3.2 Concentrating Solar Power

3.2.1 CSP Industry and Market Overview

Concentrating solar power plants produce power by first converting the sun's energy into heat, next into mechanical power, and lastly, into electricity in a conventional generator. The three types of technology involved are trough-electric, dish/Stirling, and power tower systems. Trough systems concentrate the sun's energy onto a receiver tube located along the focal line of a parabolically curved, trough-shaped reflector. Oil flowing through the receiver tube is heated to about 400°C (752°F); the heat is collected and used to generate electricity in a conventional steam Rankine cycle. Trough systems can be hybridized or use thermal storage to dispatch power to meet utility peak load requirements.

Dish/Stirling systems focus the sun's energy at the focal point of a parabolically shaped dish, which tracks the sun over the course of the day; temperatures reach about 800°C (1452°F). An engine/generator located at the focal point of the dish converts the absorbed heat energy into electricity. Individual dish/Stirling units currently range from 10 to 25 kW in size. Larger power plants are to be built by installing fields of these systems.

The third type of technology, power towers, includes a field of heliostats that reflect the sun's rays to a receiver located on top of a tall, centrally located tower. The solar energy is absorbed by the molten-salt working fluid flowing through the receiver, which is located on top of the tower. Power towers provide for energy storage for up to several hours at 565°C (1050°F) in large tanks located at the base of the tower. When needed, hot salt is removed from the storage tank and used to generate electricity in a conventional Rankine steam-turbine power block.

The market focus for all three of these technologies is central power generation at utility or independent power purchaser (IPP) sites in units of 50 MW or greater. Dish/Stirling systems are designed in 10 or 25 kW-sized packages and can potentially meet distributed generation applications at smaller scales. However, plans over the next 5 years focus on deploying larger numbers of systems at central power sites, pending validation and reductions in the O&M costs. Because of budgetary limitations and the fact that no power tower systems are currently being designed for deployment in the United States, the CSP Subprogram's focus is on developing trough and dish/Stirling systems in the context of this 5-year Multi-Year Program Plan. The key markets and market barriers during this period are described briefly in the following paragraphs.

The primary U.S. market for bulk power generation using CSP technology is emerging in the Southwest. Through state-led initiatives, primarily driven by renewable portfolio standards (RPS), markets for CSP are beginning to emerge in California, Arizona, New Mexico, Utah, Nevada, Texas, and Colorado. These states are asking Congress and the DOE to provide technical assistance as they move forward with an initiative to deploy 1,000 MW of CSP power over the next 5 years. The state activities are starting to be consolidated by the Western Governors' Association into the Clean and Diversified Energy Initiative, which will evolve over the course of this program plan. Under the Initiative, the states will address the barriers to CSP deployment by:

- Determining the development pathway for their projects, including schedules and milestones
- Conducting studies to determine the economic and environmental benefits from the deployment of CSP
- Forming state-level and regional task forces (New Mexico and Arizona have current task forces) to manage the project development process
- Reviewing RPS rules and modifying as required to meet mutually beneficial regional needs
- Considering establishment of a regional market in the trading of renewable energy credits
- Working with in-state and in-region utilities to establish the environment for utility purchase of CSP plants or the negotiation of long-term power purchase agreements
- Evaluating the formation of a regional utility consortium to purchase the output from a CSP plant, thereby sharing cost and risk

- Coordinating with the CSP industry to identify barriers to building plants
- Working with the DOE and CSP industry to address technical barriers to CSP deployment.

At an international level, the Royal Decree in Spain is providing incentives for 200 MW (rumored to increase to 500 MW) of CSP trough and tower technologies. Israel is supporting the development of 500 MW of trough plants. U.S. companies are involved in these international CSP projects, and their competitive position is strengthened by the state activities noted above. In addition, U.S. and German solar industries have developed a CSP Global Market Initiative (GMI) with the goal of deploying 5,000 MW of CSP power by 2010. The GMI was formally launched at the International Conference for Renewable Energies in Bonn, Germany, in 2004 and has been supported by ministers from eight countries.[1]

The DOE CSP Program participates in the International Energy Agency's Solar Power and Chemical Energy Systems Working Agreement (IEA SolarPACES). SolarPACES is an international organization that brings together teams of experts from around the world to focus on the technology development and marketing of CSP systems. Activities include sharing of information on technology and market development in the participating countries, large-scale system testing, and development of advanced technologies, components, instrumentation, and systems-analysis techniques.

Over the next 5 years, the installation of hundreds of new megawatts of CSP is likely, based on the plans to install a 65-MW trough plant in Nevada and the announcements by Southern California Edison and San Diego Gas & Electric of plans to install from 800 to 1750 MW of dish/Stirling technology in California. It is entirely possible that 1,000 MW of installed CSP potential will be achieved in the next 5 years.

3.2.2 CSP Subprogram History / Background

Starting with R&D during the mid-1970s, DOE-sponsored research transitioned CSP from the concept stage to operating central-station power plants by the early 1980s. During the late 1970s, the Central Receiver Test Facility was built at Sandia in Albuquerque, NM, establishing the feasibility of the concept and providing the impetus for the 10-MW Solar One demonstration project in Barstow, CA. Although several trough industrial process-heat projects and the Shenandoah, GA, dish project were completed in the same time frame, Solar One was the major CSP program activity through the early to mid-1980s. The cost of power from Solar One, an experiment that was far too small to achieve an economy of scale, was estimated to be about $28,000/kW, or nearly $2.00/kWh (2004 $). The cost of a commercial-scale power tower today is estimated at about $7,200/kW, or $0.16/kWh, demonstrating the decrease in the cost experienced by all CSP technologies.

Solar reflectors and their support/tracking structure comprise almost 50% of the cost of CSP power plants. Heliostats, troughs, and dishes all operated very well, but their costs were still too high. Consequently, during the late 1980s and early 1990s, a considerable amount of research went into evaluating new concentrator designs, exploring polymer films as options for replacing glass reflectors, and improving and reducing the cost of glass reflectors capable of maintaining high reflectance for 20 years or longer. Lower-cost polymer reflectors were also studied and shown to be a promising alternative, but as yet have not achieved the lifetime, cost, and structural design advantages needed to replace glass as the reflective material of choice. The structures that support the reflectors have evolved to become lighter and less expensive, while meeting the design requirement of surviving and operating in high winds. During this time, thermal receivers for towers and troughs were improved to withstand higher temperatures (i.e., higher levels of solar flux), thus increasing the efficiencies of towers and trough receivers.

In 1985, in response to the Public Utility Regulatory Policies Act (PURPA) and the California standard offer power purchase contracts, the first commercial CSP project was built near Daggett, CA, by the Luz Company. The first plant had an installed capacity of 13.8 MW (limited by PURPA regulations), and by 1991 eight other trough plants totaling

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[1] CSP Global Market Initiative Protocols, established at the Renewables 2004 Conference, Bonn, Germany, 1–4 June, 2004.

354 MW installed capacity were built at Kramer Junction and Harper Lakes, also in California. At the time, these were the largest solar power plants in the world, and they continue to be so to this day. They were built because of favorable power purchase agreements and tax incentives, and when these incentives were terminated in the early 1990s, no more CSP plants were built.

In the early 1990s, a consortium of utilities convinced the DOE to modify the Solar One demonstration plant to incorporate a molten-salt receiver concept developed by the CSP program and shown to have significant dispatchability because it directly incorporated thermal storage. This increases the value of electricity from the plant because it enables utilities to dispatch electricity to the grid when it is most needed. The project, called Solar Two, successfully demonstrated the molten-salt receiver and storage technologies and resolved O&M issues. Several utilities had plans for commercially viable, 100-MW follow-up plants, but deregulation and restructuring of the electricity markets in the mid-1990s eliminated the incentives and, in fact, made it difficult for the utilities to invest in generation; therefore, developing a power tower plant was no longer a viable option.

The power conversion technology for troughs and power towers is a conventional steam Rankine power cycle, similar to the technology used for coal-fired power plants. As a consequence, the Solar Program has historically focused more on developing the solar-specific components and integrating them with the power blocks than on the R&D associated with developing advanced power systems. On the other hand, dish/Stirling technology uses a small Stirling-cycle engine (10–25 kW) that is mounted at the focal point of the parabolic dish concentrator. Historically, the Solar Program explored three types of engines (i.e., Stirling, Brayton, and organic Rankine) until down-selecting to the Stirling cycle as the most promising technology in the mid-1980s. In 1984, a 25-kW dish/Stirling system achieved a 29.4% solar-to-electric system efficiency, a record that stands to this day. Adapting Stirling engines to dishes became a major CSP program R&D activity during the middle of the 1990s and into the early 2000s. More recently, R&D has shifted to the systems engineering and integration of the components, with the focus of increasing the reliability of dish systems and adapting the design of the dish/Stirling system for mass manufacturing.

With the relatively large budgets of the early 1980s, DOE CSP research invested in large-scale demonstration plants to prove the feasibility of the technology. With more modest budgets in the 1990s, the CSP Subprogram worked more closely with industry partners on cost-shared R&D. In the late 1990s, a National Academy of Sciences (NAS) Review Panel suggested that CSP would never be deployed because the system costs were too high and would never achieve the deployment levels required. This resulted in a decrease in the CSP budgets. Since 2000, the CSP Subprogram has been forced to narrow its focus on technical pathways that leverage the CSP industry and relationships with southwestern U.S. states to start to open markets for CSP. In 2003, a second, detailed independent review of CSP technologies was conducted by an engineering firm, Sargent & Lundy (S&L), under the guidance of the NAS' National Research Council (NRC) Committee for the Review of a Technology Assessment of Solar Power Energy Systems. The NRC Committee concurred with the overall technical findings of S&L, which predict that troughs and towers can be cost competitive with as little as 3 GW of deployment. (Note that dishes were not reviewed because they were not identified as a problem by the first NRC review.) But the concern was raised that the lack of significant deployment could still limit the ability of CSP technologies to realize the cost reductions.

As noted earlier under markets during the last two years, several southwestern states have shown strong interest in deploying CSP projects, including a 65-MW trough project in Nevada, a 1-MW trough project in Arizona, 800 to 1750 MW of dish/Stirling systems in California, and the formation of a CSP Task Force in New Mexico. This interest, coupled with a Congressional direction to examine the potential for deploying 1,000 MW of CSP in the Southwest, has provided further impetus for DOE and Congress to reexamine the CSP Subprogram. The result is a new strategy

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[2] M. Lotker, 1991. Barriers to Commercialization of Large-Scale Solar Electricity: Lessons Learned from the Luz Experience, Report No. SAND91-7014, SNL, Albuquerque, NM.

[3] Efficiency for CSP systems is defined as the ratio of the power output divided by the total direct-normal insolation incident on the concentrator.

and a five-year plan to transition CSP from proven concepts to marketable products. The strategy coordinates R&D and deployment activities to advance CSP toward cost-competitiveness and market penetration in the context of working with the CSP industry and the southwestern states through the Western Governors' Association. The core element of the strategy is to expand R&D to increase the efficiency and reliability of CSP technologies, while decreasing their costs through manufacturing and deployment.

3.2.3 CSP Strategic and Performance Goals

The following goals and objectives are planned over the 2007–2011 time frame based on the long-term goal that CSP will be directly competitive with fossil-generated electricity within a 10–15-year horizon.

Strategic Long-Term Goal

The long-term goal of the CSP Subprogram is to develop parabolic trough and dish/Stirling power plant technologies that produce electricity that is competitive with electricity from conventional fossil power technologies in identified markets. The market for parabolic trough systems is dispatchable, intermediate-load, wholesale generation where the value of electricity is in the mid to high range of $0.05–$0.08/kWh, based on a natural gas price of $5/MMBtu.[4] The market for dish/Stirling systems during the next 5 years is central-station, wholesale power generation, although longer-term markets will likely include niche markets such as utility grid support, remote power, and village power. The value for power in non-dispatchable markets is $0.04/kWh.

5-Year Performance Goals and Technical Objectives

By 2011, the CSP Subprogram will assist technology development for and validate the performance of a 150-MW trough plant. A 100-MW reference plant is projected to:

- Achieve a design point solar-to-electric efficiency of 25.6% and annual solar-to-electric efficiency of 15.5%
- Use an advanced thermocline thermal storage system that provides up to 6 hours of storage (capacity factor of ~0.43) and cost ~$20/kWh
- Have an installed system cost of $4100/kW (including the cost of thermal storage and oversized solar field) and an O&M cost of $0.016/kWh, resulting in an LCOE of $0.089/kWh.

By 2011, the CSP Subprogram will assist technology development for and validate the performance of a 25-kW commercial dish/Stirling system that will:

- Achieve a design point solar-to-electric efficiency of 30% and annual solar-to-electric efficiency of 24%
- Have an installed system cost of $4500/kW and O&M cost of $0.05/kWh, resulting in an LCOE of $0.25/kWh[5]

The LCOE figures described above are based on a standard set of assumptions for financing of a utility-scale IPP project. Note that many non-technical factors can interfere with achieving cost goals, despite achieving technical targets. Such factors include, but are not limited to, the following:

- Real cost of capital to the developer
- Return on investment required by the project equity partners
- Time and cost of obtaining approvals for starting or completing construction
- Cost of land needed for the project
- Federal, state, and local taxes, such as property taxes, that impact solar technologies much more than fossil-energy technologies.

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[4] Note that natural gas prices are currently about $8/MMBtu in the southwestern states. The electricity cost targets will increase proportionally with the higher gas prices.

[5] These numbers are based on laboratory assumptions and analysis for dish/Stirling system development over the next 5 years. They do not fully reflect industry's aggressive mass production efforts and the anticipated cost reductions during this time frame.

3.2.4 CSP Approach

The CSP Subprogram's approach involves improving the performance of systems, reducing the cost of systems and supporting pre-commercial and commercial deployment through targeted R&D and problem solving. The performance and cost issues are captured in the LCOE metric discussed throughout this document. Each of the three focus areas is described briefly below.

1. Performance Improvement: This area of activity focuses R&D on improving the technical performance of systems through developing new system concepts, components, operational strategies, materials, and more.
2. Cost Reduction: Cost reduction, both for the systems and for individual system components, is not independent of focus area 1, but may drive the selection of new components and/or systems and materials.
3. Deployment Support: This focus area addresses the immediate needs of CSP industry partners who are in the process of fielding pre-commercial and commercial systems. These needs include issues associated with the manufacture, installation, design, and/or operation of systems and how they can best be addressed to make the deployment successful.

The integration of these three focus areas is managed using the Stage Gate processes outlined in Sec. 2.4. The activities in each area are prioritized and weighted in terms of their relative importance in meeting goals and subject to the Solar Program's annual budget cycle. At set intervals, we review the progress made on each activity and compare the progress to strategic goals and performance targets. Programmatic decisions are made based on needed R&D activities and subject to available funding levels.

3.2.5 CSP Reference System Descriptions

The reference system descriptions for parabolic trough and dish systems are presented here. These reference systems are used in the systems-driven approach to define the status of current systems and to predict and measure our progress toward our 5-year and long-term targets.

The solar field of a parabolic trough plant consists of long parallel rows of trough-like reflectors—typically, glass mirrors (see Figs. 3.2.5-1 and 3.2.5-2). As the sun moves from east to west, the troughs follow the trajectory of the sun by rotating along their axes. Each trough focuses the

National Solar Thermal Test Facility, Sandia National Laboratories, Albuquerque, NM

The National Solar Thermal Test Facility (NSTTF), located in Albuquerque, NM, is operated by Sandia National Laboratories for the U.S. Department of Energy. The test facility is devoted to developing and testing next-generation systems for concentrating solar power. The facilities and staff of the NSTTF are available for use by U.S. industry, universities, other laboratories, state and local governments, and the general scientific community.

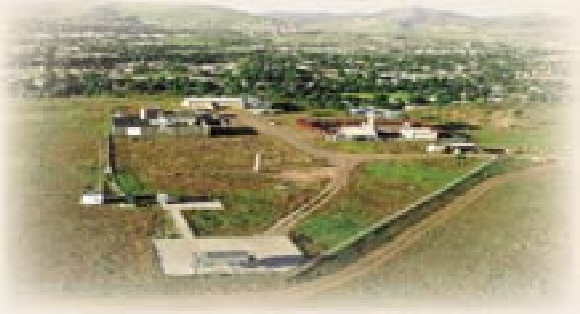
The NSTTF was built in the late 1970s on 115 acres and comprises an 8-acre heliostat field and power tower, a molten-salt test loop, a rotating platform for solar-thermal testing of trough concentrators, a solar furnace, facilities for dish/engine testing, an engine test facility, and numerous buildings and specialized test equipment.

Some of the tests performed at the NSTTF include:

Solar-Thermal Testing
- Thermal receiver for Solar 1
- Heliostat evaluation
- Molten-salt receiver for Solar 2
- Molten-salt components
- Trough system testing
- Trough thermal/optical testing
- Dish/engine systems
- Dish concentrators
- Flux gage testing/calibration

User-Facility Testing
- Air-to-ground target
- Low-light laser
- Radar and sensor evaluation
- Thermal radiation effects
- Space technology systems
- Astronomy

Fig. 3.2.5-1 Solar Electric Generating Stations (SEGS) in Boron, CA.

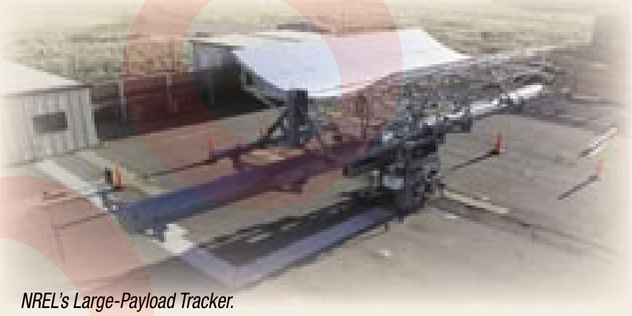


High-Flux Solar Furnace / Mesa Test Facility, National Renewable Energy Laboratory, Golden, CO

The power generated at the High-Flux Solar Furnace (HFSF) at the National Renewable Energy Laboratory in Golden, CO, can be used to expose, test, and evaluate many CSP components, such as receivers, collectors, and reflector materials. The 10-kilowatt HFSF consists of a tracking heliostat and 25 hexagonal mirrors to concentrate solar radiation. The solar furnace can nominally provide flux at 2,500 suns, but using specialized secondary optics, can boost the flux to 20,000 suns.

The operational characteristics and size of the facility make it ideal for testing over a wide range of technologies with a diverse set of experimental requirements. The high heating rates make the HFSF an ideal tool for testing high-temperature materials, prototype advanced converters and chemical reactors for solar electric and solar chemistry applications. Researchers can also use the HFSF to evaluate and develop state-of-the-art measurement systems for the extreme solar environment.

NREL recently acquired a multipurpose, large-payload tracker to support testing of solar components that require tracking the sun in elevation and/or azimuth. Concentrating collectors require 1- or 2-axis tracking to focus sunlight on a thermal or PV receiver. For flat-plate collectors, flat-plate PV, or solar hot water, this would imply tracking to minimize variation in solar resource during on-sun testing. As applicable, the site can be used to supplement metrology activities that require 2-axis tracking for simultaneous calibration of a large number of solar radiation measurement instruments. The large-payload tracker is capable of carrying a maximum vertical load of 9,000 pounds.



NREL's Large-Payload Tracker.

sun's energy on a pipe located along its focal line. A heat-transfer fluid—typically, oil at temperatures as high as 400°C (750°F)—is circulated through the pipes and then pumped to a central power block area, where it passes through a heat exchanger. The heat-transfer fluid then generates steam in a heat exchanger, which in turn is used to drive a conventional steam turbine generator.

