exhibits.
- Managed key components of, and staffed the, 2005 Solar Decathlon (took place in FY 2006).
- Participated in critical lessons learned, selection, and planning activities for the 2007 Solar Decathlon.
- Provided critical and timely support to SETP for the Solar America Initiative (SAI).
- Supported the 2005 National Solar Tour.

Future Directions

- Plan and conduct activities for Core Program Support including development and distribution of annual SETP programmatic documents; maintaining, improving, and/or developing 10–15 Web sites; editing/processing for publication about 400 technical manuscripts; producing a concentrating solar power (CSP) overview publication; and supporting the CSP 1000 MW initiative.
- Participate in merit reviews, support management at DOE, GO, and NREL of the task, and develop a plan for communications activities associated with the Solar America Showcases/City

Strategic Partnerships Documentation, State Technical Outreach, and Utility Technical Outreach tasks.
- Conduct all planning and implementation activities for the communications and outreach tasks for Solar Decathlon 2007, which will actually occur in FY 2008.

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1. Introduction

Advances made through the DOE Solar Program must be communicated effectively to appropriate audiences if further technical and market growth will occur. In FY 2006, the Solar Communications Team implemented strategies and tactics on behalf of the Solar Program to generate awareness of solar energy technologies, the research activities, and the potential for solar energy technology advances.

These strategies and tactics were set forth in our strategic communications plan developed in FY 2004 and refined in FY 2005. At that time, our communications efforts were realigned to integrate communications across the various solar technologies and minimize redundancy; better target audiences and messages; respond better to changes in markets, technology perceptions, audiences, and funding; develop communication projects within the context of other relevant plans; leverage limited resources; and cultivate a multi-year mentality.

The planning approach includes eight key audiences and their perceptions of solar technologies; audience-specific messages and communication objectives and strategies; and communications tactics (projects) to reinforce the objectives.

The Solar Communications Team's primary objective is to get the right information to the right people at the right time in the right form. The team develops, or assists in developing, a wide range of products, including technical reports, conference papers, journal articles, proceedings, brochures, fact sheets, presentations, posters, databases, exhibits, displays, Web sites, and CDs, as well as programmatic pieces such as the Solar Program Overview, Annual Report, and Multi-Year Program Plan.

2. Technical Approach

Our planning efforts evolved from the following simple objectives:
- Represent the Solar Program appropriately.
- Save money by reducing duplication of effort among separate subprograms.
- Brand all communications and outreach products and activities in a consistent and appropriate manner.

Our team views core activities within four primary areas:
Planning. Activities associated with strategic planning, budgeting, and aligning with the Systems-Driven Approach while working on the transition to alignment with the Solar America Initiative.
Developing and producing. Activities associated with creating and producing a variety of communications products, including print, Web, and exhibits, to convey research results and the program's messages.
Transferring knowledge. Activities associated with transferring research and program information (both internally and externally) to critical audiences, from the national laboratories and program management.
Measuring. Activities associated with measuring and assessing the relationships to critical audiences and the effectiveness of messages to them.

The Communications and Outreach Project consists of the following tasks.

Agreement Title	FY 2006 Budget ($K)
NREL NCPV/PV Communications	570
SNL NCPV/PV Communications	132
DOE/GO and NETL Financial Assistance Outreach/ Communications	300

3. Results and Accomplishments

We summarize our key results and accomplishments for FY 2006 under the four core activities mentioned under Technical Approach above.

3.1 Planning
- We served on the proposal review committee to choose the teams for Solar Decathlon

2007. DOE announced the 20 teams chosen. We served on the Rules and Regulations Committee to revise the competition (about half of the 10 contests were changed significantly) and the *Rules and Regulations* for the competition.

- The Solar Program Strategic Communications Team met as a full group—including personnel from DOE, NREL, and SNL—to discuss our role in the Solar America Initiative and how communications is vital to rolling out SAI's aggressive technology acceptance and R&D efforts. (5/06)
- We prepared the Solar Communications FY 2007 Draft R&D Project Proposal for the Technology Acceptance section of the Solar Energy Technologies Program. The write-up covers communications projects by NREL and SNL within both PV and CSP. (6/06)
- The Solar Communications team participated in the SAI's Technology Acceptance meeting in San Francisco, June 2006. The Communications representative documented the industry and research communities' feedback regarding the development of the initiative, and the team will use the information in formulating business and communications strategies. (6/06)
- We prepared the FY 2007 AOP. (9/06)

3.2 Developing and Producing

- We completed the *DOE Solar Energy Technologies Program Annual Report, FY 2004*, which included a CD of proceedings from the Solar Program 2004 Review Meeting. (10/05)
- We implemented an online collection system for Solar Program Review Meeting papers, which streamlined the "by hand" collection system used in the past, and should save the Solar Program time and money. (10/05)
- We provided dynamic content for the Solar Decathlon Web site, including daily photos and journals. (10/05)
- For the *2005 Solar Energy Technologies Program Review Meeting* (November 2005), we completed the meeting Program and Abstracts book and distributed 325 copies at the meeting. (11/05)
- We completed a repurposing of the solar-heating content on the EERE Solar Program Web site. Changes were necessary to provide more information about the subprogram's current research and partnerships and to make access to basic information about solar-heating technologies more intuitive. (12/05)
- We completed the final draft of the *Solar Program Multi-Year Program Plan 2007–2011* by the end of January. (1/06)
- We completed and submitted the U.S. annual contribution to the IEA PVPS: Task 1 Annual Report: PV Technology Status in the USA. The U.S. submission is a summary of R&D, policy, U.S. industry, and DOE program accomplishments for FY 2005. (1/06)
- We completed the migration of the EERE Solar Program Web site to DOE EERE's new content management system www.eere.energy.gov/solar/. (2/06)
- We created an exhibit for the groundbreaking of a new 65-MW solar parabolic trough plant in Nevada. The exhibit highlights the research accomplishments of an NREL/industry partnership with Solargenix. (2/06)
- We completed the 3-D modeling and animation of the transfer pod/cluster tool concept, which is at the heart of the work to be conducted within the Process Development and Integration Laboratory of the Science and Technology Facility. (2/06)
- We completed the *DOE Solar Energy Technologies Program Annual Report, FY 2005*, which includes a CD of proceedings from the Solar Program 2005 Review Meeting. The Annual Report chronicles all activities of the DOE Solar Program, giving account for how funding dollars are invested. (3/06)
- We wrote and published *DOE Solar Energy Technologies Program: Overview and Highlights* (a June/July milestone). The 20-page brochure provides engaging, accessible information about Solar Program activities and capabilities to a non-specialist audience, including Congress, industry partners, government agencies, and visitors to DOE facilities. (5/06)
- We created a kiosk for the 4th World Conference on Solar Energy Conversion, held in Hawaii in May. The focus was on luminaries in the PV field during the last several decades; the display included two flat-panel monitors that allowed participants to view and listen to unique interviews with many of the highlighted individuals discussing their careers and thoughts on the direction of solar research. (5/06)
- We wrote, designed, and produced capabilities material for the NCPV's

Measurements & Characterization (M&C) Division. The content is also being used in the redesign of the M&C Web site. (6/06)

- We created new graphics for 19 display cases about PV technologies for the NREL Solar Energy Research Facility (SERF). The displays provide information on crystalline silicon, thin-film, and concentrating PV; manufacturing support; and balance of systems/systems integration. The cases are a major focus of tours to the SERF by various stakeholder groups and VIPs, such as legislators, agency heads, and industry executives. (6/06)

3.3. Transferring Knowledge

- Solar Decathlon 2005 hosted about 120,000 visitors on the National Mall. We managed several key aspects of the event. Our village design and installation activity resulted in infrastructure for special events such as the Opening Ceremony, at which Secretary Bodman spoke; consumer workshops about energy efficiency and renewable energy, (about 1,400 attendees); and two exhibits: *Energy Today* provided information about EERE's purpose and mission, and *Anatomy of a House* provided visitors with a primer on the basics of energy efficiency and solar energy for homes. Village design also included signage for the event. We managed the volunteer program—by far, the bulk of "event staff" interacting with the public is made up of volunteers from DOE and the Decathlon's sponsors. We filled approximately 650 volunteer "shifts." We also managed the Communications Contest, which requires the student teams to develop Web sites and conduct tours of their houses on the mall. The "communications team" consisted of six from NREL, two from Oak Ridge National Laboratory, and one from SNL. We staffed the event and competition, conducting and managing the aforementioned activities while producing dynamic content for the Web site (scoring data, daily photos, and journals), which received 73,000 unique visits per day during the event. We also supported the media relations team, providing information and materials as needed. And we worked extensively with the student teams to ensure their interactions with visitors went as smoothly as possible. (10/05)
- The Solar Communications Team represented the DOE Solar Program and NREL at Solar Power 2005 in Washington, DC. Attendees for this event included utility and energy service providers, the solar industry, and consumers. Our efforts focused on connecting external stakeholders with appropriate people at NREL and the EERE Solar Program. (10/05)
- Under a grant from the DOE Golden Field Office, we supported the American Solar Energy Society (ASES) 2005 Tour of Solar Homes. The tour is the *premier* public demonstration event of deployed solar energy technology for the built environment, most frequently featuring energy efficiency, passive solar design, solar domestic hot water, photovoltaics, and daylighting. The tour reaches consumers interested in energy efficiency and renewable energy technologies, and, via media coverage, the general public who sees stories about the tour and the buildings in print and on the Internet, radio, and TV.
- We produced material explaining the Science & Technology Facility, which was subsequently used by David Garman in presenting to the President's Council of Advisors on Science and Technology (PCAST). (11/05)
- We developed and produced several key posters to help NREL PV managers, as well as NREL Director Dan Arvizu, clearly explain the scope and value of the solar research being conducted at NREL. The posters were used in December, when NREL had separate visits from Clay Sell (DOE Deputy Director) and Ray Orbach (Director, Office of Science). (12/05)
- On behalf of the Solar Program, we participated in the International Builders' Show (IBS) in Orlando, FL (January 10–15). Exhibit participation at the show provides the Solar Program the opportunity to meet with builders, answer questions about all solar technologies, and distribute builder-oriented publications. With 100,000 attendees, IBS is the largest gathering of the buildings audience in the world. Participation in this event satisfies a strategic communications objective of disseminating information to the buildings audience. (1/06)
- The NREL Solar Communications Team assisted DOE/EERE in publicizing the Solar America Initiative and the Notice of Program Interest (NOPI) for the initiative. Announcements regarding both events were developed and posted in strategic locations on the EERE Web site. (2/06)

