Mobilizing the nation's
resources to develop
reliable and affordable
solar energy technologies

Solar Energy Technologies Program

Multi-Year Technical Plan 2003-2007 and beyond

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean,
abundant, reliable, and affordable

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Foreword

Welcome to the first integrated Solar Energy Technologies Multi-Year Technical Plan of the U.S. Department of Energy. This document describes the rationale, approaches, and results we expect to achieve in this national effort to make solar energy a greater part of our nation's energy landscape.

The DOE Solar Energy Technologies Program is being managed according to the principles outlined in the *President's Management Agenda* that emphasize results-driven rather than process-oriented government management. A key aspect of this is establishing measurable program metrics to be used as benchmarks to evaluate progress. Leaders of the Office of Energy Efficiency and Renewable Energy recognized the need to change the way the office did business and implemented a new structure in July 2002. This new structure created a streamlined, integrated, and focused alignment that emphasizes strong program management for better performance. This Multi-Year Technical Plan reflects an implementation of those refined business practices.

This document includes our anticipated technical plans for the next 5 years for photovoltaics, concentrating solar power, solar heating, solar hybrid lighting, and other new concepts that can take advantage of the ubiquity of the solar resource. For the first time, we will be using a systems-driven approach to address strategic questions and make programmatic decisions. This approach is based on a rigorous analytical foundation that addresses questions of market opportunities, energy systems, individual system components, and external economic and policy factors. We believe that this effort can help balance our portfolio while continuing to measure our progress toward our quantitative objectives.

Our programmatic activities are dynamic and are continually re-evaluated based on energy market issues, Administration priorities, Federal legislation and directives, state policy implications, and technology progress. To this end, this document will be revised on a regular basis.

Thank you for your interest in the U.S Department of Energy's Solar Energy Technologies Program. We look forward to working together toward a brighter solar future!

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Energy Efficiency and Renewable Energy

Executive Summary

The sun's energy is the primary source for most energy forms found on the earth. Solar energy is clean, abundant, and renewable. Solar energy holds tremendous potential to benefit our nation by diversifying our energy supply, reducing our dependence on imported fuels, improving the quality of the air we breathe, and stimulating our economy by creating jobs in the manufacture and installation of solar energy systems.

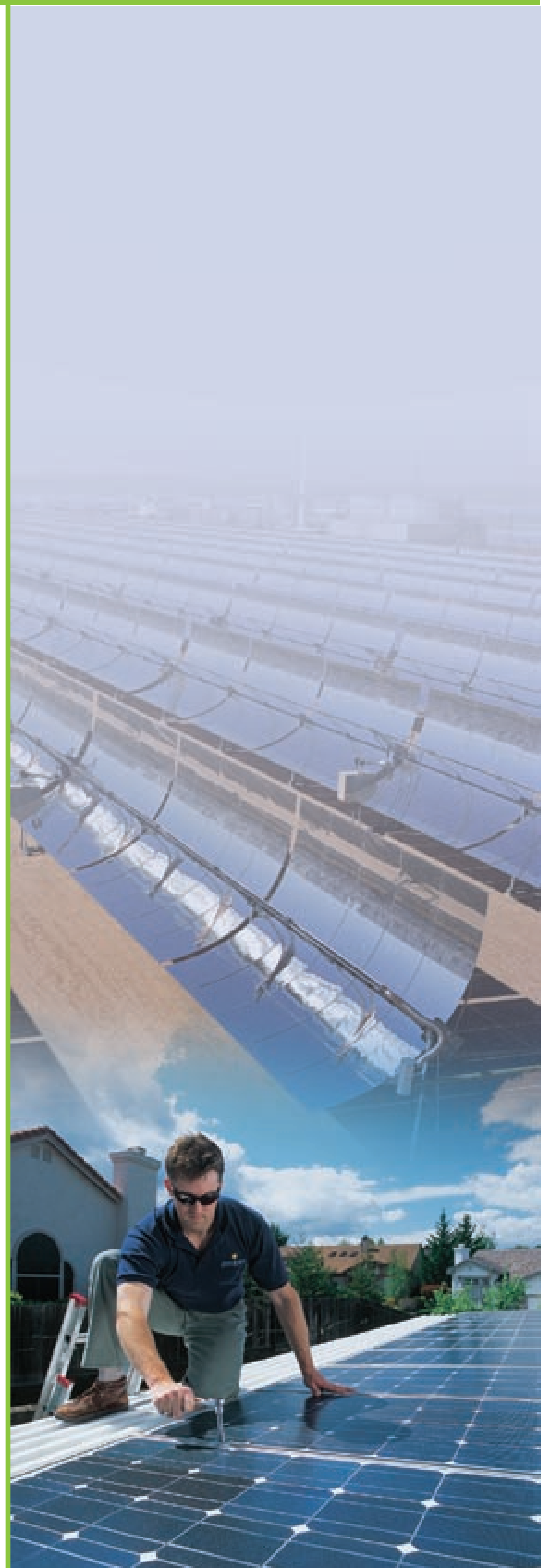
Although solar energy is clean and abundant, it is diffuse and must be captured, concentrated, stored, and/or converted to be used in the highest-value energy forms. The solar energy industry has grown steadily in just two decades and currently markets more than $2 billion annually in products. The U.S. Department of Energy's challenge is to lead the effort to research, develop, and deploy cost-effective technology to achieve its mission of expanded solar energy deployment.

This document represents the first attempt by the Department of Energy (DOE) to produce an integrated Multi-Year Technical Plan for solar energy—that is, a plan that considers all solar energy technologies in one program. The document was prepared using the policies established by the President's *National Energy Policy* (May 2001) and is implemented according to guidelines in the President's Management Agenda, which emphasize results-driven, rather than process-oriented, government management.

This first integrated solar plan includes research, development, deployment, analytical efforts, and partnerships aimed at producing photovoltaic, concentrating solar power, solar heating, and solar lighting systems that are cost effective. These solar systems have the potential to achieve penetration in markets that include residential solar water/space heating, distributed (electric) energy, process heating, cooling and refrigeration, daylighting, portable power, and village (non-grid-connected) power, and larger solar power plants.

The DOE Solar Energy Technologies Program has implemented a systems-driven approach that incorporates a rigorous analytical framework to define and evaluate efforts in technology development. In essence, all technical targets in the Solar Program's research and development are derived from a common market perspective and national energy goals, and the resultant technologies are tested and validated in the context of established criteria for each market. Thus, each technology is aimed at specific market applications and evaluated vis-à-vis all competitive options in the context of their market potential.

At the heart of this document are detailed technical plans—presented in Chapter 4.0—for four solar energy areas: Photovoltaics, Concentrating Solar Power, Solar Heating and Lighting, and New Concepts. Each technical section includes a technology status overview, programmatic goals and objectives, description of key technical challenges, detailed technical targets (often for each component of the identified solar energy system), detailed technical



barriers, a roster of activities that address the target barriers, and a summary chart that highlights key programmatic milestones and decisions anticipated over the next 5 years.

The Solar Program is managed and directed for results by professionals at DOE and its multi-program national laboratories, including the National Renewable Energy Laboratory, Sandia National Laboratories, Oak Ridge National Laboratory, and Brookhaven National Laboratory. Two results-oriented subprogram teams manage R&D programs for photovoltaics and solar thermal. A third team is charged with integrating and coordinating activities to manage crosscutting and analytical efforts. DOE carries out critical management functions through its Golden Field Office, and out-reach and communication functions are carried out via six regional offices in Atlanta, Boston, Chicago, Denver, Philadelphia, and Seattle.

This Multi-Year Technical Plan for the Solar Energy Technologies Program is a snapshot in time—a product that demonstrates the current thinking of the Solar Program management team. The Plan is constantly in flux as market forces, national policies, and technology advances combine to influence research direction. To that end, DOE encourages interested members of the solar energy community to submit comments about this document.

Table of Contents

Executive Summary i

1.0 Solar Energy: A National Perspective 1
1.1 Solar Energy Technologies: Goals, Objectives, and Strategies 2
1.2 Federal Role 5
1.3 Integrated Solar Program 7

2.0 Solar Energy Industry, Markets, and Applications 9
2.1 National Needs and Benefits 9
2.2 Existing Solar Industry 11
2.3 Existing and Future Markets: Potential for Solar 14
2.3.1 Central Generation 15
2.3.2 Distributed Energy Resources 17
2.3.2.1 Building-Integrated Systems 17
2.3.2.2 Ground-Mounted Distributed-Energy Systems 20
2.3.2.3 Off-Grid Solar-Electric Applications 21
2.4 Solar-Systems Descriptions and Requirements 23
2.4.1 Photovoltaics 23
2.4.2 Concentrating Solar Power Systems 25
2.4.3 Solar-Thermal Systems 27
2.4.4 Hybrid Lighting 29

3.0 Implementing a Systems-Driven Approach 31
3.1 Systems-Driven Approach Status 32
3.2 Goal and Objectives 33
3.3 Key Technical Challenges and Barriers 34
3.4 Approach and Tasks 35
3.4.1 Systems Model Development 35
3.4.2 Technical Target Development and Impact Estimates for Solar Systems 35
3.4.3 Benchmarking, Validation, and Analysis Updates 35
3.5 Schedule and Milestones 37

4.0 Introduction to Technical Sections 41
4.1 Photovoltaic Systems 43
4.1.1 Flat-Plate Photovoltaic Systems 43
4.1.1.1 Technology Systems Status 44
4.1.1.2 Technology and Component Goals and Objectives 47
4.1.1.3 Key Technical Challenges 50
4.1.1.4 Technology Approach and Tasks 54
4.1.1.5 Schedule and Milestones 62
4.1.2 Concentrator Photovoltaic Systems 67
4.1.2.1 Technology Systems Status 67
4.1.2.2 Technology and Component Goals and Objectives 70
4.1.2.3 Key Technical Challenges 72
4.1.2.4 Technology Approach and Tasks 74
4.1.2.5 Schedule and Milestones 75
4.2 Concentrating Solar Power Systems 78

4.2.1 Technology Systems Status 78
4.2.2 Technology and Component Goals and Objectives 80
4.2.3 Key Technical Challenges 82
4.2.4 Technical Barriers 84
4.2.5 Approach and Tasks 85
4.2.5.1 Trough Technology Approach and Tasks 85
4.2.5.2 Tower Technology Approach and Tasks 88
4.2.5.3 Dish Technology Approach and Tasks 91
4.2.6 Schedule and Milestones 93
4.3 Solar Heating and Lighting 99
4.3.1 Technology Systems and Status 101
4.3.2 Technology and Component Goals and Objectives 103
4.3.3 Key Technical Challenges 103
4.3.4 Technical Barriers 106
4.3.4.1 Passive Solar Water Heating 106
4.3.4.2 Active Cold-Climate Solar Water Heating and Solar Heating and Cooling 107
4.3.4.3 Active Solar Combined Heating and Cooling 107
4.3.4.4 Hybrid Solar Lighting 108
4.3.5 Technical Approach and Tasks 108
4.3.6 Schedule and Milestones 114
4.4 New Concepts 118
4.4.1 The Solar Technology Incubator 118
4.4.2 New Technologies and Concepts 119
4.4.2.1 Beyond the Horizon and Future Generation Photovoltaics 119
4.4.2.2 Advanced Building-Integrated Concepts 127
4.4.2.3 Other Advanced Solar Conversion 130
4.4.3 Schedule and Milestones 136

5.0 Managing the Solar Energy Technologies Program 139
5.1 Program R&D Portfolio 140
5.1.1 Photovoltaics and Solar Thermal R&D 140
5.1.2 Systems Integration and Coordination 141
5.2 Analytical Activities 141
5.2.1 Decision-Making Using Systems-Driven Analysis 141
5.2.2 Resource Assessment 142
5.2.3 Environmental Safety and Health 142
5.3 Communications and Outreach 143
5.4 Program Coordination 144
5.4.1 Facilities and Capital Equipment 144
5.4.2 DOE Energy Efficiency and Renewable Energy Programs 144
5.4.3 Other Federal Programs 145
5.4.4 State Programs 146
5.4.5 Industry Trade and Professional Associations 147
5.4.6 International and Intergovernmental Programs 147
5.5 Program Organization Control and Implementation 148
5.5.1 Program Planning 149
5.5.2 Program Budget Formulation 149
5.5.3 Program Implementation 149
5.5.4 Program Evaluation 150
5.5.5 Schedule and Milestones 151

6.0 Abbreviations and Acronyms 153

List of Figures

Figure 1-1. The goals of the Solar Program align with the National Energy Policy goals 2

Figure 1.2. With improved technology, the cost of solar energy in the United States has steadily declined 3

Figure 1-3. The Solar Program's support spans partners from industry, universities, and national laboratories across the U.S. ... 5

Figure 1-4. The Solar Program's research performers and their share of total funding 6

Figure 1-5. The framework for the systems-driven approach 7

Figure 2-1. Increase in the world market for PV cells and PV modules as reported by the National Renewable Energy Laboratory 12

Figure 2-2. Example of the benefit of a solar plant that can generate 1250 MW of solar energy 17

Figure 2-3. Examples of everyday uses of photovoltaic systems 23

Figure 2-4. Concentrating PV (point-focus Fresnel lens) 25

Figure 2-5. Parabolic trough 26

Figure 2-6. Power tower 26

Figure 2-7. Dish concentrator 27

Figure 2-8. Solar water-heating systems 28

Figure 2-9. Hybrid solar lighting 29

Figure 3-1. A systems-driven approach to program management requires the identification of market-based requirements for each of the technologies funded under the Solar Energy Technologies Program 33

Figure 4.1.1-1. This schematic shows the elements of a PV system and two applications, each with unique system requirements 43

Figure 4.2.1-2. Goal for U.S.-manufactured PV modules installed in U.S. domestic applications, for a U.S. market share that increases linearly from 30% to 50% from 2000 to 2020 44

Figure 4.1.1-3. Price breakout (by percentage) of an installed residential PV system 45

Figure 4.1.2-1. A CPV system connected as a distributed-generation source 67

Figure 4.1.2-2. Schematic of a point-focus Fresnel lens concentrator 68

Figure 4.1.2-3. Schematic of a linear-focus Fresnel lens concentrator PV system 69

Figure 4.1.2-4. Schematic of a point-focus dish concentrator PV system 69

Figure 4.2-1. Schematic of a parabolic-trough system 78

Figure 4.2-2. Schematic of a solar power tower system 79

Figure 4.2-3. Dish/engine system schematic. The combination of four 25-kWe units shown here is representative of a village power application 80

Figure 4.3-1. Passive integral-collector-storage system for warm climates 99

Figure 4.3-2. Active glycol solar water-heating system 100

Figure 4.3-3. Schematic and photos of actual installation of hybrid solar lighting system 101

Figure 4.3-4. Roof-integrated thermosiphon (RITH) solar water-heating system 102

Figure 5-1. Schematic of the EERE strategic management system, showing the four key activities and their relationship to customers and to one another 139

Figure 5-2. Activities performed in concert with the PV and solar thermal teams to implement the systems-driven approach ... 142

Figure 5-3. Organizational chart for the Solar Energy Technologies Program, showing its DOE Headquarters executive management, operations management in the field, and Program partners 146

List of Tables

Table 2-1. Solar Technologies and their Applicability to Various Market Sectors ... 14
Table 2-2. Market Value of the Various Classes of Power Plant ... 16
Table 2-3a. Solar Technologies and Some Competing Conventional Sources ... 19
Table 2-3b. EIA Annual Energy Outlook Average Residential Costs 2000-2025 (2001 Dollars) ... 19
Table 2-4a. Application Types and Conventional Alternatives ... 22
Table 2-4b. Cost of Transmission ... 22
Table 3-1. Tasks for Systems-Driven Approach Development and Implementation ... 36
Table 3-2. Systems-Driven Approach Development and Implementation Milestones ... 37
Table 4.1.1-1. Targets for Flat-Plate PV Systems in Large Utility-Scale Applications ... 50
Table 4.1.1-2. Targets for Flat-Plate PV Systems in Residential Applications ... 51
Table 4.1.1-3. Targets for Flat-Plate PV Systems in Residential Applications (with Storage) ... 51
Table 4.1.1-4. Targets for PV Balance of Systems ... 52
Table 4.1.1-5. Tasks for Flat-Plate PV Modules ... 57
Table 4.1.1-6. Tasks for Flat-Plate PV Systems and Balance of Systems ... 58
Table 4.1.1-7. Milestones for Flat-Plate PV Subprogram ... 62
Table 4.1.2-1. Technical Targets for CPV Technologies ... 72
Table 4.1.2-2. Tasks for CPV Technology R&D ... 74
Table 4.1.2-3. Schedule and Milestones for CPV ... 75
Table 4.2-1. Technical Targets: Parabolic Trough Power ... 83
Table 4.2-2. Technical Targets: Power Tower ... 83
Table 4.2-3. Technical Targets: Dishes ... 84
Table 4.2-4. Tasks for Parabolic Trough Technology R&D ... 86
Table 4.2-5. Tasks for Power-Tower Technology R&D ... 89
Table 4.2-6. Tasks for Dish-Engine/Converter Technology R&D ... 92
Table 4.2-7. Trough Technology Development Milestones ... 93
Table 4.2-8. Power Tower Technology Development Milestones ... 94
Table 4.2-9. Dish Technology Development Milestones ... 94
Table 4.3-1. Technical Targets—Passive Solar Water Heating ... 104
Table 4.3-2. Technical Targets—Active Solar ... 105
Table 4.3-3. Technical Targets—Hybrid Solar Lighting ... 106
Table 4.3-4. Technology R&D Tasks—Passive Solar Water Heating for Warm Climates ... 109
Table 4.3-5. Technology R&D Tasks—Active Cold-Climate Solar Water Heating ... 112
Table 4.3-6. Technology R&D Tasks—Active Solar Combined Heating and Cooling ... 112
Table 4.3-7. Technology R&D Tasks—Hybrid Solar Lighting ... 113
Table 4.3-8. Technology Development Schedule and Milestones—Solar Water Heating ... 114
Table 4.3-9. Technology Development Schedule and Milestones—Hybrid Solar Lighting ... 115
Table 4.4-1. Tasks for New Concept Development ... 133
Table 4.4-2. New Concept Development Milestones ... 136
Table 5-1. Schedule and Milestones: Solar Energy Technologies Management Plan ... 151

1.0 Solar Energy: A National Perspective

Solar energy is a clean, abundant, renewable energy resource that can benefit the nation by diversifying our energy supply. Solar energy holds tremendous long-term potential to reduce our dependence on imported fuels, improve the quality of the air we breathe, and stimulate the economy by creating jobs in the manufacture and installation of solar systems.

The following are key drivers for pursuing greater use of solar energy:

- Solar technologies provide electricity, heating, cooling, and daylighting, and can even be used to produce hydrogen, which is a clean transportation fuel for the future.
- Solar energy is the most plentiful and widely available form of renewable energy in the United States and throughout the world.
- Solar energy is the origin for all fossil fuels, and we never need to worry about solar energy being depleted, as long as the sun continues to shine.

Using current solar technology, an area just 100 miles by 100 miles (10,000 square miles) in the southwestern United States could generate as much energy as the entire nation currently consumes. To put the land area in context, 40,000 square miles of Wyoming overlies coal beds. Though generating all the electrical energy we use via solar energy is not the goal of the Solar Energy Technologies Program of the U.S. Department of Energy (DOE), it does show that solar has the potential to be a significant part of a diversified national energy portfolio.

Viable solar energy is not limited to the Desert Southwest, however. In fact, the average sunshine across the United States is 1,800 kilowatt-hours per square meter (kWh/m^2) annually, whereas the average sunlight in the Desert Southwest is 2,300 kWh/m^2, or about 25% higher than the nation's average. Solar electricity can actually be more cost effective in New York than Arizona, because electricity prices can be 50% higher in New York than in Arizona. Thousands of small solar power plants—on rooftops, installed as shading for parking lots, or put on brownfields and other abandoned land in every state in the nation—could generate enough solar energy to play a major role in our nation's energy supply.

In the near term, solar energy can reduce demand for natural gas used by utilities to generate electricity or used in buildings for space, water, and process heat. This would allow natural gas—a relatively clean, domestically available, and flexible fuel—to be used in its highest-value applications, which include peak electrical power, transportation fuels, and chemicals, while diversifying our portfolio beyond fossil fuels.

Further into the future, solar energy could produce hydrogen to provide transportation fuels, chemicals, and electricity and to serve as energy storage at times when sunshine is not an option.