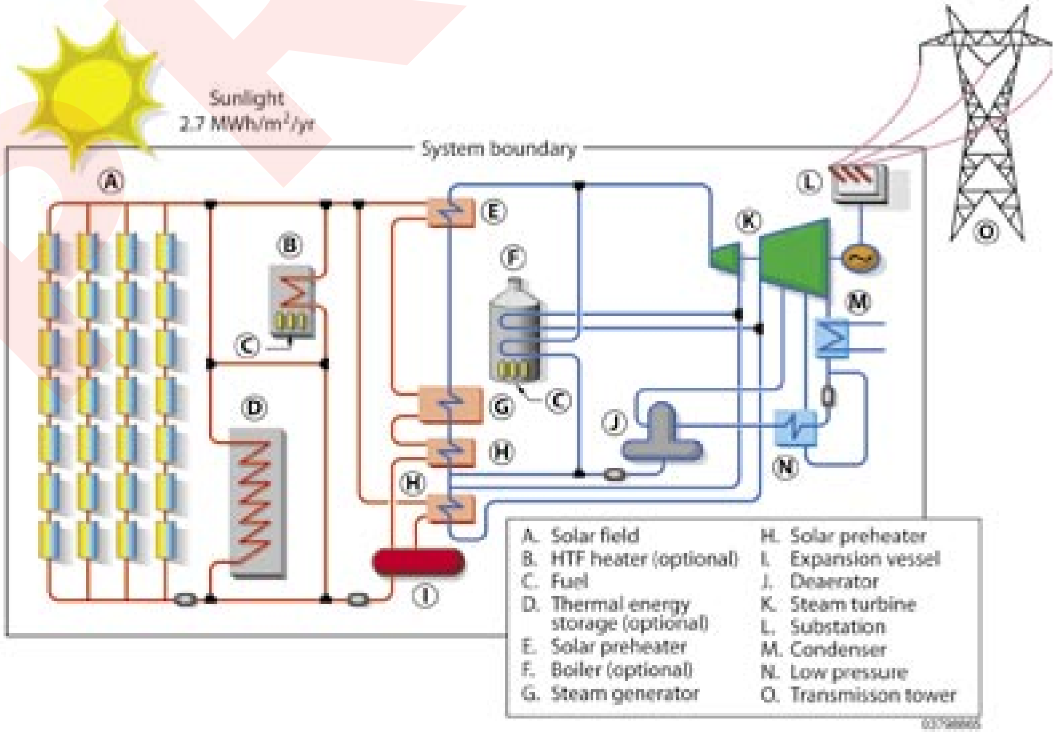


Fig. 3.2.5-2 Schematic of a parabolic trough CSP plant.

Beyond the heat exchanger, parabolic trough plants are just conventional steam plants. Therefore, parabolic trough plants can use thermal storage or hybridization with fossil fuel to generate electricity when the sun does not shine.

Parabolic Trough Reference System

The 2006 technology baseline is a 100-MW trough plant with 6 hours of thermal storage:

- The net solar-to-electric efficiency of the last SEGS plants, built in 1990, was about 11%. The 2006 reference plant built is projected to have a system efficiency of 11.9%.
- The solar field cost and performance is based on the Solargenix DS-1 concentrator and Solel UVAC1 receiver. Both components have been field validated.
- Thermal-storage cost and performance is based on an indirect, two-tank, molten-salt storage system. Molten-salt storage has been identified as the near-term storage solution for two 50-MW trough plants to be built in southern Spain.
- LCOE ≈ \$0.12/kWh, in solar resource regions of 7.65 kWh/m^2-day. Although 150 MW of CSP capacity exist in regions with solar resources higher than 8.0 kWh/m^2-day (i.e., Kramer Junction, CA), a more conservative solar resource is used for the reference system.

Dish/Stirling System Description

Dish/Stirling systems track the sun and focus solar energy into a cavity receiver; the receiver absorbs the energy and transfers it to a heat engine/generator that generates electrical power (represented pictorially in Fig. 3.2.5-3). Three dish/engine systems are under development today: one is a 25-kW unit (being developed by Stirling Energy Systems in the United States, see Fig. 3.2.5-4) and two are 10-kW units. One of the 10-kW units is also being developed by SES and the other one is being developed by Schlaich, Bergermann and Partner (SBP) in Germany. All these systems use kinematic Stirling engines, which are high-performance, externally heated engines based on the Stirling cycle; they use a mechanical connection to a generator to produce electricity. Stirling engines have been used for these systems because of their high efficiencies, high power density (i.e., power output per unit volume), tolerance of non-uniform flux distributions, and potential for long-term, low-maintenance operation.

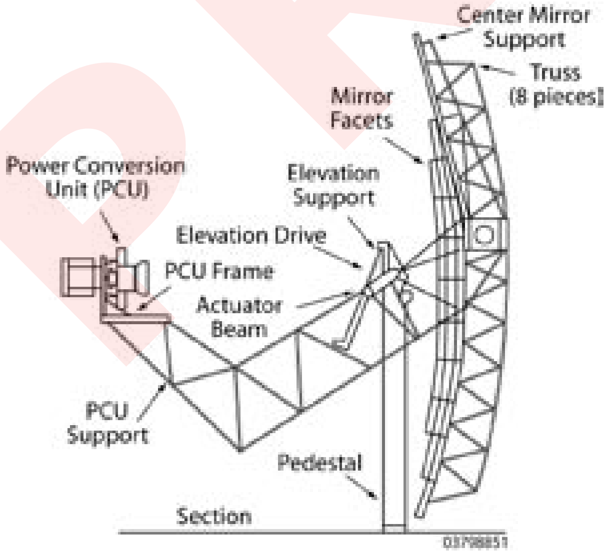


Fig. 3.2.5-3 Schematic diagram of a dish/Stirling system.

Fig. 3.2.5-4 SES 25-kW dish/Stirling system.

Stirling engines are also considered to be potentially low maintenance because, although similar to an automotive engine, they have far fewer parts and are cleaner because the heat source is external to the engine. A dish/Stirling system has demonstrated a peak, instantaneous, net solar-to-electric conversion efficiency of nearly 30% and an average annual conversion efficiency of 22%.

Dish/Stirling Reference System

The 2006 technology baseline is a unique, hand-built prototype 25-kW dish/Stirling system that is part of a 1-MW (40-dish system) power plant with the following characteristics:

- Glass-metal solar concentrator design
- Net annual solar-to-electric generation efficiency of 22%
- Kinematic Stirling engine
- High O&M costs ($0.10/kWh) resulting from prototype operation
- Solar-only system operation
- Demonstrated annual availability of about 80%
- Installed system costs of about $8600/kW
- LCOE of 0.49/kWh (based on current prototype costs)

3.2.6 CSP Technical (Non-Market) Challenges/Barriers and Goals

Although parabolic trough and dish/Stirling systems have similar functional components—e.g., concentrator structure, focusing mirrors, receivers, and thermal-to-electric power conversion blocks—the technical challenges differ due to differences in commercial maturity, operational scale, and the ability to include thermal storage.

The key technical challenges for parabolic trough technology relate to improving the efficiency and reducing the installed capital cost of the solar field, including the concentrator and solar receiver. To take advantage of the added value for firm, dispatchable power, an additional challenge is to develop a low-cost and thermally efficient energy-storage system that can dispatch power to meet system peak load. The cost of parabolic trough systems also benefits from scaling up plant size and the learning that results from volume production. Figure 3.2.6-1 shows the results of an independent analysis that identified the relative importance of these factors in reducing the cost of the parabolic trough technology.

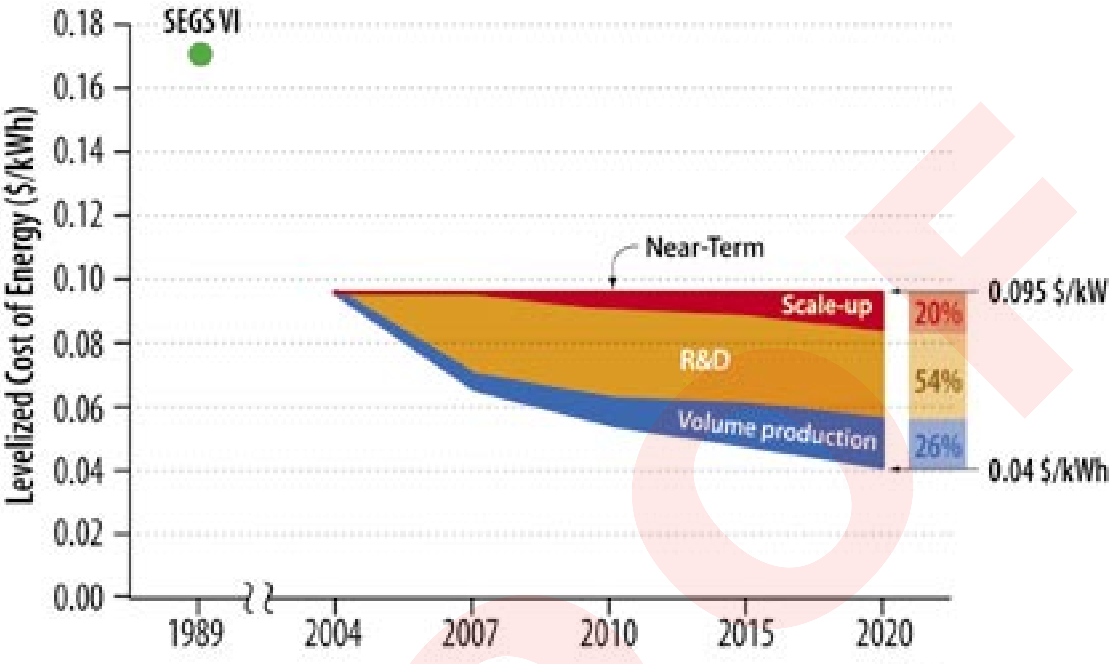


Fig. 3.2.6-1 Breakdown of LCOE reduction for parabolic trough systems.

The technical activities for the parabolic trough and dish/Stirling systems development for the next 5 years are described. We developed the following list of activities by evaluating their impact on the LCOE subject to the following:

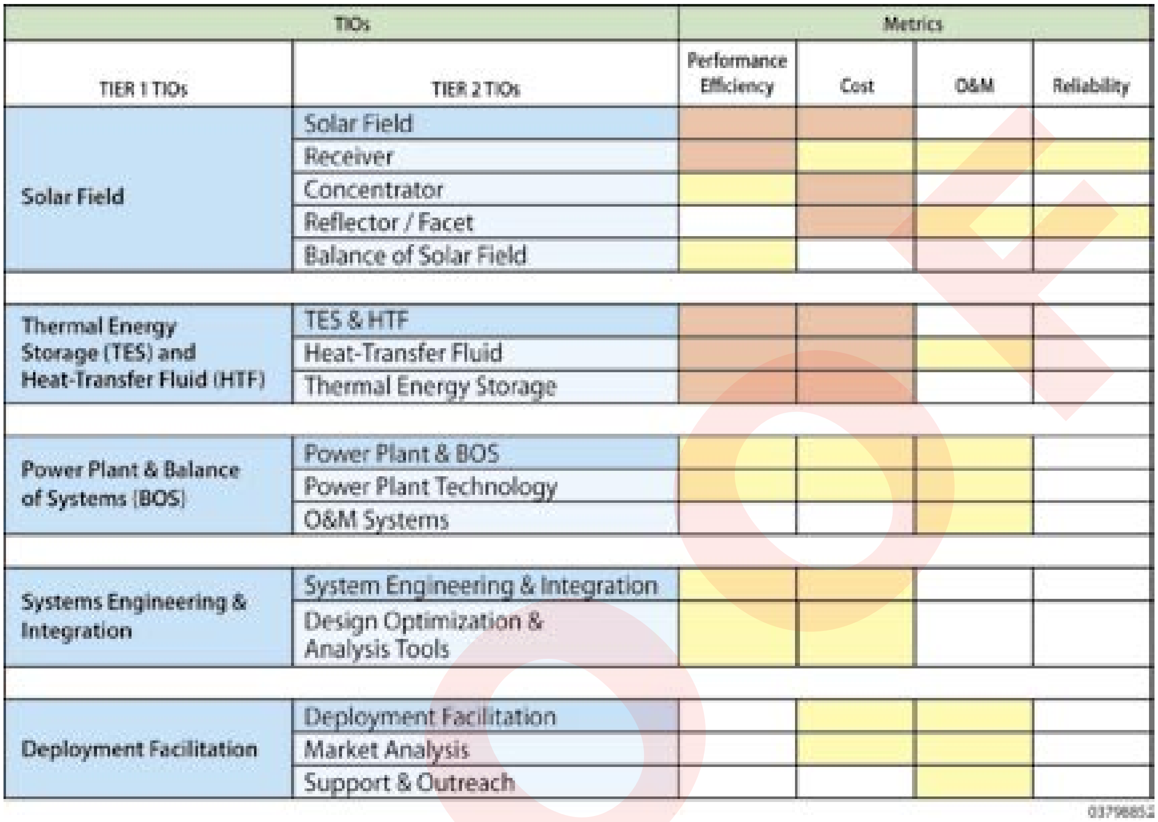
- Using the reference systems in the analysis
- Considering the logical and required flow of work activities
- Prioritizing activities
- Applying projected budgets for the 5-year period.

Analysis of the reference systems leads to the identification of the technical opportunities to overcome barriers related to the cost, performance, and reliability of the systems. The technology improvement opportunities and associated activities are presented in the following sections for parabolic trough and dish/Stirling development activities.

Trough Technology TIOs

Parabolic trough TIOs shown in Fig. 3.2.6-2 relate to performance improvements and cost reductions associated with the parabolic trough solar field, thermal storage and heat-transfer fluid, power plant, and balance of systems. Indirect costs are those costs associated with project development and construction, project siting, and project financing. And indirect costs and the impact of increased deployment of parabolic trough systems, although not directly supported by laboratory R&D, also represent significant opportunities for reducing cost.

Activities associated with addressing each of these TIOs are described in more detail in Fig. 3.2.6-2 and in Sec. 3.2.8. The colored boxes in Fig. 3.2.6-2 indicate areas of programmatic R&D or outreach over the 5-year period of this plan.



TIOs		Metrics			
TIER 1 TIOs	TIER 2 TIOs	Performance Efficiency	Cost	O&M	Reliability
Solar Field	Solar Field	🟥	🟥		
	Receiver	🟥	🟨	🟨	🟨
	Concentrator	🟨	🟥		
	Reflector / Facet		🟥	🟨	🟨
	Balance of Solar Field	🟨			
Thermal Energy Storage (TES) and Heat-Transfer Fluid (HTF)	TES & HTF	🟥	🟥		
	Heat-Transfer Fluid	🟥	🟥	🟨	
	Thermal Energy Storage	🟥	🟥		
Power Plant & Balance of Systems (BOS)	Power Plant & BOS	🟨	🟨	🟨	
	Power Plant Technology	🟨	🟨	🟨	
	O&M Systems			🟨	
Systems Engineering & Integration	System Engineering & Integration	🟨	🟨		
	Design Optimization & Analysis Tools	🟨	🟨		
Deployment Facilitation	Deployment Facilitation		🟨	🟨	
	Market Analysis		🟨	🟨	
	Support & Outreach			🟨	

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Fig. 3.2.6-2 CSP parabolic trough technology improvement opportunities. Shading indicates the degree of impact each TIO has on the respective metric and overall LCOE. Red is high; yellow is medium; and no shading indicates low impact.

Figure 3.2.6-3 shows the TIO impacts on LCOE for a hypothetical parabolic trough system. The cost reductions represented by the first three bars in the graph are based on the reference 100-MW trough plant with 6 hours of thermal storage and also include the impacts of R&D efforts only. The final bar represents R&D improvements, in addition to expected cost reductions that result from plant scale-up (200-MW plant) and projected deployment (2000-MW total installed capacity).

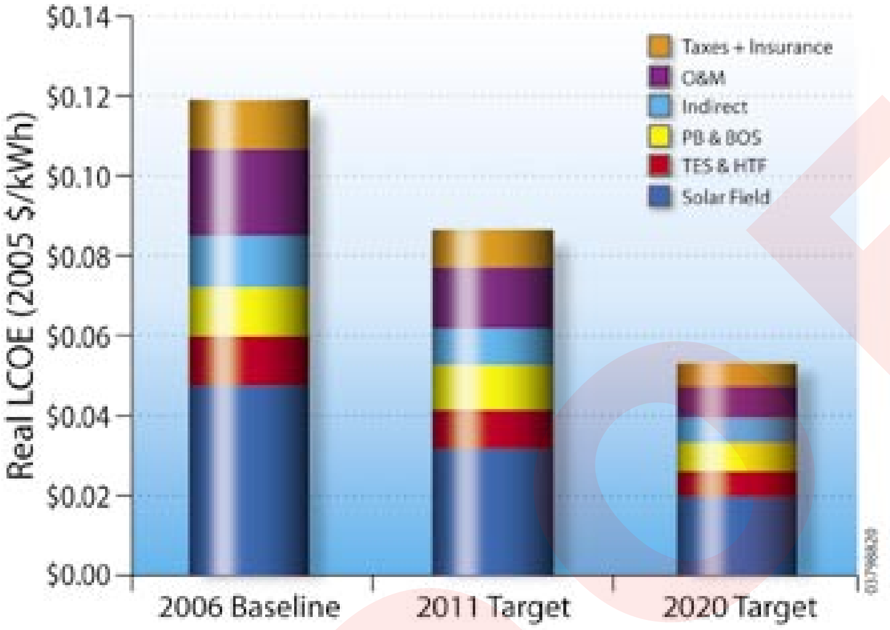
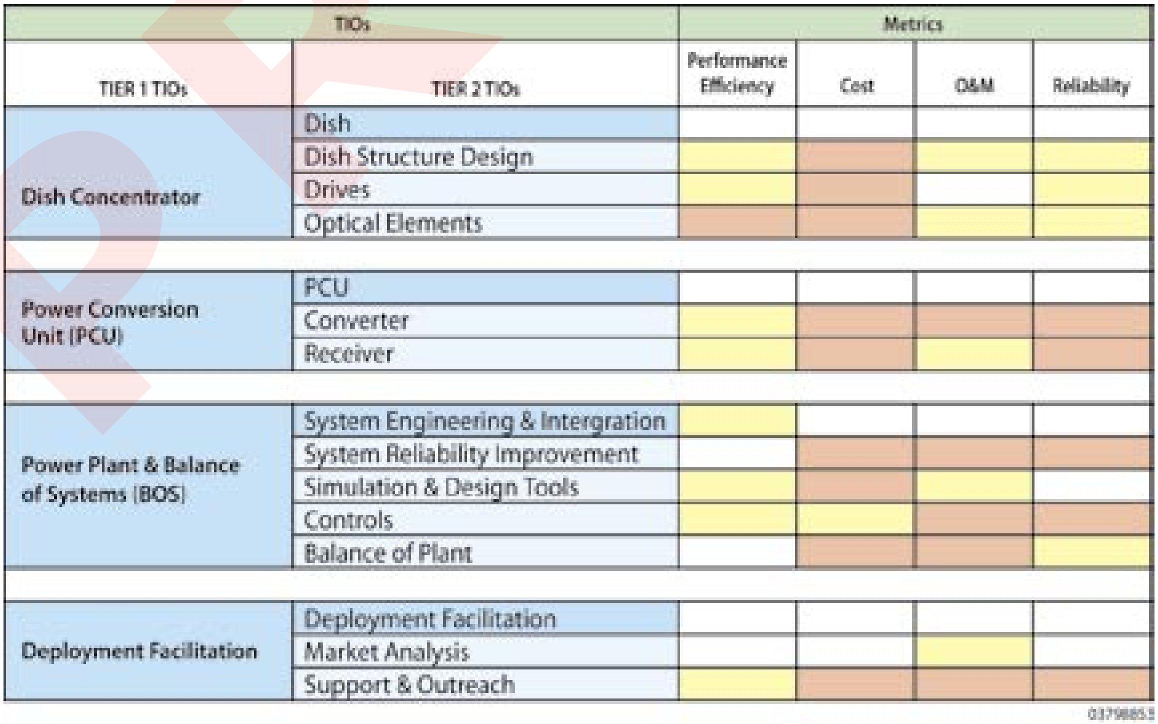


Fig. 3.2.6-3 TIO impact for parabolic troughs.

Dish Technology TIOs

The main activities for dish/Stirling systems during the 5-year period of this plan are increasing system reliability, reducing costs, and improving analytical/cost models. Figure 3.2.6-4 shows Tier 1 and 2 TIOs and the related dish technology activities. The colored boxes indicate areas of programmatic R&D over the 5-year period of this plan. The general classes of activities are described after the figure.