- The Solar Communications Team participated in the regular Task 1 meeting in Vancouver, BC, on behalf of the DOE Solar Program. The Photovoltaic Power Systems (PVPS) Programme is a collaborative R&D Agreement, established within the International Energy Agency, and conducts projects on the application of PV. IEA PVPS operates worldwide via a network of national teams in member countries, and promotes and facilitates the exchange and dissemination of information on the technical, economic, environmental, and social aspects of PV power systems. (3/06)

3.4 Measuring

- We prepared responses to questions asked by the Solar Program Review Meeting Review panel. We then participated in a question-and-answer period with three reviewers. Feedback helped to assess aspects of our work. (11/05)
- We conducted a Web site survey and lessons learned on all communications and media outreach activities for Solar Decathlon 2005, which informed our development of the 2007 identity, brochure, and Web site, as well as shaped our planning efforts for the next event. (12/05)
- During the 2005 Decathlon, we managed photographers to ensure adequate documentation of the event. We also performed research and conducted interviews with teams. This preliminary work became part of *Solar Decathlon 2005: the Event in Review*, a technical report we produced about the event. The report overviews the competition, including final results, team strategies, and detailed descriptions of each of the 18 competition homes. A major goal of the Solar Decathlon is that each successive competition should advance the state of the art of solar-powered, energy-efficient homebuilding. This report was written with an eye toward guiding and educating the 2007 Decathlon competitors. (6/06)

4. Planned FY 2007 Activities

Core Program Support: Develop and distribute Annual Report, Solar Program Overview, MYPP, and AOP. Maintain and improve some 12 Web sites and redesign the NREL PV, Measurements & Characterizations, and TroughNet Web sites. Edit/process the publication of ~400 technical papers. Produce a CSP overview publication. Support the CSP 1000 MW initiative through audience analysis and developing targeted information campaigns.

Solar America Showcases/City Strategic Partnerships Documentation task: Participate in merit reviews, support task management (at DOE, GO, and NREL), and develop a communications plan.

State Technical Outreach task: Participate in merit reviews, support task management (at DOE, GO, and NREL), and develop a communications plan.

Utility Technical Outreach task: Participate in merit reviews, support task management (at DOE, GO, and NREL), and develop a communications plan.

Solar Decathlon 2007: Preparations for the FY 2008 event must be completed by the end of FY 2007 and include developing an RFP for event management, and planning for special events, consumer workshops, volunteer program, and Communications Contest. Support the media outreach team, update Web content, prepare the Competition Program, write talking points for speakers, and serve on the Rules and Regulations Committee.

National Solar Tour 2007: Conduct the 2007 National Solar Tour with ASES under a grant from the DOE Golden Field Office. In coming years, add energy efficiency construction practices, information on appliances, and design support to an online energy calculator created to provide simple calculations for solar electric, solar thermal, and solar pool/spa heating. This tool will eventually provide a comprehensive vendor listing and localized insolation, utility rates, and incentive data to use in calculations, allowing consumers to determine for their property and locale the possibilities of renewable energy technologies and energy efficiency construction practices and potential vendors or contractors who could compete for their project.

Interstate Renewable Energy Council (IREC): Maintain the Web-based Database for State Incentives for Renewable Energy (DSIRE), an ongoing project of the North Carolina Solar Center and IREC funded by DOE.

Support projects such as Connecting to the Grid, Schools Going Solar database, Community Outreach, Training & Certification, Small Wind Energy News, Workshop-in-a-Box, Annual

Renewable Energy Recognition Awards videos, public service announcements, guide, and newsletters.

As the SAI Market Transformation activities, develop and conduct workshops, as appropriate, similar to the former Million Solar Roofs (MSR) Initiative Peer-to-Peer exchanges, which provided forums for MSR partners to learn from each other, receive training, and become informed on important issues.

Focus on some current and often difficult issues impacting expanded renewable energy use; for example, rules that support renewable energy and distributed resources in a restructured market, connecting small-scale renewables to the utility grid, developing quality credentials that indicate a level of knowledge and skills competency for renewable energy professionals, and getting the right information to the right people.

5. FY 2006 Special Recognitions, Awards, and Patents

2006 International Association of Business Communicators (IABC)/Southern Region Silver Quill; Award of Merit; Print Communications: Special Publication, handbook, Brochures, One-Time Publications; for the *DOE, Solar Energy Technologies Program: Overview and Highlights*

2005 Society of Technical Communicators (STC), FY 2006 Technical Communication Competition; Award of Excellence; Informational Materials Design; for the *National Renewable Energy Laboratory 2005 Research Review* (not solely a solar document, but it contained articles and information on solar technologies and was designed and written, in part, by members of the Solar Communications Team.

6. Major FY 2006 Publications

D. Gwinner et al., *Solar Energy Technologies Program Multi-Year Plan 2007-2011*. Final version not released, but draft posted at http://www1.eere.energy.gov/solar/about.html.

S. Moon et al., *DOE Solar Energy Technologies Program: FY 2004 Annual Report*. (2005). 196 pp.; NREL Report No. MK-520-36804; DOE/GO-102005-2173.

S. Moon et al., *DOE Solar Energy Technologies Program FY 2005 Annual Report*. (2006). 218 pp.; NREL Report No. BK-520-38743; DOE/GO-102006-2246.

S. Moon et al., (2006). *Solar Decathlon 2005: The Event in Review*. 62 pp.; NREL Report No. BK-520-38264; DOE/GO-102006-2328.

S. Pedigo et al., *Solar America Initiative Web portal on Solar Energy Technologies Program Web site*: http://www1.eere. energy.gov/solar/solar_america.

J. Zuboy et al., *DOE Solar Energy Technologies Program: Overview and Highlights.* (2006). 20 pp.; NREL Report No. BR-520-39081; DOE/GO-102006-2314.

J. Zuboy et al., *DOE Solar Energy Technologies Program: FY 2005 Annual Report and Proceedings, Program Review Meeting* (CD-ROM). (2006). ; NREL Report No. CD-520-38557; DOE/GO-102006-2245.

7. University and Industry Partners

The following organizations partnered in some of the project's activities during FY 2006.

Organization/ Principal Investigator	Location/e-mail	Description/Title of Research Activity	FY 2005 ($K)	Cost Share ($K)
Interstate Renewable Energy Council (IREC) Jane Weissman	Latham, NY jane@irecusa.org	Million Solar Roofs Outreach	300	0
American Solar Energy Society Brad Collins	Boulder, CO bcollins@ases.org	2005–2009 National Solar Energy Tour	125*	247**

*Funded with prior year (FY 2005) funds. **Spread over 5 years. No 2006 funds were obligated to this grant.

International Activities

Performing Organizations: National Renewable Energy Laboratory (NREL)
Sandia National Laboratories (SNL)

Key Technical Contacts: Cecile Warner (NREL), 303-384-6516, cecile_warner@nrel.gov
Vipin Gupta (SNL), 915-491-1158, vpgupta@sandia.gov

DOE HQ Technology Manager: Tom Kimbis, 202-586-7055, tom.kimbis@ee.doe.gov

FY 2006 Budgets: $150K (NREL), $130K (SNL)

Objectives

- Understand the drivers associated with international growth in PV sales.
- Determine the performance of PV products abroad.
- Help U.S. industry bring more affordable and reliable PV technology to the global marketplace.
- Execute DOE commitments in international agreements and activities.

Accomplishments

- Published the *Solar International Activities: Strategic Plan* developed by our team and adopted relevant elements of plan into the newly formed Solar America Initiative (SAI) Market Transformation activities.
- Supported participation in both International Energy Agency (IEA) Task 9, “Coordination of Renewable Energy Training and Certification Activities,” and IEA Task 10, “Urban Scale PV Applications."
- Drawing from insights and information gained as a result of participation in IEA tasks, developed solar technical assistance package for large-scale installations (Solar America Showcase) and city projects (City Strategic Partnerships) that use new solar technologies with the potential of achieving DOE cost goals.

Future Directions

- Execute SAI Market Transformation activities (e.g., technical assistance, acceptance testing, performance evaluations) to get new solar technologies developed through SAI’s Technology Pathway Partnerships adopted by the U.S. and international marketplace.
-
- Devise specific ways to overcome newly IEA-identified barriers to international market transformation that may be associated with lack of consumer confidence, inadequate training, poor technology performance, regulatory obstacles, and high cost.
- Support participation in IEA Task 10, “Urban Scale PV Applications,” for which the United States is the operating agent (NREL) and IEA Task 1, “Exchange and Dissemination of Information of Photovoltaic Power Systems” (NREL and Sandia).

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1. Introduction

The primary mission of the Solar Program International Activities task was to continually learn from the international adoption of solar technologies and improve U.S. solar technologies sold domestically and abroad. Because Germany, Japan, and Europe continue to drive the growth of the solar market, our task included: keeping current on why this is happening, understanding policy impacts, sharing this information with interested U.S. constituents, and determining how to improve U.S. PV product performance at a lower cost. Through our IEA involvement, as well as our strategic planning exercise, our team members also tried to provide timely data on emerging markets, nurture relationships with key manufacturers and integrators abroad, and distribute this information, where appropriate, to U.S. industry.

2. Technical Approach

DOE's international activities have involved NREL, SNL, and multiple university and corporate partners. This multi-institutional approach has focused on gathering useful field information in the United States and abroad on solar technology adoption (or rejection), conducting analysis on why this happened, and doing field performance assessments to determine how and why specific deployed solar systems are behaving in a particular manner. This information has then been disseminated to the DOE solar R&D community through written reports, technical papers, posters, and briefings.

Based on our newly developed strategic plan, we enumerated four strategies to carry out this technical approach:

1. Contribute international market and system data to the Systems-Driven Approach (SDA) process for improved modeling and analysis.
2. Provide market information to DOE to increase the competitive edge for the U.S. solar industry.
3. Use international experience as a surrogate for U.S. market development.
4. Contribute to improved performance and reliability for U.S. solar products using international systems application samples for testing and monitoring.

Task Title	FY 2006 Budget ($K)
PV International (NREL)	150
PV International (SNL)	130

3. Results and Accomplishments

One month after our international strategic plan was completed, President Bush announced in his 2006 State of the Union address his advanced energy initiatives, including solar technologies. This became DOE's new Solar America Initiative (SAI). Within a couple of months, our multi-institutional team worked hand-in-hand with new staff at the DOE Solar Program to define and detail the planned SAI Technology Acceptance activities—activities to reduce market barriers and transform the market (focused on the U.S. market) for wider use of solar energy technologies. This work included our team's participation in multiple Technical Exchange Meetings to solicit and garner input from U.S. industry, consumers, and state and local government officials on these new activities. All of this input—including relevant elements of the recently published international strategic plan—were then incorporated by DOE into a wider Technology Acceptance plan. This became our new guide for future activities, and the plan was used as the substantive basis for the first, second, and ongoing third round of funding opportunity announcements in Technology Acceptance.