We all know that the sun does not shine all of the time. So how can we use solar energy when we need it? Fortunately, there are many solutions to this problem. Buildings can store thermal energy from the sun without appearing radically different in design than conventional buildings. Solar cells can store electricity in batteries for use when needed. Solar power plants can collect and store thermal energy during the daytime and generate electric power as needed throughout the day and night.

The DOE Solar Program has developed a broad portfolio of electricity-generation and thermal-energy systems founded on two basic concepts: (1) solid-state solar cells producing electricity directly from sunlight via the "photovoltaic effect," and (2) solar-thermal technologies collecting heat from the sun and then using it directly to provide thermal energy or converting it to electricity through conventional steam cycles, heat engines, or other generating technologies.

1.1 Solar Energy Technologies: Goals, Objectives, and Strategies

Secretary of Energy Spencer Abraham has challenged the DOE Office of Energy Efficiency and Renewable Energy (EERE) to revolutionize how we approach energy efficiency and renewable energy technologies, to "leapfrog the status quo," and to pursue "dramatic environmental benefits." This research plan includes work on new solar energy concepts such as organic solar cells, solar/hybrid lighting, dye-sensitized cells, and advanced solar-thermal hydrogen that have the potential to create the breakthroughs the Secretary envisioned. Creating substantial quantities of useful energy from the sun's rays is the "holy grail" for renewable energy. Achieving this high-risk proposition requires a substantial program of fundamental materials, chemistry, physics, and electronics—central aspects of the Solar Program. This high-payoff, high-risk research can yield great benefits to the nation and is a prime example of research and development (R&D) worthy of Federal support.

Mission and Vision

The mission of the DOE Solar Program is to improve America's security, environmental quality, and economic prosperity through public-private partnerships that bring reliable and affordable solar energy technologies to the marketplace.

Once solar energy becomes economically viable for everyday applications, it could foretell a future where all Americans benefit from this pure and clean primary energy resource. In this future, millions of homes and commercial buildings across the nation would use solar technology to provide all or much of their energy needs. The Sun Belt states would get much of their electricity from solar power plants sited near the communities that need it. The southwestern states would generate more electricity from solar energy than they need, enabling them to export power to other states. Solar energy would power thermochemical and photolytic processes that produce hydrogen to provide transportation fuel that relieves our dependency on imported fossil fuels.

As Figure 1-1 illustrates, the DOE Solar Program plays an integral role in the National Energy Policy and in helping EERE reach its goal of increasing the

Figure 1-1. The goals of the Solar Program align with the National Energy Policy goals.

viability and deployment of renewable energy technologies. The figure indicates how the Solar Program goals are inextricably linked to the current National Energy Policy.

Goals and Objectives

The goals of the Solar Program are to reduce the cost of solar energy to the point that it becomes competitive in relevant energy markets (e.g., buildings and power plants) and for solar technology to reach a level of market penetration to enable a sustainable solar industry. The curves in Figure 1-2 show that the cost of energy from each of the technologies supported by the Solar Program has been reduced over the past 15 to 20 years. The curves also indicate that further cost reduction is projected.

The Solar Program is committed to developing solar technology that provides the country with an economically competitive energy option and that helps U.S. industry remain the world leader in the technology. The Solar Program combines research, design, and development of technology with value analysis, an integrated systems-driven approach, and partnering to attain its goals and objectives.

The Program's objectives are to:

- Improve the cost, integration, and performance of solar heating, cooling, electricity, and lighting technologies in combination with building systems to levels where they are a competitive, reliable option for building owners and occupants.

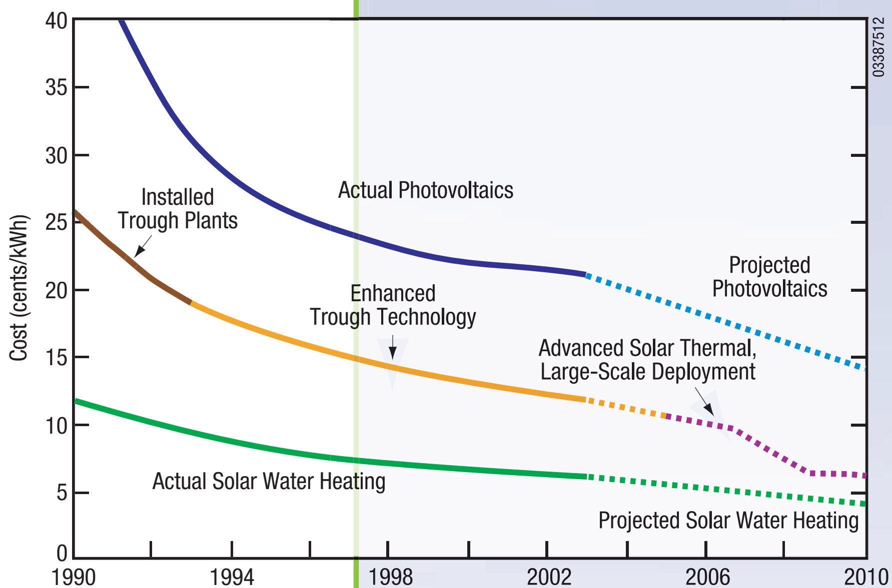


Figure 1-2. With improved technology supported by DOE, the cost of solar energy in the United States has declined steadily. The projected costs (shown as dashed lines in the graph) are based on continuing the proposed budget support for the Solar Program. The long-term cost goals are even more ambitious. For example, the goal for photovoltaics in 2020 is $0.06/kWh.

- Add significant security, reliability, and diversity to the U.S. energy system and improve the quality of life in this country by providing clean, distributed electricity to all.

- Make solar technologies and systems an accepted and easily integrated option for distributed-energy production both on and off the electric utility grid.

- Develop next-generation technologies and systems with the potential to create new high-value applications of solar energy in producing hydrogen fuel, generating competitive bulk power at central stations, desalinating water, or creating other products that are beyond present capability.

- Reduce the environmental signature (air emissions) by displacing fossil-fuel energy systems with cost-effective solar energy systems.

R&D 100 Awards

Research sponsored by the DOE Solar Energy Technologies Program has produced more than 235 patents and received numerous awards. R&D Magazine presents the prestigious R&D 100 awards annually to the 100 top research breakthroughs for that particular year. The DOE Office of Energy Efficiency and Renewable Energy has received more than 105 R&D 100 awards—more than any other agency other than NASA, more than any private company except General Electric, and more than any single country in the world except Japan. Of that total, more than 10% of these awards were given to the Solar Program, including:

1984	Copper Indium Diselenide Solar Cell
1985	Volume-Indexed Secondary-Ion Mass Spectrometry
1989	Spectroscopic Scanning Tunneling Microscope
1991	Gallium Indium Phosphide/Gallium Arsenide Tandem Solar Cell
1991	Cadmium Telluride Photovoltaic Modules
1992	Atomic Processing Microscope
1992	Solar Detoxification of Hazardous Organic Materials in Groundwater
1993	Scanning Defect Mapping System
1993	Dish-Stirling System
1993	Aqueous Chelating Etch
1994	High-Performance Photovoltaic Cell
1994	Transpired Solar Collector
1997	"PV Optics" Software Light-Trapping Model for Solar Cells
1998	UNI-SOLAR Triple-Junction Amorphous-Silicon Solar-Electric Modules
1999	Siemens Solar Industries' High-Performance Thin-Film Photovoltaic Modules
2001	Triple-Junction Terrestrial Concentrator Solar Cell
2002	Power-View Semi-Transparent Photovoltaic Module

Near-Term Goals: The 2005 goals for the Solar Program will promote the increased use of solar energy by reducing solar energy system costs as follows:

- Electricity from photovoltaic systems reduced to $0.18/kWh
- Polymer solar water heater reduced to $0.04/kWh—the thermal equivalent of $4 per million Btu (MBtu)
- Electricity from concentrating-solar-power systems reduced to $0.10/kWh.

Long-Term Goals: The 2020 goal for the Solar Program is for the cost of solar energy to be competitive with fossil fuels. Although it is difficult to predict the cost of energy that far into the future, it is projected that by 2020, intermediate load electricity will be $0.04 to $0.06/kWh, while homeowners will pay $0.08 to $0.10/kWh, and thermal energy will be $4 to $6/MBtu. Solar must be at or below the cost of fossil fuels if it is going to play a major role in the market. If photovoltaic (PV) goals are met, industry projects that PV capacity could reach 30,000 megawatts (MW) in the United States by 2020. Projections for applications of concentrating solar power and solar thermal are under development. These levels of market penetration will be attained by sustaining a Federal R&D program that results in technology improvements and breakthroughs that steadily decrease the cost of solar energy, in combination with Federal and state policy actions that encourage the increased use of solar energy (e.g., renewable portfolio standards, system-benefit charges, tax incentives, net-metering standards).

Strategy

The Solar Program's strategy is to develop a portfolio of technologies that can provide:

- Electric power for applications as diverse as emergency roadside telephones, single-family homes, and entire communities
- Sunlight for illumination in the interior rooms of buildings
- Thermal energy for space heating and cooling, pool heating, and domestic water heating
- Combinations of electric and thermal energy for producing hydrogen or the desalination of water.

The Program will pursue this strategy using a systems-driven approach with a solid analytical foundation based on an accurate understanding of these questions:

- What drives business and consumer energy investment decisions?
- How do energy markets operate?
- What are the policy implications of laws and regulations?

- What other EERE Programs (e.g., Distributed Energy Resources [DER], Hydrogen, Buildings) provide crosscutting opportunities?
- What are the R&D needs of industry players as they develop solar products?

1.2 Federal Role

Emphasis is given to high-risk research and development (R&D) that industry is unable or unlikely to do on its own. The Solar Program supports the R&D of world-class scientists and engineers in industry, universities, and the national laboratories. This R&D is the heart of the Program's strategy for positioning solar technologies to help meet the new demands of a restructured energy industry. This R&D has been recognized through numerous awards for scientific excellence and innovation (see R&D 100 Award sidebar to left).

Field testing of solar systems is supported to learn where improvements in the technology are required to attain cost and reliability goals. This information is fed back to researchers and engineers to help guide their work. Commercialization and deployment of the technology is outside of DOE's mission. As such, those important steps are left to industry.

Stakeholder Partnerships are Key

The Solar Program works closely with Federal and state agencies, industry, and universities to leverage their expertise and resources. More than 50 universities are partners in the Program, contributing both their technical expertise and experimental facilities. In addition, industry also provides cost sharing to many projects, with the amount varying from a small percentage of research projects to more than 50% for some technology development projects. The Solar Program uses partnerships to shorten the time of project completion and to ensure the rapid transfer of the technology from the research laboratory to the factory floor. Partnerships are typically initiated through competitive procurements from the national laboratories, Golden (Colorado) Field Office, or Albuquerque (New Mexico) Field Office. The map in Figure 1-3 indicates the breadth of the Program's support of industry, universities, and national laboratories throughout the United States.

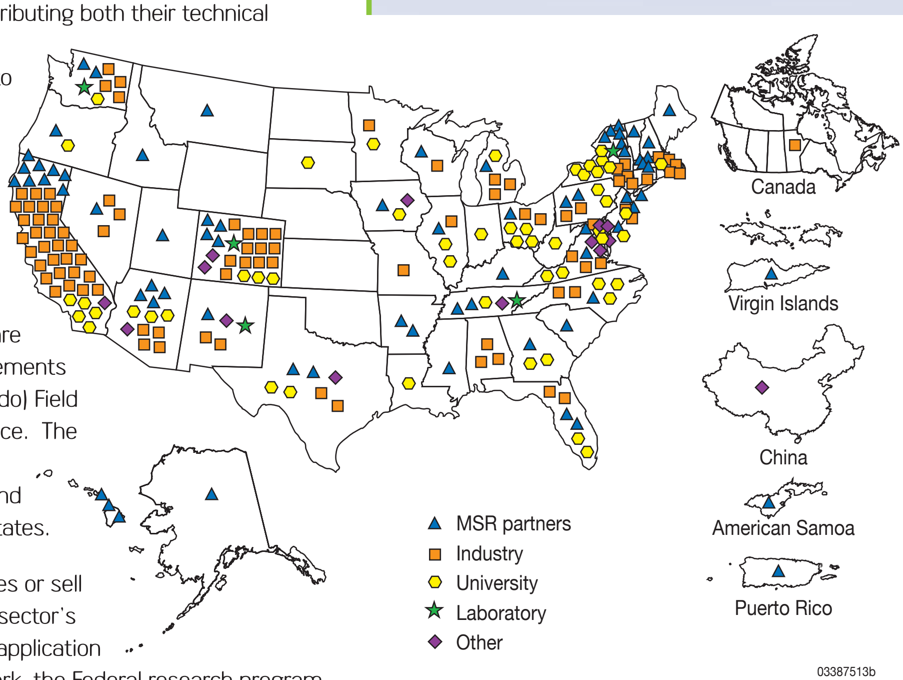


Figure 1-3. The Solar Program's support spans partners from industry, universities, and national laboratories across the United States.

DOE does not commercialize solar technologies or sell them in the marketplace—that is the private sector's responsibility. When technology reaches the application and market end of the development framework, the Federal research program needs information and feedback from the private sector to help guide early stages of technology development. The most effective way to get the necessary feedback is through partnering with industry and with the states to learn from their experience and insight.

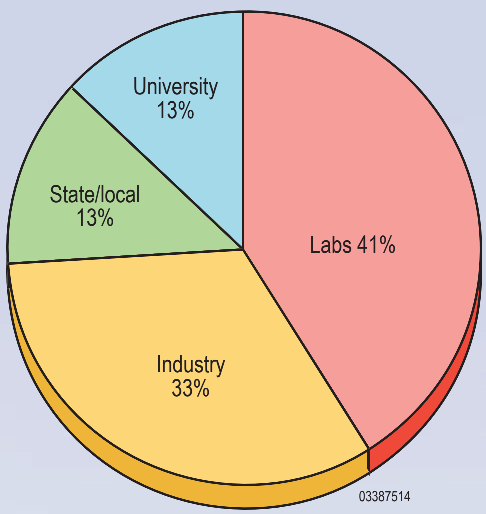


Figure 1-4. The Solar Program's research performers and their share of total funding.

The DOE Solar Energy Technologies Program Multi-Year Technical Plan is founded on cost sharing and collaboration at every stage of technology development. This includes working with universities, where academic expertise can contribute greatly to basic and applied research. In the future, solar energy will play a role in generating hydrogen for transportation fuel; therefore, cooperation and information sharing with the Hydrogen Program is important. Buildings and solar energy are inextricably linked, so cooperation with the Buildings Program in developing zero-energy buildings is a key part of the Solar Program.

Outside DOE, the Environmental Protection Agency, Agency for International Development, International Energy Agency, the World Bank, and other organizations play an important role in shaping markets for solar technologies. Considering their interests and capabilities is part of planning effective research.

Government-Industry Partnerships

Figure 1-4 shows the allocation of Solar Program funds to industry, national laboratories, universities, and state/local organizations. Industry is a vital part of the Solar Program, which emphasizes partnering at every level of research and in every research area. Partnering with industry generates more effective research by leveraging resources. In areas such as thin-film photovoltaic research, Million Solar Roofs, and advanced manufacturing, industry partnerships leverage Federal funds through cost sharing and increase the chances for achieving technical goals by creating a team approach to solving research problems. Industry partnering will ensure that the practical, everyday end-use is firmly in mind when basic and applied research is conducted. Beyond research and cost sharing, industry partners will be involved in program planning and strategy development to ensure that the Solar Program is accountable and makes measurable progress toward its goals.

University Partnerships

To achieve its goals, the Solar Program must enlist the aid of the best scientists and engineers in the country. More than 50 university partners provide the expertise to solve complex technical problems and the creativity to formulate concepts that propel the Program toward its goals. The Georgia Institute of Technology and University of Delaware have been designated by DOE to be centers of excellence and to provide the Program with unique research capabilities. Similarly, the Program enjoys a long-standing relationship with the Southeast Regional Experiment Station managed by the University of Central Florida and the Southwest Regional Experiment Station managed by New Mexico State University. The Program also has a long-standing, productive relationship with historically black colleges and universities, providing support for both research and student programs in solar energy.

Partnerships with other DOE Programs

A key part of the Solar Program's strategy involves coordinating solar-technology research and integrating it with other EERE programs, such as the Hydrogen, Buildings, and Distributed Energy Resources programs, and the Federal Energy Management Program (FEMP). A prime example is the collaboration with the Zero Energy Buildings activity, which is the responsibility of the Buildings Technology Program. The Solar and Buildings Programs work closely in the integration of solar products into energy-efficient buildings. At the DOE level, the Solar Program collaborates on basic research in nanotechnology with the Office of Science. This is cutting-edge research that may provide the foundation for a new generation of solar technology.

Intergovernmental Partnerships

The Solar Program works with the Federal Emergency Management Agency (FEMA) in providing solar technology to provide power while the electric grid is down following periods of natural disaster. The states are particularly valuable partners because many states actively promote the use of solar energy through the adoption of policies such as renewable portfolio standards, tax incentives, and system-benefit charges. The Program is working with the Western Governors' Association to address the potential of solar energy in the Southwest, where an abundant solar resource could provide much-needed energy to this fastest-growing part of the country. Through the Million Solar Roofs activity, the Program has more than 60 state and local partners, educating hundreds of thousands of people on the benefits of their use of solar energy. Thus, the Program employs a strategy of working with a wide variety of entities, merging their interests with ours to further the development of solar energy.

1.3 Integrated Solar Program

The solar-thermal and photovoltaic approaches to solar energy conversion are distinct, yet they are complementary components of an integrated solar research program. Both types of solar technology have many common challenges in entering markets and developing competitive applications, systems, and subsystems. Each approach also has its own unique positive attributes and specific technical challenges that need to be addressed in R&D. The Solar Program's Multi-Year Technical Plan focuses resources and efforts on the most critical research challenges facing solar energy development as a whole, whether the research focuses on solar-thermal approaches, photovoltaic approaches, or research challenges common to both.

Systems-Driven Perspective

This broad perspective on solar energy R&D is part of a renewed emphasis on understanding the challenges facing solar energy and identifying the most important research required to create effective solar systems. This philosophy is implemented by using a systems-driven approach (Figure 1-5), which emphasizes the importance of how materials and processes, components, products, applications, and markets for a technology are related to each other. It emphasizes how changes in a component might affect an application or market (e.g., the development of low-cost polymer solar water heaters) or how changes in a market might change requirements for component cost and performance (e.g., how national interconnection standards could impact inverter design).

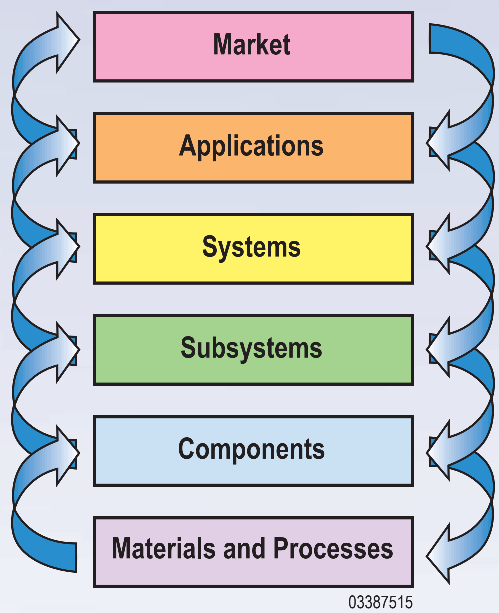


Figure 1-5. The framework for the systems-driven approach.

At the program level, a systems-driven approach helps identify common elements that impact R&D. For example, all solar technologies targeting central-station generation for "firm power" share similar assumptions about the value of dispatchability and the cost of competition in different regions. Applications integrated into building roofs or installed on roofs have common challenges in satisfying builder and owner preferences and in interconnecting with the utility system (if they generate electricity in grid-connected systems).

At the technology level, a systems-driven approach can help identify common research concerns, avoid duplication of effort, and explore how advances in an area such as subsystems might change the assumptions or requirements for systems, applications, and markets.

A national perspective on solar energy is inconsequential without specific actions to improve technologies, understand markets, evaluate policies, and work in partnership with stakeholders who purchase and incorporate solar energy systems into the U.S. energy economy. Those specifics are presented in the following sections of the DOE Solar Energy Technologies Program Multi-Year Technical Plan.

Solar Power Goes Mainstream

PV power is showing signs of going main-stream. After testing the waters in three San Diego, California, stores in September 2001, The Home Depot® expanded the number of stores selling residential solar-electric power systems, as well as the geographic locations where these stores are located.