TIOs		Metrics			
TIER 1 TIOs	TIER 2 TIOs	Performance Efficiency	Cost	O&M	Reliability
Dish Concentrator	Dish				
	Dish Structure Design	🟨	🟧	🟨	🟨
	Drives	🟨	🟧		🟨
	Optical Elements	🟧	🟧	🟨	🟨
Power Conversion Unit (PCU)	PCU				
	Converter	🟨	🟧	🟧	🟧
	Receiver	🟨	🟧	🟨	🟧
Power Plant & Balance of Systems (BOS)	System Engineering & Intergration	🟨			
	System Reliability Improvement		🟧	🟧	🟧
	Simulation & Design Tools	🟨	🟧	🟨	
	Controls	🟨	🟨	🟧	🟧
	Balance of Plant		🟧	🟧	🟨
Deployment Facilitation	Deployment Facilitation				
	Market Analysis			🟨	
	Support & Outreach	🟨	🟧	🟧	🟧

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Fig. 3.2.6-4 CSP dish TIOs and associated metrics.

Shading indicates the degree of impact each TIO has on the respective metric and overall LCOE. Red is high; yellow is medium; and no shading indicates low impact.

A key technical challenge for dish/Stirling systems is reducing the capital cost and improving the annual reliability. Because dish/Stirling systems are currently at the prototype stage of development, their costs are projected to drop substantially over the 5-year period of this plan. However, an additional challenge for these systems is to reduce the current O&M costs by improving system reliability. A major focus of DOE activities is to develop components that can operate reliably for long periods of time between scheduled maintenance and to improve system efficiency.

As we pursue the TIOs above, we expect to reduce the cost of energy from dish/Stirling systems from the current reference of 49.4 ¢/kWh to about 25 ¢/kWh. Our long-term goal for this technology is about 7.7 ¢/kWh. Figure 3.2.6-5 shows the current status, our 5-year target, and our long-term goal for dish technology. (Note that these numbers require substantial refinement, which is one of the key activities addressed in this 5-year plan.)

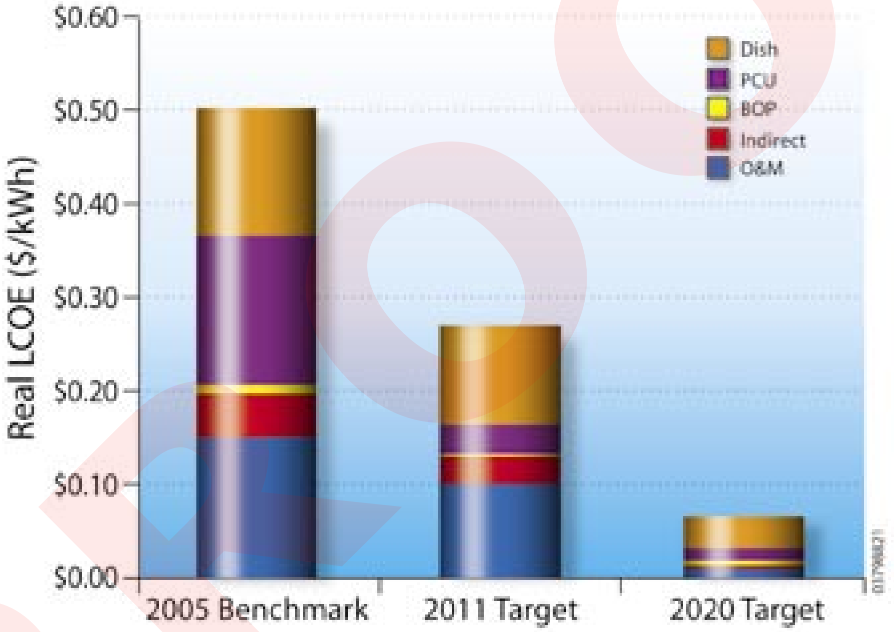

Fig. 3.2.6-5 CSP dish current status, 5-year and long-term targets.

3.2.7 Market Opportunities and Strategies for Overcoming Challenges

Promote and Support Deployment by Industry

Near-term deployment of systems is critical to the long-term success of trough and dish technologies, helping to address system cost and performance and starting to reduce costs through mass production for commercial deployments. DOE's role is not the deployment itself, which is industry's responsibility, but rather, to provide support to industry in developing solutions to technical problems that occur in the field and applying them to next-generation systems. Industry must address manufacturing issues and scale-up of production from single, hand-built components to large-scale production of collectors, receivers, controls, and storage and conversion systems. In some cases, DOE may provide value in the R&D of advanced manufacturing processes.

Support State Government Project Development

In 2002, Congress asked DOE to "develop and scope out an initiative to fulfill the goal of having 1000 megawatts of new parabolic trough, power tower, and dish engine solar capacity supplying the southwestern United States." In June 2004, the Western Governors' Association (WGA) formally adopted a resolution that called for 30 GW of renewable energy by 2015 and specified an initiative of 1,000 MW of CSP as a critical component. In support of the 1000-MW component, the CSP program provides technical support to the southwestern states and to the WGA to support analysis of CSP technologies and to coordinate ongoing CSP-related activities in each state. This support includes participating on state and WGA task forces, conducting economic and systems analyses to help the states and WGA understand the impacts of the projects on their economy, and helping to locate the best sites for solar power plants.

3.2.8 CSP Technical Tasks

The tasks for developing CSP trough and dish technology over the 5-year period of this plan are discussed.

Parabolic Trough Technology Tasks

Solar Field (Tier-1 TIO)

To achieve long-term goals, the cost of the solar collector technology must be reduced by about 40%, from about \$260/m^2 to \$160/m^2, and the annual solar field efficiency must increase from 42% to 52%. At the same time, the peak operating temperature must be increased from 390°C (734°F) to 450°C (842°F), which will raise the power-cycle efficiency from 37.5% to 39.6%. The increased operating temperature will require a more advanced thermal receiver. The key to reducing solar field costs is to reduce the cost of the structure, mirrors, and receivers.

In the longer term, costs can be further reduced through technology advances. For mirrors, this is accomplished by moving from heavy glass mirror reflectors to lightweight front-surface reflectors that include surface coatings to reduce soiling. Advanced-receiver cost reduction focuses on improving the reliability of the glass-to-metal seal and developing a lower-cost, higher-performing selective coating. Maintaining the coating absorptance at 0.96 while reducing the emittance from 0.13 to 0.09 (near term) to 0.07 (long term) will drive most of the projected improvement in receiver thermal efficiency from 72.1% to 83.9%. Advanced concentrator designs that use integrated structural reflectors are expected to allow the cost of the structure and reflectors to be significantly reduced.

Receiver (Tier-2 TIO)

- Develop technology to maintain receiver vacuum and removal of hydrogen.
- Develop improved solar selective coatings with lower thermal emittance and high solar absorptance.
- Develop receiver technologies that reduce cost, or improve overall collector performance.
- Develop improved receiver testing and characterization capabilities.

Concentrator (Tier-2 TIO)

- Optimize near-term concentrator designs through cost-shared R&D with industry.
- Develop advanced concentrator concepts and designs to reduce the cost of next-generation collectors.
- Develop improved concentrator testing and characterization capabilities.

Reflector/Facet (Tier-2 TIO)

- Develop advanced solar reflectors with improved solar reflectance and lower cost.
- Develop glass anti-soiling coatings for mirrors to reduce mirror-washing requirements.
- Encourage development of U.S. mirror supply.
- Develop accelerated reflector testing and characterization capabilities to qualify new and existing solar reflectors.

Balance of Solar Field (Tier-2 TIO)

- Develop improved collector interconnection (replacement for flexhose).
- Develop improved low-cost drives for new larger collectors.

Thermal Energy Storage and Heat-Transfer (Tier-1 TIO)

The integration of thermal energy storage (TES) is needed to boost overall plant capacity factors for solar-only operation from about 25% in current plants without thermal storage to greater than 50% in the future. This will enable dispatching without hybridizing the system with natural gas or other fossil fuels and will thus significantly increase the value of the power.

A near-term high-temperature TES option has been developed that uses molten nitrate salt as the storage medium in a two-tank system; it has an oil-to-salt heat exchanger to transfer thermal energy from the solar field to the storage system. Near-term TES R&D efforts optimize this design to reduce cost and minimize technical risk. The current near-term TES option has a unit cost of more than $30 to $40/kWht depending on storage capacity. A 50% cost reduction is required to meet longer-term TES cost goals. Future TES cost reduction approaches would progress from an indirect system that requires a heat exchanger to a direct system that uses the same fluid in the solar field and storage system, move from a two-tank system to a single-tank thermocline storage system, and increase the hot- and cold-temperature differential in the storage system.

The key technical challenge is to find a heat-transfer fluid (HTF) that is suitable for both the solar field and storage system. Two HTF approaches are currently being pursued. The first option is an inorganic molten nitrate salt; the ternary molten salt, HitecXL™, has been identified as the most promising. The key technical issues with HitecXL™ are its relatively high freeze point (120°–140°C) and the need for appropriate valve and ball-joint packing materials that survive the high temperatures (450°–500°C). The R&D plan for this HTF will focus on developing reliable collector interconnect piping, resolving freeze protection and packing issues, demonstrating the lifetime of the TES filler material, and demonstrating the system elements in the field.

The second HTF option is to develop an advanced HTF that is thermally stable at high temperatures, has a high thermal capacity, has a low vapor pressure, and remains a liquid at ambient temperatures. The R&D plan for this advanced HTF will focus on identifying commodity materials that can be modified at low cost to achieve these desired properties.

Heat-Transfer Fluid (Tier-2 TIO)

- Develop low-cost HTFs with low vapor pressure and increased operating temperature.
- Develop improved HTF system components and system design.

Thermal Energy Storage (Tier-2 TIO)

- Develop thermocline TES.
- Develop direct TES system.
- Evaluate and develop advanced TES concepts.

Power Plant and Balance of Systems (Tier-1 TIO)

The primary power plant of choice remains the Rankine steam power cycle. Future plants will look to scale up plant size, optimize the integration of the solar field and power plant, and reduce water consumption used for cooling. Alternative power cycles (e.g., combined-cycle and organic Rankine cycles) will be considered for niche applications.

Future power plant O&M costs will be reduced primarily through the scale-up of plant size and increasing capacity factor. Continued development of improved automation and control systems and O&M data integration and tracking systems will also be necessary to achieve longer-term O&M cost targets.

Power Plant Technology (Tier-2 TIO)

- Support R&D necessary to scale up power plant size and to optimize the advantage of developing solar power parks.
- Develop standardized trough power plant designs.
- Develop optimized dry and hybrid wet/dry power plant cooling systems.

- Support the integration of trough solar plants into advanced power cycles (e.g., steam Rankine cycles, combined cycles, combustion turbines, organic Rankine cycles).

O&M Systems (Tier-2 TIO)

- Develop improved solar O&M tools and procedures.
- Develop approaches for improved automation and optimization of plant operations.

Systems Engineering and Integration (Tier-1 TIO)

These tasks focus on developing systems integration tools for evaluating trough technologies and assessing program activities. Continuous tracking of technology metrics and development of a methodology for tracking them are key to supporting the CSP Subprogram's systems-driven approach. Many of the models used for technical and economic analysis of parabolic trough solar power plant technologies will be updated and validated. These include models for collector optics and thermal performance, plant process design and integration tools, annual performance and economic assessment, and capital and O&M cost models.

Developing testing standards, facilities, and data reporting requirements is an ongoing task for key solar field components, systems, and power plants. We will continue to work with appropriate stakeholders, including the solar industry and utilities, to collect and document performance data from trough plants in Arizona and Nevada. The data will be used to validate the projected performance of next-generation technologies and to validate performance models used to support decisions regarding technology R&D directions.

Design Optimization and Analysis Tools (Tier-2 TIO)

- Develop improved performance simulation models.
- Develop baseline parabolic trough cost and performance data.
- Develop enhanced design tools for optimizing parabolic trough solar power plants.
- Develop the tools necessary to support the DOE systems-driven approach.
- Provide technical support to near-term projects.
- Support the development of industry testing standards and component qualifications.

Deployment Facilitation (Tier-1 TIO)

A major focus of this task is to provide technical information to stakeholders (i.e., state energy officials, utilities, developers) that allows them to make informed decisions about CSP projects. Tasks currently include siting studies, policy analysis, and technical support to interested states and utilities; these will continue and be provided to appropriate stakeholders in support of the 1,000 MW initiative.

Market Analysis (Tier-2 TIO)

- Conduct market assessment for R&D program feedback.
- Develop improved resource assessment data and tools.

Support and Outreach (Tier-2 TIO)

- Provide technical support for utilities and state agency stakeholders.
- Keep TroughNet Web site updated with current reports and information.
- Conduct annual stakeholder RD&D input and review meetings.

Dish Technology Tasks

Dish Concentrator (Tier-1 TIO)

After reliability, cost is the major barrier to the deployment of dish systems. Developing advanced dish concentrators that maintain the high performance levels of current systems at a substantial reduced cost is critical to the commercial success of dish/Stirling systems. However, higher-priority reliability improvement is the major task of this plan.

Dish Structure Design (Tier-2 TIO)

- Start to develop the design of next-generation dish structure.

Drives (Tier-2 TIO)

- No work planned at anticipated budget level.

Optical Elements (Tier-2 TIO)

- Start advanced facet/optical element design for 10,000 facets/year.

Power Conversion Unit (Tier-1 TIO)

For dish applications, current Stirling engines are built as single units or in small lots at high cost. The next step is to make the engines mass producible, thereby reducing their costs by an order of magnitude or more. Like concentrator drives, Stirling engines will not achieve needed cost reductions through economies of scale alone. This plan focuses on improving the reliability of the Stirling engine and examining new concepts for the thermal receiver.

Converter (Tier-2 TIO)

- Design new gas management system for Stirling engine.
- Design modern robust engine controller for kinematic Stirling engine.
- Improve the reliability of current Stirling engine.

Receiver (Tier-2 TIO)

- Start to evaluate advanced receiver design concepts.

Systems Engineering and Integration (Tier-1 TIO)

This task is the primary focus of this 5-year plan. Performance and some operational data are available for dish-Stirling systems.[6] Stirling Energy Systems of Phoenix, AZ, has installed six next-generation, 25-kW systems at the National Solar Thermal Test Facility in Albuquerque, NM. A team of SES and SunLab engineers and laboratory researchers is focused on improving these systems for commercial deployment by systematically identifying the root causes of failures and implementing design changes and upgrades. Two figures of merit—mean time between incident (MTBI) and mean time between failure (MTBF)—will be used to track progress toward achieving reliability goals. An “incident” is defined as any event that requires any unplanned action by an operator. A “failure” is defined as any event that requires repairing and/or replacing a major component of the system.

System Reliability Improvement (Tier-2 TIO)

- Operate systems and collect reliability improvement data.
- Baseline the performance of the SES system.
- Develop and implement improvement plans for problem areas.
- Optimize system installation logistics and procedures.

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[6] T.R. Mancini et al., “Dish-Stirling Systems: An Overview of Development and Status,” *Journal of Solar Energy Engineering,* Vol. 125, No. 2, May 2003, pp.135–151.

Simulation and Design Tools (Tier-2 TIO)

- Develop improved systems performance and cost models.
- Develop in-field dish alignment schemes/tools.
- Optimize system/field control strategies.
- Develop field layout optimization.

Controls (Tier-2 TIO)

- Develop next-generation dish controller.
- Identify and develop new sensors for kinematic Stirling engine.

Balance of Plant (Tier-2 TIO)

- Design new foundation and installation procedure.
- Develop system design for installation.
- Design power factor correction for field.
- Design/develop secure supervisory control and data acquisition (SCADA).

Deployment Facilitation (Tier-1 TIO)

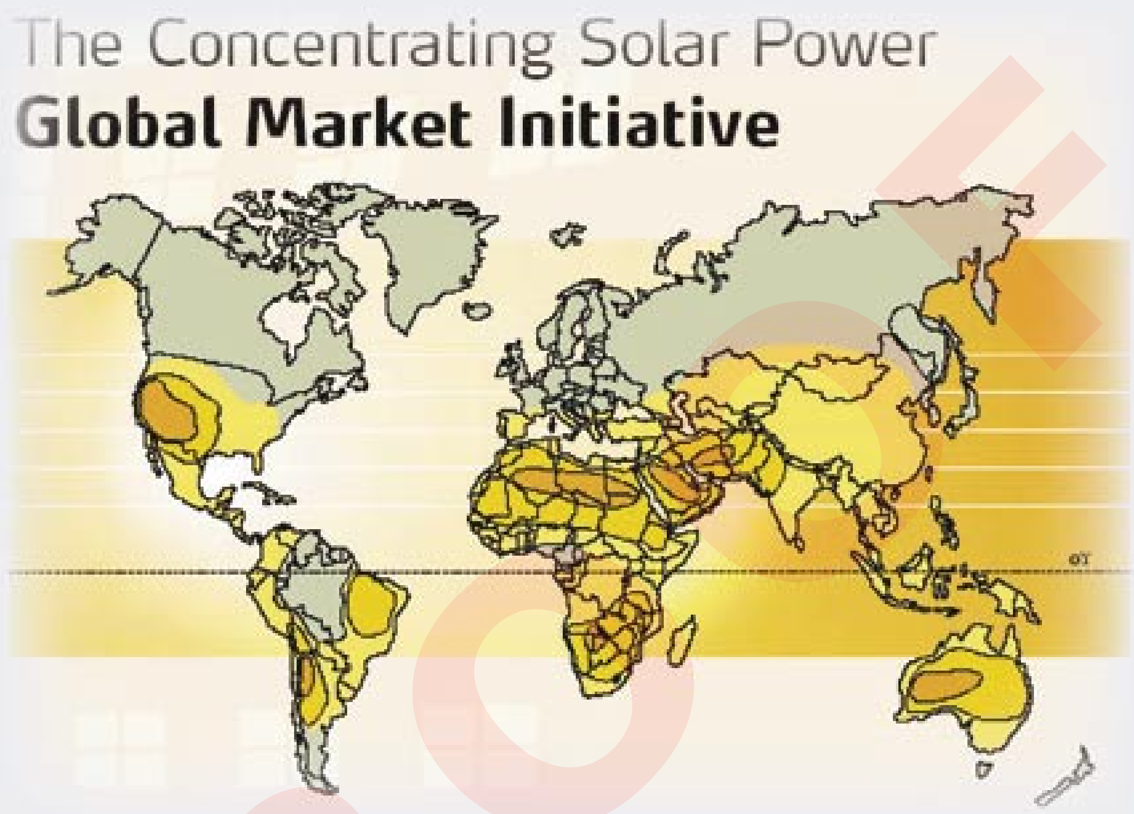
One key task for dish/Stirling systems is to better identify and quantify the markets and market characteristics for these systems. In addition to supporting the proposed deployments in California, this task is aimed at better characterizing potential markets for dish/Stirling systems.

Market Analysis (Tier-2 TIO)

- No work at anticipated budget level.

Support and Outreach (Tier-2 TIO)

- Support the WGA activities and pending dish/Stirling deployments in California.



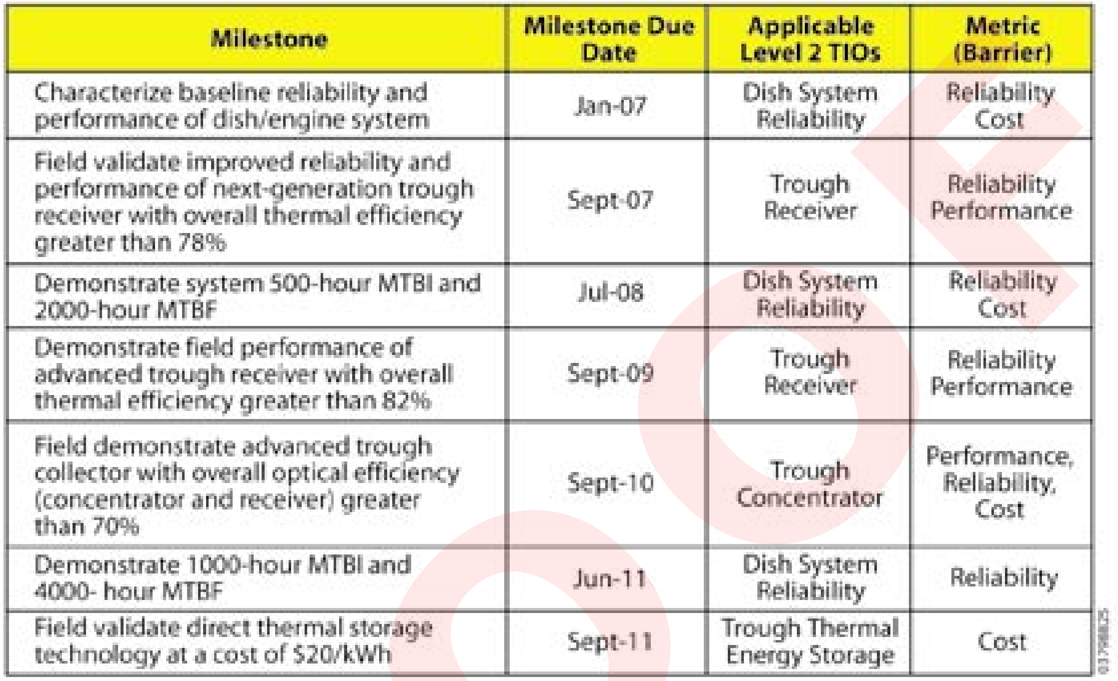
The Global Market Initiative goal is to deploy 5.000 MW of CSP systems by 2015.