4. Ongoing and Planned FY 2007 Activities

SAI represents a change from DOE's past international activities to present and future activities focused on markets and applications that can result in wider utilization of solar technologies in the United States. This transformation is well under way and consists of the following activities conducted by our team:

- Review and selection of winning Federal Opportunity Announcement proposals for Solar America Showcases, City Strategic Partnerships, Code and Standards, and State and Utility.
- Organization and formation of tiger teams for provision of technology assistance and sharing of solar knowledge gleaned from the field among the DOE solar R&D community.
- Development of specific ways to overcome identified market barriers (e.g., lack of consumer confidence, inadequate training, poor technology performance, regulatory obstacles, and high cost).
- Continuation of support for U.S. participation in IEA Task 10, "Urban Scale PV Applications," and IEA Task 1, "Exchange and Dissemination of Information on Photovoltaic Power Systems."

5. Major FY 2006 Publications

Robert Foster, Paul Gilman, Vipin Gupta, Don Gwinner, Robert Hassett, Christy Herig, Al Hicks, Marguerite Kelly, Jean Ku, Debra Lew, Jeff Nelson, Wendy Parker, Susannah Pedigo, David Renne, John Thornton, and Harin Ullal, *Solar International Activities: Strategic Plan,* Solar Energy Technologies Program, U.S. Department of Energy, January 2006, pp. 1–26.

6. University and Industry Partners

The following organizations partnered in the project's research activities during FY 2006 (no cost share).

Organization/ Principal Investigator	Location/e-mail	Description/Title of Research Activity	FY 2006 ($K)
Segue Energy Consulting, LLC Christy Herig	Redington Shores, FL cherig@tampabay.rr.com	IEA PV Power Systems Task 10 (Urban PV) Support	109
Institute for Sustainable Power Roger Taylor	Evergreen, CO roger_taylor@nrel.gov	Coordination of Renewable Energy Training and Certification Activities and Support of IEA Task 9 Activities	38.8

Process Integration, Capital Equipment, and Facilities

Performing Organizations: National Renewable Energy Laboratory (NREL)
Sandia National Laboratories (SNL)

Key Technical Contacts: Larry Kazmerski (NREL-NCPV, Primary Contact), 303-384-6600, larry_kazmerski@nrel.gov
Brent Nelson (NREL-S&TF), 303-384-6407, brent_nelson@nrel.gov
Tom Mancini (SNL, Primary Contact), 505-844-8643, trmanci@sandia.gov

DOE HQ Team Leaders: Thomas Rueckert, 202-586-0942, thomas.rueckert@ee.doe.gov
Robert Hassett, 202-586-8163, robert.hassett@ee.doe.gov

FY 2006 Budgets: $1,872K (NREL, S&TF Essential Capital Equipment) $580K (NREL, Process Integration), $425K (SNL)

Objectives

Related to the Process Integration Project at the Science and Technology Facility (S&TF) at NREL:

- Develop infrastructure that will allow researchers to gain new knowledge that is difficult—if not impossible—to obtain with existing equipment.
- Implement the process-integration design standards for hardware and software in the development and integration of research tools. These tools include deposition, characterization, and processing technologies in support of the core research technologies and their collaborations with university and industrial partners.

Related to the National Solar Thermal Test Facility (NSTTF) at SNL:

- Operate and maintain facilities at the NSTTF.
- Support the DOE Concentrating Solar Power (CSP) Subprogram test and work-for-others activities at the NSTTF.

Accomplishments

S&TF:

- Project management support for the construction of a cluster tool to support silicon research.
- Project management and engineering development leading to the delivery, acceptance, and operation of a stand-alone tool for transparent conducting oxides.
- Project management and engineering development leading to the delivery, acceptance, and operation of an inter-tool transport pod to move samples between tools in a controlled ambient (high vacuum). Successful transfer of samples between the stand-alone tool for transparent conducting oxides and the transport pod.
- Project management support leading to the competitive bid of a molecular beam epitaxy (MBE)-type deposition chamber for copper indium (gallium) diselenide (CIGS) materials.
- Project management support leading to the competitive bid and contract awarding of an Auger electron spectrometer that is compatible with other tools as a mobile diagnostic tool.
- Project management and engineering development in the design of an automated chemical bath deposition system for cadmium sulfide growth.
- Project management support leading to the delivery and acceptance of a spectroscopic ellipsometer.
- Project management support leading to the delivery and acceptance of thickness monitoring equipment consisting of a profilometer and an interferometer.
- Project management support leading to the procurement of a UV-visible spectrophotometer.
- Earned Value Management System project management of the S&TF Essential Capital Equipment.

NSTTF:

- Support of the operation of the Dish Stirling Model Power Plant.
- Completed preliminary testing of a theoretical overlay photographic (TOP) trough alignment approach on the trough rotating platform.
- Started modification of the Engine Test Facility to accommodate 24-hour, gas-fired operation of Stirling engines.
- Held a NASA contractors meeting on aerocapture and provided a site demonstration of high-flux test support for the program.
- Performed minimal level of maintenance and required environmental health and safety (EH&S) activities at the NSTTF.

Future Directions

S&TF:

- Finalize the unfinished procurements in the previous section.
- Design and construct a general use current-voltage (JV)/quantum efficiency (QE) system.
- Design and construct an X-ray photoelectron spectrometer (XPS) and ultraviolet photoelectron spectrometer (UPS).
- Design and construct a cluster tool capable of Fourier transform infrared (FTIR) and visible optical analysis, ellipsometry, lifetime measurement, and thermal processing.

NSTTF:

- Due to the age of equipment and minimal maintenance over the last five years, we need to start planning a major maintenance upgrade to NSTTF equipment.
- Maintain NSTTF activities in support of ES&H requirements and site training.

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1. Introduction

The purpose of the Process Integration Project of the National Center for Photovoltaics (NCPV) is to develop an infrastructure at the Science and Technology Facility (S&TF) at NREL that will allow researchers to gain new knowledge that is difficult—if not impossible—to obtain with existing equipment. This difficulty is due, in part, to the state of our existing tool set, which lacks sufficient in-situ or real-time measurement capabilities, or lacks access to analytical tools where the sample remains in a controlled environment between deposition and processing or measurement. This new infrastructure will provide flexible and robust integration of deposition, processing (e.g., etching, annealing), and characterization tools via a standardized transfer interface such that samples move between tools in a controlled ambient. Ultimately, this synergistic effort between NREL staff, universities, and the PV industry—around an integrated tool base—will add to the PV knowledge base and help move many PV technologies forward.

We will achieve this purpose by building a collection of integrated deposition, characterization, and processing tools. These integration standards must be flexible to allow for changing research needs, yet be robust and reliable. Deposition tools must be able to deposit uniformly and reproducibly over areas that are large enough to be meaningful to industry and be able to handle a wide variety of sample substrates. The benefits of having integrated tools include allowing researchers to:

- Answer previously inaccessible research questions.
- Control and characterize critical surfaces and assess the impact of these interfaces on subsequent layers.
- Assess process-related source chemistry, surface chemistry and kinetics, and bulk reconstruction.
- Grow layers and alter interfaces using controlled transfer ambients (without exposure to air).
- Develop new techniques, methodologies, device structures, materials, and tools.

Activities at the National Solar Thermal Test Facility (NSTTF) at SNL focus on supporting the six-dish mini power plant of Stirling Energy Systems (SES) and the operation and maintenance (O&M) of the facility in the context of complying with all maintenance and ES&H requirements. No new facilities or equipment are being developed.

2. Technical Approach

2.1 S&TF

Individual deposition, processing, and characterization techniques will be integrated via one of several different modes. Ideally, characterization techniques will be used for real-time analysis of deposition and processing techniques. The next best solution is in-situ diagnostics (in the original place, but not real-time data). When neither of these integration methods is possible, techniques will be integrated by transferring samples from one location to another either via intra-tool or inter-tool sample transport. Intra-tool transport is the movement of samples between techniques within the same set of interconnected chambers, that is, a cluster tool. The actual transfer mechanism could be robotic or a linear track transport mechanism. Initial cluster tools will use robotic transfers. Inter-tool transport is the movement of samples between techniques where those techniques do not share direct connection. These techniques could be in a stand-alone tool or a part of a cluster tool. The sample is moved from one tool into the pod, which is sealed and disconnected from that tool before being wheeled to another tool, where the process is reversed. The transfer ambient within the pod can be either an atmosphere of ultrahigh-purity inert gas or high vacuum. This is similar to the Standard Mechanical InterFace (SMIF) used by the integrated-circuit (IC) industry to enclose and transport wafers between 200-mm tools or the newer Front-Opening Unified Pods (FOUP) used on 300-mm tools. One of the keys to the success of the IC industry was the creation of these mini-environments, in which the industry significantly reduced the contamination of wafers between processing steps. The transport pods being implemented under this project have two significant advantages over the SMIFs and FOUPs in the microelectronics industry. First, they protect samples and interfaces from contamination at the molecular level (not just from particulates). Second, these pods allowed us to save money on the building construction (no clean rooms).

The main design goals of the NCPV Process Integration Project are to:

- Develop a standard sample transport between tools.
- Ensure the sample transport mechanism is robust.
- Control the ambient of that sample transfer.
- Be able to deposit uniformly and reproducibly over areas large enough to be meaningful to industry.
- Handle a wide variety of sample substrates.
- Standardize control and data logging software.
- Integrate as many techniques as practical.

Because of our need to handle a variety of substrate sizes, shapes, and materials in a sample platen, there are no "off-the-shelf" solutions to integrating our tools. Therefore, we had to develop our own set of design standards for future tool development, especially for the pod. The progress on each of the various tools in this project is discussed in the next section. Each custom tool involves the following development steps:

- Conceptual design specifications
- Obtain budgetary quotes
- Scope adjustment (to fit budget)
- Final specifications
- Award contract and vendor fabrication
- Site preparation (for tool hookup at NREL)
- Acceptance and full operation at NREL.

2.2 NSTTF

The technical approach to operating and maintaining the NSTTF is to support the six-dish mini power plant and to assure that all ES&H requirements are met.