By August 2002, Home Depot® stores were selling and installing PV systems under its "At-Home Services" program. In addition to 18 stores in greater San Diego and 16 in the Los Angeles metropolitan area, Home Depot® stores throughout Long Island, New York, five stores in southern New Jersey, and four in Delaware were providing this solar product and service. The Home Depot® is extending two convenient financing options: The Home Depot® Consumer Credit Card and The Home Depot® Home Improvement Loan.

Fueled by generous state rebates, a number of builders in California are building entire solar-powered communities. A few of these progressive homebuilders in California that offer solar-electric power as a standard feature are: Clarum Homes (Vista Montana in Watsonville, Shorebreeze IV in East Palo Alto), Premier Homes (Premier Point II in Lincoln), Standard Pacific (Maravu in San Diego), and US Home (Bickford Ranch in Placer County). In addition, Shea Homes is offering both solar-electric power and solar-thermal energy systems as standard features in its Scripps Highlands com-munities in San Diego. Homebuilders such as Clarum Homes and Shea Homes are now working with DOE' s Zero Energy Homes teams to combine energy efficiency with solar energy and work toward the long-term goal of zero net energy use during the course of a year.

The proposed Bickford Ranch community will be the largest grid-connected residential solar project in the country, with PV installed on 917 homes, community clubhouses, and main-tenance buildings. The plan also allows up to 83 neighboring homes to participate in the volume-discount PV purchase. Total peak energy production from the Bickford Ranch solar power systems is projected to be equivalent to a 2-megawatt power plant.

2.0 Solar Energy Industry, Markets, and Applications

Solar energy technologies offer the potential to assist our nation with several critical national problems. First, solar energy can be used to produce heat or electricity in homes, factories, and power plants—displacing fossil fuels—and eliminating harmful pollutants that can contribute to climate and health issues. Second, solar energy captured and used to create electricity or thermal energy enables diversity in our energy mix and reduces our dependence on foreign oil. Finally, solar energy components are high technology and their manufacture creates high-paying jobs. Thus, solar energy can provide critically needed energy, reduce the impact on our environment, enhance our nation's security, and create economic development.

Currently, a significant and growing solar industry in the United States is serving customers by providing solar water heating, pool heating, and solar-electric systems. However, the national benefits will only be achieved with significant capture of market share in larger energy markets. Solar energy components must be successfully integrated into homes, buildings, and power plants to provide value to customers. To date, many of the solar energy systems are significantly more expensive than the traditional options available to customers (e.g., engines, gas heaters, grid electricity). The cost, performance, and convenience of these systems must be improved if solar energy is going to compete in energy markets against more traditional alternatives. Some large-scale solar technologies are close to being cost competitive, but the risk of making such a large investment is an obstacle to commercialization.

This section puts into perspective the extraordinary potential that solar energy offers to the nation. This potential will be realized only through research, development, and deployment into a variety of markets and applications. Subsequent sections will discuss in detail the potential applications and benefits of solar energy.

2.1 National Needs and Benefits

Solar energy can directly benefit the nation by substantially contributing toward resolving three national problems—air quality, energy reliability and security, and economic development. Our nation's economic health and security increasingly depends on reliable, clean, abundant, and affordable energy. Energy consumption in the United States is projected to increase by about 32% by 2020.[1] Solar energy systems have the versatility to provide clean electric and energy systems for grid-connected power, grid-independent power, water and space heating, industrial process heating, and power plants. Solar energy has enormous potential as a supplement or alternative to fossil fuels for serving energy markets in the United States and developing nations.

Clean Energy

The advancement of solar energy provides the United States with an opportunity to lead the world to a clean energy future. Solar energy is harnessed by a diverse mixture of technologies that can meet the environmental challenges of today, while safeguarding the future. In 2002, President Bush introduced the Clear Skies and Global Climate Change Initiatives. This plan is an aggressive initiative to reduce power-plant emissions, as well as a new strategy for handling global climate change.[2] The major goals of the President's plan include reducing air pollutants (nitrogen oxide, sulfur dioxide, and mercury), establishing market-based emission trading credits, and reducing overall greenhouse-gas emissions.

[1]White House Web site, National Energy Policy, http://www.whitehouse.gov/energy/Chapter1.pdf
[2]White House Web site, http://www.whitehouse.gov/news/releases/2002/02/20020214.html, Fact Sheet: President Bush Announces Clear Skies and Global Climate Change Initiatives

Solar energy produces no pollution while harnessing the inexhaustible resource of sunlight. Solar energy systems can reduce the impact of global warming by replacing fossil-fueled technologies that pollute the air with nitrogen oxide, sulfur dioxide, carbon dioxide, and particulates. By taking advantage of solar energy, the United States can meet the Clear Skies Initiative, which requires a mandatory 70% reduction in air pollution. Furthermore, incorporating solar energy can reduce particulate emissions, which have been inextricably linked to adverse health effects, particularly on the elderly and children.

Parabolic-trough technology is currently the most proven of the solar-thermal-electric technologies. Nine commercial-scale solar-electric generating stations, the first of which began operating in 1984, produce electricity in the California Mojave Desert. Ranging in size from 14 to 80 MW, together they have a total installed capacity of 354 MW—enough power for 100,000 homes. The current cost of parabolic-trough electricity production is about $0.12 per kWh. Through a range of updates including technical and operating improvements, increasing plant size, and use of thermal storage, industry expects to reduce costs to between $0.05 and $0.06 per kWh.

Beyond electricity production, solar energy can be integrated into building designs to provide heat and light. Current applications of solar water heating have already lowered energy bills for millions of homes worldwide. In addition to cheap and reliable energy, Americans are demanding clean, environmentally friendly energy that does not contribute to pollution or global warming. For example, a recent survey in Massachusetts revealed that nearly 51% of persons polled said were willing to pay more for renewable energy.[3] Future research into innovative solar-energy concepts will further reduce energy consumption in buildings—perhaps to zero net-energy use—while increasing the solar signature as part of our nation's energy supply.

Diversity and Reliability of Electric Supply (Energy Security)

Domestic solar energy will increase the nation's energy supply and provide expanded opportunities to enhance the reliability of our energy infrastructure, thus creating a more stable environment for economic growth. The distributed, modular characteristics of solar energy offer tremendous flexibility for both grid-connected and off-grid electricity applications. Distributed energy technologies are expected to supply an increasing share of the electricity market to improve power quality and reliability problems that have cost the United States economy $119 billion a year[4] from power outages and disturbances.

[3]Opinion Dynamics Corporation Survey for the Massachusetts Technology Collaborative, http://www.mtpc.org/RenewableEnergy/green_power/cons_agg/cons_summary.htm
[4]Electric Power Research Institute, Consortium for Electric Infrastructure to Support a Digital Society, http://ceids.epri.com/ceids/Docs/outage_utilityspotlight_072301.pdf

Solar energy systems can be distributed to generate power at the point of use, decreasing the need for vulnerable and costly power lines. Solar energy systems are already the technology of choice for remote and portable power markets. Solar energy is available during peak daylight hours when electricity use (and price) is at its highest level, thereby easing the burden on current peak-load energy production.

Thus, the use of solar energy enhances the security of our national energy supply because sunlight—as an indigenous resource—can be harvested for use in commercial and industrial heating and for electricity production, avoiding the need for fossil fuels in these applications. It will indirectly reduce our need for fossil fuel imports, allowing U.S. supplies of oil and natural gas to meet the demands of transportation and other markets. By reducing our reliance on imported oil and avoiding volatile fossil-fuel markets, solar energy can improve the U.S. trade balance and minimize the effects of world energy price-shocks.

Economic Benefits

The solar industry continues to grow steadily as costs for solar systems decline in the expanding markets for renewable energy. Since the late 1990s, the market for solar energy from photovoltaics has grown at an annual rate of 20%. The solar industry estimates that growth rates above 25% annually are possible, resulting in a $27 billion market by 2020. This market growth would result in a U.S. solar industry that could employ 150,000 people by 2025.[5] With technological innovations lowering costs and increased market growth leading to new jobs and export opportunities, solar energy can become a major high-technology growth industry that contributes significantly to our country's economic growth while concurrently serving to improve our trade balance.

2.2 Existing Solar Industry

The existing solar industry has experienced steady growth throughout the past decade, but has achieved only a fraction of its potential toward solving our nation's energy problems. Since the 1970s, when the solar-energy market was virtually nonexistent, the business of solar energy has realized 100-fold price decreases, resulting in the production of millions of watts of generating power per year and achieving multibillion-dollar markets. The current U.S. solar industry employs some 20,000 men and women, representing about 300 companies, universities, and utilities.[6] The companies range from small-installation contractors to large multinational corporations. These companies have recognized the growing market for solar energy and are investing millions of dollars to increase their market share by diversifying product lines and improving product performance.

PV cells and modules and solar-thermal collectors primarily define the current state of solar manufacturing in the United States. The solar industry is growing: according to the *Renewable Energy Annual 2001*, published by the Energy Information Administration (EIA), solar-thermal-collector shipments surged 34% in 2001 to 11.2 million square feet. The total revenue for all shipments of solar-thermal collectors was $32.4 million in 2001, up 18% from 2000. Nearly 73% of all solar collectors are for pool-heating applications.[7] Solar water heaters comprise the remaining 27% of U.S. solar-thermal applications. The energy output of the pool-heating systems installed in 2001 was the equivalent of 664 MW—the size of a conventional power plant.

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[5] U.S. Photovoltaic Industry Roadmap Steering Committee, Solar Electric Power—The U.S. Photovoltaic Industry Roadmap Reprinted 2001. p. 11

[6] U.S. Photovoltaic Industry Roadmap Steering Committee, Solar Electric Power—The U.S. Photovoltaic Industry Roadmap Reprinted 2001. p. 17

[7] Energy Information Administration, Renewable Energy Annual 2001

Alongside the growth in solar-thermal technologies, international PV markets continued to grow (Figure 2-1). EIA reports that U.S. PV shipments increased 11% in 2001 to almost 98 peak MW. In 2001, the overall value of PV cell and PV module shipments rose by 13% to $305 million. In terms of price per peak watt, prices have remained stable at $2.46 for PV cells and $3.42 for PV modules. The EIA reports that most PV shipments went to the residential market, with a total of 33 MW in 2001. The industrial market remains the second-largest market for PV cells and PV modules, with 28 peak MW shipped in 2001.[8]

The year 2001 marked the first decline in PV exports in a decade. Exports declined 10% during 2001, in part because of a significant reduction of shipments to Japan and India as these countries commissioned greater PV production capacity. During 2001, Germany continued to be the main destination for U.S. PV exports.[9] According to the International Energy Agency (IEA), the worldwide installation of PV has seen increases in many countries outside of the United States. From 1990 to 2000, Germany saw the amount of installed PV peak at an annual rate of 50.6%. The IEA reports nearly similar growth rates in Korea, where PV capacity grew by more than 400% between 1991 and 2001.[10]

Statistics from 2001 reveal an increase in the use of PV cells and modules for solar electrical generation with grid-interactive applications posting a 25% increase, and the village power/remote application market growing by 43%.[11] PV continues to provide a cost-effective alternative for rural electrical needs where transmission lines are scarce or too costly to build.

Barriers to Future Growth

Although the growth in the solar industry is impressive, several barriers are keeping the industry from reaching its potential. First, despite impressive cost reductions over the last few decades, the cost of solar systems remains higher than traditional energy alternatives. But unlike coal or natural gas, solar energy's cost is not dependent on resources typically located far from generation or refinery facilities, but rather, on technical and cost limitations of existing materials and systems. Solar energy systems are capital intensive, while the cost of the primary energy resource is free. New generations of solar technologies will improve conversion efficiencies, reduce manufacturing cost, and improve systems integration that will drive the market growth and rapid expansion in the solar industry.

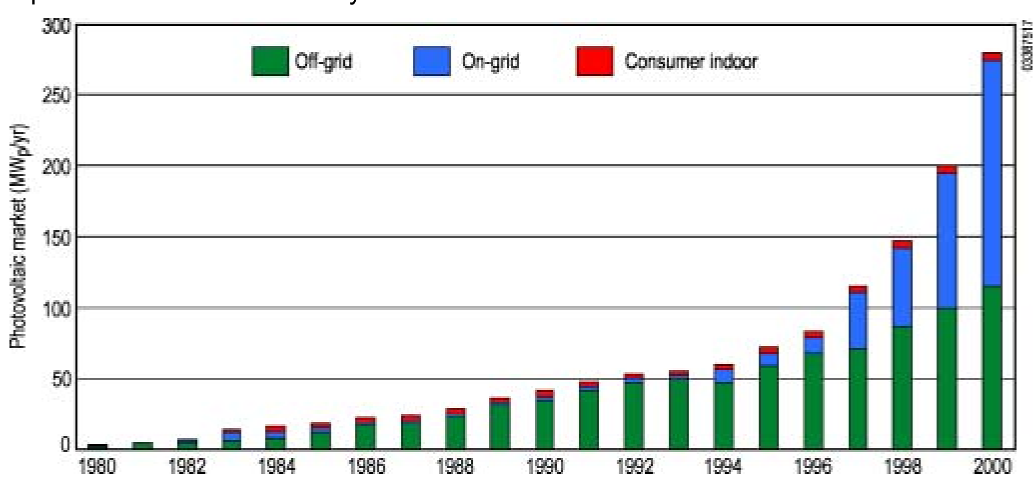

Figure 2-1. Increase in the world market for PV cells and modules. (Source: Solarbuzz, Inc.)

[8]Energy Information Administration, Renewable Energy Annual 2001
[9]Energy Information Administration, Renewable Energy Annual 2001
[10]International Energy Agency, Renewables Information 2002
[11]Ibid.

A second barrier to expansion of the solar industry is the lack of private-sector R&D investment. The immature industry does not yet generate profit margins large enough to allow for significant reinvestment. For example, one of the leading manufacturers of PV cells spent only 7.6% of its sales revenue on product development.[12] Relative to other industries, such as the pharmaceuticals industry where companies spend an estimated 17% of sales on R&D, the solar industry relies on the Federal government and public-funded university programs for the bulk of R&D on new technologies and materials.[13]

Other non-technical barriers have stymied the growth of solar energy. Institutional barriers, including the lack of interconnection standards for distributed energy and net-metering provisions, are hindering market adoption. Furthermore, the air-quality and economic benefits of solar energy are not part of the complicated rate calculus of traditional electricity regulation. Overcoming these, in parallel with technology improvements, will be critical to significant market adoption.

International Competition

Finally, most American PV products are being shipped overseas into growing solar markets, often subsidized by national government support. Japan and Germany have created incentives and mandates to increase the use of solar technologies. In Germany, the "Feed-In" Law allows energy consumers to receive credit of 45.7 Euro cents per kWh ($0.50 per kWh) for solar-generated electricity. The law also mandates 1000 MW of new PV installations.[14] Incentives have contributed to the growth of Germany's PV industry, which in 2000 totaled 1.5 billion German Deutsche Marks (roughly $840 million).[15] In Japan, the "Green Credit System" provides financial incentives to electricity producers who use renewable energy. In 1999, Japan passed the "Revised Energy Savings Law," which specifically encourages the use of solar energy.[16] During 2001, Japan's "Residential Solar Rooftop Program" received applications for 114 MW of new solar installations that reached 29,389 households.[17] Japanese companies such as Kaneka, Matsushita Battery, Sanyo, Sharp, and Showa Shell Sekiyu lead the world in terms of the highest capacity of operational manufacturing plants.[18]

With regard to concentrating solar power, there is a very active international community of both potential markets and potential suppliers. Spain's market is the most definitive, with a solar premium of about 12 Euro cents/kWh on top of the market price of power. Other major international markets include South Africa, Italy, Australia, and Brazil. In addition, several developing countries (India, Egypt, Mexico, and Morocco) are looking at concentrating solar power technology (e.g., troughs or towers) with support from the Global Environment Fund. Key international competitors to U.S. suppliers are already eyeing potential project-development opportunities in the United States. Our continued participation in the IEA's concentrating solar power working group, SolarPACES, keeps us up to date on both international project opportunities and the capabilities of highly qualified and skilled competitors.

In the solar water-heating area, the volume of production of foreign suppliers is much larger than that in the United States. International competitors are already supplying some U.S. markets; if those markets were to expand significantly, exports to the United States of highly competitive technology would expand rapidly to meet the demand.

[12] AstroPower Web Site, http://www.astropower.com/shareholder_services.htm, *2001 Annual Report*
[13] In 2001, Pharmaceutical Research and Manufacturers (PhRMA) member companies spent more than $30 billion on research to develop new treatments for diseases (an estimated 17% of sales). This was a higher R&D-to-sales ratio than any other industry in the United States. Source: Pharmaceutical Research and Manufacturers of America Web site, *http://www.phrma.org/issues/researchdev/*
[14] International Energy Agency PVPS as quoted in http://www.solarbuzz.com/StatsCountries.htm
[15] Solar Buzz, Fast Solar Energy Facts-Germany, ***http://www.solarbuzz.com/FastFactsGermany.htm***
[16] Energy Information Administration, http://www.eia.doe.gov/emeu/cabs/japanenv.html#RENEWABLE, *Japan Country Analysis*
[17] Ministry of Economy, Trade and Industry Web Site, http://www.meti.go.jp/english/index.html
[18] Solar Buzz, Fast Solar Energy Facts-Japan, ***http://www.solarbuzz.com/FastFactsJapan.htm.***

In summary, the solar industry will only reach its potential and the nation will only realize its benefits if Federal investment continues to improve products, reduce costs, and stimulate markets. This Federal role must continue throughout the next decade to ensure that these high-technology products from the United States can compete with products from Europe and Japan in growth markets being driven by increasing electricity demands throughout the world.

2.3 Existing and Future Markets: Potential for Solar

Solar technologies have been developed that can serve a wide range of the nation's energy needs. Current solar technologies produce electrical or thermal energy. Research has also been performed on technologies for daylighting of building interiors and for direct (non-electrical) production of fuels and chemicals such as hydrogen. Solar energy can be collected locally to serve local needs or by large solar plants to serve broader distant needs. Table 2-1 illustrates the range of solar technologies and their applicability to various market sectors. These markets include the following:

- Central generation: Production of electricity by large-scale plants that are connected to loads via the electric-power transmission system.
- Distributed energy: Production of energy in close proximity to the use, including
  - Building-integrated: Solar systems mounted on or integrated into building structures to produce the energy needed by the building and its contents
  - Ground-mounted: Non-building-integrated solar systems near loads that are associated with the conventional energy-distribution infrastructure
  - Off-grid: Solar systems providing energy to applications that are not connected to a conventional energy-delivery infrastructure.
- Fuels and chemicals: Current solar technology is limited to electrical and heat generation, but future technologies will be able to produce fuels and chemicals.

Table 2-1. Solar Technologies and their Applicability to Various Market Sectors

		Distributed Energy			Central Generation	Fuels and Chemicals
		Building-Integrated	Ground-Mounted	Off-Grid		
PV	One-Sun	● Electrical Generation	● Electrical Generation	● Electrical Generation	● Electrical Generation	● Transportation
PV	Concentrating		● Electrical Generation	● Electrical Generation	● Electrical Generation	● Transportation
Thermal	Dishes		● Electrical Generation	● Electrical Generation	● Electrical Generation	● Transportation
Thermal	Towers				● Electrical Generation	● Transportation
Thermal	Troughs	● Electrical Generation ● Thermal	● Electrical Generation ● Thermal		● Electrical Generation	
Thermal	One-Sun Thermal	● Thermal	● Thermal	● Thermal		
Thermal	Air[a]	● Thermal				
Thermal	Passive Solar[a]	● Thermal				
Hybrid Lighting		● Solar Lighting				

[a]DOE Solar Energy Technology Program does not conduct research in thermal air and passive solar collectors, and these technologies are not discussed further in this plan.

● Electrical Generation ● Thermal ● Solar Lighting ● Transportation

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In the long term, the role of solar energy in these markets will be determined largely by economic factors, such as the cost of energy from solar versus conventional sources. A levelized energy cost (LEC) calculation provides a means of calculating the cost of energy for solar energy systems, as well as for conventional-energy sources and equipment. Major factors to be considered are capital cost, operating and maintenance costs, and financing costs.

Solar energy has other values that may not be recognized in the conventional marketplace:

- Price stability relative to volatile markets for fuels such as natural gas
- Reduced emissions
- Local economic development
- Eliminates need for transmission and distribution in many applications.

Legislative and regulatory authorities may recognize these benefits through various policy mechanisms:

- Renewable portfolio standards
- Emissions credits
- Production and investment tax credits for large systems
- State and Federal tax credits for small systems
- Other buy-downs or credits for installation of a solar system
- Favorable mortgage interest rates for solar-equipped buildings.