The Global Market Initiative for Concentrating Solar Power (GMI-CSP) is part of the worldwide action program adopted by the participants in the International Conference on Renewable Energies, Bonn, Germany, in July 2004.

The GMI-CSP aims to create conditions conducive for the worldwide implementation of projects to generate electrical power from CSP systems by helping to coordinate the efforts of all parties concerned. Eliminating existing obstacles in the electricity markets of the suitable countries situated in the Earth's sunbelt is just part of the initiative.

The participants of this initiative include the governments of Algeria, Egypt, Germany, Israel, Italy, Jordan, Morocco, Yemen, State of New Mexico (USA), and Spain, as well as R&D institutions and other international organizations.

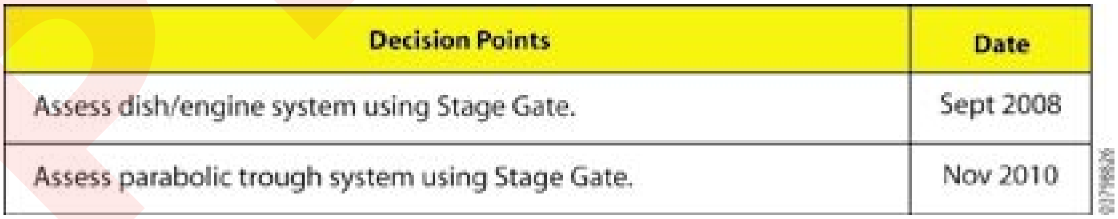
3.2.9 CSP Milestones and Decision Points



Milestone	Milestone Due Date	Applicable Level 2 TIOs	Metric (Barrier)
Characterize baseline reliability and performance of dish/engine system	Jan-07	Dish System Reliability	Reliability Cost
Field validate improved reliability and performance of next-generation trough receiver with overall thermal efficiency greater than 78%	Sept-07	Trough Receiver	Reliability Performance
Demonstrate system 500-hour MTBI and 2000-hour MTBF	Jul-08	Dish System Reliability	Reliability Cost
Demonstrate field performance of advanced trough receiver with overall thermal efficiency greater than 82%	Sept-09	Trough Receiver	Reliability Performance
Field demonstrate advanced trough collector with overall optical efficiency (concentrator and receiver) greater than 70%	Sept-10	Trough Concentrator	Performance, Reliability, Cost
Demonstrate 1000-hour MTBI and 4000- hour MTBF	Jun-11	Dish System Reliability	Reliability
Field validate direct thermal storage technology at a cost of $20/kWh	Sept-11	Trough Thermal Energy Storage	Cost

Decision Points

Using the Stage Gate process, the CSP subprogram will assess the progress made toward achieving technical goals. Assessments will follow intermediate milestones identified for key parabolic trough and dish/engine metrics. For dish/engine systems, progress will be assessed following the July 2008 milestone for obtaining 2000-hour MBTF. For parabolic trough systems, progress will be assessed following field demonstration of an advanced trough collector. Insufficient progress toward achieving these objectives would require reassessing the activities or technical approach, per the Stage Gate process.



Decision Points	Date
Assess dish/engine system using Stage Gate.	Sept 2008
Assess parabolic trough system using Stage Gate.	Nov 2010

3.3 Solar Heating and Lighting

The Solar Heating and Lighting (SHL) Subprogram conducts activities within the areas of solar water heating (SWH) and hybrid solar lighting (HSL). Topics covered on SWH and HSL will be handled separately in each section below, except for the last section that lists milestones and decision points.

3.3.1 SHL Industry and Market Overview

Solar Water Heating

The United States has about one million solar water-heating systems—most of which were installed during the 1978–1985 federal tax credit era when more than 150,000 systems were installed per year. Since 2000–2001, about 6,000 SWH systems per year have been installed in the United States, with about 3,000 per year installed in Hawaii, which has a 35% state income tax credit, relatively high electricity prices, little natural gas, and a successful utility incentive program. In stark contrast, in 2003, due to an aggressive solar energy policy, about 80,000 solar water heaters were sold and installed in Germany, whose population of 82 million is about a quarter of the United States'. Internationally, installations of SWH systems are also increasing at annual growth rates of 27% in China, 23% in Australia and New Zealand, and 22% in the European Union.

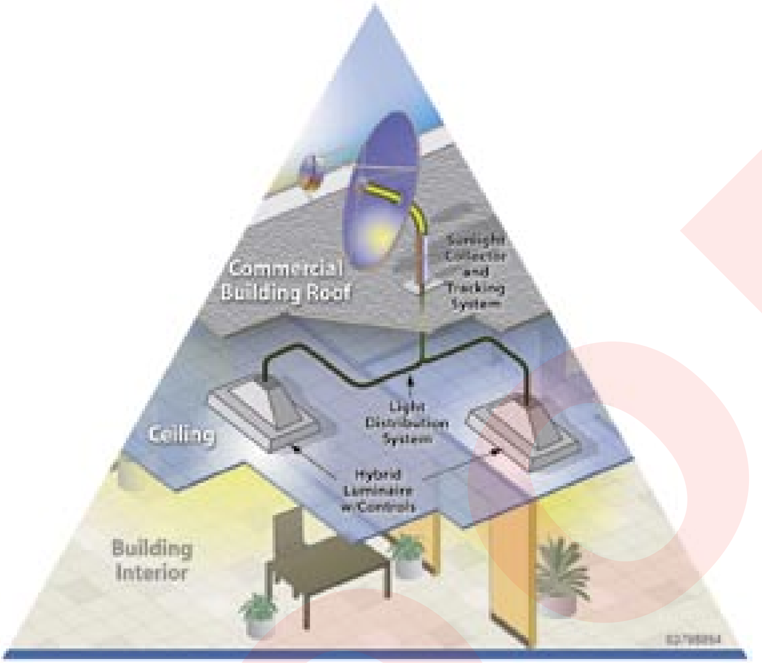
Conventional electric and gas-fired storage water heaters dominate the U.S. residential water heater market, accounting for 99% of the residential water heaters sold in the United States. Most U.S. homeowners do not give much thought to the method or fuel used to heat their water until their current water heater stops working; then, they replace it as quickly and cheaply as possible. Although any one person seemingly uses relatively little hot water during a day, in aggregate, we Americans use a great deal of energy to heat water: 13% of residential and 6% of commercial building energy is consumed to heat water—a total of 3.8 quadrillion Btu of energy.

Currently, solar water heaters are significantly more expensive to purchase and install than conventional water heaters—in some cases, up to ten times more expensive. Driving down this first (purchase) cost is essential to improving the economics of solar water heaters, and, in turn, their marketability. Solar water heating is a mature technology, but R&D can contribute to significant advances in materials, design, and manufacturability that will lower the cost of solar water heaters, improve their performance, and ease installation.

Market barriers outside of technology and cost include codes, covenants, and restrictions (CC&Rs) that may not permit the use of solar systems on homes and commercial buildings; the availability of trained and licensed contractors in some locations of the country; and barriers to consumer accessibility to information about the performance, cost, and benefits of SWH systems.

Hybrid Solar Lighting

Hybrid solar lighting is a technology that uses sunlight to illuminate building interiors (see Fig. 3.3.1-1). The HSL systems use roof-mounted solar concentrators to collect and separate the visible and infrared portions of sunlight. The visible portion is distributed through optical fibers to hybrid lighting fixtures containing both electric lamps and fiber optics. When sunlight is abundant, the fiber optics in the lighting fixtures provide all or most of the light needed in an area. During times of little or no sunlight, sensor-controlled electric lamps operate to maintain the desired illumination level.



Credit: J. Muhs, ORNL, redrawn by NREL.

Fig. 3.3.1-1 Illustration showing the use of hybrid solar lighting to illuminate an indoor space with natural sunlight.

In the United States, artificial lighting represents the single largest component of electricity use in commercial buildings and costs building owners nearly $17 billion a year. Despite the high energy consumption 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 results from the architectural limitations of skylights and windows and the uncontrollable nature of the sunlight itself (i.e., 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.

The HSL technology can meet this need and can potentially provide a product with an economic payback of 3 to 4 years for commercial buildings in the Sunbelt regions worldwide. In the U.S. Sunbelt alone, 20 billion ft^2 of commercial space exist that meet the requirements for implementing an HSL system. Each year, this applicable space grows by 600 million ft^2 of new construction. Commercializing the HSL technology will initially focus on a small subset of retailers representing the jewelry, furniture, and apparel markets. This niche market of early adopters is expected to increase sales volumes of the HSL technology, permitting cost reductions through economies of scale. Reduced system prices should anticipate great market penetration into other niche markets and the larger commercial building market, which includes office buildings.

HSL delivers the benefits of natural lighting without the disadvantages of conventional daylighting technologies such as windows or skylights. Skylights have been around for many decades and function as a simple means of bringing natural light into a building; however, they can have some of the following drawbacks that can limit their application: significant source of heat loss or heat gain, can constrain design of building shape and orientation, difficult\complicated to specify, point of condensation, uncontrolled and uneven illumination, susceptible to water leakage, susceptible to ventilation leakage, not appropriate for low ceilings, difficult to relocate or reconfigure, suitable for downlighting only (i.e., not applicable for directional lighting or uplighting), does not maximize the use of available sunlight, source of light pollution at night, cannot easily be turned off, and security concerns.

3.3.2 SHL Subprogram History / Background

Solar Water Heating

In the early 1980s, the solar water-heating industry experienced rapid growth fueled by federal and state tax credits. However, poorly designed incentives and a lack of standards led to sales of some expensive, poorly performing systems installed by inexperienced and/or unscrupulous firms. This situation hurt the entire industry's reputation. When the 40% federal tax credit ended in 1985, there was a severe contraction of the industry. To help overcome some of these problems, the Solar Heating and Lighting Subprogram helped establish the Solar Rating and Certification Corporation (SRCC) to test and certify the performance of solar collectors and systems. SRCC and the shakeout of marginal producers helped reduce a major barrier to solar water heating—reliability—and significant progress was also made in reducing costs. The SWH firms that remain today generally have high-quality products and good service records.

Technologically, the glass/metal designs and shortcomings in freeze protection were the major barriers to reducing costs and expanding potential markets beyond the Sunbelt, which has been the focus of near-term research. Initially, the SHL Subprogram began with a robust research effort in active solar space heating and cooling. Advances were made, but markets have been fairly limited. Budget reductions forced the SHL Subprogram to narrow its focus to its current portfolio, which focuses mainly on water heating and solar hybrid lighting.

R&D to reduce costs is a principal reason for the federal government being involved in solar water heating and space heating for buildings. Solar manufacturers are generally small businesses with limited resources and expertise. These manufacturers are constantly facing manufacturing and system design issues that affect the reliability, lifetime systems costs, and overall cost effectiveness of their products; yet they do not have the resources to conduct cost reduction R&D. However, the DOE and its national laboratories have extensive expertise and facilities that can be critical to the long-term success of these manufacturers. The systems currently being developed (e.g., all-polymer systems, as in Fig. 3.3.2-1) by the SHL Subprogram are a radical departure from past/currently available technology (e.g., copper, glass, aluminum). It is highly unlikely that the U.S. SWH industry would be developing these low-cost systems without DOE financial and technical assistance.

Fig. 3.3.2-1 Prototype polymer solar water heater for warm climates.

Also extremely important to understand is the connection of the SHL Subprogram to the Building Technologies Program. The long-term goal of EERE's Building Technologies Program is to develop buildings that are "capable of generating as much energy as they use." To meet this goal in the residential building market and have large-scale, market-viable "Zero Energy Homes," significant advances are needed in efficiency and cost reduction. Optimization analysis confirms that increasing building equipment and envelope efficiency to maximum technology will reduce energy needs by 69% in new homes. The remaining 31% of energy needs must be supplied by renewable energy sources. Photovoltaic and solar-thermal space and water heating can provide this energy supply in all U.S. climate regions, but currently, only for a large installed cost. It is critical that the cost of these high-priority technologies be minimized to ensure that affordable solutions are available to reach the Zero Energy Home goal. At a quarter of the cost of PV, solar-thermal systems can be used quite effectively to meet space-conditioning loads, in addition to water-heating loads. Therefore, the costs of solar water and space heating systems must be reduced if the Building Technologies Program is to reach its strategic goal.

Hybrid Solar Lighting

The HSL concept dates back to the early 1970s. In 1999, Oak Ridge National Laboratory (ORNL) initiated work with funding provided by ORNL's internal R&D program, by the Office of Building Technologies, and the Solar Program. This work led to the FY 2003 working prototype of the HSL system. Funding by the Solar Program in the last few years has led to a simpler, more-efficient, and less-expensive second-generation system. Recent technical developments include a high-precision linear actuator in combination with a gear-train drive unit that is expected to reduce the system's tracker unit cost from $25,000 to $8,000, while still providing high-accuracy tracking. A New Zealand vendor is under contract to provide a mirror that will replace the current 48-inch-diameter, 50-pound glass mirror that costs $3,5000 with a 9-pound acrylic mirror estimated to cost less than $300.

ORNL is working with the Hybrid Lighting Partnership, a broad-based public/private alliance to commercialize HSL. This partnership also includes the Tennessee Valley Authority (TVA), Wal-Mart, the Sacramento Municipal Utility District (SMUD), JX Crystals, SAIC, 3M, Honeywell, ROC Glassworks, Array Technologies, Edison Electric Institute, Sunlight Direct, several prominent universities, and other national laboratories.

3.3.3 SHL Strategic and Performance Goals

Solar Water Heating

In FY 2002, the SHL Subprogram set a goal of reducing the LCOE of solar water heating in mild Sunbelt climates from today's $0.08–$0.10/kWh to $0.04–$0.06/kWh by 2006. Although progress has been slowed by both diversion of funds to congressionally directed activities and funding at roughly half the levels requested, laboratory research is nearly complete on new polymers and manufacturing processes for SWH systems in warm climates. The SHL Subprogram is now ready to prove the reliability of these polymer systems in the field. Also, the new goal is to reduce the cost of solar water heating in freezing climates from today's $0.11–$0.12/kWh to $0.05–$0.06/kWh by 2011.

The following strategic goals and performance targets are planned over the 2007–2012 period, based on the long-term goal of solar water heating and solar space heating being competitive with electric or gas alternatives within a 10-year horizon. As with all solar-driven technologies, performance depends on solar incidence and depends on location; therefore, cost goals are stated for an average climate within the target market.

Strategic Long-Term Goals

- Develop low-cost solar water heaters for warm climates that will be cost-competitive with conventional technologies, with LCOE of 4–6¢/kWh. This represents a 25%–50% reduction in LCOE.
- Develop low-cost systems for solar water heating in cold climates and for combined building heating and cooling that have LCOE of 6¢/kWh. This represents a 50%–70% cost reduction, depending on application.

5-Year Performance Goals and Technical Objectives

- By 2007, develop and evaluate SWH prototypes for cold climates; develop and evaluate active concepts for combined solar heating and cooling systems; and assist industry in implementing new concepts in integrated roof/hot-water systems for cold climates.
- By 2009, field test cold-climate SWH prototypes; develop combined solar heating and cooling system prototypes.

- By 2011, complete code approval of cold-climate SWHs; field-test combined solar heating and cooling system prototypes.
- By 2012, SWHs become standard in many building developments. Integrated roof/hot water/heating/cooling systems are in widespread use, and solar energy for process heat is expanding.

Hybrid Solar Lighting

The HSL project has the following goal: to save the nation more than 100 million kWh/yr in avoided fossil-based generation for illumination and air conditioning, while also improving lighting quality in commercial buildings. Through commercialization efforts with industry partners, more than 5000 HSL systems will be installed by 2011 in U.S. regions where solar availability and electricity rates make this technology cost-effective to consumers. The most likely first market for this technology is commercial buildings having mixed fluorescent and incandescent lighting, which is common in retail applications. An installed system cost of $4000 has been identified as the necessary goal so that customers in this market achieve a net savings.

3.3.4 SHL Approach

Solar Water Heating

The main research pathways in solar heating address reducing material costs while maintaining energy performance, combined with innovations that can extend the geographic range of lower-cost materials into areas that experience freezing temperatures. Replacing copper and glass with polymers reduces material costs and weight, which can reduce installation costs, as well. Polymers are also potentially easier to manufacture. Manufacturability, durability, and reliability are key issues addressed in multi-year planning, and they are linked directly to the budget request for solar heating and lighting.

To develop lower-cost solar heating systems, the SHL Subprogram works with university and industry partners in a Stage Gate process of R&D phases:

1. Concept Generation / Exploratory Research—Identify general system configurations that could conceivably reach the project's cost goal.
2. Concept Development / Prototype Test—Develop detailed designs for promising concepts and construct and evaluate prototypes.
3. Advanced Development / Field Test—Develop second-generation prototypes and conduct limited field testing and evaluation.
4. Engineering / Manufacturing Development—Construct third-generation units and evaluate "near-final" systems in "real-world" applications.

At the end of each phase, progress is evaluated, compared to strategic goals and performance targets, and a go/no-go decision is made regarding moving on to the next phase.

Hybrid Solar Lighting

The HSL project will continue developing and demonstrating HSL technology as a high-quality, natural lighting source that can help reduce operating costs for commercial buildings in terms of illumination and air-conditioning loads. In parallel, the commercial market potential will be evaluated through a third-party market assessment.

The first target market will be large retailers located in the Sunbelt region of the United States that use some level of halogen lighting and are planning to lease newly constructed commercial spaces. HSL offers three quantifiable benefits to users: energy savings for lighting, energy savings for cooling, and less frequent replacement of conventional light bulbs. Early adopters of HSL may also value less quantifiable benefits of natural lighting such as improved employee productivity, increased sales, less absenteeism, and better employee wellness; such benefits are also likely to be strong drivers in the early adoption of HSL. R&D will improve system performance, increase system lifetime, and reduce system cost. And these accomplishments will likely lead to greater penetration into the larger market of existing buildings and commercial buildings with fluorescent lighting only. As system price declines and secondary benefits of the technology are demonstrated (particularly improvements in employee productivity), the use of HSL systems in commercial building spaces to replace other lighting will become more cost effective and attractive.

3.3.5 SHL Reference System Descriptions

Solar Water Heating

Two distinct system types are used for solar water heating: passive and active. Passive systems use supply water pressure to move water through the system whenever hot water is drawn; thermal energy storage is integral to the collector. Figure 3.3.5-1 shows an integral collector-storage (ICS) system. Another type of passive system is the thermosiphon system. The collector in these systems is more like an active collector in that it has only a small inventory of water in it. The storage tank is placed above the collector and water circulates through the collector to the tank due to temperature differences as the sunlight warms the water. A limitation of passive systems is that the water in the system can freeze during extended periods of freezing weather. Thus, their application is limited to mild climates.