3. Results and Accomplishments

3.1. S&TF

There is a three-year budget for essential capital equipment associated with the construction and operation of the S&TF. This essential capital equipment includes the following projects, which are divided by status according to the development steps listed above.

Projects with equipment that is delivered, accepted, and fully operational at NREL:

- TCO sputtering stand-alone tool (AJA International)
- Transport pod (Transfer Engineering)
- Profilometer (Veeco/Dektak)
- Interferometer (Veeco/Wyko)
- Ellipsometer (Woolam).

Projects with contracts awarded and equipment being fabricated:

- UV/visible spectrophotometer (Varian)
- Silicon CVD cluster tool (MVSystems)
- Auger electron spectrometer mobile tool (DCA).

Projects with final specifications and that are in the procurement process:

- MBE-type chamber to deposit CIGS
- CBD CdS-controlled ambient stand-alone tool.

Projects undergoing budgetary rescoping:

- CIGS cluster-tool robotic hub
- JV/QE multi-user work station.

Projects developing final specifications:

- X-ray and ultraviolet photoelectron spectrometer stand-alone tool
- Electro-optical/processing cluster tool.

Software Integration. Software is critical to having fully integrated tools, not only for automation, but for easy access to the data from which information can be gleaned and knowledge built. The approach we are pursuing is illustrated in Fig. 1. This is an effort to go beyond the tools built to the process-integration hardware standards to integrating data management of other equipment and collaborations. Currently, we are working with the Scientific Computing Center (SCC) at NREL to test Web-based data storage and recovery systems. We are also working with the Manufacturing Research Center at the Georgia Institute of Technology (MARC/GT) to test their data-brokering scheme (CAMX). Ultimately, having integrated data will allow us to work with the SCC using sophisticated data-mining and visualization tools. Also, we will have the ability to pull a recipe out of a database and load it to a tool for implementation, and then have the tool data-log back to the database (aka, recipe in/ results out).

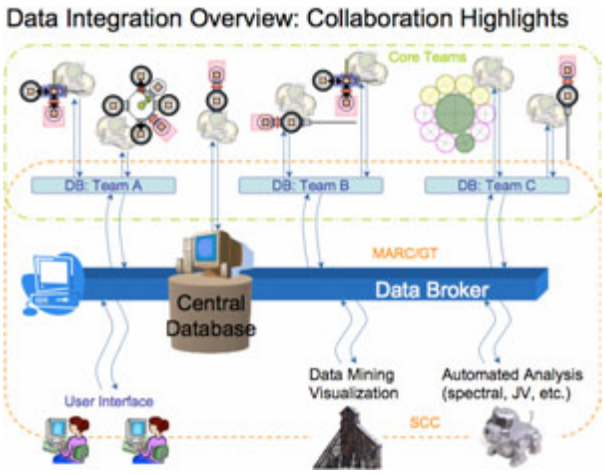

Fig. 1. Schema for software integration

3.2 Operation and Maintenance of the NSTTF

Accomplishments include that we:

- Continued operating the SES six-dish mini power plant.
- Supported NASA testing of high-flux materials.
- Operated the rotating trough platform in support of TOP alignment testing.
- Started modification of the Engine Test Facility to accommodate long-term Stirling engine testing.
- Complied with all ES&H and training requirements.

4. Planned FY 2007 Activities

4.1 S&TF

Projects with equipment to be delivered to NREL in FY 2007:

- UV/visible spectrophotometer (Varian)
- Silicon CVD cluster tool (MVSystems)
- Auger electron spectrometer mobile tool (DCA)
- MBE-type chamber to deposit CIGS
- CBD CdS-controlled ambient stand-alone tool
- CIGS cluster-tool robotic hub
- JV/QE multi-user work station.

Projects to place under contract in FY 2007:

- X-ray and ultraviolet photoelectron spectrometer stand-alone tool
- Electro-optical/processing cluster tool
- Develop and construct a substrate cleaning, platen assembly, pod loading station. It will include the ability to measure particulates on a substrate surface will be incorporated on this station or the pod diagnostic chamber.
- Develop pod and chamber diagnostic capabilities. This includes a pod diagnostic chamber (e.g., vacuum, interface controls) and making functional and available a mobile residual gas analyzer cart.
- Improve the pod design and procure multiple pods in “bulk" order. This includes getting new, more robust, tooling for pod alignment to the dock.

Software Integration. Software integration is an exceedingly time-consuming process requiring dedicated personnel. The microelectronics industry has determined that if software integration is developed along with the hardware development, it is about 40% of the development cost. When software integration is developed after the hardware is developed, it can account for more than 400% of the hardware development costs. For this part of the effort to be successful we need

to hire two software engineers: one to help with tool integration into the overall architecture (within the green, or top dashed, line in Fig. 1) and the other to implement the over all architecture and continuously improve the user interface. These software hires and efforts will be a major effort in FY 2007.

4.2 NSTTF

At SNL, O&M of the NSTTF will continue in an EH&S-compliant manner. We will also start planning for a major maintenance upgrade to reestablish the operational capability of the NSTTF.

5. University and Industry Partners

This project ensures consistency of hardware and software between equipment within the core research groups of the NCPV and also helps them build state-of-the-art infrastructure. This equipment is owned and operated by those groups. Therefore, these core research groups design the projects utilizing this equipment, including specific collaborations with the university and industrial partners. This project facilitates those partnerships.

EERE Crosscutting Activities

Energy efficiency and renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for the United States. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) invests in a diverse portfolio of energy technologies. These include solar-related research, development, and deployment projects that crosscut with, and complement, the objectives of the DOE Solar Program.

Small Business Innovation Research (SBIR) is a highly competitive program that encourages small businesses to explore their technological potential and provides the incentive to profit from its commercialization. By including qualified small businesses in the nation's R&D arena, high-tech innovation is stimulated and the United States gains entrepreneurial spirit as it meets its specific research and development needs. Each year, ten federal departments and agencies (including DOE) are required by the SBIR Program to reserve a portion of their R&D funds for award to small, U.S.-owned businesses.

The DOE Solar Program funded nine Congressionally Directed Projects through financial assistance awards in FY 2006. The scope of the projects varies significantly from research into carbon-nanotube transparent conductive coatings for thin-film photovoltaic cells, to development of electron microscopes for science students in college, to research in quantum dot light-emitting diodes.

Some accomplishments in this arena for FY 2006 are listed below.

Small Business Innovation Research

- Developed "Smart Skin," a sturdy coating for solar-thermal mirror concentrators.
- Achieved single-step wafer fabrication from metallurgical-grade silicon.
- Developed a hydrogen electrolyzer powered by PV concentrators.

Congressionally Directed Projects

- Developed and evaluated a new PV device structure in which carbon nanotubes replaced the indium tin oxide and Cu_xTe back contact layer of the top cell in a CdTe tandem thin-film cell. NREL reported a maximum efficiency of 12.9%.
- Produced carbon nanotube-based, highly conductive polymer coatings (to be used as screens for PV panels) with an optical transparency greater than 80%.
- Turned a "brownfield" site into a "brightfield" site by installing a 425-kW PV system.
- Completed development of six prototype tabletop scanning electron microscopes to be used in postsecondary schools.

Small Business Innovation Research

Performing Organization:	DOE HQ Solar Energy Technologies Program
Administrative:	DOE HQ Germantown
Support (Proposal Evaluation):	National Renewable Energy Laboratory Sandia National Laboratories
Key Technical Contact and DOE HQ Technology Manager:	Alec Bulawka, 202-586-5633, alec.bulawka@ee.doe.gov
FY 2006 Budget:	$1,800K

Objectives

- Support small business energy R&D.
- Implement Executive Order 13329, which involves assisting the private sector in manufacturing innovation.
- Continue to pursue wise cost/benefit investments.
- Augment the core research of the DOE Solar Program.
- Support effectively the Solar America Initiative.

Accomplishments

Awards that advanced/matured in FY 2005/2006:

- "Smart Skin," development of sturdier coating for solar-thermal mirror concentrators
- Single-step wafer fabrication from metallurgical-grade silicon
- Effective removal of impurities in silicon under vacuum
- Development of highly versatile and portable, stackable, more compact inverter
- Development of a hydrogen electrolyzer powered by PV concentrators
- Refinement of a process to convert waste thermal energy into electricity by luminescence up-conversion.

Future Directions

- Focus on material and process cost-saving techniques, as well as associated manufacturing diagnostics for manufacturing solar/PV (silicon and other thin films, as well as organics).
- Seek new solar concentrator structural (non-cell) designs for ease of manufacturing and cost reduction.
- Incorporate emerging innovative ways to use waste thermal energy in PV concentrators' electric output.
- Continue aggressive pursuit of organic PV solar cells incorporating nanotechnology.
- Achieve significant cost reduction in manufacture of crystalline silicon PV products.
- Seek effectiveness in PV-powered, renewable, hydrogen production as storage for PV energy.
- Focus on cost reduction via improvement of non-cell mechanical ancillary hardware.

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1. Introduction

Each year, ten federal departments and agencies (including DOE) are required by the Small Business Innovation Research (SBIR) Program to reserve a portion of their R&D funds for award to small, U.S.-owned businesses. Over the life of the SBIR Program, the Solar Program has contributed $16 million and received $34 million in research funding.

The Solar Program has also benefited to a large extent from the Office of Basic Energy Sciences contribution in nanotechnology topics for PV in 2006. The 2007 Solar Program is nested mainly in the Renewable Energy Sources SBIR category (Topic 2). SBIR activities fit very nicely into the *DOE Solar Program Multi-Year Technical Plan,* because they continue to augment and support the core program, in

all aspects, with integrated solutions from the vast U.S. small business community. Also, this year, the community has the opportunity to partake actively in the Solar America Initiative (SAI) through carefully selected and tailored supportive solicitations.

2. Technical Approach

Renewable energy technologies have achieved significant advances in recent years, but further improvements are needed if they are to reach their full potential. The solar technologies included in the scope of this SBIR work address both solar electric (photovoltaic or PV) and concentrating solar power (CPS) systems. Grant applications for FYs 2006 and 2007 were required to clearly demonstrate the applicants' ability to proceed to hardware development, fabrication, testing and manufacture of technologies.

2.1 *FY 2006 Phase 2 Awards*
There were no new Phase 2 awards initiated in 2006.