These incentives can help encourage early adoption of solar energy and bridge the gap between the levelized cost of solar energy systems and the lower-cost conventional alternatives. In the long term, solar prices will have to be competitive with conventional technologies without these incentives; therefore, long-term R&D goals should be set accordingly.

Solar energy is already in use for a wide variety of applications and markets. Some markets are growing rapidly, some are stagnant, and others are yet to develop. In the following sections, these markets are identified and characterized. In addition, the market characteristics of major competing technologies are documented to assist in establishing development targets for solar-energy systems. Other aspects of solar systems that create value in the marketplace are also discussed.

2.3.1 Central Generation

"Central generation" refers to plants that are connected to the utility grid at transmission voltages and are typically 20 MW or larger in size. Because of the land area required for large solar power plants, these systems will most often be located away from urban areas, and access to transmission facilities is important.

Market Characteristics: Electric utilities may own their own power plants or may contract for power from independent power producers. In either case, utilities are concerned that power is a competitive value and is available when and where they need it. Utility power plants generally fall into three classes:

- Baseload power plants, which operate nearly continuously
- Intermediate-load power plants, which operate to supply daily periods of increased power demand
- Peak-load plants, which only operate for limited hours as needed to meet peak power needs.

The addition of some types of renewable-energy generating sources adds a fourth type of power. “Non-firm” power is power generated only when the renewable resource is available, for example, power from wind turbines. Utilities tend to place a lower value on non-firm power because it generally provides fuel savings, but not capacity unless the output of the non-firm source can be shown to be highly correlated to the utility’s load profile.

Benchmark Cost of Energy: Table 2-2 summarizes the market value of the various classes of power plants and indicates the types of solar plants that can serve these markets. Because of the intermittent nature of solar energy, serving baseload and intermediate markets on demand requires either energy storage or hybridization, which provides the capability to use other fuel sources to generate energy when needed. Also, solar energy is available much of the time that it is most needed—for example, during hot summer afternoons and evenings when air conditioners are running full blast. A few hours of energy storage, whether in batteries or thermal media, enable solar systems to supply that demand.

Solar-System Economics: A utility evaluating the viability of building a large solar power plant in a regulated environment will consider the LEC from the solar plant relative to costs associated with conventional plants (Table 2-2). A more likely scenario is that a third party will build a solar plant and will sell power into the wholesale market. In this case, the determining factor in assessing project viability is the wholesale price of power, which is also indicated in the table. Market demand for renewables, driven by a renewable portfolio standard or customer choice, may lead to higher wholesale prices for solar power than for nonrenewable alternatives.

Table 2-2. Market Value of the Various Classes of Power Plants

							Candidate Technologies			
Market Characteristics	**Capacity Factor (%)**	**Benchmark Competition**	**Capacity Cost ($/W)**	**O&M Cost (¢/kWh)**	**Fuel Cost (¢/kWh)**	**Wholesale Price (¢/kWh)**	**Power Towers**	**Parabolic Troughs**	**Dish Engine**	**PV/ Concentrating PV**
Baseload	85	Coal	1.2	0.3–0.4	0.5–0.8	4.1–4.2	Massive storage or hybrid	Massive storage or hybrid	Hybrid	Hybrid
	90	Nuclear	2.1	0.7	0.4–0.5	6.4–6.5				
Dispatchable Intermediate Power	55	Combined-cycle gas turbine	0.5–0.6	0.2	2.8–3.1	4.8	Massive storage or hybrid	Massive storage or hybrid	Hybrid	Hybrid
Dispatchable Peak Power	15 30	Simple-cycle gas turbine or diesel	0.40–0.45	0.2–0.3	4–5	8.8–9.1 6–7	Massive storage or hybrid	Massive storage or hybrid		
Non-Firm Power	36–48	Wind	1	0.4–0.5	n/a	4–5	Solar only	Solar only	Solar only	Solar only

Source: *Annual Energy Outlook, 2003* (DOE/Energy Information Administration) 03387519

Value Considerations: On the wholesale market, the value of solar power to a utility will depend on the marginal cost of the power that is being displaced. The output of a solar-only power plant will closely follow the solar input, which may or may not correspond closely with the utility's load profile. Energy storage can be employed to capture the solar energy when it is available and then provide electricity to the utility when it is needed (Figure 2-2). The utility load profile shown in the figure is typical for utilities in the southwest United States. Alternatively, hybridization—in which fossil energy is used to generate power when the sun is not available—is another way of enhancing the value of a plant by providing the assurance of plant availability.

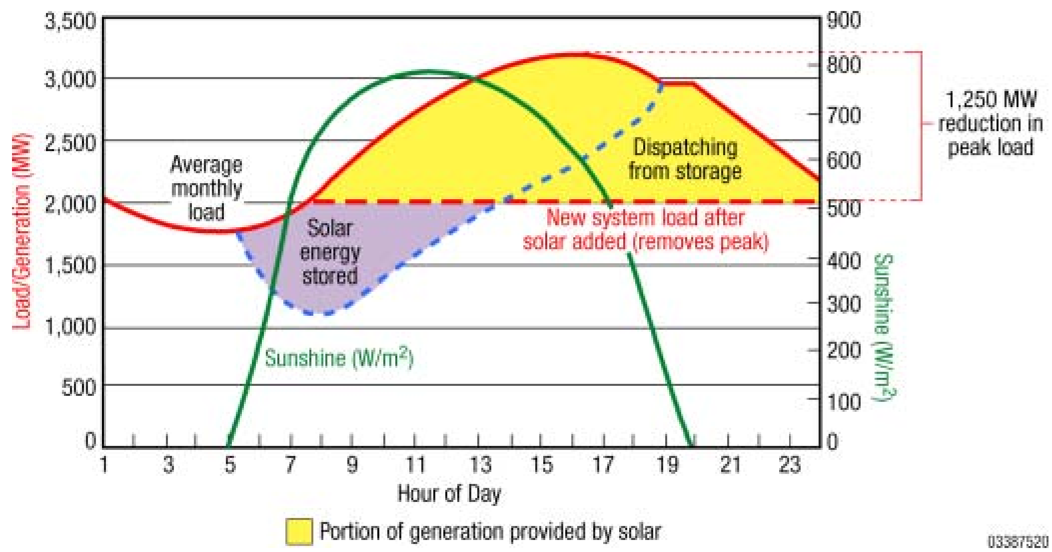

Figure 2-2. Example of the benefit of a solar plant that can generate 1250 MW of solar energy with storage during Nevada Power's summer peak month of August. (Source: Platts Research and Consulting)

2.3.2 Distributed Energy Resources

Solar is an excellent distributed energy resource because it is widely available and can be converted locally to meet local electrical and thermal-energy needs. "Distributed generation" refers to electric power plants that operate at distribution voltages and below and are typically less than 20 MW in size. The following sections discuss the uses for solar-energy technologies in the distributed-energy resource market. These applications can be located off-grid, as well as integrated to the grid.

2.3.2.1 Building-Integrated Systems

Electrical and thermal solar energy systems can be installed on or as part of building surfaces. These systems supply energy at the point of need without requiring additional land area.

Market Characteristics: Most buildings in the United States are connected to the utility grid (off-grid buildings are addressed in a following section) and obtain electricity at retail rates. The retail rate structure is complex, with different rates for residential, commercial, and industrial customers of various sizes. Rates further vary between the more than 3,000 utilities within the country. Use of on-site generation and cogeneration is also increasing.

Sources of thermal energy are varied, with natural-gas service common in most urban areas, fuel oil in parts of the Northeast, and propane in rural areas. All-electric buildings are also common.

Demand for energy from conventional sources can be reduced through the use of building-integrated solar-energy systems. Because solar-electric systems can be connected to the utility, excess energy can be exported to the grid. Excess thermal energy produced by a building-integrated solar system is usually stored for later use.

Benchmark Cost of Energy: In considering solar as an option for a building, builders and buyers will consider a number of factors, including economics, value, and aesthetics. Applicable solar technologies and some of the competing conventional sources are shown in Tables 2-3a and 2-3b.

Solar-System Economics: For a grid-connected solar-electric system, the competing cost of energy is the retail electric rate. All of the energy produced by the system is used since excess power (not consumed by the building loads) is provided to the utility grid. If net metering is permitted (where the meter runs backwards when the building is producing more solar energy than it uses), then power is bought and sold at the portion of the full retail rate that is billed as a function of kWh consumed. Without net metering, the building owner may receive a much lower "avoided cost" rate for the electricity produced and pay full retail for the electricity used. These rates may vary during the day, if time-of-day metering is applied.

The calculation of energy collected by a water-heating system is more complex, because the amount of energy used is a function of the load profile. For example, when demand exceeds the rate of collection of thermal energy by a solar water heater, all of the collected energy is used. When demand is lower than the collection rate, storage is charged. When storage is fully charged, for example, when a homeowner goes on vacation, no hot water is used and no conventional energy is displaced. The levelized cost of the offset energy is also more complex, because the cost and energy-conversion efficiency of the conventional source, such as a solar water heater, must be considered.

Maintenance costs, scheduled or unscheduled, can have a major effect on system economics. Large systems generate enough energy to support significant maintenance. But for residential-scale PV and solar water heating systems, the value of energy is insufficient to support significant maintenance. For example, if $0.01/kWh were budgeted for maintenance in a 1-kW PV system, only about $20/year would be available for service calls. Thus, high reliability is important to good economic value in residential solar systems.

For hybrid lighting systems**,** the LEC of the system includes the elements identified for other solar systems above, including the incremental cost of hybrid luminaries and controls. The LEC of the conventional alternative would include energy costs and the cost of labor and parts for more frequent replacement of lightbulbs required to obtain the equivalent level of illumination.

Table 2-3a. Solar Technologies and Some Competing Conventional Sources
(building integrated)

Applications	Benchmark Competition	PV	Trough/Combined Heat and Power	Unglazed Polymer	Passive (integral collector storage)	Pumped Flat-Plate	Evacuated Tube	Air	Hybrid Lighting
Electricity	Utility grid	● Electrical Generation	● Electrical Generation						
Pool	Gas, heat pumps			● Thermal					
Domestic hot water	Gas, utility grid	● Electrical Generation	● Electrical Generation ● Thermal		● Thermal	● Thermal	● Thermal		
Space heat	Gas, oil, utility grid	● Electrical Generation	● Electrical Generation ● Thermal			● Thermal	● Thermal	● Thermal	
Cooling, refrigeration	Utility grid or engine-driven compressors. Fuel-driven absorption and desiccant, CHP	● Electrical Generation	● Electrical Generation ● Thermal			● Thermal	● Thermal	● Thermal	
Process heat	Gas, oil, biomass		● Thermal	● Thermal		● Thermal	● Thermal	● Thermal	
Daylighting	Skylights								● Solar Lighting

● Electrical Generation ● Thermal ● Solar Lighting

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Table 2-3b. EIA Annual Energy Outlook Average Residential Costs 2000–2025
(2001 dollars)

Source	Benchmark Price	Energy
Electricity	\$0.078–\$0.086 per kWh	Net metered at retail price or time-of-day metered
Gas	\$7.31–\$9.41 per MM Btu (\$0.025–\$0.032 per kWh)	Conversion losses must be considered. Gas water-heater energy factors are less than 0.6
Oil	\$7.96–\$9.67 per MM Btu (\$0.027–\$0.033 per kWh)	

Value Considerations: On a life-cycle basis, economics would favor a solar system for which the mortgage payments plus utility bills for the building equipped with the solar system are lower than for the comparable building without the solar system. However, builders and buyers may view economics differently. For example:

- Builders may avoid including a solar system as standard equipment because the resulting higher price of the building might not be competitive in the market place.
- Buyers may be unable to finance the additional cost of a solar system, even though the utility bills plus mortgage payments are lower (however, some lenders will take this into account).
- Buyers may want a shorter payback on their investment.
- Builders may be more concerned about the cost of the home than the cost of operating it.

Improving Value: In addition to economics of the solar-system cost versus conventional energy, builders and buyers may consider other values associated with solar-energy systems, which become a part of the design and marketing of the system. These values may include the following:

- Capability for autonomous operation in the event of loss of conventional-energy sources
- Environmental benefits associated with clean energy
- Making solar an attractive architectural design element
- Selecting solar products that both provide energy and replace conventional building materials, such as roofing materials
- Quality of lighting. Daylighting is higher-quality light than light from artificial sources and is valued for improving attractiveness of building interiors while increasing productivity of building occupants and leading to higher retail-store sales
- Taking advantage of available solar incentives.

Improving Aesthetics: When large-scale deployment of solar energy systems occurred during the late 1970s and early 1980s, solar systems were mounted at a steeper angle than the roof pitch to maximize energy collection. As a result, many of these systems were unattractive, and when a building needed to be reroofed, many operational systems were removed.

Today, solar systems are more likely to be mounted flush with the roof surface. Some solar thermal systems are mounted directly on the roof deck and are indistinguishable from skylights. PV products that are integral to, or even replace, conventional roofing materials are commercially available today. Some swimming pool solar-collector manufacturers offer terra cotta-colored products (as opposed to the typical black collector color), and some PV manufacturers are working on alternative module colors to enhance their architectural appearance. And, as described above, some solar collectors have been used as attractive and energy-producing building facades.

2.3.2.2 Ground-Mounted Distributed-Energy Systems

Distributed energy generally includes energy systems that are smaller scale than transmission-connected central-generation systems. In addition to the building-integrated applications already discussed and off-grid applications to be discussed in the following sections, there are other systems that are connected to the conventional energy-distribution systems and are ground-mounted. Therefore, they do not fit in the off-grid or building-integrated classifications. These systems include the following:

- Ground-mounted, customer-sited solar systems to provide energy for various purposes, including electricity, district heating and cooling, and industrial process heat.
- Ground-mounted, utility-owned solar-electric systems located within the distribution system.

Benchmark Cost of Energy: Customer-sited solar systems are similar to building-integrated systems in that they are designed to serve local loads. Thus, the benchmark cost of energy is the retail cost of energy.

Utility-owned systems are similar to central-station systems, but are sited within the distribution system and provide energy at a point between wholesale energy connected to the transmission system and retail energy at the customer's meter. The avoided cost of energy for the utility may include savings on transmission and distribution of energy to the point of interconnection, relative to the wholesale cost of energy.

Economics and Value Considerations: Customer-sited systems have economics and benefits that are similar to building-integrated systems discussed previously in this report. A primary additional consideration is the need for land to site the ground-mounted system.

The economics of a utility-owned system will be similar to a central-generation system because most of the same considerations apply. However, systems connected to the distribution system will typically be much smaller. To meet customer needs for "green energy," utilities may site these smaller-scale solar power plants wherever land is available—such as reuse of former brownfields, which are former industrial sites that may have residual pollution that discourages other uses. Utilities have also evaluated the use of solar to provide grid support. If a utility distribution system is overloaded, energy from central-generation sources cannot be delivered to the customers when needed. Where overloads are correlated with available solar energy (for example, air-conditioning loads), then a solar system located within the distribution-system can provide energy at the point of need. This energy has higher value because it offsets the capital cost of a distribution-system upgrade. The value of distribution support was extensively studied for the Kerman substation system within the service territory of Pacific Gas and Electric (PG&E). However, the value of distribution support is likely to be quite specific, as well as being time dependent, because distribution support requirements will likely change over the 20- to 30-year life of a solar system.

2.3.2.3 Off-Grid Solar-Electric Applications

Solar-electric applications that are not connected to the utility grid are referred to as off-grid applications. Unlike grid-tied systems, where excess energy can be supplied to the utility grid, the energy from off-grid systems is used immediately or is stored. Building and other applications of solar-thermal systems have been discussed in the preceding section and are not discussed further.

Market Characteristics: Off-grid solar-electric systems use available sunlight to meet local energy needs without requiring a road, wire, or pipe for supply of conventional energy sources. As a result, these systems not only offset the cost of energy from conventional sources, they also offset the cost of extending delivery of conventional energy sources to the point of use. This leads to high-value, diverse markets for solar electricity. The scale of off-grid applications can range from 1 watt or less (solar calculator) to hundred of kilowatts for a village or facility power system, with diverse applications in between.

Benchmark Cost of Energy: Tables 2-4a and 2-4b provide a summary of application types and conventional alternatives. In addition, wind is a competing renewable technology for some remote applications.

Table 2-4a. Application Types and Conventional Alternatives
(off-grid)

Application	Plant Size	Competing Energy Sources			Solar Sources		
		Primary Batteries	Line Extension	Engine-Generators	PV	CPV	Dish-Engine
Solar-only direct use (e.g., water pump)	Up to ~100 kW, most less than 10 kW		●	●	●	●	●
Solar with storage (e.g., lighting)	Watts to kilowatts	Small loads only	●	●	With storage	~1-kW units with storage	
Hybrid power systems (e.g., Village Power)	Kilowatts to 100s of kilowatts		●	●	With storage and backup engine	With storage and backup engine	Hybrid or with storage and backup engine

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Table 2-4b. Cost of Transmission

Benchmark Price	Capacity Cost	Energy Cost	O&M Cost
Primary Batteries[a]		300¢/kWh	
Line Extension	$15,000/mi[b]	7.7–8.6¢/kWh[c]	
Diesel Gen-Set[c]	$350–500/kW	4.5–7.0¢/kWh	0.5–1.0¢/kWh
Propane Gen-Set[c]	$600–1000/kW	7.7–15.0¢/kWh	0.7–1.5¢/kWh

[a]12V, 18AH sealed lead-acid battery, www.RadioShack.com
[b]*The Potential Market for Photovoltaics and Other Distributed Resources in Rural Electric Cooperatives*, Hoff and Cheney. http://www.clean-power.com/research/microgrids/HistoricOpportunity.pdf
[c] *EIA Annual Energy Outlook* Average Residential Costs 2000-2025 (2001 Dollars)
The Role of Distributed Generation in Competitive Energy Markets, A Gas Research Institute summary completed March 1999, http://www.distributed-generation.com/Library/GRI_Role_of_DG.pdf
Fuel costs: EIA Annual Energy Outlook Average Industrial Costs 2000–2025 (2001 Dollars)

Solar-System Economics: The economics of off-grid applications can be quite different from grid-connected applications. Often, the PV system is lower in first cost than extending conventional energy sources to the point of need. However, off-grid PV systems with storage require replacement of the batteries every few years. Thus, the cost of O&M can be high relative to O&M for a grid-connected system. Often, other non-economic factors lead to the selection of solar for off-grid applications.

Value Considerations: The economics of off-grid applications is highly application specific and is often driven by the value of the service provided, more than by the cost of alternate energy supplies. Unlike applications that are connected to both a solar energy system and conventional energy-delivery systems, off-grid applications rely on the solar-system alone, so the design of the system must consider the extent to which uninterrupted power must be ensured. For small-scale applications, sufficient storage will be included to provide continued service at night and in cloudy weather. In addition to storing the electrical or thermal energy produced by a solar system, the application product can be stored, such as a several-day supply of pumped water in a stock tank. If it is not acceptable for the system to go off-line after an exceptionally long cloudy period, then the storage system must be designed conservatively.

Environmental considerations can also lead to the choice of solar for off-grid applications. Large, off-grid facilities typically use diesel engines as a power source. However, the noise associated with engine generators is undesirable in remote areas, and a fuel spill in a remote, pristine site can be very expensive to clean up. When solar is used to provide facility power in conjunction with battery energy storage and a backup engine generator, engine operation is infrequent. So propane may be used as a backup fuel, rather than diesel, which is the cheaper but more environmentally hazardous fuel.

Other value considerations driving the selection of an off-grid system include the following:

- Conventional energy sources are unavailable
- Cost of a delivery system for conventional energy is high
- Maintenance cost for conventional energy-delivery systems is high
- Portability is an essential feature
- Accessory power is needed for transportation applications.

2.4 Solar-Systems Descriptions and Requirements

The following section will briefly introduce and describe the solar systems that are used in the above markets. More-detailed material will follow in the section of this report describing the Solar Program Multi-Year Technical Plan.

2.4.1 Photovoltaics

Photovoltaic systems convert light energy into electricity using semiconductor devices most commonly known as "solar cells." PV systems are composed of groups of cells wired in series to produce higher voltages and wired in parallel to produce higher currents. Their modular nature means they can be used for applications ranging from a fraction of a watt, like a handheld solar calculator, to large-scale multi-megawatt power plants containing millions of solar cells.