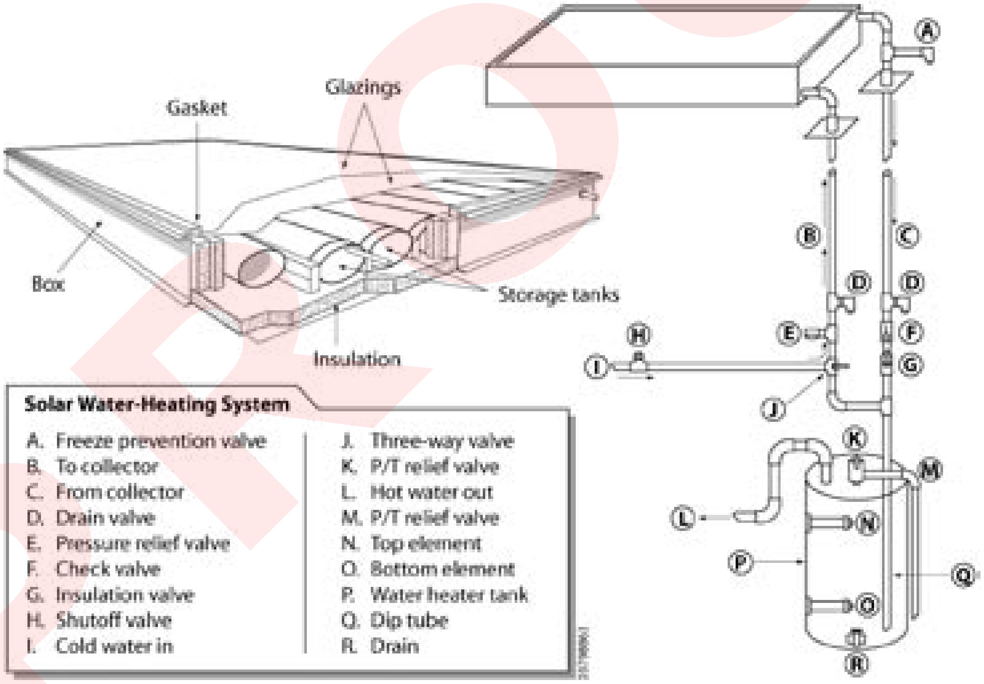


Fig. 3.3.5-1 Passive integral collector-storage solar water-heating system for warm climates.

Active systems circulate a heat-transfer fluid through the collector, transferring heat to storage (Fig. 3.3.5-2). Active systems require a pump and associated controller to circulate the fluid. In mild climates, tap water from the storage tank is circulated through the collector (i.e., direct-circulation system). In colder climates, a non-freezing mixture of water and propylene glycol is used in a closed heat-transfer loop, or water can be circulated in an unpressurized open loop and drained back at night to prevent freeze damage (i.e., drainback system). In addition to providing solar hot water, active systems can also be sized to provide space heat.

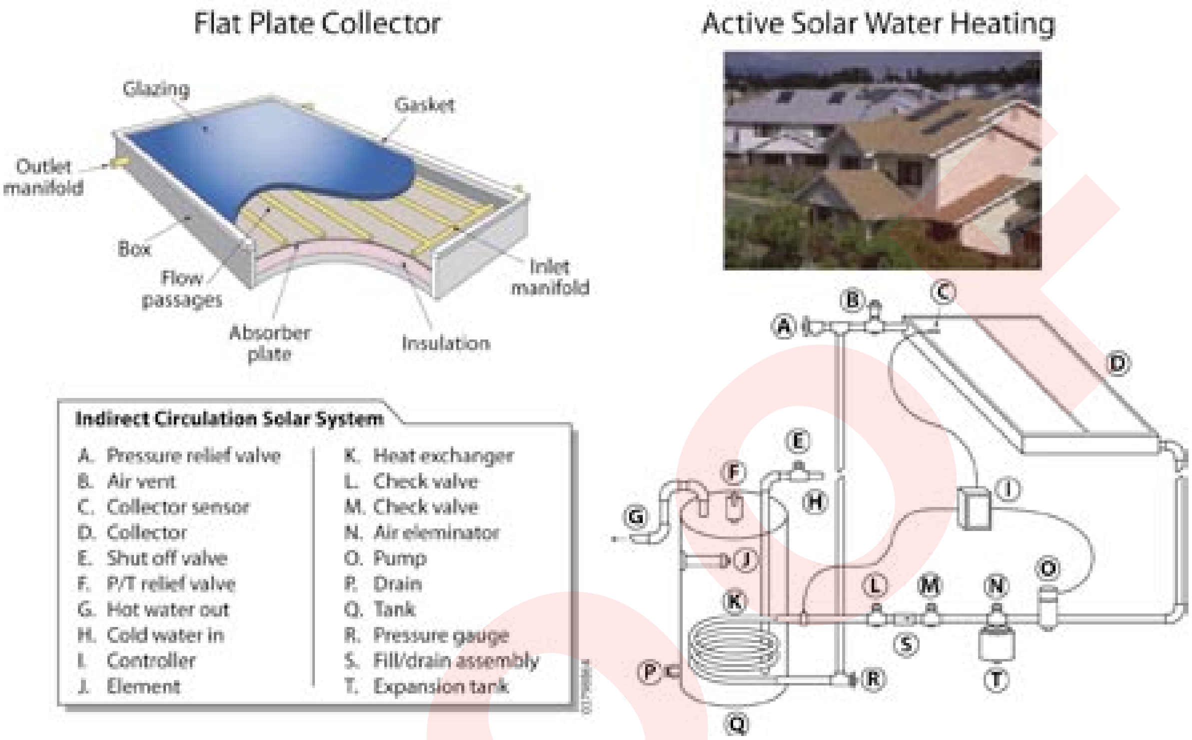


Fig. 3.3.5-2 Active solar water-heating system for cold climates.

Warm-Climate SWH Reference System. The 2006 technology baseline is a traditional ICS system: 32 ft^2 in area and 40 gallons in volume. The absorber/storage is composed of large-diameter, pressurized copper tubes in series, and the glazing is tempered glass. The auxiliary storage tank is a conventional 40-gallon electric water heater.

Cold-Climate SWH Reference System. The 2006 technology baseline is an active SWH system that uses glycol as the heat-transfer fluid. The collector area is 40 ft^2 and the solar storage tank volume is 60 gallons. The copper absorber in the glazed flat-plate collector has a selective, low-emissivity surface. The heat exchanger is a metal coil or shell-in-tube design with copper piping throughout the system. A differential controller activates the AC-powered circulating pump. The auxiliary storage tank is a conventional 40-gallon electric water heater.

Combined Heating and Cooling Reference System. The 2006 technology baseline is an active solar space-heating and water-heating system (no cooling) that uses glycol as the heat-transfer fluid. The collector area is 200 ft^2 and the solar storage tank volume is 800 gallons. The copper absorber in the glazed flat-plate collectors has a selective, low-emissivity surface. The heat exchanger is a metal coil or shell-in-tube design with copper piping throughout the system. A differential controller activates the AC-powered circulating pump.

Hybrid Solar Lighting

The HSL system uses a roof-mounted solar collector to concentrate visible sunlight into a bundle of plastic optical fibers. These fibers penetrate the roof and distribute the sunlight to multiple “hybrid” luminaires within the building. The “hybrid” luminaires blend the natural light with artificial light (of variable intensity), maintaining a constant room illuminance. When sunlight is abundant, the fiber optics in the luminaires provide all or most of the light needed in an area. During times of little or no sunlight, a sensor controls the intensity of the artificial lamps to maintain a desired illumination level. Unlike conventional electric lamps, the natural light produces little to no waste heat (with an efficacy of 200 lumens/watt) and is cool to the touch. Because the optical fibers lose light intensity with increasing length, a maximum length exists over which the light can be distributed.

HSL Reference System. The 2006 baseline HSL system has the following features:

- 48-inch-diameter glass primary mirror (collects 1 m^2 of sunlight)
- Optical-fiber bundle length is 30 feet
- System operating lifetime is 15 years
- Capable of delivering 45,000 lumens of natural light per collector.

3.3.6 SHL Technical (Non-Market) Challenges/Barriers

Solar Water Heating

SWC technical challenges will be discussed below under the three headings of warm-climate SWH, cold-climate SWH, and combined heating and cooling. Target are also given for 2006, 2011, and 2015 for warm-climate SWH, cold-climate SWH, and combined heating and cooling, respectively.

Warm-Climate SWH. The warm-climate SWH activity is planned to conclude before the 2007–2012 period addressed by this Multi-Year Program Plan. But it is presented here to reflect the current status of the SHL Subprogram. Also, the challenges experienced in this R&D effort are very similar to the challenges expected in the cold-climate SWH and combined heating and cooling system activities described in this plan.

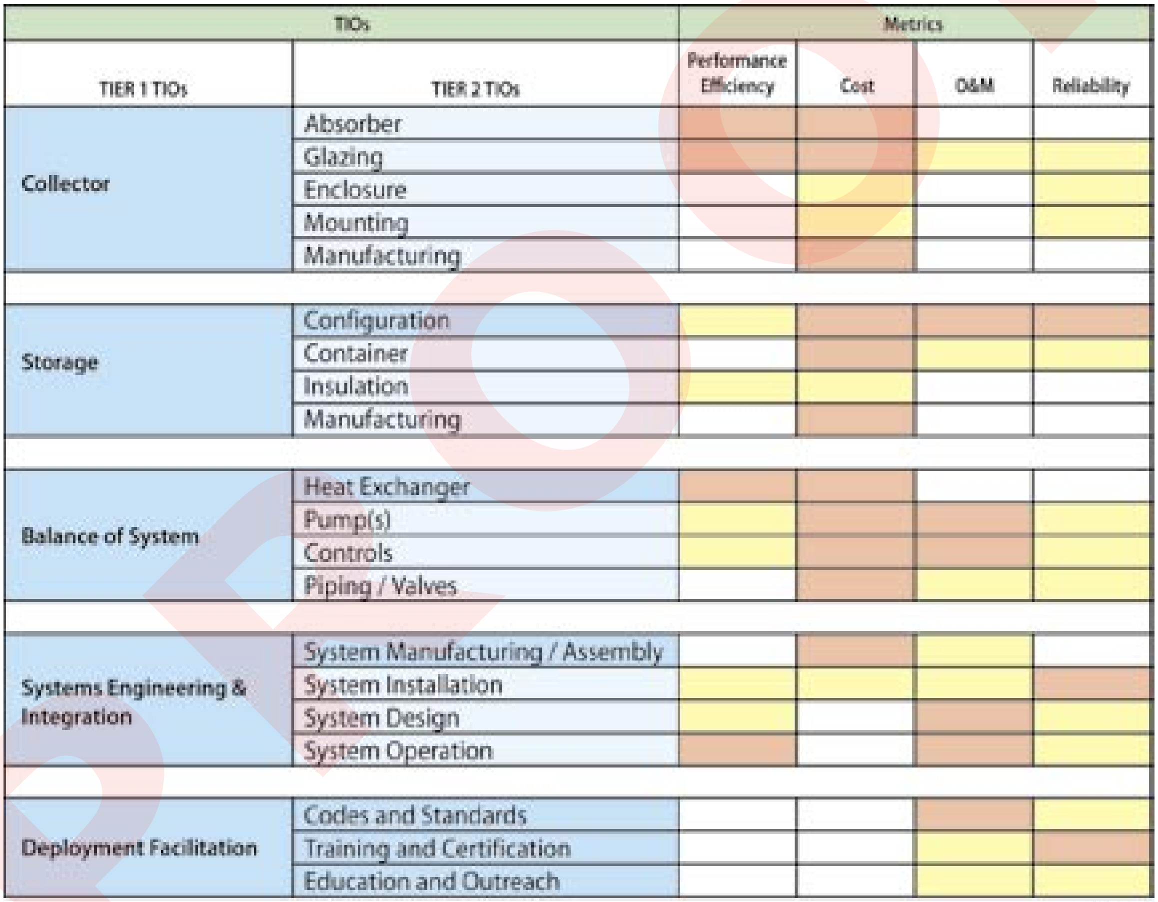
2006 Target: Develop low-cost SWHs for warm climates that will be cost-competitive with conventional technologies, with LCOE of 4–6¢/kWh.

Challenges/Barriers:

- **Cost reduction.** The primary challenge is cost reduction of the collector, storage, and balance of system, while still maintaining performance levels comparable to conventional copper/glass/aluminum systems. Other current challenges are listed below.
- **Reliability/durability.** Passive ICS collectors are appropriate for warm climates, but polymer ICS systems include materials that are new to the building market.
  - Continued exposure testing is needed to show that properly ultraviolet (UV)-protected polycarbonates and acrylics do not yellow or fail mechanically.
  - The polymer absorbers are potentially subject to degradation and failure at high temperatures; uncertainty stemming from generally unavailable high-temperature data needs to be resolved.
  - Heat exchangers—whether first-generation copper heat exchangers or polymer heat exchangers under development—can fail under high temperature and pressure because of chlorine damage and scale accumulation that blocks passageways.
  - At the system level, pipe freezing of the supply/return pipes has always been an issue for passive systems when they are installed in climates that have occasional hard freezes.
  - Expected durability of roof-integrated collectors in extended operation needs to be demonstrated.
- **Building codes.** The new materials introduced in polymer ICS systems raise several questions with building-code organizations.
  - SWH code bodies (SRCC and others) must conduct certification testing of solar collectors.
  - Polymer collector materials and system designs must be accepted by building-code officials.
  - Appropriate methods for rating unpressurized ICS systems with immersed load-side heat exchangers are required.
- **Manufacturing.** Manufacturing for polymer SWH systems must be developed, tested, and refined.

- Manufacturing processes for extruded polymer ICS systems must be developed, building on techniques of extrusion and manifold welding that are well proven for similar polymer pool collectors (more than one million collectors have been made by U.S. manufacturers).
- A polymer heat exchanger represents a leap in manufacturing technology, involving the automation of a tube clip-and-weave process and a new manifold welding process with small-diameter tubing.

Cold-Climate SWH. Analyzing the cold-climate reference system led to identifying TIOs to overcome barriers related to cost, performance, O&M, and reliability. Figure 3.3.6-1 shows the TIOs at two high levels, starting at Tier 1 and further divided in Tier 2. The estimated impact of the Tier 2 TIOs on the performance metrics is also shown in Fig. 3.3.6-1.

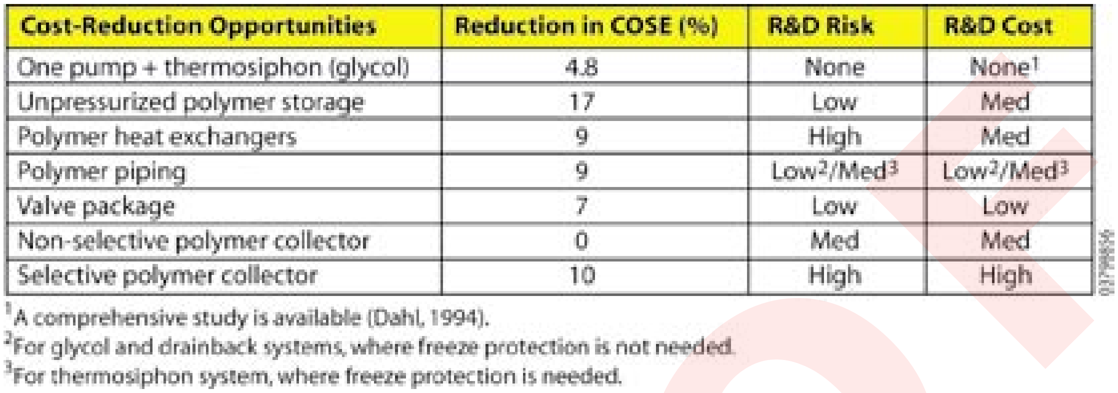


TIOs		Metrics			
TIER 1 TIOs	TIER 2 TIOs	Performance Efficiency	Cost	O&M	Reliability
Collector	Absorber	🟥	🟥		
	Glazing	🟥	🟥	🟨	🟨
	Enclosure		🟨		🟨
	Mounting		🟨		🟨
	Manufacturing		🟥		
Storage	Configuration	🟨	🟥	🟥	🟥
	Container		🟥	🟨	🟨
	Insulation	🟨	🟨		
	Manufacturing		🟥		
Balance of System	Heat Exchanger	🟥	🟥		
	Pump(s)	🟨	🟥	🟥	🟨
	Controls	🟨	🟥	🟥	🟨
	Piping / Valves		🟥	🟨	🟨
Systems Engineering & Integration	System Manufacturing / Assembly		🟥	🟨	
	System Installation	🟨	🟨	🟨	🟥
	System Design	🟨		🟥	🟨
	System Operation	🟥		🟥	🟨
Deployment Facilitation	Codes and Standards			🟥	🟨
	Training and Certification			🟨	🟥
	Education and Outreach			🟨	🟨

Fig. 3.3.6-1 Solar water-heating TIOs. Shading indicates degree of impact each TIO has on each metric: red (dark) is high; yellow (light) is medium; no shading is low.

The impacts of different TIOs on overall cost of avoided energy were analyzed, in some cases at additional levels of detail. For example, in FY 2004, analysis using the systems-driven approach was conducted to determine the most effective cost-reduction opportunities for three types of SWH systems in cold climates. Table 3.3.6-1 shows the results for the cost of saved energy (COSE). The highest priority was determined to be replacing conventional pressurized solar storage tanks and metal heat exchangers with unpressurized polymer tanks with immersed polymer heat exchangers. In fact, BOS and storage improvements were shown to be of higher priority than collector improvements. The table lists the percentage reduction in COSE for some of the opportunities that were investigated, as well as the estimated R&D risk and the estimated R&D cost.

Table 3.3.6-1 Cost-Reduction Opportunities—Cold-Climate SWH



Cost-Reduction Opportunities	Reduction in COSE (%)	R&D Risk	R&D Cost
One pump + thermosiphon (glycol)	4.8	None	None[1]
Unpressurized polymer storage	17	Low	Med
Polymer heat exchangers	9	High	Med
Polymer piping	9	Low[2]/Med[3]	Low[2]/Med[3]
Valve package	7	Low	Low
Non-selective polymer collector	0	Med	Med
Selective polymer collector	10	High	High

[1] A comprehensive study is available (Dahl, 1994).

[2] For glycol and drainback systems, where freeze protection is not needed.

[3] For thermosiphon system, where freeze protection is needed.

2011 Target: Develop low-cost SWH systems in cold climates that will be cost-competitive with conventional technologies, with LCOE of 6¢/kWh.

Challenges/Barriers:

- **Collector**
  - **Cost.** Reduce current manufacturing cost from \$110–170/m^2 (\$10–15/ft^2) to ~\$54/m^2 (\$5/ft^2) for active SWH systems and ~\$22/m^2 (\$2/ft^2) for active combined heating and cooling (CHC) systems.
  - **High temperatures.** Collectors must withstand stagnation temperatures of ~250°–450°F, depending on glazing and absorber properties. Generally speaking, metal-glass collectors handle dry stagnation without major issue, although insulation or gaskets may degrade more rapidly over time. High temperature becomes critical generally only for polymer-based absorbers.
  - **Installation.** Today's metal-glass collectors weigh about 3 lb/ft^2, which is heavier than desirable for efficient installation.
  - **Durability/reliability.** Lifetime of polymer collectors is expected to be less than that for metal-glass collectors.
- **Storage**
  - **Cost.** For active systems with storage separate from collector, storage is a major cost component. Today's pressurized storage tanks start at ~\$3/gallon, or ~\$250 for an 80-gallon storage. Costs increase drastically if a heat exchanger is included in the storage.
  - **Lifetime/reliability.** Today's pressurized tanks in conventional applications have a mean life of about 12 years. Tank replacement represents the largest single expense in O&M costs. Tank lifetime should be longer than the expected collector/system lifetime to avoid any significant costs from tank replacements.
- **Balance of system** (BOS includes pump/controls and piping/valving)
  - **Cost.** Typical cost for a differential-temperature (ΔT) controller plus AC-powered pump combination is ~\$200 in hardware, with ~\$100 incremental installation cost. Running, soldering, and insulating hard copper piping is a significant part of installation cost, estimated at \$450.
  - **Reliability.** ΔT-controller-pump failures contribute about \$300 to O&M present-value cost. Plumbing valves and other components individually have been identified as the cause of most installation error and a significant contributor to be reduced.

Combined Heating and Cooling. A 2015 target is given before describing several challenges or barriers for the CHC technology.

2015 Target: Develop low-cost systems for combined building heating and cooling that will be cost-competitive with conventional technologies, with LCOE of 6¢/kWh.

Challenges/Barriers:

- **Collector.** To supply the same amount of space-heating saving as SWH savings, the glazed system area devoted to space heating must be larger (due to lower incidence, lower ambient temperatures and efficiencies). For an unglazed system, collector areas are roughly twice that required for a glazed system for equivalent savings.
- **Storage.** Compared to SWH, space heating requires larger ratios of storage volume per unit collector area, because energy must be stored for a longer time. The optimal storage size range is not well established as yet.
- **Balance of system.** CHC systems need distribution systems, which may present additional cost. Distribution options include radiant floor and/or ceiling and duct fan coils. Circulation strategies and controls for CHC systems must accommodate seasonal switchover between heating and cooling.
- **System integration.** System control is more complex with CHC systems. For unglazed systems both collecting and rejecting heat (cooling), there will likely be a separate domestic hot water (DHW) and space-conditioning (heating and cooling) tank. Control of flow of heat to DHW and space-heating storage must be managed optimally.