2.2 *FY 2006 Phase 1 Awards (September 2006)*
Nanosolar, Inc.: Printed Solar Cell Using Nanostructured Ink
TDA Research: Improved Fullerenes for Organic Photovoltaics
MicroCell Technologies: Ultrahigh Moisture Barrier Coatings for Photovoltaic Systems
Midwest Optoelectronics: Novel Interconnection Process for Lightweight Flexible PV Modules
Wakonda Technologies, Inc.: Alternative Thin Film Semiconductor Materials
NanoSonic, Inc.: High Performance, Low Cost Nanostructured Mirror Surfaces

See the SBIR Web site (http://sbir.er.doe.gov/sbir) for details on FYs 1998–2006 awards.

3. Results and Accomplishments

Several SBIR awards advanced their goals and produced very encouraging results of their R&D to date. Significant progress was made in the development of low-cost, high-performance nanostructured mirror surfaces and indestructible "smart skin" for solar dish-concentrating systems by Nanosonic. GT Equipment Technologies has developed a single-step wafer-fabrication process in which metallurgical-grade silicon is purified and solar silicon wafers are then drawn directly, bypassing several intermediate steps. This approach is much more cost effective than other options, with a 25:1 reduction in raw material cost. Crystal Systems, Inc., in an alternative approach, has developed a crucible and a process that, under vacuum, will be used for effective removal of impurities in metallurgical-grade silicon in the production of solar-grade Si. UQM Technologies was successful in the design and production of a very high power density, reliable, stackable (5 kW and up) inverter for anticipated use by multiple alternative energy source customers. It will operate more efficiently, deliver more power capability, and be more cost effective than what is presently available on the market. A 25-kW High Concentration Photovoltaic System prototype, in conjunction with a hydrogen electrolyzer incorporating a DC-DC converter and a low-pressure storage tank to produce clean hydrogen, is emerging for testing from Amonix, Inc. Hence, this is an alternative renewable energy source to produce clean hydrogen. MetroLaser is furthering its development of the process of luminescence upconversion to convert the infrared (excess waste heat) directly into electricity. Application will maximize absorption across the solar spectrum in a cell, while minimizing fundamental heat losses.

4. Planned FY 2007 Activities

Further development of PV and CSP systems will be addressed through creative and innovative approaches in engineering and design, and new materials and processes. A concerted effort has been made to have the SBIR activity dovetail in support of the SAI.

4.1 *Monitoring and Self-Diagnosing PV Systems, Components, and Modules*
Reliability is particularly important for new module and inverter technologies. Innovative methods will be sought to monitor PV system and component performance and to relate performance to actual weather, so as to ascertain failure and loss mechanisms as quickly as possible. Such monitoring and diagnostics can be embedded in system components resulting in, for example, state-of-health system sensors, smart metering, load-management controllers, and smart inverters.

4.2 *PV (Crystalline Silicon and Thin Film) Manufacturing Diagnostics*
Diagnostic technologies will be sought to improve yield and reduce cost of crystalline silicon PV manufacturing of cells and modules. Focus will be on identification and resolution of wafer stress and wafer cracks, wafer-handling technologies in production, improved interconnect technologies for wafer assembly, stress management, and improved manufacturing data tracking. Also, diagnostic and control technologies to improve yield, increase

materials utilization, and reduce the cost of thin-film PV module manufacturing will be pursued.

4.3 *Non-Inverter Balance-of-System (BOS) Components and Net-Metering Technologies*
This effort involves improving non-inverter BOS components for PV applications for grid-interactive systems. Customized circuit breakers, simplified or standardized wiring methodologies for building-integrated PV applications, junction boxes and innovative inter-array wiring, as well as mounting methodologies and installation concepts, will be pursued. State-of-system health monitoring capabilities, system-predictive monitoring, and safety and logic controls for complete system code and standards compliance will also be solicited. These are only some examples of a vast complement of ancillary needs.

4.4 *Non-Cell Concentrator Photovoltaic System Components*
With the development of the high-efficiency (40%) multijunction solar cell, concentrating PV (CPV) systems will become much more cost effective. The SBIR focus will shift to innovation in optical concentration designs (refractive, reflective, and holographic concepts). Tracking structures, control logic, torque leveraging, gears, hydraulics, and wind-loading protection schemes will now be addressed. Reduction of costly steel content (yet maintaining structural integrity), avoidance of mechanical resonances under wind loading, and innovative ideas in cell cooling will also get attention. Integrated CPV concepts, building CPV, and luminescent concentration are also on the agenda.

5. Major FY 2005 and 2006 Publications

The SBIR Program holds the awardee responsible for a final report at the end of both Phase 1 and Phase 2. The SBIR Office in Germantown, MD, has on file the final reports of all the projects awarded in the past.

6. University and Industry Partners

The following organizations partnered in the project's research activities during FY 2006 (no cost share).

Organization/ Principal Investigator	Location/e-mail	Description/Title of Research Activity	FY 2005 ($K)
GT Equipment Kedar Gupta	Merrimack, NH gupta@gtequipment.com	An Innovative Technique of Preparing Solar-Grade Silicon Wafers from Metallurgical-Grade Silicon by In-Situ Purification	600
Crystal Systems Fred Schmid	Salem, MA fschmid@crystalsystems.com	Development of Solar-Grade Silicon	600
UQM Technologies Jon Lutz	Frederick, CO jlutz@uqm.com	Power Converters for Diverse Applications	600
Amonix, Inc. Vahan Gharboushian	Torrance, CA drvahan@earthlink.net	A High Efficiency PV-to-Hydrogen Energy System	600
GT Equipment Kedar Gupta	Merrimack, NH gupta@gtequipment.com	Novel Low-Cost Process for Production of Crystalline Wafers for the Photovoltaic Industry	100
MetroLaser, Inc. Bauke Heeg	Irvine, CA bheeg@metrolaserinc.com	Thermal (Solar) Photovoltaics Using Luminescence of Upconverters	100
Distributed Power, Inc. Richard West	San Luis Obispo, CA Rick.west@distributedpower.us	Improved Performance, System-Integrated Power Converter with Advanced Circuit Topology for Renewable Energy Applications	100
NanoSolar, Inc. Chris Eberspacher	Palo Alto, CA Chris@nanosolar.com	Printed Solar Cell Using Nanostructured Ink	500
TDA Research Michael D. Diener	Wheat Ridge, CO Mikee@tda.com	Improved Fullerenes for Organic PV	100
Microcell Technologies Richard M. Formato	Littleton, MA Rformato@microcell-tech.com	Ultrahigh Moisture Barrier Coatings for Photovoltaic Systems	100

Organization/ Principal Investigator	Location/e-mail	Description/Title of Research Activity	FY 2005 ($K)
Midwest Optoelectronics Aarohi S. Vijh	Toledo, OH Vijh@mwoe.com	Novel Interconnection Process for Lightweight Flexible PV Modules	100
Wakonda Technologies, Inc. Leslie G. Fitzemeier	Fairport, NY lfitzemeier@earthlink.net	Alternative Thin Film Semiconductor Materials	100
NanoSonic, Inc. Michelle Berg	Blacksburg, VA mberg@nanosonic.com	High-Performance, Low-Cost Nanostructured Mirror Surfaces	100

Conductive Coatings for Solar Cells Using Carbon Nanotubes

Performing Organizations: Eikos, Inc., Franklin, Massachusetts
National Renewable Energy Laboratory (NREL)

Key Technical Contacts: Paul Glatkowski, Eikos, 508-528-0300, pglatkowski@eikos.com
Tim Coutts, NREL, 303-384-6561, tim_coutts@nrel.gov
Glenn Doyle, DOE-GO, 303-275-4706, glenn.doyle@go.doe.gov

DOE HQ Technology Manager: Jeffrey Mazer, 202-586-2455, jeff.mazer@ee.doe.gov

FY 2006 Budgets: $1,410K (DOE), $371K (Eikos cost share), $75K (NREL)

Objectives

- Develop requirements list for each solar cell type, wherein the transparent conductive coating (TCC) specifications are listed and the advantages and disadvantages of applying the carbon nanotube (CNT) technology are assessed and compared to existing TCCs.
- Improve optoelectronic performance to achieve greater than 90% transmission at 100 ohms/square through improved purification, dispersion, and morphology and helicity control.
- Determine the best application method(s) in terms of compatibility with the solar industry.
- Define photovoltaic design and determine commercial obstacles for implementation in commercial markets.

Accomplishments

- Successful use of CNTs in solar applications focused on further improvement of electrical conductivity and optical transmittance of CNT coatings.
- Continued research to develop better understanding of underlying mechanisms responsible for CNT sensitivity to surface resistance instability, known as R_s-drift.
- Explored ways, such as barrier materials, to minimize or eliminate changes in electrical resistance (R) and optical transparency (T), or R/T, during use.
- Explored avenues of performance enhancement by focusing on: CNT purification and metallic tube separation techniques, chemical doping, CNT patterning and alignment, advances in commercial and research materials, and field-effect schemes.
- Continued to develop improved efficiency coating materials and transfer methods suitable for batch and continuous roll-to-roll fabrication requirements.
- Developed and evaluated a new PV device structure in which CNTs replaced the indium tin oxide (ITO) and Cu_xTe back contact layer of the top cell in a CdTe tandem thin-film cell. NREL reported a maximum efficiency of 12.9%.

Future Directions

- Future directions target the following areas of research and development: Further CNT ink purification through “High G” centrifuging; examining metallic CNT harvesting methods; studies on conductive coating scale-up activities; studies on connectivity between CNT and external circuitry; further characterization on CNTs as PV material; publication of scientific results on CNT-enabled solar cells; and exploration of commercial interests and use of CNTs in PV systems.
- The results of research into CNT in PV cells has the potential to benefit researchers make progress toward the goal of making tandem CdTe top cells 25% efficient, which brings the technology closer to the performance of ITO cells.

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1. Introduction

The project consists of conducting research to prove that transparent conductive coatings (TCCs) based on carbon nanotubes (CNTs) can perform at an electrical resistivity and optical transparency in the range required for use in solar cells. Today’s solar cells are fabricated using metal-oxide-based

TCCs with optoelectronic performance significantly exceeding that currently possible with CNT-based TCCs. The motivation for replacing metal-oxide-based TCCs is their inherent brittleness, expensive deposition cost, and relatively high deposition temperatures, which leads to reduced optoelectronic performance on plastic. Alternatively, CNT-based TCCs overcome all these shortcomings while offering the ability to be applied in existing, very low cost, plastic film-processing equipment, such as continuous roll-to-roll coating.