Lighted bus shelter

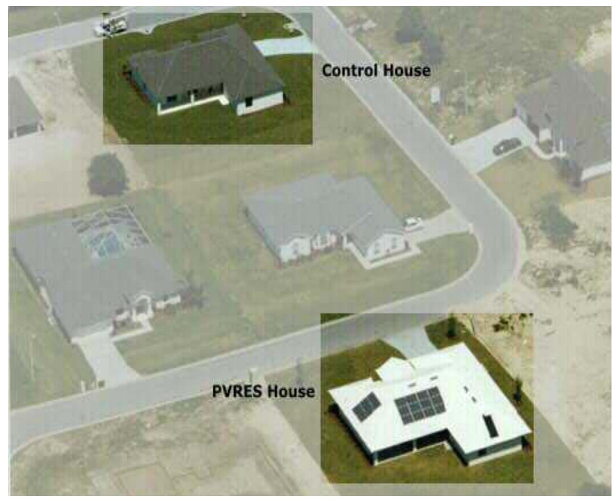
Grid-tied residence

Figure 2-3. Examples of everyday uses of photovoltaic systems

The most common types of PV devices are flat-plate modules, which are flat sheets of glass or other materials containing the solar cells. Typical module sizes range from 10 to 300 watts. A ground-mounted array of modules is typically mounted on an east-west axis at a tilt angle equal to the local latitude to optimize solar-energy production. Solar cells can also be integrated into products, like calculators or building materials. Building-integrated photovoltaics become an unobtrusive part of building walls and roofs. In some applications, flat-plate modules are placed on one- or two-axis tracking structures to increase power output by following the sun.

The simplest PV applications directly power a device, such as a water pump, whenever the sun is shining. Many applications incorporate energy storage, such as batteries, which are charged during sunny periods and then discharged to provide energy overnight and during cloudy periods. Grid-connected PV systems use inverters to convert the direct current (DC) output of the solar cells to alternating current (AC) and interact with the utility grid to provide continuous service. When more energy is available than is used by local loads, the excess energy flows into the utility grid for use by other loads. When less energy is available locally than needed, energy flows from the grid to local loads. About 340 MW of PV were manufactured in the world in 2001, with about 97 MW sold in the United States.

During the balmy summer of 1998 in Lakeland, Florida, a PV demonstration project showed that an energy-efficient residential building (PVRES House), producing its own solar-electric power, exerted almost no electric demand on the Florida electricity grid during peak hours—in stark contrast to a standard home (Control House). This experiment demonstrated the strong influence that photovoltaics, solar water heating, and energy-efficient design can have in areas where peak electricity demand—and electricity cost—is driven by air-conditioning loads. The Florida Solar Energy Center conducted the demonstration project with the assistance of Sandia National Laboratories and Lakeland Electric and Water.



Concentrating photovoltaic (CPV) systems use lenses or mirrors to focus sunlight onto the solar cells. Because of the concentrated sunlight, the output of each solar cell is greater than for one-sun devices, and fewer devices are required. Only the direct component of the sunlight is effectively concentrated, so the solar cells and associated optical concentrator must be mounted on a structure that tracks the sun. System sizes range from about 1 to tens of kilowatts and can be deployed in groups to produce more power. Small numbers of systems have been installed to date.

Figure 2-4. Concentrating PV (point-focus Fresnel lens)

2.4.2 Concentrating Solar Power Systems

Concentrating solar power systems concentrate the thermal energy of the sun to drive a heat engine. The heat engine then drives a generator to produce electricity.

Line-Focus Parabolic Troughs

Parabolic troughs use single-axis tracking mirrors to focus sunlight onto a glass-jacketed, tubular receiver containing a heat-transfer fluid, such as synthetic oil. The heated oil passes through a heat exchanger to generate steam that then drives a turbine generator. Nine plants, ranging in size from 13 to 80 MW, were installed between 1984 and 1990 in California. Most of these plants are hybrid power plants, with the capability to be dispatched to meet intermediate loads by providing up to 25% of the thermal input to the power block using natural gas to supplement the solar-thermal energy. These plants continue to operate and provide power to the electricity grid. Plans for two power plants in the United States have been announced recently. A solar-only, 50-MW power plant is to be built in Nevada, and a 1-MW power plant using an organic Rankine-cycle power block is to be built in Arizona. Other projects are pending in Spain, Israel, and, using Global Environmental Facility funds,[19] in several developing countries.

[19]Status of GEF Projects: www.gefweb.org/Map/orgp_2000-12.pdf- The Global Environment Facility (GEF) is a financial mechanism that provides grant and concessional funds to recipient countries for projects and activities that aim to protect the global environment. GEF resources are available for projects and other activities that address climate change, biological diversity, international waters, and depletion of the ozone layer. Countries can obtain GEF funds if they are eligible to borrow from the World Bank IBRD and/or IDA) or receive technical assistance grants from UNDP through a country program.

Figure 2-5. Parabolic trough

Solar Power Towers

Solar power towers use many large, sun-tracking mirrors (heliostats) to focus sunlight on a receiver at the top of a tower. A heat-transfer fluid heated in the receiver is used to generate steam, which, in turn, is used in a conventional turbine-generator to produce electricity. From 1996 to 1999, the Solar Two power plant demonstrated solar-power-tower technology at the 10-MW pilot-scale level using molten-salt thermal transport and storage technology. Storage allows solar energy to be collected and stored when the sun is shining, and steam is generated to drive a power turbine when electricity is needed. The next plant may be built in Spain, where a solar premium of about $0.12/kWh is available. A commercial-scale power plant is likely to be sized at the 50- to 200-MW level.

The high-concentration capability and size of solar power towers make them attractive for large-scale production of fuels and chemicals via thermochemical receivers. A number of processes for generating hydrogen with high-concentration solar have been investigated.

Figure 2-6. Power tower

Point-Focus Dishes

Similar to some concentrating photovoltaic systems, solar-dish/engine systems use parabolic mirrors to concentrate the sunlight. In the most common approach, the concentrated sunlight is absorbed by a solar receiver to directly or indirectly heat the hydrogen or helium working fluid of a Stirling-engine generator. Grid-interactive dish/engine systems have been demonstrated in small numbers at the 10-25-kW scale. These modular systems can be installed in large groups to serve utility needs or fielded in smaller numbers for distributed-energy applications. Limited operation as dispatchable, hybrid systems has also been demonstrated. In the hybrid configuration, when sunlight is not available, the solar receiver can be heated with natural gas to maintain system output. An off-grid system, dedicated to water pumping, has also been demonstrated.

Figure 2-7. Dish concentrator

The high-concentration capability of dishes also offers the potential to drive thermochemical receivers to produce fuels and chemicals, such as hydrogen. Several institutions have conducted research in this area.

2.4.3 Solar Thermal Systems

Solar thermal systems heat a working fluid for various thermal applications, such as domestic water heating, pool heating, space heating and cooling, and process heat.

One-sun (non-concentrating) thermal collectors are made in a variety of ways for different applications. Low-cost, unglazed arrays of polymer tubing are used for low-temperature applications, especially swimming-pool heating. These systems are connected to the pool pump and filter. Pool heating is a strong, commercial market with 8 million sq. ft. of collectors being installed each year, equivalent to 300 MW_t in rated capacity.

One of the simplest types of solar water heaters is the passive or integral collector storage (ICS) type. These units are typically constructed of several large-diameter copper tubes, piped in series, in a glazed housing. The thermal energy collected by these systems is stored in the volume of water in the collector, and the collector is installed in series between the building cold-water supply and the conventional solar water heater. Many of these systems are mounted, by design, directly to the roof deck like a skylight, with the roofing material surrounding the collector.

The collectors in active solar systems are typically constructed of copper tubes and absorbers in a glazed housing. The working fluid is pumped through the collector when the sun shines, and heat is stored in a tank, such as the conventional water heater tank, to provide hot water for domestic use. Pumped, direct hot-water systems circulate tap water through the collector. In hard-freezing climates, a water/glycol mixture is pumped through the collector, and a heat exchanger is used to transfer energy to the domestic hot water. Larger active systems can also be used to provide hot water for space or industrial process heat.

Figure 2-8. Solar water-heating systems

Thermosiphon solar water heaters combine the features of active and passive solar water-heating systems. The collector is similar to an active collector, but it is connected to a storage tank located slightly above the collector. Water circulates by thermal convection, without requiring a pump, and the tank is connected in series between the building cold-water supply and the conventional solar water heater. Hot water is driven from the storage tank by domestic line-pressure whenever there is a demand for it.

Two types of collectors can generate higher temperatures. The higher temperature can be used to drive absorption or desiccant air-conditioning systems, as well as for process heat, hot water, and space heat. Evacuated-tube collectors achieve higher temperatures because vacuum glass jackets surround the finned tubes, so heat loss is reduced. Some are installed with non-tracking compound parabolic reflectors. Parabolic troughs are also used for thermal applications. Industry has developed roof-mounted, trough-like systems with the intent of operating as combined heat and power (CHP) systems.

In general, sales of solar water-heating and space-heating systems in the United States have declined steadily since the end of solar tax credits in the early 1990s. However, some manufacturers have privately indicated that sales have recently increased as some builders and developers are including solar water-heating systems as standard features on new homes. Solar water heating is also very popular in Hawaii, where energy costs are especially high.

2.4.4 Hybrid Lighting

Hybrid lighting uses small solar concentrators and fiber optics to bring daylight into building interiors. The fiber optics are connected to luminaries that distribute the solar light and also include a backup artificial-light source, hence, the adjective "hybrid." This approach offers higher efficiency than the alternative of converting sunlight into electricity and then back into light. In addition, the natural sunlight delivered by the system is generally considered of better quality than artificial light.

Figure 2-9. Hybrid solar lighting

3.0 Implementing a Systems-Driven Approach

As described in Section 1.3, a systems-driven approach (SDA) will be employed to determine priorities within the Solar Energy Technologies Program. The SDA is a methodical process by which technology development efforts are driven by well-defined and well-documented requirements based on analyses of present and potential markets, technology trade-off studies, and research and development (R&D) reviews. A definition of the systems-driven approach, a variation of the definition used previously in the Office of Advanced Automotive Technologies, is as follows:

> All technical targets for R&D on the components and systems funded through the Solar Energy Technologies Program are derived from a common market perspective and national energy goals, and the resultant technologies are tested and validated in the context of established criteria for each market.

A key feature of the approach is the identification of market-based technical/economic requirements for each of the technologies funded within the Solar Program. Rigorous systems analysis is used to assess the impacts of improvements related to targets established for identified markets. This analysis applies to R&D conducted at fundamental levels (longer term) and more applied levels (nearer term). The analysis can also be used to assess the benefits of R&D efforts and related technologies relative to cost and to determine go/no-go decision points. Data are collected from laboratory and fielded systems to continually reassess goals, targets, progress, and critical technology paths. Coordination with industry and potential users of the technology is also a key ingredient in ensuring that the product meets the needs of the market. Ultimately, new technologies are graduated to the commercial marketplace through partnerships with industry.

A computer-modeling environment will be developed, similar to the ADVISOR (Advanced Vehicle Simulator) model in use by the Office of Advanced Automotive Technologies. Technology baselines will be documented in terms of cost and performance of systems, with the goal of determining the overall levelized energy costs of new systems configurations and technology developments. Using this Solar "ADVISOR" platform, analyses will be conducted in a manner that will include rigorous review by outside experts, and will be done at a level that will allow the identification of critical R&D efforts and the performance of appropriate cost/benefit/risk analyses of technology options under consideration. In this way, the SDA ensures strong, direct linkages between the technologies developed in this plan and the national goals and markets described in Section 2.

While this Multi-Year Technical Plan describes R&D activities to be conducted in a variety of technical areas, the SDA will be integrated throughout each of the technical subprograms. This section describes the development and execution of the overarching SDA for the Solar Program, whereas the technology programs described in the following sections will each use the SDA to determine their own optimal R&D paths.

Most of the activities associated with the development of the systems-driven approach for the Solar Program will be completed over the next 2 to 3 years. As more SDA functionality is developed within Solar Program subprograms, a growing number of program decisions will be based on analyses conducted with the Solar "ADVISOR" platform and other analysis tools. In this way, the SDA will be an integrated tool to guide Program direction over time, and future updates to this 5-year plan will reflect the outputs of these increased analysis activities.

The Value of a Systems-Driven Approach

A systems-driven approach, if applied correctly, offers clear advantages once market requirements are defined and understood.

- By using the market-based requirements and related system- and component-level technical targets, a systems-driven approach will allow project managers to more efficiently allocate limited resources to R&D efforts that yield the greatest impact on system cost and performance.
- A successful systems-driven program will provide researchers with tools to gain a much clearer understanding of the impacts of their specific R&D options on overall system cost and performance.
- Data generated from a well-managed systems-driven approach will provide the Solar Program with a more credible and defensible story regarding the impact of R&D efforts on DOE and national goals.

Within the Solar Energy Technologies Program, the systems-driven approach will be used to do the following:

- Align technology development efforts and objectives with market-specific requirements (e.g., requirements for grid-connected distributed, grid-connected utility-scale, residential/commercial, and remote applications).
- Apply a consistent methodology in developing and using analytical tools to analyze the impact of R&D activities (improvements in cost, performance, and reliability) and non-R&D activities (learning curve, economies of scale, financing, policy) on the costs and impacts of Solar Program technologies.
- Develop and document a consistent methodology for continuously updating information on the cost, performance, and reliability of technologies under development and funded through the Solar Program.
- Assess the relative probabilities of success among different technology R&D options, allowing informed decision-making at all levels.

3.1 Systems-Driven Approach Status

In the broad field of solar energy technologies, analytical tools have been developed and commonly used by researchers, government, and industry organizations, in the context of particular technology areas. In some cases, these tools are integrated within a technology area to determine technical targets within specific markets, based on assessments of associated costs and risks. Currently, however, no standard framework exists within the Solar Program for analyzing each of the Solar Program technologies in this manner. In some cases, analytical tools are oriented toward technology development, without consideration of end markets, capital, or associated risks of different technology investments. Thus, a standard configuration is needed to enable rigorous target-setting and decision-making at the Program level.

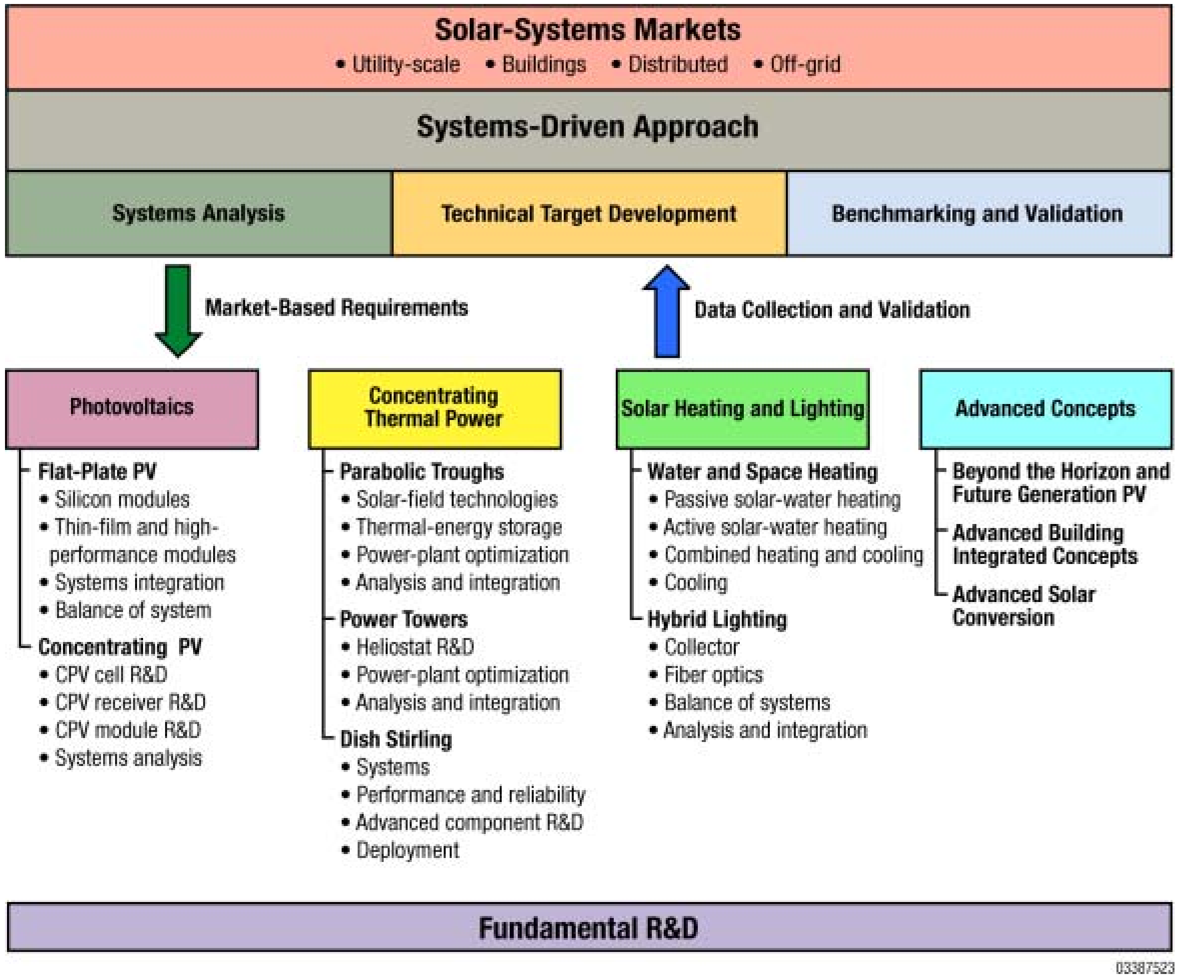


Figure 3-1. A systems-driven approach to program management requires the identification of market-based requirements for each of the technologies funded under the Solar Energy Technologies Program. Rigorous analysis is used to assess the cost and performance impact of R&D efforts and determine key go/no-go decision points, allowing managers to allocate resources efficiently to R&D efforts that yield the highest possible impact on Program goals and objectives.

3.2 Goal and Objectives

The goal of this activity is to develop a systems approach to managing each of the technologies developed within the Solar Program, thereby providing a framework for developing analytical models and for collecting and evaluating data from laboratory and fielded systems developed within each of the technology areas. This systems framework will facilitate programmatic decision-making based on the impact on key measures of success (i.e., levelized energy cost [LEC], payback, first cost) of different R&D options under study. Much of the development of this analytical capability will be conducted at the level of the individual technology programs. However, this activity will be responsible for assimilating the technology-specific analysis capabilities into an integrated management tool.

Objectives

2003: Complete a conceptual framework for a Program-level modeling and analysis capability, based on existing tools and identification of gaps and needs within the technology areas of Solar Program subprograms.

- Working with experts within each technology area, develop and document baseline technology configurations.
- Collect (or develop), validate, and document cost/performance data for each technology configuration.
- Identify existing analytical tools for each of the technology areas.
- Identify areas where it is necessary to develop additional analytical models (at the technology and Program level).

2004: Demonstrate a beta version of one or more integrated solar-analysis platforms.

- Select markets (i.e., distributed, utility, remote) for initial development of integrated analysis tool.

2006: Complete a fully implemented and integrated analysis capability that assists Program decision-making based on a standardized set of metrics, assumptions, and risk analyses within the several technology subprograms.

2007: Continue to refine and integrate systems-level analysis capabilities, including setting of technology targets, based on validation of new technology models and components, updates of simulation tools and models, and assessment of new or changing market conditions.

3.3 Key Technical Challenges and Barriers

There are several challenges to be overcome in developing this Program-level analytical environment. They include:

A. **Limited modeling and analysis tools**. Although many modeling and analysis tools are commonly used for the various solar technologies within the Solar Program, information flow among these tools is very limited.

B. **Access to data.** Sufficient data are required for analytical tools to provide relevant, defensible results. Data are needed related to costs, performance, operation, and maintenance of installed systems and components, as well as different market factors.

C. **Uncertainty of analysis.** This uncertainty exists across the range of analysis activities, from systems-level studies to assessing fundamental R&D efforts.

D. **Standardization of assumptions.** Comparisons between technologies and even between different R&D paths within particular technology sectors are often hampered by different sets of assumptions related to costs, markets, and other technology-related factors.

E. **Linkage between technology and markets.** Better market characterization is needed, along with assessments of the impacts of new technology introductions in these markets.

F. **Characterization of solar resource and its influence on technology and markets.** Improved resolution and accuracy in assessing the solar resource would greatly facilitate the capabilities of models to accurately predict the performance of solar installations and could be geographically linked to other analysis tools.

3.4 Approach and Tasks

The activities to be conducted in this program area fall into three primary categories: (1) development and implementation of a systems analysis framework, (2) development of technical targets and impact assessments for each Solar Program technology, and (3) benchmarking, validation, and periodic updating of technology analyses. A brief description for each of these categories is given below.