Figure 3.3.6-2 shows the TIO impacts on LCOE for the hypothetical reference cold-climate SWH system in 2006, the 2011 target for a cold-climate SWH, and the 2015 target for a CHC system. Three Tier 1 TIOs—collector, storage, and BOS—are shown, as well as costs related to installation, market, and O&M. Indirect costs such as overhead are included in the Tier 1 TIO costs. All costs are also referenced to the performance of the systems in Baltimore, MD, a cold-climate city fairly close to the U.S. average for solar radiation and temperatures.

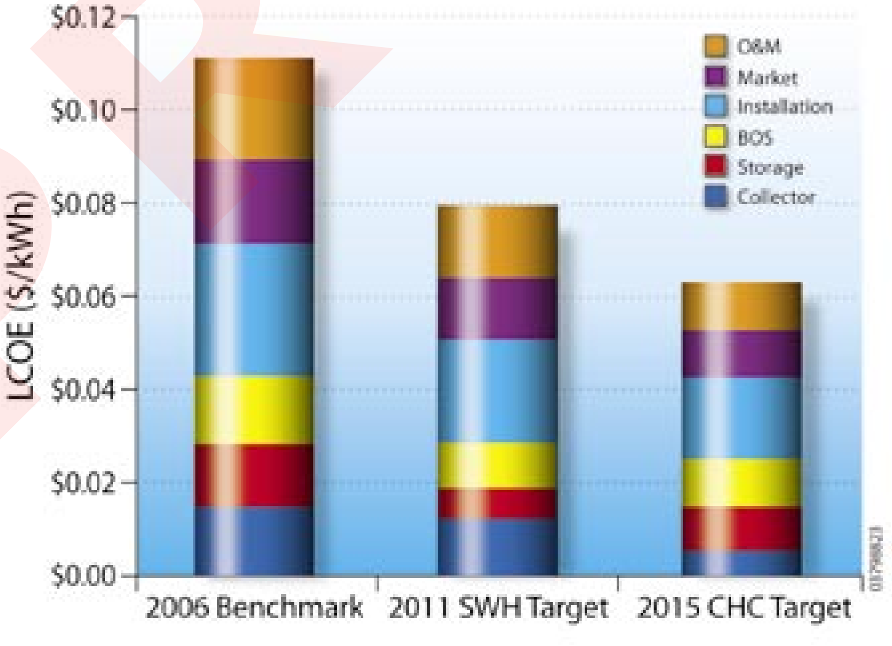
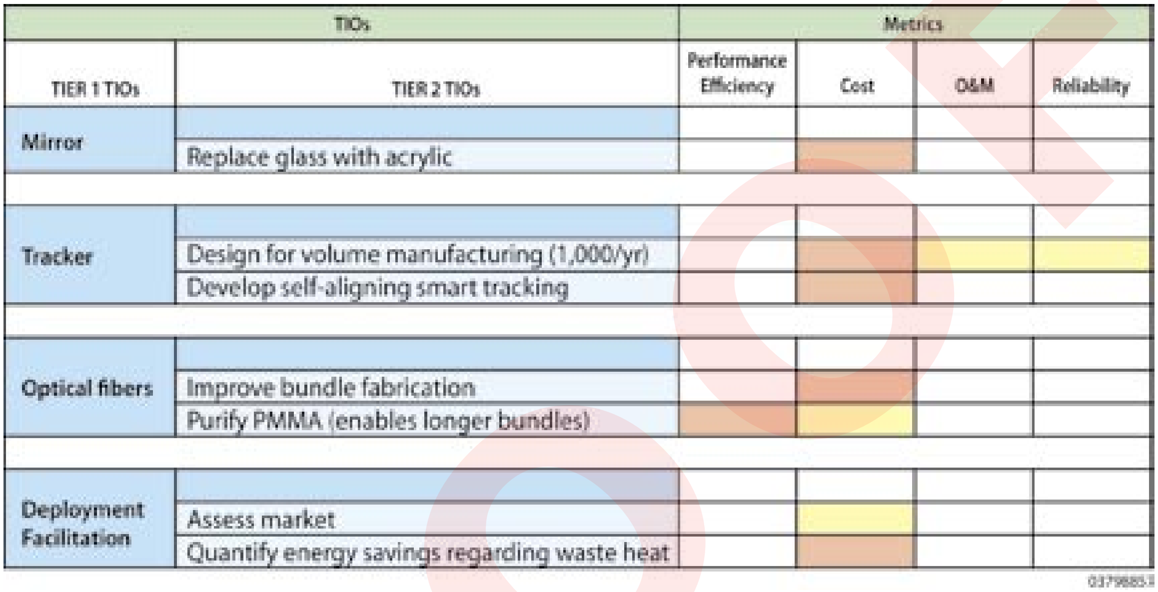


Fig. 3.3.6-2 Impact of TIO on LCOE for cold-climate solar water heating and combined heating and cooling systems.

Hybrid Solar Lighting

Analysis of the reference system has identified technical improvement opportunities for overcoming barriers related to cost, performance, and reliability. Figure 3.3.6-3 shows the Tier 1 and Tier 2 TIOs. The impacts of different TIOs on overall cost of avoided energy have been analyzed, in some cases at additional levels of detail.



TIOs		Metrics			
TIER 1 TIOs	TIER 2 TIOs	Performance Efficiency	Cost	O&M	Reliability
Mirror					
	Replace glass with acrylic		🟥		
Tracker					
	Design for volume manufacturing (1,000/yr)		🟥	🟨	🟨
	Develop self-aligning smart tracking		🟥		
Optical fibers					
	Improve bundle fabrication		🟥		
	Purify PMMA (enables longer bundles)	🟥	🟨		
Deployment Facilitation					
	Assess market		🟨		
	Quantify energy savings regarding waste heat		🟥		

Fig. 3.3.6-3 HSL TIOs and associated metrics. Shading indicates degree of impact each TIO has on each metric and overall system LEC: red (dark) is high; yellow (light) is medium; no shading is low.

The greatest technical challenges/barriers remaining for the HSL project are as follows:

1. The reliability and installed cost of the 2-axis tracking mechanism and control electronics.
2. The high optical absorption and costs associate with the system's plastic fiber-optic bundles.
3. Demonstrating and quantifying waste heat avoidance from HSL with respect to fluorescent or incandescent illumination.

In recent years, great progress has been made in improving the reliability and cost of the HSL tracking mechanism and control electronics. However, to continually improve the system's reliability and lifetime, we need smarter controls that use feedback sensors and self-learning algorithms, as well as improved mechanical designs combined with extensive field testing of the HSL tracker. The goal is to achieve a 20-year HSL system lifetime with reliable performance and self-correcting alignment capabilities under harsh environmental conditions. Tracking system costs will drop from $8,000 to $3,000, and installation costs will drop from $12,000 to $3,000.

In addition, a less expensive plastic optical fiber bundle with improved optical performance is critical to the success of the HSL project. Currently, the HSL technology distributes sunlight via a 30-foot plastic optical fiber bundle. Significantly increasing the length of the bundle results in undesirable reductions in delivered light and can result in noticeable changes to the lighting color. In addition, the cost of this 30-foot bundle is currently $3500. To reduce the overall cost of the HSL system, a bundle target cost of $1000 should be achievable by improving the bundle fabrication process and using an improved polymethyl-methacrylate (PMMA) purification technique. These improvements should result in lower optical absorption by the optical fibers, allowing for longer bundle lengths that better maintain the intensity and color of the delivered sunlight.

Figure 3.3.6-4 shows estimated costs for prototypes, initial production, and production units. Energy saved is the energy not used both for electric lighting and for cooling to remove waste heat from electric lights.

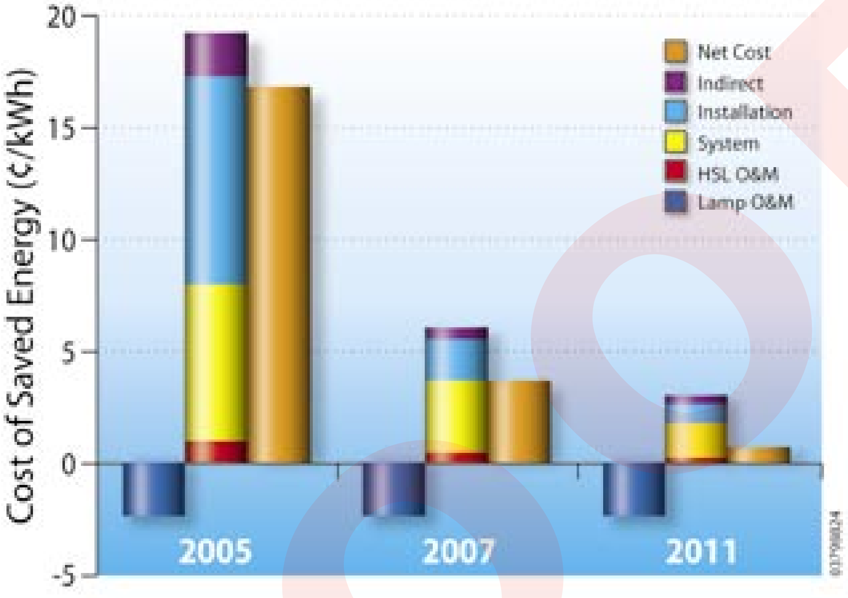


Fig. 3.3.6-4 Cost of saved energy (lighting and cooling).

3.3.7 SHL Market Opportunities and Strategies for Overcoming Challenges/Barriers

Solar Water Heating

Deployment facilitation activities help to inform R&D work by providing knowledge and information about market trends and technology gaps to researchers. And R&D activities support deployment facilitation work by providing knowledge and information about technologies to market players. Below is a brief summary of deployment-related activities in the SHL Subprogram.

Solar Rating & Certification Corporation (SRCC). The SRCC is an independent, non-profit organization whose primary purpose is to develop and implement third-party certification programs and national rating standards for solar-energy equipment. SRCC currently operates three major certification programs: solar collector cer¬tification (OG-100), solar water-heating sys¬tem certification (OG-300), and a solar swimming pool heating system certification (OG-400). The SWH system cer¬tification program (OG-300) deals with the entire solar system (i.e., collectors, controls, storage tanks, heat exchangers, pumps) used to heat domestic hot water with the sun.

Utility Solar Water Heating Initiative (USH$_2$O). USH$_2$O is a coalition of utilities and the solar-thermal industry that focuses on implementing cost-effective, reliable solar solutions for utilities and their customers. USH$_2$O provides information about utility water-heating programs and offers services to utility companies and energy service providers considering implementation.

Solar Hybrid Lighting

As an FY 2006 task, ORNL will conduct an HSL market assessment.

The benefit or advancement offered by HSL is to bring natural light into interior rooms on the top two floors of a building through optical fibers. The primary attribute of HSL systems is the light quality of sunlight compared to artificial light; but another benefit is reducing waste heat compared to other lighting systems. Fossil energy is also conserved by using solar energy for lighting applications. At this point, HSL systems have been engineered through two technology generations, many components and subsystems have been refined or reengineered, and the technology has been proven technically feasible.

To proceed in developing the HSL technology, it will be critically important to determine the size of the lighting market that cares enough about light quality and/or avoidance of excess heat gain to actually buy an HSL system. Also important is to identify other lighting technologies, already commercially available or being developed, that offer the same light quality or absence of heat gain as does HSL. HSL systems provide full-spectrum lighting or parts of the spectrum for a particular application. However, certain light bulbs and other lighting systems can provide nearly full-spectrum lighting and do not require hardware mounted on the roof, unlike HSL systems. The overall intent of this task is to assess and quantify the potential U.S. market for the HSL technology, considering the various alternatives available to lighting designers and customers.

Another objective is to quantify the reductions in waste-heat generation from HSL systems compared to incandescent and other lighting systems.

3.3.8 SHL Technical Tasks

Solar Water Heating

As in Sec. 3.3.6, the SWH tasks below will be discussed under the three headings of warm-climate SWH, cold-climate SWH, and combined heating and cooling.

Warm-Climate SWH Tasks. As indicated in Sec. 3.3.6, the warm-climate SWH activity is planned to conclude before the 2007–2012 period addressed by this Multi-Year Program Plan. However, the planned 2006 tasks for this activity are presented here to reflect the current status of the SHL Subprogram and to emphasize the R&D foundation that the cold-climate SWH and CHC system activities (described in this plan) will be built on.

In addition to research on cost reduction, key objectives in the warm-climate SWH activity have been to establish long-term durability of the materials used in polymer SWH systems, certify the systems, and assist in implementing novel manufacturing processes. These activities are heavily cost-shared.

- **Reliability/Durability.** For polymer ICS systems, a dual-level approach using both materials testing and system testing is optimal for building confidence at the lowest cost.
  - ***Materials testing.*** Accelerated materials testing is the most efficient way to project material lifetimes. Polycarbonate glazings are subject primarily to UV degradation (i.e., yellowing, cracking, and eventually mechanical failure). UV degradation testing using three complementary approaches (i.e., outdoors, chamber, and UV-concentrator) has been ongoing and will continue beyond the 20-year equivalent point for the industry samples. Previous work has identified a promising UV-protection coating product, Korad©. Polycarbonates with mechanically adhered Korad© have not shown any optical degradation at the 15-year-equivalent dose point, reached in FY 2004. Absorbers are being tested for creep and temperature-induced degradation. Prototype polymer heat-exchanger tubing is being tested for resistance to damage from high chlorine concentrations and for resistance to buildup of scale.
  - ***System testing.*** There are two types of system tests: torture tests, which focus on high-stress situations such as hail impact, high winds, high/low temperature performance, and mechanical abuse; and field tests, which verify performance and durability under normal conditions.
- **Building codes.** One polymer ICS (PICS) system has been submitted to SRCC and the International Code Council Evaluation Service (ICC-ES) on an informal basis to get feedback on any issues. SRCC needs

procedures for qualification and rating of polymer-based systems.

- **Manufacturing.** Design and implementation of manufacturing will be funded mostly by industry partners. Assistance will be provided for those aspects that are novel and necessary to achieve the low-cost goals. For rotomolded PICS, manufacturing support is minimal. For the extruded PICS, assistance will be provided for developing the tank manifold welding and fabricating the heat exchanger.

Cold-Climate SWH and CHC Tasks. As with SWH systems for warm climates, the Stage Gate technology development approach for cold climates involves four phases: moving from initial concepts through prototype and engineering development to final product testing and manufacturing development. Descriptions of specific technical issues and tasks follow. Approaches proven successful in the polymer systems for warm-climate work will lower development costs. Unit-area system cost should be reduced at least 50% for cold-climate SWH and at least 80% for CHC (including roofing credits). The tasks are first described for SHW, followed by tasks unique to CHC. Similarly, the task tables are first laid out for SWH (Table 3.3.8-1), followed by tasks unique to CHC (Table 3.3.8-2).

Cold-Climate SWH Tasks

Collector Tier-1 TIO

Glazed flat-plate collector costs need to be reduced from \$130/m^2 (\$12/ft^2) to about \$54/m^2 (\$5/ft^2).

- **Collector configuration.** When using polymer materials, overheating of the absorber under dry stagnation becomes a potential issue, because polymers generally have relatively low melting temperatures and strength is reduced at higher temperatures. Collector designs must be analyzed and tested structurally. Finite-element analysis (with attendant measurement of material mechanical properties and creep) is necessary to ensure reliability while minimizing materials.
- **Glazings.** UV degradation testing of coated polycarbonate sheets has been ongoing. Thin-film glazings (e.g., fluorocarbons such as Tefzel) are also known to weather well. They are harder to mount and maintain than sheet materials, but could be the least-cost option.
- **Absorbers.** Due to low thermal conductivity (3 orders of magnitude below copper), polymer absorbers have been designed as fully wetted (i.e., no significant fins). However, it may be possible to use recently developed low-cost conductivity-enhancing additives to develop a fin-tube design, perhaps reducing manifolding connections and increasing reliability.
- **Container/insulation.** It has proven cost-effective with polymer ICS systems to eliminate a separate “container” by forming the glazing/absorber/bottom pan constructions to join appropriately. This will likely continue with proposed flat-plate collector concepts.
- **Mounting.** Experience in the low-cost polymer ICS system development indicates that if the collector bottom is corrugated, roof drying is adequate when mounting the collector flat on the roof. This simplifies the mounting procedure.

Storage Tier-1 TIO

- For active systems with storage separate from collector, storage is a major cost component. Storage cost can be significantly reduced by using unpressurized storage, but a load-side heat exchanger with high effectiveness is then required. Historically, most active systems have used pressurized storage. Unpressurized storage can be made from thin-wall polymer tanks (rotomolded or blow-molded) or from a membrane held in place by an external structure (e.g., cylindrical insulation plus metal or nylon sleeve). Design concepts using unpressurized storage must be developed and engineered, materials tested, prototypes built, and manufacturing optimized.

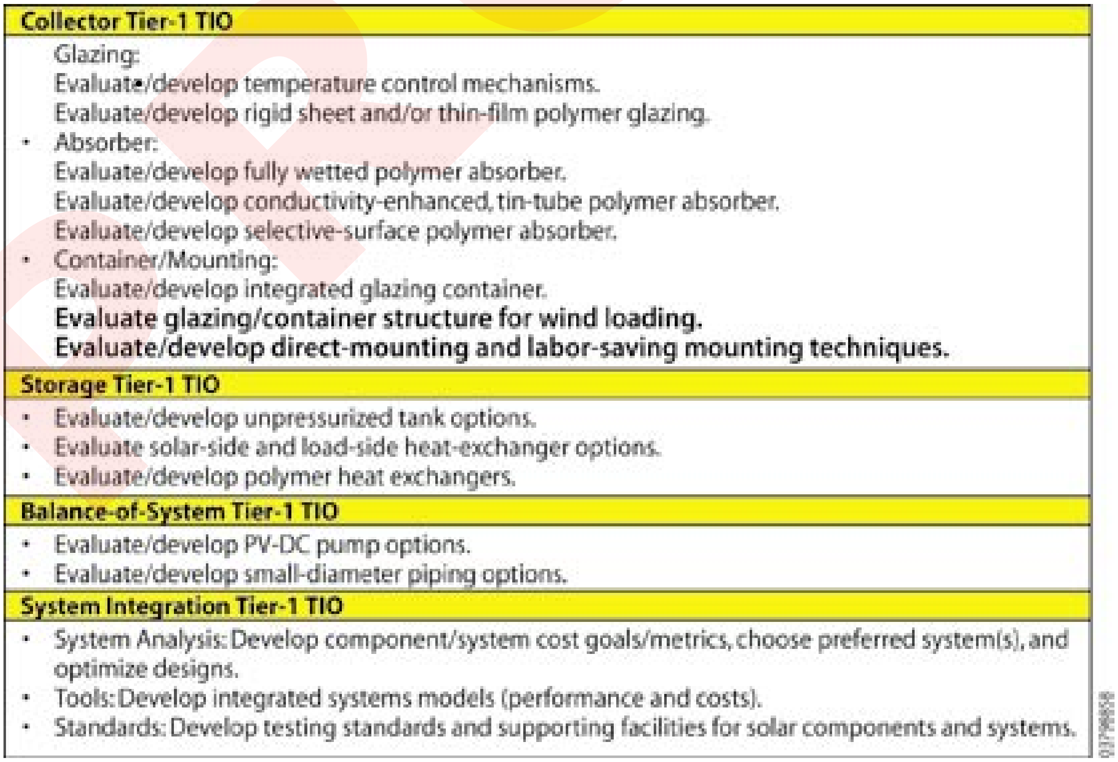
Balance-of-System Tier-1 TIO

- **Heat exchangers.** Solar-side heat exchangers (used with pressurized storage) are smaller than load-side heat exchangers (used with unpressurized storage). Depending on the approach, solar-side heat exchangers are made from copper, with designs including immersed coil, bayonet, or external wrap-around. Copper tubing for a load-side heat-exchanger immersed coil costs ~$150, or ~$2/gallon. If the polymer heat exchangers currently being developed prove successful, a load-side heat exchanger could be priced at ~$50, or ~$0.60/gallon. Nylon and polybutylene heat-exchanger development is under way for polymer ICS systems, and these designs can function here with geometric adjustments.
- **Pump/controls.** A PV-DC pump combination is likely to emerge as a good choice when installation and O&M are considered. For a glycol system, this approach works very well. For a drainback system, a low-wattage PV-pump combination providing high head on startup and reasonable flow during operation is not currently available. It will be a key item to develop if drainback with unpressurized storage remains a targeted system type.
- **Piping/valving.** Collector supply-return piping has traditionally been soldered copper piping, insulated after installation. Recent research in Europe and Canada has produced prototype "life-line" piping, where the supply-return pipes and insulation are integrated in one package that can be "snaked" between collector and storage. Such piping has significant potential to reduce piping installation costs by more than 50%.