At today's level of development, CNT-based TCCs are nearing commercial use in touch screens, some types of information displays (e.g., computer LCD monitors), and some military applications. However, the requirements for use in solar devices is nearly ten times higher than for those applications. Significant exploratory research is required on the fundamental CNT composition, dispersion, and deposition (film-forming). Theoretical calculations indicate that the current CNT TCC is capable of meeting the optoelectronic performance needed for solar cells. However, the path to reaching optoelectronic performance near theoretical limits will require successful application of carbon nanotechnology, which uses highly specialized tools and processes discovered in the past 2 years.

Specifically, Eikos will explore several potential experimental pathways expected to advance this TCC material system to the next generation of performance. Eikos will use specialized analytical services and proprietary nanotube purification processes to isolate and characterize specific types of nanotubes. Eikos will further purify, disperse, formulate, coat on films, and test the resulting TCC. Eikos will build working solar devices using the coatings, measure performance, and most importantly provide consultation on the direction, specification, and utility of the resulting TCC materials. Eikos has set a goal of a 3x improvement in optoelectronic performance and of developing an understanding of the remaining potential for further improvement. Sample films will be fabricated and used in laboratory-scale solar devices to serve as the proof of concept.

2. Technical Approach

(1) Develop requirements list for each solar cell type wherein the TCC specifications are listed and the advantages and disadvantages of applying the technology are assessed and compared to existing TCCs.
(2) Improve optoelectronic performance to achieve greater than 90% transmission at 100 ohms/square through improved purification, dispersion, and morphology and helicity control.
(3) Determine the best application method(s) in terms of compatibility with the solar industry.
(4) Define photovoltaic design and determine commercial obstacles for implementation in commercial markets.

2.1 FY 2006 Tasks

Task 1: CNT Performance Enhancement. Key areas researched under this task include: development of high-purity CNT materials; formulation of high-concentration CNT inks; identification of target morphology methods; identification of metallic CNT harvesting methods; identification and formulation of chemical doping; and investigation of the properties of commercial CNT materials.

Task 2: CNT Environmental Performance. Key areas of research under this task include: research into environmental barriers and accelerated weather testing.

Task 3: 3rd-Generation PV Cells. Key areas of research under this task include: CNT characterization and investigation and fabrication of CdTe tandem and organic PV cells. Eikos and NREL developed a new PV device structure, which is a CdTe polycrystalline high-efficiency top cell for thin-film tandem cells. At a sheet resistance of 100 ohms/square, CNT conductive coating back contacts produced efficiencies of 12.2%; at 50 ohms/square, the efficiency was 12.4%. Also, Eikos and NREL fabricated organic PV (OPV) cells with CNTs and a binder and an inverted OPV cell. Eikos and NREL also performed electrodeposition of ethylene dioxythiophene (EDOT) onto bare CNT films. No additional CIGS cells will be fabricated by NREL using CNT until Eikos can successfully demonstrate n-type doping of the CNT layer.

Task 4: CNT Conductive Coatings in PV Manufacturing. Key areas of research under this task include: investigating conductive coating uniformity; examining patterning methods; identifying interconnection methods; and identifying process scale-up options.

3. Results and Accomplishments

Progress continues on research aimed at CNT performance enhancement, CNT environmental performance, 3rd-generation PV cells, and CNT processes/methods in PV manufacturing.

4. Planned FY 2007 Activities

Plans for continued funding of Congressionally Directed Projects are the prerogative of Congress. Although this single-year funded project may extend beyond a single-year performance period, continued funding by the Solar Program is not planned.

5. Major FY 2006 Publications

T.M. Barnes, "Hole conducting CNT Transparent Contacts for Photovoltaics," *MRS Fall 2006 Conference*, Boston, November 27–December 1, 2006.

J. van de Lagemaat, "Organic, Excitonic Solar Cells with CNT Replacing ITO as Transparent Electrodes," *MRS Fall 2006 Conference,* Boston, November 27–December 1, 2006.

C. Weeks, Single Walled Carbon Nanotube Coatings as Transparent Conductors," *MRS Fall 2006 Conference,* Boston, November 27–December 1, 2006.

Dynamic Shading System with Integrated Concentrator Solar Module

Performing Organization: Rensselaer Polytechnic Institute (RPI), Troy, New York

Key Technical Contacts: Anna Dyson, RPI, (646) 872-8589, dysona@rpi.edu
Glenn Doyle, DOE-GO, 303-275-4706, glenn.doyle@go.doe.gov

DOE HQ Technology Manager: Jeffrey Mazer, 202-586-2455, jeff.mazer@hq.doe.gov

FY 2006 Budgets: $742K (DOE), $256K (RPI cost share)

Objectives

- Design, construct, and install a curtain wall unit incorporating a full-scale array of an integrated concentrating photovoltaic system.

Accomplishments

- Determined that a planar lens shape for the two-axis tracking concentrator PV cell would meet the requirements of allowing close packing at all normal incidence.
- Made progress in optimizing cell tracking while reducing thermal loading to the high-efficiency multijunction cells.

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1. Introduction

This Congressionally Directed Project is for the design, build, and extensive test of a full-scale installation of a building-integrated PV system. This system will produce electricity, capture thermal energy, provide improved indoor lighting through shading, and lower building energy loads.

2. Technical Approach

Evaluate quarter-panel scale mock-up of Dynamic Solar Window Shading (DSWS) as a test bed for system operations (4th generation); develop 5th-generation DSWS for large-scale use; refine optical modules, actuating tracking and heat transfer systems; design systems integration; fabricate 5th-generation system; test and evaluate integrated solar module at NREL; test 5th-generation system and evaluate performance.

3. Results and Accomplishments

Through research and testing, a planar lens shape for the two-axis tracking concentrator PV cell was determined to meet the requirements of allowing close packing at all normal incidence. This lens allows maximum conversion of solar irradiance to electrical power while permitting substantial daylighting. Progress continues in optimizing cell tracking while reducing thermal loading to the high-efficiency multijunction cells. Research continues on capturing the solar power not converted to electricity via a coolant flow through the receiver on which the cell is mounted. This coolant is used for hot water heating and potentially for refrigeration cycles.

4. Future Planned Activities

Plans for continued funding of Congressionally Directed Projects are the prerogative of Congress. Although this single-year funded project may extend beyond a single-year performance period, continued funding by the Solar Program is not planned.

Missouri Alternative and Renewable Energy Technology Center

Performing Organization: Crowder College, Neosho, Missouri

Key Technical Contacts: Art Boyt, Crowder, 417-455-5534, aboyt@crowder.edu
Glenn Doyle, DOE-GO, 303-275-4706, glenn.doyle@go.doe.gov

DOE HQ Technology Manager: Richard King, 202-586-1693, richard.king@ee.doe.gov

FY 2006 Budgets: $990K (DOE), $990K (Crowder cost share)

Objectives

- Design and construct pilot module and Stage 1 of the Missouri Alternative and Renewable Energy Center laboratory at Crowder College.

Accomplishments

- Completed site development plans, structural and building envelope specifications, daylighting design, and roof geometry design studies.

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1. Introduction

This Congressionally Directed Project is for the development of a 27,500-square-foot facility that functions as a living laboratory to support solar and other renewable energy development. This facility will enable professional degrees, new product commercialization, renewables-related business incubation, and consumer education.

2. Technical Approach

Design Missouri Alternative and Renewable Energy Technology (MARET) Center at Crowder College by integrating 40% solar design elements including: flat-plate silicon PV modules, balance of systems, solar hot water, combined heating and cooling, and advanced building-integrated concepts (AC building block system, PV/thermal hybrid system).

3. Results and Accomplishments

Site development plans, structural and building envelope specifications, daylighting design, and roof geometry design studies have been completed. As a result of this design development activity, Crowder College has decided to comply with U.S. Green Building Council guidelines and to apply for LEED (Leadership in Energy and Environmental Design) platinum certification for the MARET Center facility. This should impact positively the next stage of the National Environmental Policy Act application. Construction was delayed pending further design refinement and validation, including daylighting simulations. Additional tests were conducted to evaluate the structure to develop roof-wall and wall-foundation attachment details.

4. Future Planned Activities

Plans for continued funding of Congressionally Directed Projects are the prerogative of Congress. Although this single-year funded project may extend beyond a single-year performance period, continued funding by the Solar Program is not planned.

Carbon Nanostructure-Based Screens for PV Panels

Performing Organization: University of Arkansas at Little Rock

Key Technical Contacts: Alexandru Biris, U. of Arkansas, 501-569-8210, asbiris@ualr.edu
Glenn Doyle, DOE-GO, 303-275-4706, glenn.doyle@go.doe.gov

DOE HQ Technology Manager: Richard King, 202-586-1693, richard.king@ee.doe.gov

FY 2006 Budgets: $495K (DOE), $124K (U. of Arkansas cost share)

Objectives

- Develop highly conductive coatings using carbon nanotubes and optically transparent electrodes to create an electrodynamic shield to remove particulates from solar panels and optical equipment.

Accomplishments

- Produced carbon nanotube-based, highly conductive polymer coatings with an optical transparency greater than 80%.

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1. Introduction

This Congressionally Directed Project focuses on studying electrically conductive carbon nanotubes and their use for building an electrodynamic shield for particulate removal from solar panels and optical equipment.

2. Technical Approach

Grow high-purity carbon nanotubes, mix with polymer materials, and develop coatings with improved conductivity in a preferential direction for the electrodynamic screen.

3. Results and Accomplishments

This project successfully completed development of high-purity single- and multi-walled carbon nanotubes of reduced electrical resistivity that were mixed with polymeric films to produce highly conductive polymer coatings with an optical transparency >80%. The polymeric materials were formed into electrodes, connected to an electrical supply, and generate moving electrical waves that keep the surface free of particulate deposition.

4. Future Planned Activities

Plans for continued funding of Congressionally Directed Projects are the prerogative of Congress. Although this single-year funded project may extend beyond a single-year performance period, continued funding by the Solar Program is not planned.

Tools for Nanotechnology Education Development Program

Performing Organization: Oregon Nanosciences and Microtechnologies Institute (ONAMI), Eugene, Oregon

Key Technical Contacts: Skip Rung, 541-713-1331, skip.rung@oregonstate.edu
Glenn Doyle, DOE-GO, 303-275-4706, glenn.doyle@go.doe.gov

DOE HQ Technology Manager: Richard King, 202-586-1693, richard.king@ee.doe.gov

FY 2006 Budgets: $1,485K (DOE), $513K (ONAMI cost share).

Objectives

- Develop tabletop scanning electron microscope for use by postsecondary school students.

Accomplishments

- Completed design, fabrication, reliability testing, and development of six prototype tabletop scanning electron microscopes.