Table 3-1 lists specific tasks within these categories and associated barriers that these tasks address. Table 3-2 lists associated milestones, and the following Gantt chart summarizes the schedule for each of the tasks and milestones.

3.4.1 Systems Model Development

The major focus will be to develop the analytical model(s) used to estimate impacts of technology-specific R&D efforts and to establish standard frameworks for collecting and assessing performance and cost data within the technology programs. Existing simulation and modeling tools will be assessed, gaps among existing tools will be identified, and requirements will be established for creating new tools. These analytical tools will be linked in an integrated simulation environment—a Solar “ADVISOR” model—for market sectors served by the Solar Program’s portfolio of technologies. The integrated model will link to other energy models that are designed to simulate impacts of new technology introduction at national and even global scales, in terms of economic indicators, overall energy consumption, pollution or greenhouse gas emissions, or other indicators. Results will be formatted such that they can be used as input to such models, enabling the assessment of national impacts of Solar Program-driven technology-development activities.

3.4.2 Technical Target Development and Impact Estimates for Solar Systems

A primary activity within the systems driven approach is the development of technical/economic targets for systems funded within the Solar Program. These targets will be defined based on market requirement, assessments of out-year technology costs, and related estimates of penetration into existing and new markets. Working with technology experts, measures of success (i.e., LEC, payback, first cost) will be identified within market sectors, and targets will be set that align Solar Program activities with national energy goals. These high-level targets will be used within the technology subprograms to determine system- and component-level targets to meet the Program’s higher-order goals.

A system of tracking progress toward targets at all levels will be developed and implemented. This system will allow review of progress or, if necessary, modification of targets based on new data or changing national energy goals. In addition, trade-off studies for technologies under development will be conducted based on the contribution of different options toward meeting targets. Go/no-go decisions on technology options will be based on the results of these trade-off studies.

3.4.3 Benchmarking, Validation, and Analysis Updates

A major component of this effort will be the development of a standardized framework for monitoring and assessing the cost, performance, and reliability of fielded systems. Data related to cost, performance, and reliability will be collected for all technologies under development. Gaps in the baseline data will be identified, and an action plan will be produced to collect needed data. These data will be used to estimate a baseline cost for standard system configurations identified as part of the systems analysis framework activity. The baseline data described above will be updated regularly through data collection efforts undertaken by the technology programs. Continuous updating and validation is essential to demonstrate and document progress toward meeting the Program’s long-term goals for each technology. Data will be gathered through several means, including collaboration with designers and installers, periodically planned visits to project sites to perform field assessments of performance, collection of operation and maintenance information from technicians, and the use of remote data-acquisition systems to monitor operational characteristics.

Table 3-1. Tasks for Systems-Driven Approach Development and Implementation

Task	Title	Barriers
I	**Systems Model Development**	
1	**Standardization of assumptions and requirements** • Develop standard technology configurations • Develop technology benchmark input requirements • Develop standard financial/economic assumptions for baseline configurations	**E,D**
2	**Identification of analysis capabilities and gaps** • Identify existing program/technology analysis capabilities • Identify existing or recommend development of new market-based systems models • Identify solar resource data requirements necessary to support SDA systems-analysis efforts	**A**
3	**Development of Solar "ADVISOR" model** • Select candidate market(s) for near-term development of analysis tool • Develop analysis tools for remaining markets identified in the Solar Program Multi-Year Technical Plan. • Develop integrated Solar "ADVISOR" model based on integration of market-based tools	**A**
II	**Technical Target Development and Impact Estimates for Solar Systems**	
4	**Out-year technology cost and market-penetration projections** • Identify out-year technology cost projections based on existing program/technology documents (e.g., roadmaps, program plans) • Conduct rigorous due-diligence such as review of out-year projections • Refine cost and market penetration projections based on feedback from technology reviews and data collection/validation activities	**F**
5	**Development of long-term program/technology goals and estimates of technology impacts** • Align program/technology goals with EERE and national goals and interests (i.e., conservation, infrastructure, energy supply, environment, security) • Conduct analysis in support of existing or Program-developed market-penetration studies (i.e., support of National Energy Modeling System [NEMS], development of other tools) • Conduct analysis estimating long-term benefits that are aligned with National goals and interests • Conduct trade-off studies to select highest-impact technologies within market sectors	**F**
6	**Development of market-based technical/economic targets for key market sectors** • Identify high-level market-specific technical/economic measures of success for each technology (i.e., LEC, payback, first cost) • Develop system-level technical/economic targets for each high-level measure of success [MOS]. • Develop process for continuous tracking and revising of goals based on changing markets and policies	**F**

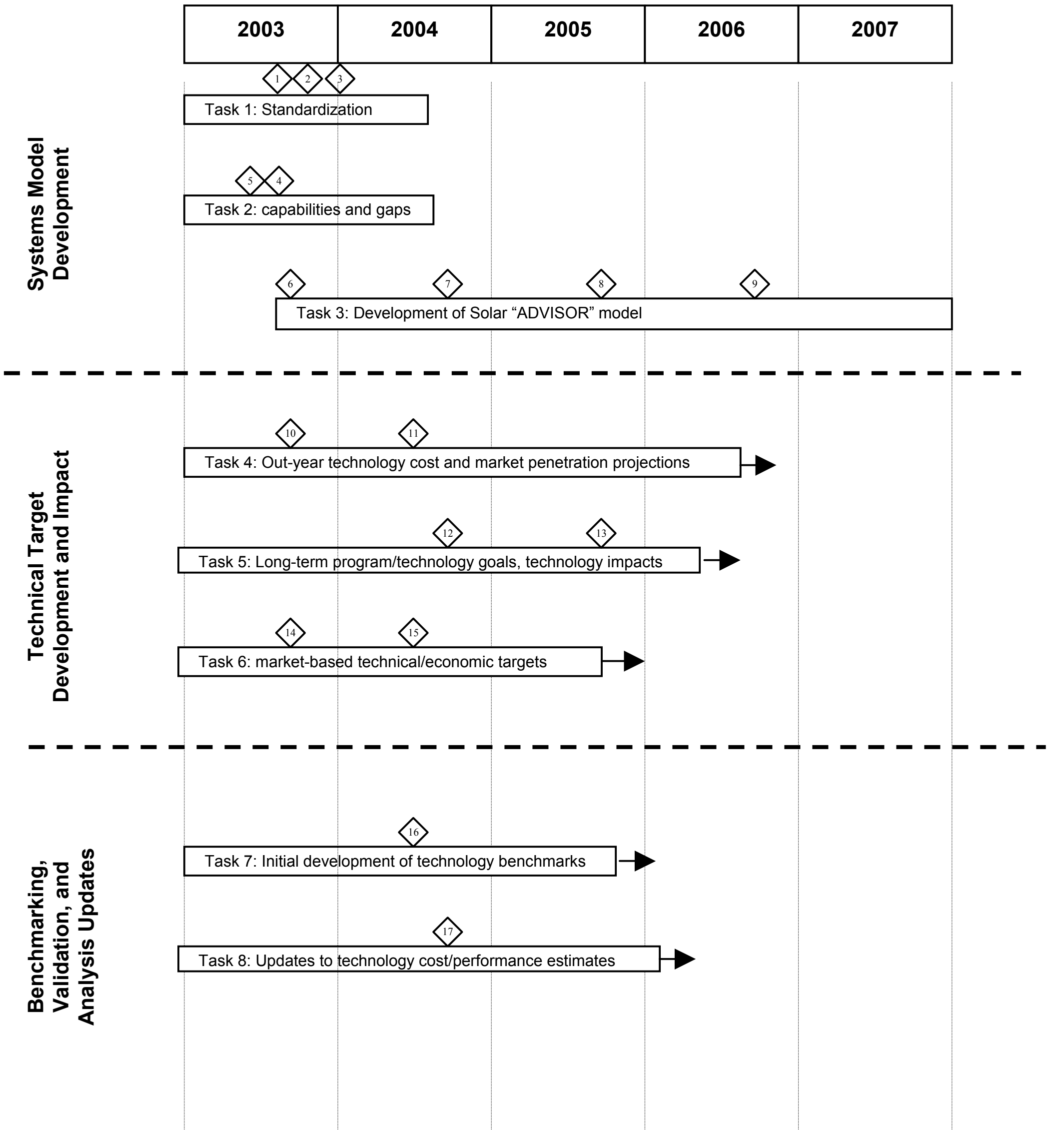
Task	Title	Barriers
III	**Benchmarking, Validation, and Analysis Updates**	
7	**Initial development of technology benchmarks** • Work with technology experts to develop cost, performance, and reliability FY03 benchmarks for each Solar Program technology based on standardized assumptions	**B,E**
8	**Updates to technology cost/performance estimates** • Define parameters of Program-wide cost, performance, and reliability data collection requirements • Develop updates of cost/performance based on field and laboratory data.	**B,E**

3.5 Schedule and Milestones

Table 3-2. Systems-Driven Approach Development and Implementation Milestones

Milestones	Task	Title	Estimated CY Date Quarter
1.	1	Develop standard technology configurations	03 Q3
2.	1	Develop technology benchmark input requirements	03 Q3
3.	1	Develop standard financial/economic assumptions for baseline configurations	03 Q4
4.	2	Identify existing program/technology analysis capabilities	03 Q3
5.	2	Identify existing or recommend development of new market-based systems-analysis platforms	03 Q2
6.	3	Select candidate market(s) for near-term development of integrated analysis platforms	03 Q3
7.	3	Demonstrate beta version of one or two integrated solar-analysis platforms for selected markets	04 Q3
8.	3	Demonstrate beta versions of integrated solar analysis platforms for remaining market sectors	05 Q3
9.	3	Demonstrate integrated analysis platform for integrated market sectors	06 Q3
10.	4	Identify out-year technology cost projections based on existing program/technology documents (e.g., roadmaps, program plans)	03 Q3
11.	4	Conduct rigorous due-diligence such as review of out-year projections (not including troughs/towers)	04 Q2
12.	5	Complete initial analysis estimating long-term benefits that are aligned with national goals and interests	04 Q3
13.	5	Complete trade-off studies identifying highest-impact technologies for each market sector	05 Q3
14.	6	Identify high-level market-specific technical/economic measures of success for each technology (i.e., LEC, payback, first cost)	03 Q3
15.	6	Complete development of initial system-level technical/ economic targets for each high-level measure of success	04 Q2

Milestones	Task	Title	Estimated CY Date Quarter
16.	7	Document cost, performance, and reliability FY03 benchmarks for each Solar Program technology based on standardized assumptions	04 Q2
17.	8	Define parameters of Program-wide cost, performance, and reliability data collection requirements	04 Q3



Legend

◇ Milestones

1. Develop standard technology configurations
2. Develop technology benchmark input requirements
3. Develop standard financial/economic assumptions for baseline configurations
4. Identify existing program/technology analysis capabilities
5. Identify existing or recommend development of new market-based systems analysis platforms
6. Select candidate market(s) for near-term development of integrated analysis platforms
7. Demonstrate beta version of 1-2 integrated solar analysis platforms for selected markets
8. Demonstrate beta versions of integrated solar analysis platforms for remaining market sectors
9. Demonstrate integrated analysis platform for integrated market sectors
10. Identify out-year technology cost projections based on existing program/technology documents (roadmaps, program plans, etc…)
11. Conduct rigorous due-diligence like review of out-year projections (not including troughs/towers)
12. Complete initial analysis estimating long-term benefits that are aligned with National goals and interests
13. Complete trade-off studies identifying highest impact technologies for each market sector
14. Identify high-level market-specific technical/economic measures of success for each technology (i.e. LCOE, payback, first cost)
15. Complete development of initial system level technical/economic targets for each high-level measure of success
16. Document cost, performance, and reliability FY03 benchmarks for each Solar Program technology based on standardized assumptions
17. Define parameters of program-wide cost, performance, and reliability data collection requirements

4.0 Introduction to Technical Sections

As briefly introduced in Section 2, the DOE Solar Energy Technologies Program encompasses three major types of solar technologies: photovoltaics (flat-plate and concentrator), high-temperature solar thermal (troughs, towers, and dishes), and low-temperature solar collectors (active and passive solar water heaters and solar hybrid lighting). Section 2 pays particular attention to the existing markets and applications for solar technologies. Sections 4.1–4.4 will describe the status of research and development for all Solar Energy Technologies subprograms.

Each technical section includes a technology status overview, programmatic goals and objectives, description of key technical challenges, detailed technical targets (often for each component of the identified solar energy system), clearly articulated technical barriers, a roster of activities that include the target barriers, and a summary chart that highlights key programmatic milestones and decisions anticipated over the next 5 years.

4.1 Photovoltaic Systems

Photovoltaics (PV) is the direct conversion of light into electricity using semiconductor materials. PV Subprogram research and development activities are divided into two main areas: flat-plate PV and concentrator PV.

4.1.1 Flat-Plate Photovoltaic Systems

Flat-plate PV systems generally consist of a collector/converter called the array (which in turn consists of modules) and several other items, often grouped together and referred to as the balance of system (BOS) components. The modules are generally composed of a number of solar cells, appropriately connected to provide desired current and voltage. The BOS includes additional power conditioning, support structures, electrical connections, and storage (typically batteries, although they are not always required). A schematic showing components of a PV system and two typical configurations is presented in Figure 4.1.1-1.

In this section, we look at R&D for technologies (technical pathways) that are candidates to make flat-plate PV systems capable of significant penetration into electrical energy markets. The status of current flat-plate PV systems and ongoing R&D are described. Goals and objectives are identified. Barriers to achieving goals will be detailed and tasks to overcome barriers presented, along with both achievement and decision milestones.

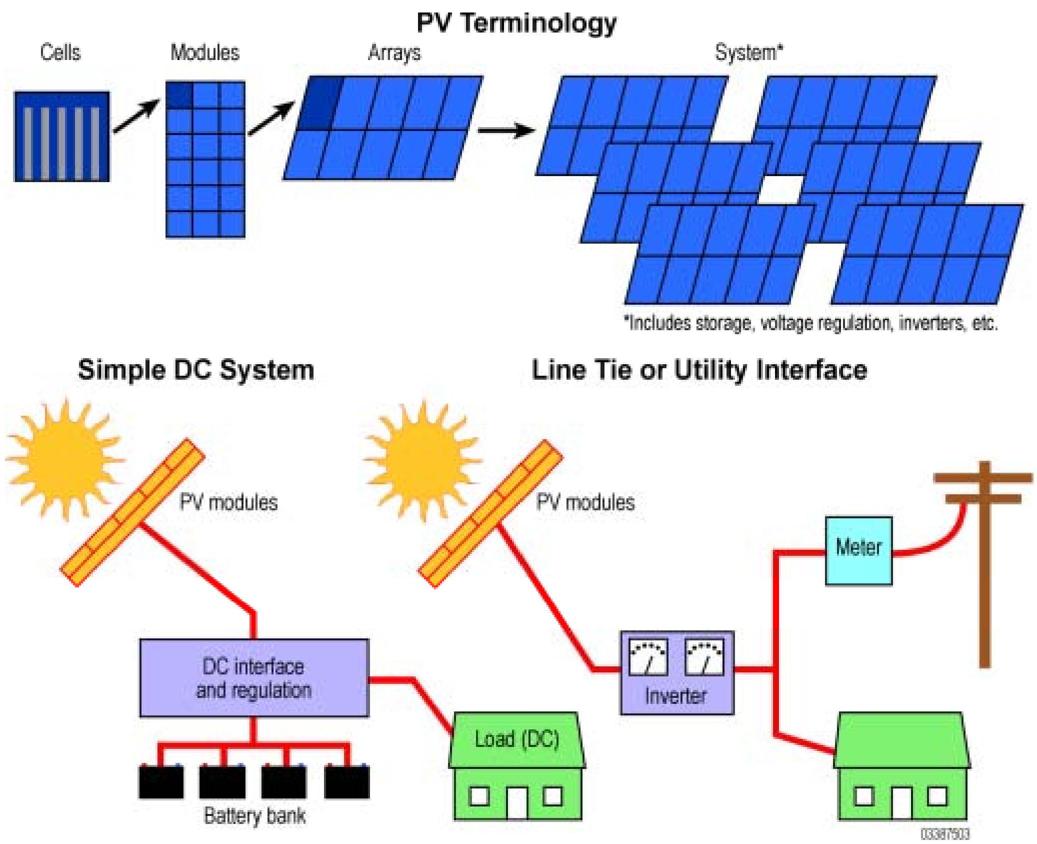


Figure 4.1.1-1. This schematic shows the elements of a PV system and two applications, each with unique system requirements. The first application (lower left-hand corner) is off-grid and requires energy storage. The second application does not require storage because it is tied to the utility grid.

Markets and applications, which were discussed in an earlier section, are of prime importance in determining the system and its goals. For a nascent technology such as PV, the markets will determine ultimate cost goals, but applications will determine the system and its components. U.S. cell and module production is estimated to have been about 120 MW_p in 2002. For the last several years, the worldwide PV market has grown by more than 25% per year, and the 2002 world market has been reported as more than 550 MW_p (*Maycock, PV News, May 2003*). Much of this present market consists of residential applications, but industrial installations are also growing in significance.

The PV Subprogram of the DOE Solar Energy Technologies Program supports R&D by national laboratories, universities, and industry in pursuit of activities intended to enable further development of a strong private industry in PV. Thus, a primary objective is to work with the U.S. industry to enable it to achieve its goals, as presented in the *U.S. Photovoltaic Industry Roadmap*. In it, the PV industry sees a time-phased entry into various markets with a progression from smaller high-value niche markets to larger utility-grid markets. The Roadmap projects a 2020 domestic PV industry that will provide up to 15% (about 3.2 GW_p) of new U.S. peak electricity-generating capacity per year. Figure 4.1.1-2 depicts the evolution of these markets, which will be both supported and driven by simultaneous developments of the PV technologies as old technology paths provide cheaper and better systems—even as they are overtaken by newer technologies.

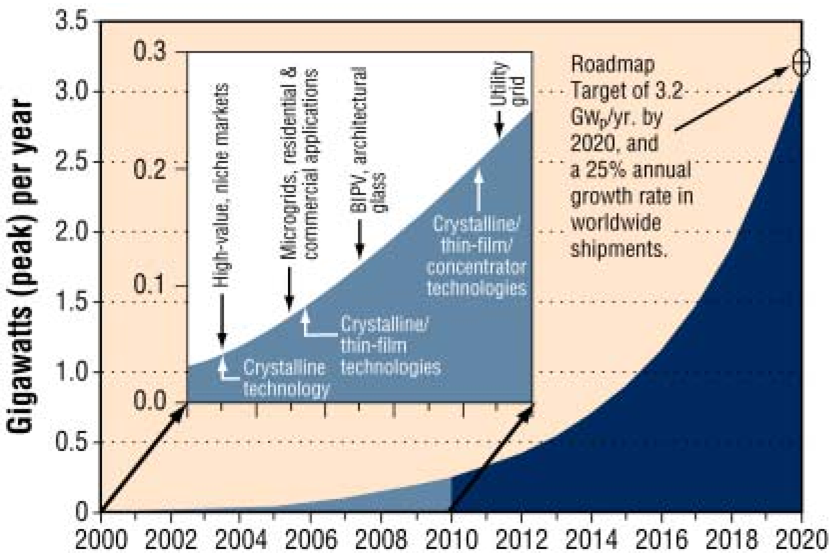


Figure 4.1.1-2. Goal for U.S.-manufactured PV modules installed in U.S. domestic applications, for a U.S. market share that increases linearly from 30% to 50% from 2000 to 2020. Inset shows the evolution of the impact of various markets and technologies. (From the *U.S. Photovoltaic Industry Roadmap*).

4.1.1.1 Technology Systems Status

PV systems must be optimized for specific applications and meet certain performance, reliability, and cost criteria if they are to satisfy the consumer requirements and compete in the energy marketplace. A key to optimizing system performance is the availability of design and analytical computer models. Although several tools do exist to assist PV system designers, installers, and technicians, improved tools are needed for this young industry. Improved modeling and analytical tools will determine technology-development paths that will produce the greatest impacts in these existing and new markets. Systems-integration tools will aid designers and installers in better optimizing performance and in avoiding component mismatches that can lead to sub-optimal system reliability and performance. Collecting data from laboratory tests and fielded systems will provide developers and researchers with a much greater understanding of root causes of failures in systems. And new codes, standards, and certification programs will bring assurance to the marketplace that a minimum quality standard has been applied throughout the design, installation, and servicing processes.