System Integration Tier-1 TIO

- Thermal performance modeling with polymer materials is no more difficult than with traditional materials, although testing is generally needed to determine properties (e.g., glazing optical and long-wave infrared transmission).

Table 3.3.8-1 Technology R&D Tasks—Cold-Climate SWH



Collector Tier-1 TIO
Glazing: Evaluate/develop temperature control mechanisms. Evaluate/develop rigid sheet and/or thin-film polymer glazing.
• Absorber: Evaluate/develop fully wetted polymer absorber. Evaluate/develop conductivity-enhanced, tin-tube polymer absorber. Evaluate/develop selective-surface polymer absorber.
• Container/Mounting: Evaluate/develop integrated glazing container. **Evaluate glazing/container structure for wind loading.** **Evaluate/develop direct-mounting and labor-saving mounting techniques.**
Storage Tier-1 TIO
• Evaluate/develop unpressurized tank options. • Evaluate solar-side and load-side heat-exchanger options. • Evaluate/develop polymer heat exchangers.
Balance-of-System Tier-1 TIO
• Evaluate/develop PV-DC pump options. • Evaluate/develop small-diameter piping options.
System Integration Tier-1 TIO
• System Analysis: Develop component/system cost goals/metrics, choose preferred system(s), and optimize designs. • Tools: Develop integrated systems models (performance and costs). • Standards: Develop testing standards and supporting facilities for solar components and systems.

Note: "Evaluate/Develop" tasks in this table typically involve iterative stages of designing, modeling, small-scale prototyping, laboratory-testing, redesigning, large-scale prototyping, outdoor testing, and field monitoring. In the Stage Gate process, competing concepts will be evaluated, compared to the strategic goals and performance targets, and down-selected, as appropriate.

CHC Tasks

The most fundamental dilemma for space heating is that the need/load is highest when the resource/irradiance is lowest. Collectors for combined water heating, space heating, and space cooling will likely be integrated into the roof, which implies high angles of beam incidence, which is a further challenge. In energy-efficient new construction, one can assume that good envelope design minimizes or eliminates the space-heating load on sunny days. This implies that a relatively larger storage volume is needed compared to solar DHW, because the load occurs mostly on cloudy days when only stored energy is available. Space cooling can be done with unglazed collectors rejecting heat at night, or with glazed systems collecting heat to drive thermally driven chillers. The former has potential only in regions that are dry and comparatively mild. The latter has historically been difficult to make cost-effective because the extra equipment (i.e., absorption or desiccant subsystem) is not mass-produced competitively, is expensive, and thermal efficiency is low at temperatures compatible with flat-plate collectors (below ~80°C).

Collector Tier-1 TIO

- To supply the same amount of space heating saving as SWH savings, the glazing devoted to space heating must be larger (i.e., lower incidence, lower ambient temperatures and efficiencies). For an unglazed system, collector areas are roughly twice that required for a glazed system for equivalent savings. These larger-area systems must be fully integrated with the roof design.

Storage Tier-1 TIO

- Storage is usually envisioned as water, but schemes employing the ground beneath the building have appeal, especially for cooling where the ground temperature is a cooling resource. Compared to SWH, space heating requires larger ratios of storage volume per unit collector area, because energy must be stored for a longer time. The optimal storage size range must be established.

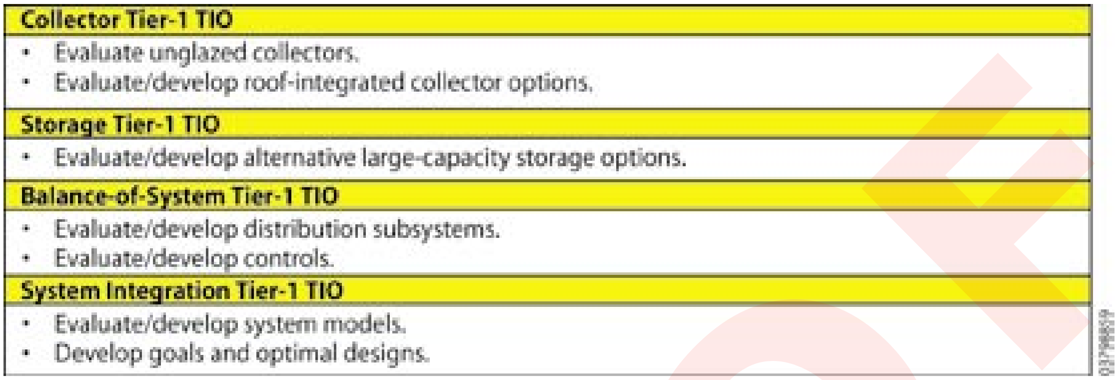
Balance-of-System Tier-1 TIO

- System control is more complex with CHC systems. Flow rates and interaction with efficiencies and stratification must be established. Depending on tank configuration, diverter strategies must be optimized. Research will focus on the collection, control, and distribution subsystems, excluding the thermal conversion machinery. Alternative control algorithms will be tested and optimized by simulation, followed by prototyping and testing. Commercially available absorption and desiccant systems are generally designed to run off natural gas supply, at temperatures higher than practical for flat-plate solar systems. However, absorption chillers designed to operate at temperatures more suitable for low-cost solar-thermal systems are now being developed in Europe and China. Liquid desiccant systems may become available that work well under 80°C.

System Integration Tier-1 TIO

- The modeling capability of system thermal performance is adequate, but models for these systems have yet to be defined, assembled, and verified. Once the performance of various system designs in various climates has been quantified, cost goals can be refined. At this stage, a decision to proceed with an industry request for proposal is made, possibly restricting the eligible system types. As the teams finalize conceptual design and provide cost estimates, potential cost/benefit can be defined for the various options and the most promising designs will be down-selected for engineering development.

Table 3.3.8-2 Technology R&D Tasks—Active Solar CHC



Collector Tier-1 TIO
• Evaluate unglazed collectors. • Evaluate/develop roof-integrated collector options.
Storage Tier-1 TIO
• Evaluate/develop alternative large-capacity storage options.
Balance-of-System Tier-1 TIO
• Evaluate/develop distribution subsystems. • Evaluate/develop controls.
System Integration Tier-1 TIO
• Evaluate/develop system models. • Develop goals and optimal designs.

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Note: "Evaluate/Develop" tasks in this table typically involve iterative stages of designing, modeling, small-scale prototyping, laboratory-testing, redesigning, large-scale prototyping, outdoor testing, and field monitoring. In the Stage Gate process, competing concepts will be evaluated, compared to the strategic goals and performance targets, and down-selected, as appropriate. Tasks are the same as for cold-climate SWH in Table 3.3.6-1, plus the following.

Hybrid Solar Lighting

In FY 2006, HSL project activities will focus on the following areas:

- Improving market understanding (market assessment effort)
- Field-testing and evaluating tracker performance
- Enhancing tracker controls ("smart" controls)
- Improving fiber-optic bundle performance and cost
- Improving total system performance and reducing system cost
- Installing and testing at commercial sites
- Quantifying waste-heat avoidance.

The market assessment will determine the potential size of the market for the HSL system. An important aspect will be to identify key customers and decision makers, such as building owners, retailers, architects, and lighting designers. Key steps in the assessment include the following:

- Literature search to identify market studies on full-spectrum lighting and/or lighting systems that reduce excess heat gain.
- Quantification of interest in the features of HSL, including:
  - Market segments that need full-spectrum lighting
  - Market segments that want to reduce excess heat gain associated with high-intensity, spot, and display applications
  - Competing lighting systems for these applications
  - Marketing and technology delivery channels for new products to these user groups
  - Realistic estimate of potential market penetration
  - Barriers to market penetration.

Also important are efforts to measure HSL system performance, waste-heat avoidance, and customer acceptance. A contract is already in place to install and operate an HSL system at the SMUD headquarters in California. ORNL is also scheduled to install an HSL system in a Wal-Mart store in Kauai, HI, to evaluate energy savings and sales trends associated with HSL daylighting. TVA is also helping fund new R&D of HSL lighting fixtures, or luminaries, that combine electrical lamps and optical fibers. The latest luminaries will be available in early 2006 as part of an HSL display at the American Museum of Science and Energy in Oak Ridge, TN. A partnership with Sunlight Direct, LLC, will allow multiple HSL systems to be installed and their performance evaluated in various environments across the United States in 2006.

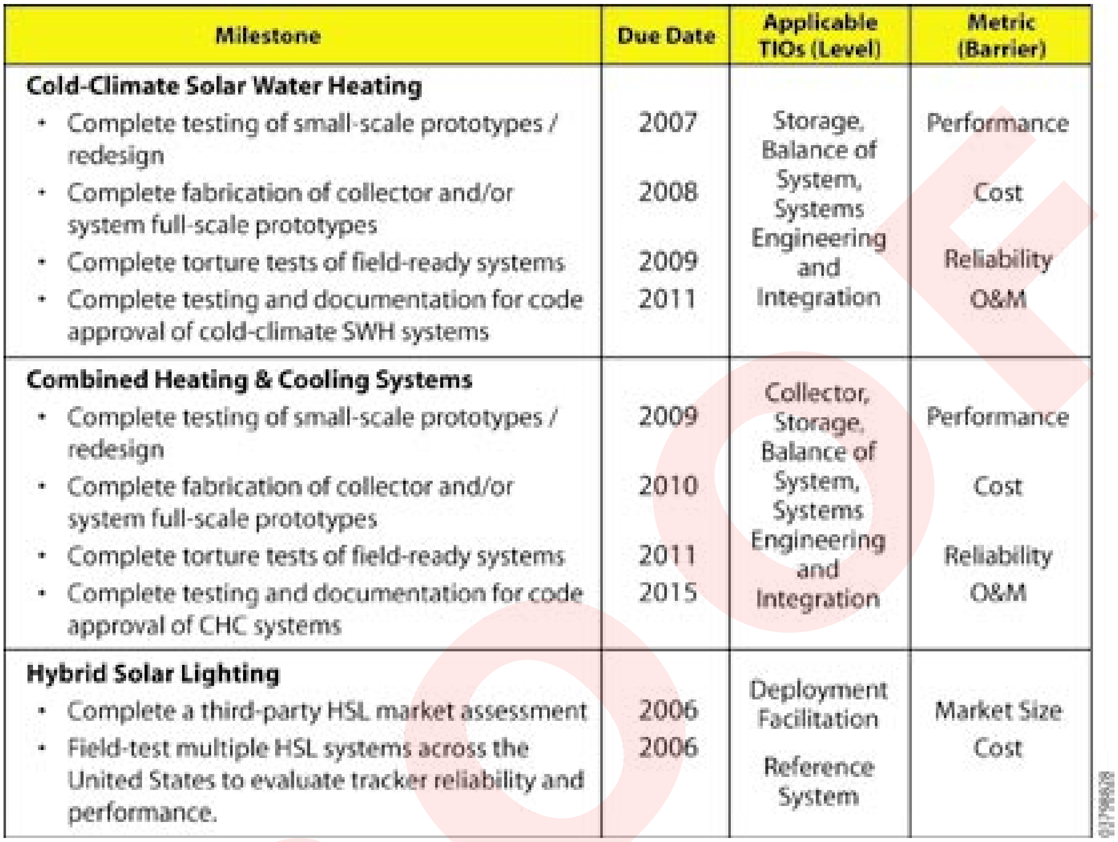
3.3.9 SHL Milestones and Decision Points

SWH and HSL Milestones

Both the cold-climate SWH and CHC research efforts will be conducted using the Stage Gate process. As described in Sec. 3.3.4, the Stage Gate process in the SHL Subprogram consists of four R&D phases:

1. Concept Generation / Exploratory Research—Identify general system configurations that could conceivably reach the project's cost goal. This Phase 1 effort is typically initiated by a competitive solicitation for new concepts and ideas.
2. Concept Development / Prototype Test—Develop detailed designs for promising concepts and construct and evaluate prototypes.
3. Advanced Development / Field Test—Develop second-generation prototypes and conduct limited field testing and evaluation.
4. Engineering / Manufacturing Development—Construct third-generation units and evaluate "near-final" systems in "real-world" applications.

At the end of each phase, progress is evaluated, compared to strategic goals and performance targets, and a go/no-go decision is made regarding moving on to the next phase. Therefore, milestones have been selected to correspond to the evaluation that occurs at the end of each phase. However, these milestones are necessarily general because the concepts to be investigated may be a plumbing component, an electrical component, or an entire system.



Milestone	Due Date	Applicable TIOs (Level)	Metric (Barrier)
Cold-Climate Solar Water Heating • Complete testing of small-scale prototypes / redesign • Complete fabrication of collector and/or system full-scale prototypes • Complete torture tests of field-ready systems • Complete testing and documentation for code approval of cold-climate SWH systems	2007 2008 2009 2011	Storage, Balance of System, Systems Engineering and Integration	Performance Cost Reliability O&M
Combined Heating & Cooling Systems • Complete testing of small-scale prototypes / redesign • Complete fabrication of collector and/or system full-scale prototypes • Complete torture tests of field-ready systems • Complete testing and documentation for code approval of CHC systems	2009 2010 2011 2015	Collector, Storage, Balance of System, Systems Engineering and Integration	Performance Cost Reliability O&M
Hybrid Solar Lighting • Complete a third-party HSL market assessment • Field-test multiple HSL systems across the United States to evaluate tracker reliability and performance.	2006 2006	Deployment Facilitation Reference System	Market Size Cost

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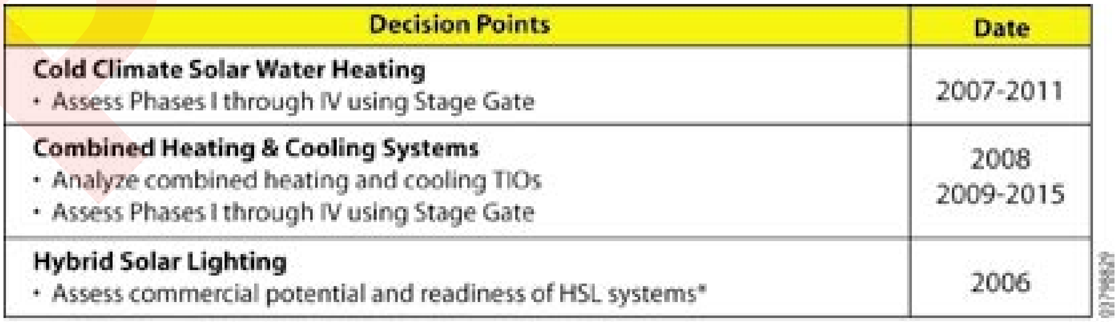
SWH and HSL Decision Points

In the Stage Gate process, competing concepts will be evaluated at the end of each phase (e.g., Prototype Development), compared to strategic goals and performance targets, and a go/no-go decision made regarding moving on to the next phase (e.g., Field Testing). Therefore, decision points occur at the end of each phase in both the cold-climate SWH and CHC research efforts.



Decision Points	Date
Cold Climate Solar Water Heating • Assess Phases I through IV using Stage Gate	2007-2011
Combined Heating & Cooling Systems • Analyze combined heating and cooling TIOs • Assess Phases I through IV using Stage Gate	2008 2009-2015
Hybrid Solar Lighting • Assess commercial potential and readiness of HSL systems*	2006

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*Depending on the outcome of this assessment, additional research activities may be planned for FY 2007 and beyond.

4.0 Program Administration

The Solar Energy Technologies Program is a dynamic R&D program. Engineers and researchers are constantly coming up with new concepts and overcoming technical barriers. Often, multiple paths can be taken to achieve an objective, and planning is a primary imperative. But also essential is the ability to respond to changing situations and redirect activities based on new information. Managing the Solar Program requires organization, continuous evaluation of technical activities, and stewardship of the budget. Additionally, it requires close coordination between the technical experts and the DOE managers.

The Solar Program has created a management structure that blends program administration with scientific oversight. Program administration is done by a relatively small DOE staff that focuses on implementing Administration policy. NREL and Sandia provide scientific oversight of the nearly 500 solar R&D tasks being performed by universities, industry, and national laboratories. Laboratory management of the tasks enables detailed technical evaluations to become a part of each programmatic decision made by DOE.

4.1 Organizational Structure

To achieve its goals quickly and effectively, the Solar Program established three subprogram elements, each with its own management team (see Fig. 4.1-1). Two of the teams manage R&D subprograms and one team manages those tasks that impact all parts of the Solar Program. One of the R&D teams manages the Photovoltaic Subprogram and the other manages the Solar Thermal Subprogram. The third is the Systems Integration and Coordination (SINC) team. To ensure that the teams are coordinated, the Solar Program holds weekly staff meetings and team leader meetings. In addition, each member of the SINC team is also a member of one of the R&D teams.

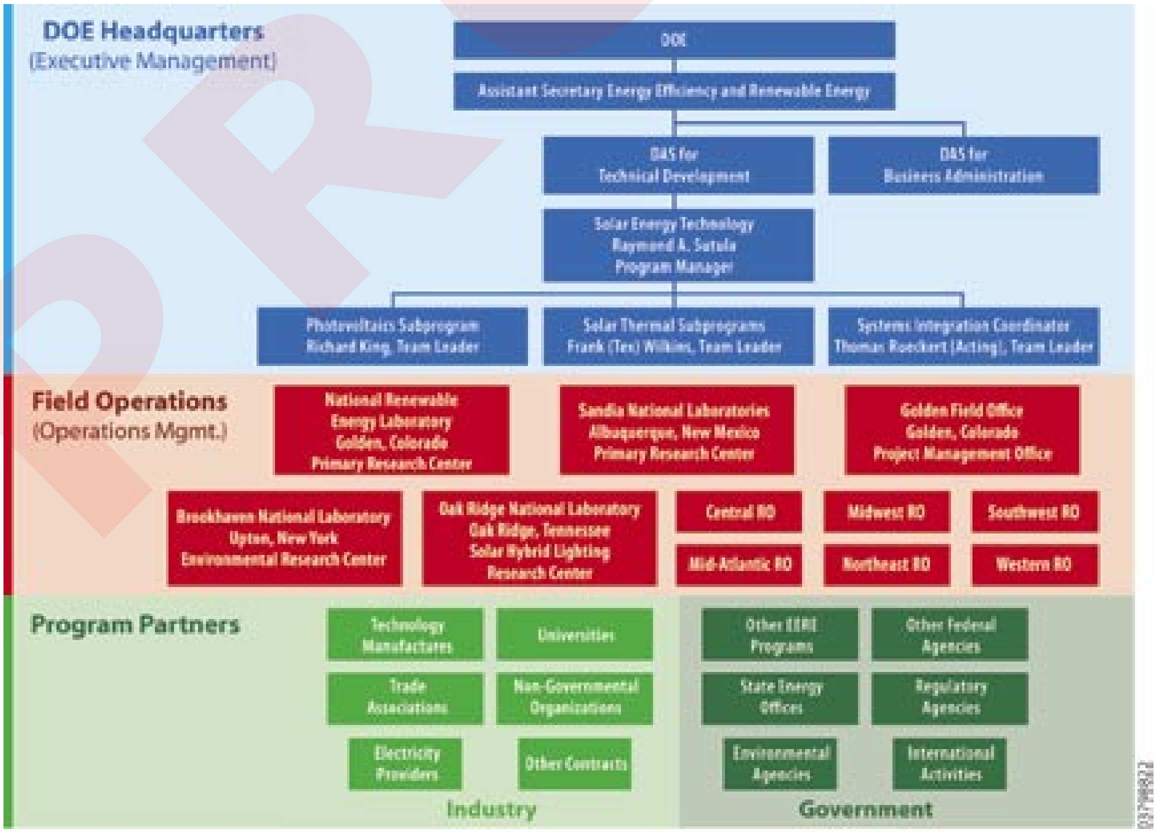

Fig. 4.1-1 Organization of the Solar Energy Technologies Program.

The R&D teams have two primary responsibilities:

- Technology management—This responsibility includes setting strategic paths for technology within the subprogram, establishing and implementing projects, and keeping track of technical progress.
- Budget management—This responsibility includes prioritizing activities, distributing the budget among activities, and monitoring how the funds are spent.