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1. Introduction

This Congressionally Directed Project is for development and delivery of a tabletop scanning electron microscope. This microscope will be easy to use by non-experts and students, will require no special facilities, and will be affordable to postsecondary educational institutions.

2. Technical Approach

Develop six prototype scanning electron microscopes (SEMs), conduct reliability analyses and implement improvements, develop and test SEM classroom simulator, train professors/ technicians on prototypes, and deploy in classrooms.

3. Results and Accomplishments

This project successfully completed design, fabrication, reliability testing, and development of six prototype tabletop scanning electron microscopes for use in postsecondary education institutions.

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4. Future Planned Activities

Plans for continued funding of Congressionally Directed Projects are the prerogative of Congress. Although this single-year funded project may extend beyond a single-year performance period, continued funding by the Solar Program is not planned.

PV Charging System for Remote Area Operations

Performing Organization: Coherent Systems International, Lexington Park, Maryland

Key Technical Contacts: Alexander Grethe, 407-929-9674, GretheA@coherentsys.com
Glenn Doyle, DOE-GO, 303-275-4706, glenn.doyle@go.doe.gov

DOE HQ Technology Manager: Richard King, 202-586-1693, richard.king@ee.doe.gov

FY 2006 Budgets: $900K (DOE); $224K (Coherent cost share)

Objectives

- Develop lightweight, remote PV-powered battery charging system generating 5–20 kWh/day for first responder and military applications.

Accomplishments

- Completed requirements definition for PV charging systems for a variety of remote applications.

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1. Introduction

This is a Congressionally Directed Project for the design and development of a PV charging system for remote-area applications. The charging system can be used by first responders such as forest fire fighters, military, and other emergency personnel. For this charging system, PV cells will be developed to operate at greatly reduced irradiance levels.

2. Technical Approach

Define requirements for charging systems, benchmark against existing designs, develop conceptual design of a next-generation system, and design a prototype charging system.

3. Results and Accomplishments

This project has completed its requirements definition for remote PV charging systems. This includes charging systems for battery-powered military vehicles, off-road electric vehicles, electric motorbikes, small water purification systems, portable high-capacity battery packs, and emergency radios. Next steps include identification of required technologies; conceptual design; system integration, test and validation; and conceptual design of a next-generation system.

4. Future Planned Activities

Plans for continued funding of Congressionally Directed Projects are the prerogative of Congress. Although this single-year funded project may extend beyond a single-year performance period, continued funding by the Solar Program is not planned.

Brightfield Solar Energy

Performing Organization:	City of Brockton, Massachusetts
Key Technical Contacts:	Michael Thoreson, 508-580-7135, mthoreson@ci.brockton.ma.us Glenn Doyle, DOE-GO, 303-275-4706, glenn.doyle@go.doe.gov
DOE HQ Technology Manager:	Richard King, 202-586-1693, richard.king@ee.doe.gov
FY 2006 Budgets:	$693K (DOE), $693K (City of Brockton cost share)

Objectives

- Install a 425-kW PV "brightfield" system at a remediated "brownfield" site in Brockton, MA.

Accomplishments

- Installed, tested, and transferred operations of a 425-kW PV system at a brownfield site.

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1. Introduction

This is a Congressionally Directed Project to fund the purchase and installation of approximately three-quarters of the solar modules needed for a solar array on a “brightfield” site in Brockton, MA.

2. Technical Approach

Design, install, test, and transfer to full operation a 425-kW PV system on a remediated brownfield site in Brockton, MA.

3. Results and Accomplishments

This project has completed installation, testing, and transfer to operations of a 425-kW photovoltaic system on a remediated brownfield cleanup site in the City of Brockton, MA.

4. Future Planned Activities

Plans for continued funding of Congressionally Directed Projects are the prerogative of Congress. Although this single-year funded project may extend beyond a single-year performance period, continued funding by the Solar Program is not planned.

National Orange Show Photovoltaics Demonstration

Performing Organization: National Orange Show Events Center, San Bernardino, California

Key Technical Contacts: Daniel Jimenez, 909-422-3780, djimenez@nosevents.com
Glenn Doyle, DOE-GO, 303-275-4706, glenn.doyle@go.doe.gov

DOE HQ Technology Manager: Richard King, 202-586-1693, richard.king@ee.doe.gov

FY 2006 Budgets: $445K (DOE), $1,500K (National Orange Show cost share)

Objectives

- Install a 400-kW PV system at the National Orange Show Events Center, San Bernardino, CA.

Accomplishments

- Completed the design, selected the contractor, and ordered materials for the PV installation.

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1. Introduction

This is a Congressionally Directed Project for the National Orange Show to support the creation of a 400-kW photovoltaic system at its National Orange Show Events Center. This PV system is expected to provide approximately 75% of the center's electricity needs.

2. Technical Approach

Design, install, test, and transfer to full operation a 400-kW PV system on existing National Orange Show buildings in San Bernardino, CA.

3. Results and Accomplishments

The design has been completed, the contractor selected, and the materials ordered for the installation of a 400-kW PV system on buildings at the National Orange Show in San Bernardino, CA. Installation and transfer to operation is scheduled to be complete by February 2008.

4. Future Planned Activities

Plans for continued funding of Congressionally Directed Projects are the prerogative of Congress. Although this single-year funded project may extend beyond a single-year performance period, continued funding by the Solar Program is not planned.

Photonics Research and Development

Performing Organization: University of Nevada Las Vegas (UNLV) Research Foundation

Key Technical Contacts: Wilbur Pittenger, 702-895-2833, bud.pittenger@unlv.edu
Glenn Doyle, DOE-GO, 303-275-4706, glenn.doyle@go.doe.gov

DOE HQ Technology Manager: Jeffrey Mazer, 202-586-2455, jeff.mazer@hq.doe.gov

FY 2006 Budgets: $2,225K (DOE), $556K (UNLV cost share)

Objectives

- Develop quantum dot light-emitting diodes (QDLEDs).
- Demonstrate commercial feasibility of hybrid solar lighting.

Accomplishments

- Developed a new method for fabricating QDs that allows for integration with the LED, improved material quality, and improved QD surface properties.

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1. Introduction

This is a Congressionally Directed Project to continue the UNLV Research Foundation efforts to perform comprehensive R&D focused on improving light-emitting diode (LED) technologies and hybrid solar lighting.

2. Technical Approach

Conduct research on green-wavelength QDLEDs using InGaN; research LEDs that use solar light source; pilot test hybrid solar lighting including task lighting for students.

3. Results and Accomplishments

Progress continues on researching QDLEDs that can be tunable over a wide spectrum and achieve red, green, and blue colors using the same materials. A new method for fabricating the QDs allows for integration with the LED, improved material quality, and improved QD surface properties. Research into green QDLEDs using InGaN QDs aimed at increasing the quantum efficiency by 2X continues to progress. Research continues on polymer fiber optics materials that would facilitate carrying sunlight through hybrid solar lighting a distance of 65 feet with minimal losses in the visible wavelength.

4. Future Planned Activities

Plans for continued funding of Congressionally Directed Projects are the prerogative of Congress. Although this single-year funded project may extend beyond a single-year performance period, continued funding by the Solar Program is not planned.
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Performing Organizations By Name

Performing Organizations By State/Country

Acronyms and Abbreviations

A2LA	American Association for Laboratory Accreditation
AC	alternating current
AES	Auger electron spectroscopy
AFM	atomic force microscopy
AIC	aluminum-induced crystallization
ALO	Albuquerque Operations Office (U.S. Department of Energy)
AOP	Annual Operating Plan
APD	antiphase domain
APS	Arizona Public Service
AR	antireflection
ASES	American Solar Energy Society
ASHRAE	American Society of Heating, Refrigeration, and Air-conditioning Engineers
a-Si	amorphous silicon
ASOS	Automated Surface Observing System
ASRC	Atmospheric Sciences Research Center (at State University of New York)
ASRM	advanced solar reflective mirror
ASSET	Analysis of State Energy Tradeoffs Databank
ASTM	American Society for Testing and Materials
ASU	Arizona State University
BES	Basic Energy Sciences (within U.S. DOE Office of Science)
BEW	Behnke, Erdman & Whitaker Engineering
BIPV	building-integrated photovoltaics
BLM	Bureau of Land Management
BNL	Brookhaven National Laboratory
BOS	balance of systems
BSC	Basic Sciences Center (within the National Renewable Energy Laboratory)
BSF	back-surface field
Btu	British thermal unit
BU	Boston University
CAD	computer-assisted design
C-AFM	conductive atomic force microscopy
Caltech	California Institute of Technology
CBD	chemical bath deposition
CdTe	cadmium telluride
CEC	California Energy Commission
CET	Center for Ecological Technology
CIGS	copper indium gallium diselenide
CIGSS	copper indium gallium sulfur selenide
CIS	copper indium diselenide
CL	cathodoluminescence
CNT	carbon nanotube
COP	coefficient of performance
COSE	cost of saved energy
COTS	commercial off the shelf
CPS	Corporate Planning System
CPUC	California Public Utilities Commission
CPV	concentrating photovoltaics
CRADA	Cooperative Research and Development Agreement
C_{save}	cost of saved energy
CSDS	Concentrating Solar Deployment System
c-Si	crystalline silicon
CSR	Climatological Solar Radiation

CSS	close-spaced sublimation
CU	University of Colorado
CVD	chemical vapor deposition
CY	calendar year
CZ	Czochralski
DC	direct current
DEG/SE	Davis Energy Group/SunEarth
DETL	Distributed Energy Technologies Laboratory (at Sandia National Laboratories)
DFMA	design for manufacturing and assembly
DFMECA	design failure mode effects and criticality analysis
DFR	design for reliability
DJ	dual junction
DLR	German Aerospace Center
DLTS	deep-level transient spectroscopy
DMA	dynamic mechanical analysis
DNI	direct normal incident
DoD	Department of Defense
DOE	Department of Energy
DSC	differential scanning calorimetry
DSP	digital signal processing
EAO	Energy Analysis Office
EBSD	electron backscatter diffraction
EERE	Energy Efficiency and Renewable Energy (U.S. Department of Energy office)
EFG	Edge-defined, Film-fed Growth
Eg	bandgap energy
EH&S	environmental health and safety
EIA	Energy Information Administration
EM&D	Electronic Materials and Devices
ENEA	Italian National Agency for New Technologies, Energy and the Environment
EPA	Environmental Protection Agency
EPAct	Energy Policy Act
EPC	Engineer, Procure, Construct
EPS	environmental portfolio standard
EPV	Energy Photovoltaics
EUL	enhanced use leasing
EVA	ethylene vinyl acetate
EVMS	Earned Value Management System
FAQ	frequently asked questions
FF	fill factor
FFPT	fixed focal point trough
FIB	focused ion beam
FOA	Federal Opportunity Announcement
FOUP	Front-Opening Unified Pod
FR	flame retardant
FSEC	Florida Solar Energy Center (at University of Central Florida)
FTIR	Fourier transform infrared
FY	fiscal year
FZ	float zone
GB	grain boundary
GE	General Electric
GIS	geographical information system
GMS	gas management system
GO	Golden Field Office (U.S. Department of Energy)
GOES	Geostationary Operational Environmental Satellite
GPRA	Government Performance and Results Act
GPS	Global Positioning System