Figure 4.1.1-3 shows relative price for labor and material components for a current typical PV system—in this case, residential. As the breakout shows, the module-price contribution is higher than 50%. For this reason, a key goal of the PV R&D effort has been to ***reduce the module manufacturing cost to less than $1.00 per watt.*** Furthermore, a primary activity of the PV Subprogram addresses module fabrication, performance, and reliability. However, a rigorous systems-analysis activity enables us to ensure that the PV systems are addressing the critical cost and performance targets set by the DOE Solar Program.

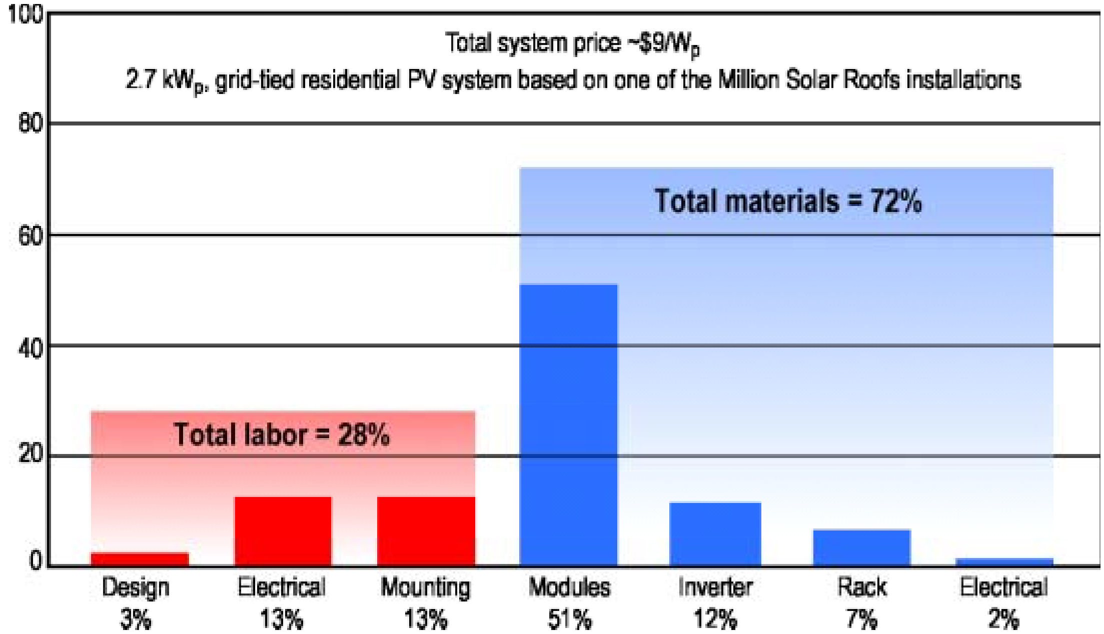


Figure 4.1.1-3. Price breakout (by percentage) of an installed residential PV system.

Current Activities

Crystalline silicon (c-Si) and thin films (with multijunction approaches included) are the two major pathways to achieve PV goals using flat-plate modules. Each of these consists of multiple options (e.g., wafered silicon and sheet silicon of several types are all c-Si approaches). This multiple-path characteristic makes the PV technology robust and offers high potential for future advances in both improved performance and reduced cost.

Crystalline silicon has a well-established technology base and the c-Si industry supplies nearly 90% of the PV market. It should continue to dominate the market for at least 5 more years. The technical progress will be evolutionary, but advances will be quickly integrated into the marketplace. This will help build the infrastructure required for continued rapid growth. Cell conversion efficiencies for current c-Si approaches vary from 12% to 17%. Module efficiencies tend to be 0.5% to 2% lower, based on total area.

Other leading candidates for very low-cost PV are the following thin-film materials: (1) amorphous silicon (a-Si), cadmium telluride (CdTe), and copper indium diselenide (CIS), which are the most mature among all thin-film technologies; (2) thin-film silicon, which may encompass both crystalline and/or amorphous silicon; and (3) high-performance multijunction combinations. The key metrics of thin-film progress are the same as those for any PV module technology: efficiency at the commercial-module level, manufacturing cost, and outdoor module reliability. Many challenges have to be overcome before all of these can be optimized. For thin films, the monolithic process blurs the distinction between cells and modules. However, commercial module efficiencies vary between 5% and 11%.

The PV Subprogram consists of R&D efforts addressing a broad spectrum of issues from material and deposition improvements to manufacturing-process R&D and in-line process-diagnostics development. These efforts are divided into three areas: Fundamental Research, Advanced Materials and Devices, and Technology Development. These areas track the development stages for PV materials, components, and systems. Essentially, all of the activities in the Fundamental Research and Advanced Materials and Devices areas are directed toward module improvements leading to lower production costs. Similarly, the Technology Development area consists mainly of systems engineering and reliability and balance-of-system (BOS) development.

Fundamental Research includes measurements and characterization, our basic research and university program, and high-performance advanced research. The measurements and characterization activities cut across all strata of the project from basic R&D to module and system performance to solar resource assessment and characterization. Therefore, throughout the discussion on the approach and tasks, we must remember an important part of any task is being able to measure and characterize both status and progress. Such activities are a constant thread though the development of basic components to the assembly of an efficient, reliable PV system.

The basic research and university programs include basic studies by our university centers of excellence, DOE laboratories, and under subcontract to industry. The work is focused on: (1) electronic materials and devices, with emphasis on the study of defects and structure; and (2) material and device processing science, including the development of a new class of deposition, processing, and characterization tools that will allow us to integrate processes and diagnostics in a flexible fashion, providing the opportunity to study research problems that were previously difficult or even impossible to pursue.

The high-performance advanced research addresses the development of higher-performance devices that can be attained by tandem or multijunction solar cells. Such structures lend themselves to higher efficiency through the utilization of both a broader portion of the solar spectrum and more efficient conversion of individual photons. Present efforts are directed toward choosing and improving materials and processes that can maximize performance and offer low-cost manufacturing potential.

The ***Advanced Materials and Devices*** area includes the Thin Film PV Partnership, crystalline silicon/module reliability, and the PV Manufacturing R&D Project. The Thin-Film Partnership is primarily a subcontracted program addressing the development of solar cells and modules based on extremely thin layers of both active PV materials and certain layers of ancillary materials (e.g., contacts). Amorphous silicon, cadmium telluride, copper indium diselenide, and thin-film silicon are leading active-material candidates in the thin-film area and are being developed because of their high potential for low-cost photovoltaics. Each thin-film technology has formed a national team comprising the nation’s best research and engineering talent drawn from industry, universities, and the national laboratories. In addition, a crosscutting national team was started in 2002 to address thin-film-module packaging issues. Key research challenges being addressed in thin films include improving every aspect of active-layer manufacturing to reach low-cost production, improving commercial module efficiencies, and assuring intrinsic device and packaged-module reliability outdoors.

The crystalline-silicon/module reliability area addresses performance, reliability, and testing. Outdoor durability testing and accelerated testing, as well as failure analysis, are performed on modules to determine areas for further R&D and improvement. Modeling is performed in support of the experimental procedures to facilitate problem understanding and to develop solutions to reliability issues.

The PV Manufacturing R&D Project is intended to improve PV manufacturing processes and products while reducing costs, providing a technology foundation that supports significant manufacturing scale-up (500 MW total U.S. capacity), and positioning the U.S. industry to meet rapidly emerging large-scale deployment opportunities. Individual manufacturers building on their own unique approaches perform the R&D efforts. The work areas include issues such as improvement of module-manufacturing processes to increase module reliability; system and system-component packaging, system integration, manufacturing, and assembly; product manufacturing flexibility; and BOS development, including storage and quality control.

The third area of flat-plate PV R&D is ***Technology Development***. This incorporates activities such as systems analysis and systems engineering, which includes benchmarking and validation, PV system performance and standards, inverter and other balance of systems, and technology-adoption activities. Technical support and outreach activities—both domestic and international—such as Million Solar Roofs, the Solar Decathlon, support to bilateral and multilateral agreements, and developments in building-integrated PV, all fall into the technology-adoption category. The building-integrated R&D addresses the incorporation of PV into traditional building components and encourages development of the symbiotic relationship that can exist between architecture and PV.

The systems-analysis activities are designed to conduct investigations into the steps needed to improve the impact of PV technologies in the marketplace through technical R&D, market analyses, and conducting value and policy analyses. System reliability and cost analyses are also being conducted. The link between all of these activities is their role in the overall systems-driven approach being applied throughout the Solar Program. Thus, systems analysis also entails the assessment of existing tools, such as computer models, and the development of new ones to facilitate these analyses. The PV Advisor Model, as part of the overall Solar Advisor model, is under development as part of this task area.

The systems-engineering area consists of: (1) benchmarking and validation through testing at all levels of the system, (2) development of activities designed to measure and characterize system performance and develop appropriate standards, (3) inverter and other BOS development, and (4) development of domestic and international market opportunities in support of industry.

Several studies have indicated that some of the key factors in the overall cost of PV systems are based on the BOS components in terms of installed costs, operational performance, and the continued costs of operation and maintenance (O&M). Thus, activities in the BOS area will be undertaken to better understand these costs and their effects on overall PV system costs in a variety of market sectors. Using a systems-driven approach, R&D will address technical barriers related to reducing installed costs of BOS components and increasing reliability, thus reducing O&M costs and overall levelized energy cost (LEC).

4.1.1.2 Technology and Component Goals and Objectives

Overall goals of the PV systems activities are to assist industry in developing PV systems that can provide quality performance and reliability at acceptable costs to the consumers. Acceptable costs are determined by a number of factors and will be fine-tuned as part of the continuing analysis, target setting, and validation conducted within the context of the ongoing systems-driven approach.

Goals

Leaders of the DOE PV Subprogram have developed goals for 2020 that they believe are appropriate for achieving national significance and are consistent with industry needs (as reported in the *U.S. Photovoltaic Industry Roadmap*). These goals are to:

- Reduce the LEC for PV to $0.06/kWh.
- For crystalline-silicon modules, increase the conversion efficiency to 20% and reduce producer module-manufacturing costs to less than for $\$67/m^2$, thus enabling PV systems with a 30-year lifetime at an installed cost of $2.00/W.
- For thin-film modules, increase the conversion efficiency to 15% and reduce producer module-manufacturing costs to less than $\$50/m^2$, thus enabling PV systems with a 30-year lifetime at an installed cost of $2.00/W.

The Solar Program Strategic Performance Goal in PV (from the FY 2004 Congressional Budget) is "…by 2006, reduce the cost of grid-tied (battery-free) photovoltaic systems to the end user (including operation and maintenance costs) to $4.50/W, from a median value of $6.25/W in 2000, which requires a reduction in the cost of the PV module itself to $1.75/W, compared with a cost of $2.50/W in 2000, and would reduce the average cost of electricity generated by PV systems from a current $0.25/kWh to $0.18/kWh;…." FY 2005 technical targets are to verify U.S.-made commercial-production PV modules with conversion efficiencies of 14% for crystalline silicon modules and 11% for thin-film modules.

The Multi-Year PV objectives and targets in the following sections are calculated to be consistent with the goals listed above. They will be refined using the systems-driven approach to incorporate and guide future progress in an iterative manner.

Objectives

Objectives of specific PV technologies depend on timing and the application. For this Multi-Year Technical Plan, the objectives are presented consistent with the goals listed above and in the time-frame context of present status (2003), fifth year of the plan (2007), and long-term (2020). Three major applications are addressed to demonstrate the range of applications. We have selected specific systems with existing data to establish the 2003 baseline technology characterization. The baseline utility system incorporates thin-film modules. The baseline residential systems use crystalline-silicon modules. However, because different material systems provide alternate pathways to achieving PV goals, trade-offs between performance and cost characteristics exist for each of the examples. Present time-phased objectives follow for: (1) a 2-MW utility-scale application, (2) a 2.7-kW grid-connected residential application, and (3) a 2.7-kW grid-connected application with storage.

Utility-Scale Applications

The 2003 baseline technology for utility-scale applications is a 2-MW facility:

- Direct module-manufacturing costs are $3/W.
- Inverter costs are $0.60/W.
- System prices are $5.30/W.
- LEC is $0.24/kWhr and depends on financing and solar resource assumptions. It is the cost to the utility to provide electricity and does not include land, site preparation, or marketing costs.

By 2007, the objectives are to:

- Reduce direct module-manufacturing costs to $1.65/W.
- Reduce inverter costs to $0.40/W.
- Achieve 12% module conversion efficiency and resolve device-level issues necessary for 20-year lifetime for thin-film modules.

- Reduce system prices to $3.60/W.
- Obtain LEC of $0.15/kWh with assumptions as in 2003.

By 2020, the application size for utilities will probably be larger than 20 MW. The objectives are to:

- Reduce direct module-manufacturing costs to the range of $0.33 to $0.50/W.
- Reduce inverter costs to $0.25/W.
- Achieve 15% conversion efficiency and 30 -year lifetimes for commercial modules with less than 1% per year degradation.
- Reduce system prices to the range of $1.50 to $2.00/W.
- Obtain LEC of $0.06/kWh.

Grid-Connected Residential Applications

Because BOS requirements are expected to be more costly in the residential applications, the resulting system and LEC are somewhat higher than for utility applications. However, in this application, the target is the retail cost of electricity as opposed to the wholesale cost for utility applications. The baseline described here is for crystalline silicon, but various PV approaches may reach the later-year targets.

The 2003 baseline technology for grid-connected residential applications is a 2- to 3-kW residence.

- Direct module-manufacturing costs are $3.00/W.
- Inverter costs are $1.10/W.
- System prices to the consumer are $6.25 to $9.45/W and are highly dependent on installation costs and available incentives from local and state entities.
- LEC is $0.25 to $0.40/kWh and depends on financing and solar resource assumptions.

For 2007, grid-connected residential application objectives are to:

- Reduce direct module-manufacturing costs to $1.65/W.
- Reduce inverter costs to $0.50/W.
- Achieve module efficiencies of 15% with a 20-year lifetime.
- Reduce system prices to $5.25/W.
- Obtain LEC of $0.22/kWh.

By 2020:

- Reduce direct module-manufacturing costs to the range of $0.33 to $0.50/W
- Reduce inverter costs to $0.30/W.
- Achieve module efficiencies in the range of 15% to 20% with a 30-year lifetime.
- Reduce system prices to the range of $2.30 to $2.80/W.
- Obtain LEC in the range of $0.08 to $0.10/kWh.

Grid-Connected Application with Storage

The objectives for this application are similar to those for the grid-connected residential without storage. The added storage is intended for backup in the case of power outages, but is not adequate for continuous off-grid operation. This market for grid-connected applications with storage has been growing and is likely to become a standard application, so we include it here as a third example. The differences from the previous example may be summarized by noting the changes in the system costs and LEC. The baseline for this 2- to 3-kW PV system with storage in 2003 has a system cost of $11.30/W and LEC of $0.59/kWh. For 2007, the costs are $7.30/W and $0.38/kWh, respectively. For 2020, the system cost ranges from $3.90 to $4.40/W and LEC from $0.25 to $0.27/kWh.

4.1.1.3 Key Technical Challenges

The key technical challenges for flat-plate PV systems are to:

- Reduce the cost of material used in the manufacture of modules through reduced material requirements and improved material usage.
- Improve processes and in-line diagnostics to enable increased throughput and yield for module production.
- Improve system reliability by improving related module and power-conditioning lifetimes.
- Improve system conversion efficiencies through both higher-performance cells and reduced system losses.
- Improve the quality of installed PV systems through system modeling that will identify both essential and high-impact R&D areas.
- Support the development of codes, standards, and certification programs necessary for a mature and established infrastructure.

Technical Targets

As with the objectives above, the technical targets and the specific PV technology depend on timing and application. The systems-driven approach will be used to further analyze the market-driven differences in various applications. The following three tables (4.1.1-1 through 4.1.1-3), which present targets developed for flat-plate PV, demonstrate anticipated characteristics for the 2-MW utility-scale application, the 2- to 3-kW grid-connected residential application, and the 2 to 3-kW grid-connected application with storage.

Table 4.1.1-1. Targets for Flat-Plate PV Systems in Large Utility-Scale Applications
(2-MW example)

System Element	Units	2003	2007	2020
Design	$\$/W_{ac}$	0.10	0.08	0.02
Module Price	$\$/W_{p,dc}$	3.60	2.50	1.00–1.50
Direct cost/power	$\$/W_{p,dc}$	3.00	1.65	0.33–0.50
Conversion efficiency	%	8	12	15
Direct cost/area	$\$/m^2$	240	200	50–75
Inverter Price	$\$/W_{ac}$	0.60	0.40	0.25
DC-AC conversion efficiency	%	94	96	97
Replacement	Years	5	10	20
Other BOS	$\$/W_{ac}$	0.40	0.25	0.15
Installation	$\$/W_{ac}$	0.60	0.40	0.10
INSTALLED SYSTEM PRICE	$\$/W_{ac}$	5.30	3.60	1.50–2.00
System Efficiency	%	6	9	12
Lifetime	Years	20	20	30
Degradation	%/Yr	2–3	2–3	1
O&M cost	$\$/kWh_{ac}$	0.03	0.02	0.005
LEVELIZED ENERGY COST	$\$/kWh_{ac}$	0.24	0.15	0.05–0.07

Considerations:
LEC is cost to utility to provide electricity with PV system.
LEC is dependent on solar resource (2500 kWh/m^2/yr used for lower case on 2003 numbers).
O&M: inverter maintenance contract; 5-yr replacement; 15-yr replacement.
Design: One-person month.

Table 4.1.1-2 presents targets for a residential application comprising crystalline-silicon modules in the 2003 baseline example, and Table 4.1.1-3 adds a storage capacity to these parameters. Because BOS requirements are expected to be more costly in the residential applications, the resulting system and LEC targets here are somewhat higher than in Table 4.1.1-1 above. However, for comparable applications (markets), the ultimate targets for thin films and crystalline-silicon technologies (including new thin-silicon approaches) are the same.

Table 4.1.1-2. Targets for Flat-Plate PV Systems in Residential Applications
(2–3-kW grid-tied example)

System Element	Units	2003	2007	2020
Design	$\$/W_{ac}$	0.25	0.15	0.10
Module Price	$\$/W_{p,dc}$	4.80	2.50	1.00–1.50
Direct cost/power	$\$/W_{p,dc}$	3.00	1.65	0.33–0.50
Conversion efficiency	%	14	15	15–20
Direct cost/area	$\$/m^2$	420	250	50–100
Inverter Price	$\$/W_{ac}$	1.10	0.50	0.30
DC-AC conversion efficiency	%	94	96	97
Replacement	Years	5	10	20
Other BOS	$\$/W_{ac}$	0.85	0.60	0.40
Installation	$\$/W_{ac}$	2.50	1.50	0.50
INSTALLED SYSTEM PRICE	$\$/W_{ac}$	6.20–9.50*	5.20	2.30–2.80
System Efficiency	%	11.5	14	16
Lifetime	Years	20	20	30
Degradation	%/Yr	1–2	1-2	1
O&M cost	$\$/kWh_{ac}$	0.08	0.02	0.005
LEVELIZED ENERGY COST	$\$/kWh_{ac}$	0.25–0.40*	0.22	0.8–0.10

Considerations:
LEC is cost to consumer.
2003 numbers taken from example of Figure 4.1.1-3.
LEC is dependent on solar resource (2000 $kWh/m^2/yr$ assumed here).
2003 data assume retrofit market; 2007 and 2020 are for new construction.
O&M primarily based on one inverter replacement every 5 years for 2003 figures; every 10 years for 2010 and 2020 figures.
*The ranges reflect the variability in calculations including various incentives and financing assumptions. LECs have been reported previously for year 2000 with incentives included.