The Systems Integration and Coordination team has several responsibilities:

- Executing the budget
- Implementing the systems-driven approach
- Developing and implementing communication projects
- Coordinating international activities.

4.1.1 R&D Teams

Photovoltaic R&D Team

Photovoltaics R&D is the largest portion of the Solar Program. In FY 2005, activities within this team comprised nearly 90% of the Solar Program's budget. The PV team is responsible for managing a comprehensive PV Subprogram that includes three activities: Fundamental Research, Advanced Materials and Devices, and Technology Development. This subprogram encompasses 20 projects distributed among three national laboratories, 60 universities, and 40 solar companies. Each of these projects is structured to support a PV technical improvement opportunity.

Solar Thermal R&D Team

Solar Thermal R&D includes two activities: Concentrating Solar Power and Solar Heating and Lighting. This R&D effort includes 12 projects distributed among three national laboratories, 2 universities, and about 20 solar companies. Each of these projects is structured to support either a CSP or SHL technical improvement opportunity.

4.1.2 Systems Integration and Coordination Team

The SINC team is responsible for crosscutting activities within the Solar Program. The chief activities include the following:

- Budget execution—The team coordinates budget tasks with the R&D teams and the Office of Energy Efficiency and Renewable Energy's (EERE's) Office of Planning, Budget Formulation and Analysis. It serves as the primary author for the funding documents that transfer money to the Golden Field Office, National Energy Technology Laboratory, and the national laboratories. It also ensures that the funds are allocated to the proper project and included in the DOE financial plan that tracks the expenditure of the Solar Program's funds. The team provides weekly financial updates to the R&D teams.
- Systems-driven approach—This process uses knowledge of energy markets to set technical goals and a detailed analysis of the technology's key components to make decisions on priorities and budget distribution. Section 2.2 provides a detailed description of SDA. It is the team's responsibility to implement this process throughout the Solar Program.
- Communications and outreach—The team implements activities that promote solar energy to new and potential customers. It works with EERE's Office of Communications and Outreach to develop an annual communication plan for the Solar Program. It also works with EERE's Office of Information and Business Management Systems to develop and implement the Corporate Planning System (CPS). CPS is a database that includes information describing all the projects within EERE and is an increasingly important management tool. The SINC team has implemented a process by which the national laboratories input technical data. It is a SINC Team responsibility to ensure that CPS is kept up to date.

- International activities—The Solar Program participates in International Energy Agency Implementing Agreements that support PV and CSP. It also supports several multilateral and bilateral agreements. The team coordinates all foreign travel, participates in international meetings, coordinates international tasks performed by the national laboratories, and is responsible for planning annual and multi-year international activities.

4.2 Program Funding Mechanism

4.2.1 Technology Administration

The first step in effectively administering an R&D program is to determine the goals for the technology. Following the principles of SDA, the Solar Program's goals are determined by the energy market in which the technology must compete. PV, for example, must compete with the retail cost of electricity paid by homeowners. In 2005, this retail rate ranged from 5.8 to 16.7 ¢/kWh. CSP, on the other hand, must compete with the cost of intermediate power paid by utilities. In 2005, this cost ranged from 5.6 to 7.6¢/kWh. Because solar energy is trying to break into existing markets, the Solar Program's technology goals tend to be on the lower side of the competition's cost. Achieving the goals will provide incentive for customers to switch to solar energy.

The R&D teams establish projects designed to advance solar technology to its goal. Each project is established to reduce cost, improve performance, increase reliability, or lower the system O&M cost. Module reliability, trough R&D, and low-cost polymers are examples of projects. A project consists of one or more agreements that could include contracts with universities and industry, as well as laboratory research. The laboratories establish milestones and periodic decision points for each project, agreement, and contract. The decision points, also called stage-gates, determine whether the project should be continued, redirected, or terminated. The teams determine the budget for the projects and the laboratories are given the responsibility for managing them. Laboratory management of the projects is an important part of the Solar Program's management strategy.

Laboratory management of the projects provides a number of benefits. Most of the laboratory managers were once researchers and understand the intricacies of the technology and of the R&D process. This prior experience is valuable because it provides them a basis to assess the practicality of a new concept, the length of time it will take to accomplish the task, how much it would cost, and if the researchers proposing the concept have the necessary expertise. They also have the analytical tools to assess the potential impact of the proposed task toward lowering the cost of the system.

This information is essential to the R&D team, which is focused on programmatic issues such as implementing DOE policy, planning, and developing budgets. Members of the team must understand the technical implications of the project and then weigh its potential benefits against the benefits of all the other projects that need to be funded.

One of the primary methods the teams use to track the progress of projects and agreements is EERE's Corporate Planning System. CPS is a database that includes information about each of the Solar Program's projects, agreements, and contracts, and it is updated monthly by the laboratory responsible for the project. CPS is a central repository of information that enables the teams and EERE management to track project accomplishments, milestones, and spending. Other methods used by teams to track their projects include communicating with project researchers, attending technical meetings, and giving project reviews.

The Solar Program has developed several mechanisms to monitor the progress of ongoing projects—weekly highlights from the laboratories, monthly video conference meetings with laboratory staff, semiannual program reviews, and a biannual peer review.

The purpose of R&D is to explore new concepts. Inherent in this exploration is the risk that projects will fail to meet their objectives. The R&D teams manage risk by establishing, when possible, multiple pathways aimed at achieving technical goals. Projects that present significant technical barriers or are particularly important to accomplishing the system goal are likely to have more agreements and contracts than other projects. EERE is exploring a variety of ways to manage risk, and more sophisticated risk analysis will likely be incorporated into the Solar Program during the time covered by this multi-year plan.

4.2.2 Program Coordination

Most of the Solar Program's activities are done using the exceptional and unique capabilities of DOE's multi-purpose national laboratories. The Solar Program has established two primary research centers: the National Renewable Energy Laboratory and Sandia National Laboratories. Oak Ridge National Laboratory (ORNL) and Brookhaven National Laboratory (BNL) also contribute their expertise to solar projects. The DOE Golden Field Office and the National Energy Technology Laboratory help DOE headquarters administer and manage projects not assigned to the laboratories.

4.2.3 Facilities and Capital Equipment

The DOE national laboratories are government-owned, contractor-operated facilities that rely on government funding for buildings and equipment. The Solar Program uses two existing research facilities at NREL to conduct world-class solar R&D: the Solar Energy Research Facility and the Outdoor Test Facility. A third facility, the Science and Technology Facility, is currently under construction and is expected to open in the summer of 2006. In addition, the National Solar Thermal Test Facility for testing CSP technologies is located at Sandia. These facilities are continually outfitted with the most advanced equipment to conduct research in materials science, electrochemistry, thermal science, and other disciplines.

4.3 Funding Mechanisms

Each year, the Solar Program develops an annual operating plan (AOP). The AOP is the agreement between the Solar Program, Golden Field Office, National Energy Technology Laboratory, and the national laboratories on how the money will be spent and what will be accomplished with it. The AOP is developed during the summer and finalized shortly after Congress appropriates a budget for the Solar Program.

Projects and their supporting agreements and contracts are established in adherence to the Solar Program's strategy for maintaining a balanced portfolio among industry, universities, and the laboratories. The objective is to combine the best researchers in the country with industrial partners that have the capability of commercializing the technology. The Solar Program has a guideline that at least 50% of its funds should go to industry and universities. The remainder goes to the national laboratories, principally NREL and Sandia, which, over the years, have established staffs that are recognized as world leaders in solar R&D. The two laboratories have also developed unique solar testing facilities. The 50/50 balance enables scientific breakthroughs and improvements to be transferred quickly from the laboratory to the manufacturing plant. Establishing partnerships with industry is important in several ways: it provides a partner who can make and sell the solar product, it creates a partner who can share in the cost of the task, and it often enables the task to be completed sooner than otherwise possible. Industry thus provides the final link in the R&D process and enables the Solar Program to leverage its resources through cost sharing.

The Solar Program follows DOE guidelines on cost sharing. If the project assists industry in the engineering development of a product, then 50% or greater cost sharing by industry is required. But if the project is research oriented, then cost sharing may be as little as 10%. The laboratory or Field Office has the responsibility of ensuring that the contract provides cost sharing.

R&D projects are funded through the national laboratories. As mentioned previously, about half of the R&D money sent to the laboratories is subsequently provided to industry or universities through subcontracts. Programmatic activities such as outreach, communications, and conferences are funded, in part, by the Golden Field Office or the National Energy Technology Laboratory through cooperative grants or contracts. The Solar Program also provides funding to programs established by DOE that sometimes support projects other than solar energy. These programs include the Small Business Innovative Research (SBIR) program, Historically Black Colleges and Universities (HBCU) program, and State Energy Program (SEP). In some cases—for example, SBIR and SEP—the projects are managed by other DOE offices with interaction by the Solar Program.

The Solar Program has established a policy that, except for unusual situations, all projects must be selected through a competitive process. This process often involves the release of a Request for Proposals, followed by the evaluation and selection of the best responders. All technical contracts are set up through the national laboratories. Exceptions to the competition directive must be agreed to by the Solar Program. Sole sourcing is sometimes justified, and in those instances, a formal EERE process is followed called the Determination of Noncompetitive Financial Assistance (DNFA).

4.4 Cost Management and Monitoring

Developing the budget begins with discussions with the national laboratories, universities, and industry to understand what resources are required to achieve the technical objectives of the projects. The team leader is responsible to obtain agreement within the team for the priorities and budget distribution to the projects. The team leaders then work with the Program Manager to develop a priority list and budget distribution that encompasses the entire Solar Program. Once a budget has been appropriated, the team works with the laboratories to finalize the budget distribution. The result is the AOP, which is the basis on which funds are spent.

During the year, the Solar Program keeps track of how the money is spent, the rate at which it is spent, and if it is consistent with the AOP. This is done through information obtained from the laboratories and from DOE's Standardized Tracking and Reporting System (STARS). STARS provides information at a relatively high level—for example, the amount of money sent to and spent by NREL for PV each month. The laboratories, on the other hand, provide data for all levels of the Solar Program—projects, agreements, and contracts—and much of this information is included in the CPS system. If, during the year, unanticipated problems arise, the laboratories can move funds from one project to another if they obtain Solar Program agreement. However, this shifting is usually done only for strong technical reasons.

In addition, EERE has strict guidelines limiting the amount of money a program can carry over from one year to the next. Thus, the R&D teams receive monthly updates on the rate at which its funds have been expended and the projected amount of money that will not be spent by the end of the fiscal year. To manage the amount spent each year, the teams plan solicitations far enough in advance so that new contracts can begin early in the fiscal year.

4.5 Environmental Safety and Health

EERE is committed to successfully integrating environment, safety, and health (ES&H) into its activities and objectives. In its Safety Management System Policy, the Department adopted an approach that requires the integration of ES&H into planning, execution, and measurement of all work performed at its sites and facilities. The EERE ES&H staff advises the Solar Program on ES&H policy; performance and resources; adherence to statutory, regulatory, and DOE requirements; the National Environmental Policy Act (NEPA); occupational safety and health; and emergency management activities. The EERE ES&H staff also monitors EERE Headquarters and Field ES&H performance to apprise the Solar Program of organizational performance.

The Solar Program is responsible for ES&H of its workplace and workers, as well as for ensuring that ES&H is fully considered and implemented in program planning, R&D, budgeting, and contracting. The Solar Program, when executing projects and acquiring items over which EERE has acquisition/procurement responsibility, addresses ES&H commensurate with the severity of the associated hazards and the potential for injury or illness, loss or damage, or environmental mishaps to private or government resources, consistent with mission requirements and economical considerations. The scope, complexity, and level of documentation of each ES&H effort are tailored to the size, mission, hazards, and complexity of each project. The approval of specific requirements to be included in contracts is delegated to an EERE Contracting Officer, and the Solar Program reviews the requirements prior to their approval and implementation.

A number of environmental benefits are associated with solar energy. Because developing an environmentally friendly energy supply is an important aspect of the National Energy Plan, the Solar Program makes every effort—through research and a rigorous industry outreach program—to minimize the environmental impacts of solar technologies, and to address issues of manufacture, installation, and disposal. These activities also include working with the staff and management of DOE's national laboratories to ensure that workplace safety is maintained at all times.

4.6 Communications and Outreach

Information dissemination, communications, and outreach activities in EERE are done by the Office of Communications and Outreach (OCO). OCO manages the EERE public Web site, in which the Solar Program's Web site is located, and EERE's centralized public information clearinghouse, where it distributes solar information, among other things.

OCO coordinates outreach and information activities with the Solar Program, integrating communications efforts from all the EERE programs to provide a united approach to audiences. Thus, consumers will learn about all EERE technologies that may apply to them, rather than simply receiving information on only one aspect of energy efficiency or renewable energy. Such coordinated efforts are designed for several purposes: to target opportunities where rising prices or tight energy supplies may spur the acceptance for new technologies; remove barriers to technology acceptance and implementation; and provide accurate information regarding EERE technologies.

Promoting and communicating benefits and results are key elements of effective partnering. At the most basic level, technology cannot be transferred from DOE-sponsored research without communication—in scientific journals, technical conferences, workshops, and meetings. The public, as well as decision-makers in business and government, needs reliable, understandable information on the benefits, costs, and potential of solar energy to support research, place a value on solar energy's benefits, and understand solar energy's role in the national energy policy.

Each year, the Solar Program works with OCO to develop an integrated communications and outreach plan that puts all of the Solar Program's communication activities in the context of desired audience and priority. OCO provides recommendations of new approaches to reach energy consumers and ways to communicate successes, results, and status of all R&D projects and initiatives. The Solar Program teams determine the primary audiences for the coming year and the amount of funding to allocate for communications and outreach activities.

Developing the communications plan is an integral part of the Solar Program's budget planning. Potential audiences include builders, general public, utilities, state governments, federal agencies, and educators. In FY 2005, for example, the primary audiences selected for communications projects were builders and the general public. These were selected to develop materials supporting the Solar Decathlon, which was a major Solar Program event held in early FY 2006.

The purpose of the solar communications and outreach plan includes the following:

- Describes to all relevant stakeholders the major activities in the Solar Program's communications effort over the next year.
- Promotes the development and distribution of training and education materials about solar energy and allocates sufficient funding and other resources.
- Focuses on materials such as descriptive brochures, fact sheets, and briefing materials. Although these materials are still printed, more emphasis is being given to their availability for downloading from the Solar Program Web site.
- Highlights updates of the Solar Program Web site, and the coordination of events and trade-show exhibits.

5.0 Abbreviations and Acronyms

AC	alternating current
ADVISOR	Advanced Vehicle Simulator
AOP	annual operating plan
AR	antireflective
a-Si	amorphous silicon
a-Si:H	hydrogenated amorphous silicon
ASTM	American Society for Testing and Materials
BES	DOE Office of Basic Energy Sciences
BIPV	building-integrated photovoltaics
BNL	Brookhaven National Laboratory
BOP	balance of plant
BOS	balance of systems
BSF	back-surface field
BT	Building Technologies Program
Btu	British thermal unit
c-Si	crystalline silicon
CC&R	codes, covenants, and restrictions
CCGT	combined-cycle gas turbine
CdTe	cadmium telluride
CEC	California Energy Commission
CHC	combined heating and cooling
CHP	combined heat and power
CIGS	copper indium gallium diselenide
CIS	copper indium diselenide
COE	cost of energy
COSE	cost of saved energy
CPS	Corporate Planning System
CPV	concentrator photovoltaics
CRADA	cooperative research and development agreement
CSP	concentrating solar power
CY	calendar year
DAS	Deputy Assistant Secretary
DC	direct current
DER	distributed energy resource
DHW	domestic hot water
DNFA	Determination of Noncompetitive Financial Assistance
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
EERE	DOE Office of Energy Efficiency and Renewable Energy
EFG	edge-defined, film-feed growth

EIA	Energy Information Administration
EPA	Environmental Protection Agency
EPAct	Energy Policy Act of 2005
EPRI	Electric Power Research Institute
ES&H	environment, safety, and health
FEMA	Federal Emergency Management Agency
FEMP	Federal Energy Management Program
FSEC	Florida Solar Energy Center
FY	fiscal year
GaInNAs	gallium indium nitrogen arsenide
GEF	Global Environment Facility
GFDI	ground-fault detection/interruption
GMI	Global Marketing Initiative
GO	Golden Field Office
GPRA	Government Performance Results Act
GW	gigawatt
GWp	peak gigawatt
HALT	highly accelerated lifetime testing
HBCU	Historically Black Colleges and Universities
HCE	heat-collection element
HFSF	High-Flux Solar Furnace
HIT	heterojunction with intrinsic thin layer
HSL	hybrid solar lighting
HTF	heat-transfer fluid
IAPG	Interagency Advanced Power Group
IBRD	International Bank for Reconstruction and Development
IDA	International Development Association
ICC-ES	International Code Council Evaluation Service
ICS	integral collector storage
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IPP	independent power producer
IR	infrared
ISO	International Organization for Standardization
kW	kilowatt
kg	kilogram
kWe	kilowatt electric
kWh	kilowatt-hour
kWht	kilowatt-hour thermal
LCOE	levelized cost of energy
LEC	levelized energy cost

LED	light-emitting diode
m^2	square meter
MACRS	Modified Accelerated Cost Recovery System
MBE	molecular-beam epitaxy
MMBtu	million Btu
MOS	measure of success
MPPT	maximum power-point tracking
MSR	Million Solar Roofs
MTBF	mean time between failure
MTBI	mean time between incident
MYPP	Multi-Year Program Plan
MYTP	Multi-Year Technical Plan
MW	megawatt
MWe	megawatt-electric
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NCPV	National Center for Photovoltaics
NEC	National Electrical Code
NEMS	National Energy Modeling System
NEPA	National Environmental Policy Act
NFPA	National Fire Protection Association
NRC	National Research Council
NREL	National Renewable Energy Laboratory
NSTTF	National Solar Thermal Test Facility
NTRC	National Transportation Research Center
O&M	operations and maintenance
OCO	Office of Communications and Outreach
OLED	organic light-emitting diode
OMB	Office of Management and Budget
ORC	organic Rankine cycle
ORNL	Oak Ridge National Laboratory
PCU	power control unit
PDIL	Process Development and Integration Laboratory
PE	program element
PICS	polymer integral collector storage
PPAF	Program Performance and Accountability Framework
PPMA	polymethyl-methacrylate
PURPA	Public Utility Regulatory Policies Act
PV:BONUS	Photovoltaics Building Opportunities in the United States
PV	photovoltaics
PVRES	PV energy-efficient residential building
PVUSA	PV for Utility-Scale Applications

PWF	present worth factor
QD	quantum dot
R&D	research and development
REC	renewable energy credit
RET	renewable energy technology
RFP	request for proposal
RITH	roof-integrated thermosiphon
RO	Regional Office
RPS	renewable portfolio standard
S&L	Sargent & Lundy
S&TF	Science and Technology Facility
SAM	Solar Advisor Model
SBIR	Small Business Innovative Research
SBP	Schlaich, Bergermann and Partner
SCADA	supervisory control and data acquisition
SCE	Southern California Edison
SDA	systems-driven approach
SDHW	solar domestic hot water
SEGS	Solar Electric Generating Systems
SEP	State Energy Program
SERES	Southeast Region Experiment Station
SERI	Solar Energy Research Facility
SES	Stirling Energy Systems
SET	Solar Energy Technologies
SETP	Solar Energy Technologies Program
SHL	solar heating and lighting
Si	silicon
SINC	Systems Integration and Coordination (Team)
SMS	Strategic Management System
SMUD	Sacramento Municipal Utility District
SNL	Sandia National Laboratories
SolarPACES	Solar Power and Chemical Energy Systems
SRCC	Solar Rating and Certification Corporation
STARS	Standardized Tracking and Reporting System
STTR	Small Business Technology Transfer Research
SWH	solar water heating
SWRES	Southwest Region Experiment Station
SWTDI	Southwest Technology Development Institute
TBD	to be determined
TCO	transparent conducting oxide
TES	thermal energy storage
TIO	technology improvement opportunity

TMY	typical meteorological year
TVA	Tennessee Valley Authority
UL	Underwriters Laboratories
USH2O	Utility Solar Water Heating Initiative
UNDP	United Nations Development Programme
UV	ultraviolet
USAID	U.S. Agency for International Development
W	watt
Wp	peak watt
WGA	Western Governors' Association
ZEB	Zero Energy Buildings
ZEH	zero energy home