GSE	Global Solar Energy
GW	gigawatt
HALT	highly accelerated lifetime testing
HBCU	Historically Black Colleges and Universities
HEM	heat exchanger method
HFSF	High-Flux Solar Furnace
HFSS	high-flux solar simulator
HIPSS	high-intensity pulsed solar simulator
HiPerf PV	High-Performance Photovoltaics Project
HQ	headquarters
HRII	High-Reliability Inverter Initiative
HRTEM	high-resolution transmission electron microscopy
HSL	hybrid solar lighting
HVAC	heating, ventilating, and air-conditioning
HWCVD	hot-wire chemical vapor deposition
IBAD	ion-beam-assisted deposition
IC	integrated circuit
ICP	inductively coupled plasma
ICS	integral collector storage
IDIP	In-Line Diagnostics and Intelligent Processing
IEA	International Energy Agency
IEC	Institute of Energy Conversion (at University of Delaware)
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IEP	Independent Energy Producer
IMA	impact-modified acrylic
IPO	initial public offering
IPP	independent power producer
IR	infrared
IREC	Interstate Renewable Energy Council
IRR	internal rate of return
ISES	International Solar Energy Society
ISET	International Solar Electric Technologies
ISIS	Integrated Surface Irradiance Study
ISO	International Standards Organization
ISP	Institute for Sustainable Power
IST	Industrial Solar Technology
ITN/ES	ITN Energy Systems
ITO	indium tin oxide
I-V	current voltage
JEDI	Jobs and Economic Development Impact
JGCRI	Joint Global Change Research Institute
J_{sc}	short-circuit current
J-V	current density voltage
KIESD	Kentucky Institute for the Environment and Sustainable Development
kW	kilowatt
kWhe	kilowatt hour electric
kWht	kilowatt hour thermal
LACSS	large-area, continuous-solar simulator
LBNL	Lawrence Berkeley National Laboratory
LCA	life-cycle analysis
LCOE	levelized cost of energy
LD	laser diode
LED	light-emitting diode
LEED	Leadership in Energy and Environmental Design
LIPA	Long Island Power Authority

LOI	letter of interest
LP QCM	liquid-phase quartz crystal microbalance
MBE	molecular beam epitaxy or mean bias error
MBMDPE	metallocene-based multi-density polyethylene
mc	multicrystalline
MDC	McDonnell Douglas Corporation
MEG	Multiple-exciton generation
MLTE	module long-term exposure
MOCVD	metal organic chemical vapor deposition
MPP	model power plant
MPPT	maximum power point tracking
MSR	Million Solar Roofs
MTBF	mean time between failure
MURA	Minority University Research Associates
MW	megawatt
MYPP	Multi-Year Program Plan
MYTP	Multi-Year Technical Plan
NABCEP	North American Board of Certified Energy Practitioners
NAHB	National Association of Home Builders
NASA	National Aeronautics and Space Administration
NCPV	National Center for Photovoltaics
nc-Si	nanocrystalline silicon
NEC	National Electrical Code
NEMS	National Energy Modeling System (of the International Energy Agency)
NEPA	National Environmental Policy Act
NETL	National Energy Technology Laboratory
NGO	non-governmental organization
NIR	near infrared
NIST	National Institute of Standards and Technology
NMSU	New Mexico State University
NOCT	normal operating cell temperature
NRCC	Northeast Regional Climate Center
NREL	National Renewable Energy Laboratory
NSRDB	National Solar Radiation Data Base
NSTTF	National Solar Thermal Test Facility (at Sandia National Laboratories)
NTUA	Navajo Tribal Utility Authority
NWS	National Weather Service
NYSERDA	New York State Energy Research and Development Authority
OATS	Outdoor Accelerated-weathering Testing System
O&M	operations and maintenance
OMB	Office of Management and Budget
OMCVD	organometalic chemical vapor deposition
OPV	organic photovoltaics
ORC	Organic Rankine Cycle
ORNL	Oak Ridge National Laboratory
OTF	Outdoor Test Facility (at National Renewable Energy Laboratory)
OWIP	Office of Weatherization and Intergovernmental Programs
PAE	planning, analysis, and evaluation
PBA	Office of Planning, Budget, and Analysis
PC	polycarbonate
PCD	photoconductive decay
PCU	power conversion unit
PDIL	Process Development and Integration Laboratory
PEC	photoelectrochemical
PECVD	plasma-enhanced chemical vapor deposition
PED	pulsed electron-beam deposition

PERT	Performance and Energy Ratings Testbed
PET	polyethylene terephthalate
PI	principal investigator
PIER	Public Interest Energy Research (program of the California Energy Commission)
PLD	pulsed laser deposition
PMMA	polymethyl methacrylate
PNNL	Pacific Northwest National Laboratory
PP	polypropylene
PPR	polypropylene random copolymer
PTL	Photovoltaic Testing Lab (at Arizona State University)
PV	photovoltaics
PVD	physical vapor deposition
PVME	polyvinylmethylether
PVMR&D	PV Manufacturing R&D
PVPS	Photovoltaic Power Systems Programme (of the International Energy Agency)
PVSAC	Photovoltaic Systems Assistance Center
PVSAM	PV Systems Analysis Model
PVSC	Photovoltaic Specialists Conference
PVSOL	PV System Optimization Laboratory (at Sandia National Laboratories)
QCM	quartz crystal microbalance
QD	quantum dot
QDLED	quantum dot light-emitting diode
QE	quantum efficiency
QSSPC	quasi-steady-state photoconductance
RCPCD	resonant-coupled, photoconductive decay
R&D	research and development
REAP	Renewable Energy Academic Partnership
REC	renewable energy certificate
RES	Regional Experiment Station
RFP	request for proposal
RFQ	request for qualifications
RITH	roof-integrated thermosiphon
RMOTC	Rocky Mountain Oilfields Testing Center
RMSE	root mean square error
RO	reverse osmosis
ROI	return on investment
ROWPU	reverse osmosis water purification unit
RPS	renewable portfolio standard
RSM	reciprocal space map
RT	room temperature
RTA	rapid thermal annealing
RTSE	real-time spectroscopic ellipsometry
RUS	Rural Utilities Service (of the U.S. Department of Agriculture)
SAIC	Science Applications International Corporation
SAM	Solar Advisor Model
SBC	systems benefit charge
SBIR	Small Business Innovation Research
SDA	Systems-Driven Approach
SDHW	solar domestic hot water
SDSU	South Dakota State University
SEGS	Solar Energy Generating Systems
SEIA	Solar Energy Industries Association
SEM	scanning electron microscope
SEPA	Solar Electric Power Association
SERES	Southeast Regional Experiment Station (at University of Central Florida)
SERF	Solar Energy Research Facility (at National Renewable Energy Laboratory)

SETP	Solar Energy Technologies Program
SES	Stirling Energy Systems
SHC	solar heating and cooling
SHGR	Solar Hydrogen Generation Research
SHJ	silicon heterojunction
SHW	solar hot water
SIF	stress intensity factor
SIMS	secondary ion mass spectrometry
SKPM	scanning Kelvin probe microscopy
SMIF	Standard Mechanical InterFace
SMUD	Sacramento Utility District
SNL	Sandia National Laboratories
Solar PACES	Solar Power and Chemical Energy Systems
SolarDS	Solar Deployment Systems (model)
SOW	statement of work
SPC	solid-phase crystallized
SPIE	International Society for Optical Engineering
SRCC	Solar Rating and Certification Corporation
SRP	Salt River Project
SSE	Surface Meteorology and Solar Energy (a NASA project)
SSI	Shell Solar Industries
STC	Standard Test Conditions
STCH	solar thermochemical hydrogen
S&TF	Science & Technology Facility (at National Renewable Energy Laboratory)
SUNY	State University of New York
SURFRAD	Surface Radiation Budget Network
SWH	solar water heating
SWRES	Southwest Regional Experiment Station (at New Mexico State University)
SWTDI	Southwest Technology Development Institute (at New Mexico State University)
TA	technical assistance
TBD	to be determined
TCA	thermal cycle annealing
TCC	transparent conductive coating
TCO	transparent conducting oxide
TDMS	thermal-desorption mass spectrometry
TEM	transmission electron microscopy; also technical exchange meeting
TEP	Tucson Electric Power
TES	thermal energy storage
TIO	Technology Improvement Opportunity
TMY	typical meteorological year
TOP	theoretical overlay photographic
TOU	time of use
TPD	temperature-programmed desorption
TPP	Technology Pathway Partnership
TRNSYS	TRaNsient SYstem Simulation Program
TRPL	time-resolved photoluminescence
TVA	Tennessee Valley Authority
TW	terrawatt
UHV	ultrahigh vacuum
UL	Underwriters Laboratories
ULRF	University of Louisville Research Foundation
UN	United Nations
UNLV	University of Nevada Las Vegas
UNM/ME	University of New Mexico Mechanical Engineering Department
U of L	University of Louisville
UPS	ultraviolet photoelectron spectroscopy

USAID	U.S. Agency for International Development
USDA	U.S. Department of Agriculture
USGBC	U.S. Green Building Council
UV	ultraviolet
VASE	variable-angle spectroscopic ellipsometry
VB	valence band
VBM	valence band maximum
V_{oc}	open-circuit voltage
VSHOT	Video Scanning Hartmann Optical Test
VTD	vapor transport deposition
WCPEC	World Conference on Photovoltaic Energy Conversion
WGA	Western Governors' Association
WIP-I	Weatherization and Intergovernmental Program-International
WMO	World Meteorological Organization
WOM	weatherometer
WREC	World Renewable Energy Congress
WRR	World Radiometric Reference
WVTR	water vapor transport rate
XPS	X-ray photoelectron spectroscopy
XRD	X-ray diffraction
YDR	yield, durability, and reliability
ZEH	zero energy homes

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