Table 4.1.1-3. Targets for Flat-Plate PV Systems in Residential Applications
(2–3-kW grid-connected with storage example)

System Element	Units	2003	2007	2020
Design	$\$/W_{ac}$	0.55	0.30	0.20
Module Price	$\$/W_{p,dc}$	4.80	2.50	1.00–1.50
Direct cost/power	$\$/W_{p,dc}$	3.00	1.65	0.33–0.50
Conversion efficiency	%	14	15	15–20
Direct cost/area	$\$/m^2$	420	250	50–100

Inverter Price	$/W$_{ac}$	1.10	0.50	0.30
DC-AC conversion efficiency	%	94	96	97
Replacement	Years	5	10	20
Other BOS	$/W$_{ac}$	1.10	1.00	0.40
Storage	$/W$_{ac}$	0.75	0.75	0.75
Installation	$/W$_{ac}$	3.00	2.20	1.20
INSTALLED SYSTEM PRICE	$/W$_{ac}$	10.30	7.30	3.90–4.40
System Efficiency	%	11.5	14	16
Lifetime	Years	20	20	30
Degradation	%/Yr	1–2	1–2	1
O&M Cost	$/kWh$_{ac}$	0.20	0.14	0.125
LEVELIZED ENERGY COST	$/kWh$_{ac}$	0.59	0.38	0.25–0.27

Considerations:
LEC is cost to consumer.
2003 numbers taken from example of Figure 4.1.1-3 with storage added.
LEC is dependent on amount of kWh of sunshine per year (2000 kWh/yr assumed here).
2003 data assume retrofit market; 2007 and 2020 are for new construction.
Storage: 25 kWh of batteries.
O&M: inverter replacement (5 yrs in 2003); battery replacement (5 years +$400 labor); battery maintenance ($200/yr)

The following BOS targets (Table 4.1.1-4) show the difference in cost for various-sized inverters and is shown here for correlation to the above target tables. Additional lower-level targets will be developed as the systems-driven approach is applied further to PV systems

Table 4 .1.1-4. Targets for PV Balance of Systems

	Indicator	Units	2003	2007	2020
Inverters					
1–10 kW	Inverter replacement	Years	5*	10	20
	Hardware cost	$/W	0.73–1.50	0.50	0.30
	O&M per lifetime (labor)	$/W	0.10–0.20	0.15	0.10
10–100 kW	Inverter Replacement	Years	5*	10	20
	Hardware Cost	$/W	0.75	0.40	0.30
	O&M per lifetime (labor)	$/W	0.01–0.10	0.05	0.01
>100 kW	Inverter Replacement	Years	5*	10	20
	Hardware cost	$/W	0.60	0.40	0.25
	O&M per lifetime (labor)	$/W	0.04	0.03	0.02
Charge controllers	Replacement	Years	5	10	20
	Hardware Cost	$/W	0.10–0.25	0.10	0.10
	O&M per MTFF (labor)	$/W	0.025	0.025	0.025
Batteries	Lifetime	Years	3–8**	10	10
Array mounting	Installed cost	$/W	1.85	1.50	0.50

*Information needs updating.
**Highly dependent on battery technology, system design and maintenance.

Barriers

Preliminary barriers to the achievement of system and lower level goals and objectives have been identified. These barriers will be further examined as we continue our systems-driven analytical activities and identify key cost and performance drivers. Barriers for flat-plate PV are listed below.

Fundamental Research

A. Crystalline cells—need improved understanding of chemistry and physics of material and devices, understanding defects and impurities and their impacts on cell efficiencies.
B. Thin-film modules—need improved understanding of chemistry and physics of active absorber material as related to all aspects of the module-production process (from initial contact deposition on the support stratum through compatibility of different layer processes to encapsulation).

Advanced Materials and Devices

C. A key driver in module cost is based on low utilization efficiency and high cost of raw materials. This can be improved through reduction and recycling of waste materials and use of thinner cells (crystalline).
D. Low or limited yields in the manufacturing processes for both crystalline and thin-film modules.
E. Environmental impacts in the manufacturing processes, through generation of potentially hazardous waste substances.
F. Need for better understanding of the properties of encapsulants and their effects on module cost, performance, and reliability.
G. Need for improved processes related to in module fabrication—reduced cost, improved reliability, stability, and performance.
H. Crystalline cells—limitations in effectiveness of cell-to-module processing of strings and tabs.
I. Thin films—temperature sensitivity of inexpensive non-conducting continuous substrates for monolithic production
J. Thin films—low deposition rates for all thin layers limit commercial production capacities.
K. Limitations in cost and reliability of module packaging—in terms of frame components, module ruggedness in an outdoor environment, and overall short and long-term performance.

Technology Development

L. Need for improved modeling and analysis tools to provide in-depth trade-off studies of different combinations of all components within a PV system in different market sectors.
M. Lack of adequate baseline data for the cost and performance of fielded PV systems and individual components.
N. Need for improvements in design tools to provide clear, well-organized methodologies for PV systems to support sustainable-design practices.
O. Need for continued monitoring of installed systems and benchmarking of new product integrations, to generate new data related to performance, reliability, O&M costs, and degradation or "aging" characteristics.
P. Need for updating of established codes and standards that fully promote the safe and reliable use of PV systems and components.
Q. Lack of standardized practices for certification of PV system designers, practitioners, and hardware.
R. Lack of systems-engineering approach, including modern manufacturing quality control techniques, to product design and fabrication—resulting in frequent product replacements, redesigns, or retrofits.
S. Lack of modularity and standardization in product design keeps volume low and production costs high. Although larger PV systems can use the same modules as smaller systems, in most cases, the same is not true of inverters.
T. The root causes of failures in commercially available inverters are not well documented.
U. Better designs are needed to integrate PV into buildings that address function, cost, aesthetics, and performance

4.1.1.4 Technology Approach and Tasks

As discussed earlier, the flat-plate area of the PV Subprogram is divided into three principal areas: Fundamental Research, Advanced Materials and Devices, and Technology Development. At present, work done on modules falls primarily into the first two areas, and work done on BOS components and at the overall systems level are discussed in the third area. As application of a systems-driven approach continues and the PV technology matures, this arrangement will likely be modified, with module, BOS, and overall systems development in each of these areas. However, for present purposes, we will start with a discussion of all module work that is being done in the first two areas, and follow with tasks in the Technology Development area.

In each of these task areas, universities, national laboratories, and private companies carry out R&D on flat-plate PV devices, components, and systems. Contracts awarded to the companies are generally cost-shared with increasing cost-share requirements as the R&D advances. Collaboration with in-house researchers and use of measurement and characterization facilities at the national laboratories are encouraged.

I. Fundamental Research; Advanced Materials and Devices

Three general technical areas, crystalline silicon, thin films, and modules, are discussed herein. Further levels of detail are provided within the discussions.

Crystalline silicon. Many areas within the c-Si field are ripe for R&D improvements. These include lowered cost and improved-quality feedstock material, decreased metallic impurities and grain boundaries and dislocations, larger-sized ingots/planks/ribbons/boules, increased growth speeds, and lowered environmental costs (i.e., waste reductions, reducing kerf loss, and yielding thinner wafers through improved material properties), all of which have been improved but also possess potential for further development.

Technological advancement is being made in two ways: through research on materials and research on process and devices. If we improve the starting material and our knowledge about it, we improve devices made with the material. If we improve the devices, we increase efficiencies and decrease fabrication costs. By improving processes, we also reduce costs. For example, expensive laboratory cells have achieved efficiencies as high as 24.7%, whereas commercially produced cells typically have efficiencies less than 16%. The idea is to develop fabrication processes and device structures that can translate some of the performance features of laboratory cells into manufacturing.

Researchers continue to explore highly versatile techniques—such as plasma processing, which can etch surfaces, deposit dielectric coatings, and passivate surface and bulk defects—to form high-efficiency cell structures using manufacturing procedures. This can be thought of as developing new processes that require less energy, material, and labor than conventional approaches and that will result in greater throughput. The goal is to double the output of a manufacturing plant without increasing its size; this will help industry reduce manufacturing costs while increasing output. One research approach that could help reach this goal is rapid thermal processing, a low-cost method that uses high-intensity light to rapidly heat substrates and optically enhance processing steps. Finally, researchers are investigating radically new device structures that have the potential to significantly reduce the cost of cells and modules. Although the Solar Program and its partners have continually reduced costs, it has been done largely through constant refinement in production processes. New approaches that are based on cells and modules specifically designed for easy manufacturability will considerably simplify the assembly of PV modules and can continue to reduce costs.

Another approach is thin-film silicon, combining the low cost of thin films with the high efficiency of crystalline silicon by using innovative designs that employ low-cost substrates and techniques that trap light in silicon for total absorption. (Being an indirect-band gap material, c-Si requires substantial device-design innovations to allow it to work well as a thin film.) With proper light-trapping within the silicon layer, silicon as thin as 2 micrometers (100–200 times thinner than traditional crystalline silicon) can be used while aiming for reasonable efficiencies. Although this approach is relatively new, progress on cell efficiencies to about 10% has been made. Further work will emphasize both efficiency (a minimum of 14% to 15% at the cell level is crucial to make 12% modules) and increased film-deposition rates to make economical modules. In addition, this area may also blend into the a-Si area by providing new hybrid approaches that derive benefits from both c-Si and a-Si, as well as lending themselves to multijunction approaches.

Thin Films. The research challenges facing the more mature thin films (a-Si, CIS, CdTe) can be simplified to:

(1) Improving every aspect (e.g., rate, yield, capital cost, throughput, materials use) of the active-layer manufacturing to reach the low, desired capital investment level (while maintaining all other qualities such as module efficiency)
(2) Improving commercial module efficiencies to levels above 10% (and toward 15%, incrementally)
(3) Assuring intrinsic device and packaged-module reliability outdoors (at low costs). Achievements can only be meaningful if modules are reliable outdoors, and this breaks down into two challenges: intrinsic materials and device stability and robust, yet inexpensive, module packaging.

Amorphous Silicon. Amorphous silicon was the first thin-film material to provide a commercial product. Initially, a-Si was used mostly in consumer items such as calculators. With increasing efficiencies, proven manufacturability, and innovative products such as modules that double as roof shingles and others that can be semitransparent for building-integrated uses, a-Si is expanding its markets.

Research on a-Si focuses on several of today's challenges. These include improving the stability and conversion efficiency of fielded a-Si modules, which lose efficiency when first exposed to light. Another key research area involves reducing the capital equipment costs for manufacturing a-Si panels through improved manufacturing processes that include increasing the rates of material deposition. Also under study are improvements to module-packaging designs to make them more resilient in outdoor environments and less susceptible to glass breakage or moisture ingression. Another promising research area involves developing new module designs for building-integrated applications.

Copper Indium Diselenide. After two decades of R&D, CIS is being introduced to the market, with prototype modules made by Shell Solar (Camarillo, CA) consistently reaching efficiencies greater than 11%—beating a goal set in the last PV Subprogram 5-year plan by more than a year. CIS is also enjoying success in the laboratory, with cell efficiencies climbing to a world-record 19.2% at NREL. Researchers are investigating ways to push efficiencies even higher by exploring the chemistry and physics of the junction formation and by examining concepts to allow more of the high-energy part of the solar spectrum to reach the absorber layer. They are also trying to drop costs and facilitate the transition to the commercial stage by increasing the yield of CIS modules (i.e., by increasing the percentage of modules and cells that make it intact through the manufacturing process). Manufacturing complexity and cost, and module packaging, are also areas of research focus.

Cadmium Telluride. Researchers on the CdTe Team are trying to boost efficiencies by, among other things, exploring innovative transparent conducting oxides that let more light into the cell to be absorbed and that more efficiently collect the current generated by the cell. Others are studying mechanisms such as grain boundaries that might limit cell voltage.

Some CdTe devices exhibit degradation at the contacts. Understanding the degradation and redesigning devices to minimize it will be major efforts of the PV Subprogram during the next few years. A similar focus will be on designing module packages that minimize any exposure to water vapor outdoors. Both indoor and outdoor cell and module stress testing is under way aggressively. A Request for Proposal to test modules in hot and humid climates (contracts due in FY 2003) was designed to partially meet this need (along with helping the other thin films).

High-Performance Multijunction Thin Films. Researchers are investigating the development of higher-performance devices that take advantage of tandem or multijunction solar cells. Polycrystalline thin-film tandem cells include combining high- and low-bandgap single junctions. High-bandgap alloys based on I-III-VI_2 and II-VI compounds and other novel materials can be used for the top cell. Low-bandgap CIS and its alloys, thin silicon, and other novel approaches are being considered for the bottom cell. Integration of the thin-film tunnel junction (interconnect) with the top cell is a difficult task and is under study, including the role of defects, and how they affect the transport properties of this junction, as well as diffusion of impurities into the bulk.

The device structure in terms of a monolithic integration or mechanical stack cannot be disregarded while exploring the top- and bottom-cell materials. With a monolithic configuration and/or possible alternative device structures and approaches, the processing limits of the top and bottom cells, as well as the tunnel junction, are extremely important. For example, the fabrication of a monolithic, two-terminal tandem cell based on polycrystalline thin-film materials is likely to require the use of low-temperature deposition processes for several of the layers. Thus, if a low-gap cell is fabricated after a superstrate-structure wide-gap cell such as CdZnTe, the bottom-cell fabrication will need to avoid causing deterioration of the top cell. Conversely, a wide-gap cell fabricated on top of a CIS bottom cell will need to avoid temperatures and processes that could damage the CIS. Research efforts will address these and related issues.

Modules. PV modules must be optimized to push the performance beyond their present limitations. Consequently, R&D efforts are addressed not only by studying specific material areas (such as doping profile, morphology, short-range order, stoichiometry, process uniformity, and more), but also by general research areas such as module performance and reliability. These efforts are key to understanding and improving module performance.

Higher yields, redesigning of junction boxes, frameless modules, back-skin material, integration of interconnect/lamination/fabrication processes, development of larger modules with larger cells, improved packing density, and automation assembly for reducing labor content also continue to be areas of investigation for decreasing final module-manufacturing costs.

II. Technology Development

Systems Modeling and Analysis. Systems modeling and analysis are needed to provide an understanding of the potential for PV in today's market—and to design optimal system configurations to meet that potential and to guide R&D efforts to meets the needs of future markets. This will be done through rigorous assessment of the performance, reliability, installed costs, and LEC of a wide variety of flat-plate PV system configurations and applications. A key function of this modeling and analysis is to delineate the relative influences of various PV module and BOS options on the installed cost (e.g., dollars per peak watt, W_p) of the total system and on the LEC over the lifetime of the system. Such results provide feedback to the efforts to develop certain module and BOS technologies that will improve system performance, reliability, costs, and LEC. The improved models, developed in collaboration with industry, will be used to improve system-design methods and to provide accurate assessments and characterizations of the delivered PV electricity resources throughout the United States. Such results can be used to understand the optimum system configurations (e.g., fixed array, tracking array) for various solar energy climates and applications (e.g., utilities, residential, commercial buildings). The key elements/inputs of the system model are component performance and reliability, component installed costs, installation costs, and other costs such as finance.

Balance-of-Systems Technology. BOS activities focus on research, development, testing, and evaluation of power-electronics hardware. This includes both the power electronics themselves and the interaction of power-electronics inverters with other similar devices. This research is aimed at developing new BOS technologies, improving reliability, lowering cost, removing implementation barriers, and developing a better understanding of existing technologies. In addition, BOS activities will improve system efficiency and reduce life-cycle cost by improving structures and installation techniques, improving the use of storage, and developing selected non-power electronics components.

Specific tasks for the entire PV Subprogram are given in Tables 4.1.1-5 and 4.1.1-6. We expect to refine these efforts as the systems-driven approach is applied throughout the Solar Program.

Table 4.1.1-5. Tasks for Flat-Plate PV Modules

Task	Title	Barriers
I	**Fundamental Research; Advanced Materials and Devices**	
1	**Basic Science** • Develop better understanding of materials, leading to higher cell and module efficiency. • Initiate theoretical studies for doping of high-bandgap and organic materials. • Initiate fundamental R&D with universities to enhance scientific understanding in key thin-film PV technologies. • Develop theoretical understanding for doping high-bandgap PV materials. • Explore and develop novel characterization techniques to obtain microstructural and chemical information with high spatial resolution and chemical sensitivity.	**A,B**
2	**Crystalline silicon: cell and device improvements** • Develop improved raw material sources. • Improve material utilization. • Issue competitive solicitations to universities to address key research issues in crystalline silicon.	**C**
3	**Crystalline Silicon: module improvements** • Improve contact processes, material, and reliability. • Develop better processes for cell-to-module tabbing and stringing. • Develop better, more reliable encapsulant system. • Improve module packaging. • Develop high-efficiency screen-printed metallization process for commercial silicon substrates. • Identify mechanisms of hydrogen diffusion during the nitridation process.	**D,F,G,H**
4	**Thin Films and High Performance: material and device improvements** • Improve material utilization to reduce manufacturing costs. • Test water-vapor sensitivity levels for CdTe and CIS cells to provide. quantitative input to industry for designing adequate module packaging. • Implement Thin Film Process Integration Concept. • Initiate partnerships with industry/universities to develop next-generation process diagnostics necessary to enhance yield and throughput.	**I,J**
5	**Thin Films: module improvements** • Accelerate R&D devoted to thin-film module reliability achievements via the Thin Film Module Reliability Team. • Improve contact performance and stability. • Increase deposition rates in module manufacturing. • Examine substrate trade-offs based on contacts, active materials, etc., as functions of deposition processes, temperatures, etc.	**D,F,G**

- Assist the thin-film industry with advanced module-packaging designs that lead to at least 20-year warranties.
- Support a-Si industry adoption of higher-deposition-rate processes (e.g., 5 A/sec).

6	**Modules: crosscutting activities** • Investigate and characterize service lifetimes for all commercial PV module technologies. • Develop and implement activities to improve module reliability. • Improve integrated manufacturing processes (throughput, yield, and cost). • Initiate research on applications of combinatorial techniques for high-throughput studies of PV materials and devices. • Solicit new partnerships to address processes capable of $1/watt direct module-manufacturing costs with gigawatt production capacity and emphasis on module and component yield, durability, and reliability. • Initiate next in series of international module-performance intercomparisons. • Initiate new PV Manufacturing R&D projects directed to durability and reliability issues. • Validate accelerated test methods that reproduce failures/degradation observed in the field. • Establish and operate dedicated outdoor-weathering test sites in hot and humid climates. • Investigate and characterize service lifetimes for all commercial PV module technologies. • Assess status of PV measurement and characterization facilities and needs, and prepare multi-year plan for equipment upgrades. • Facilitate improved and cost-reduced standardized qualification test protocols for advanced PV technologies. • Assess and document correlation of accelerated environmental stress testing with results from long-term field data and observations.	**C,D,E,F**

Table 4.1.1-6. Tasks for Flat-Plate PV Systems and Balance of Systems

Task	Title	Barriers
II	**Technology Development**	
7	**Systems Analysis** • Develop a PV ADVISOR model, to be integrated into the overall Solar ADVISOR, through the development and integration of new analysis capabilities. • Conduct PV market, value, and policy analyses in support of DOE and national goals. Perform trade-off studies and update goals on a regular basis. • Continue development of a PV cost/reliability database for tracking fielded systems to identify failure mechanisms impeding 25-year lifetimes, to accurately quantify O&M and life-cycle-related costs, and to provide updated data for the analysis tools. • Assess environment, safety, and health issues associates with multi-hundred-megawatt manufacturing and deployment of PV. • Examine PV Subprogram contributions to meeting the 20-year *U.S. PV Industry Roadmap.*	**L**

8	**System Benchmarking and Validation** • Assess, test, and validate existing tools for system- and component-level analysis of flat-plate PV systems, in terms of performance, cost, and reliability. • Establish baselines through the characterization of existing flat-plate PV systems. • Define formats for data collection from fielded systems and component-level developments. • Continually test and validate tools through data collection and technology benchmarking activities. • Conduct laboratory and field evaluation of PV systems for users and the PV industry for validation of designs, specifications, and modeling and analysis tools. • Accurately determine degradation rates of current PV components and systems to establish technical requirements for 25-year system lifetimes. • Extend c-Si system-performance monitoring activities to thin-film systems. • Perform long-term monitoring /evaluation tests under realistic outdoor conditions with interim evaluations and total performance evaluations. • Conduct an analysis of safety-related aspects of installed PV systems and components, to understand and minimize hazards in the field.	**M,O**
9	**PV System Performance and Standards** • Develop accurate PV system life-cycle models. • Apply modeling and analysis tools to define optimal systems configurations for fielded applications with industry and user partners. • Conduct R&D related to improved PV system packaging, system standardization, and new technologies to facilitate system deployments. • Provide leadership and support of development of domestic and global codes and standards, accreditation, and certification that promote safe and reliable use of PV systems and components. • Establish standardized metrics and test procedures for PV systems and hardware certification. • Develop national voluntary certification program for PV installers, designers, and inspectors. • Develop hardware-certification program evolving from test and measurement protocols that begin with components and inverters. • Evolve hardware-certification program to complete PV systems that will be tested by independent labs.	**N,P,Q**

10 PV Technology Adoption **N**

- Establish practical, sustainable design methodologies and new PV applications, impacting high-fuel-consumption industry sectors.
- Provide technical support for Federal and other agencies in the specification, design, procurement, and use of PV systems, with appropriate plans for data collection from fielded systems.
- Carry out DOE-led initiatives, such as Million Solar Roofs, the Solar Decathlon, university programs, and others.
- Meet the international commitments of DOE related to PV through bilateral and multilateral agreements, as well as targeted international programs. This includes support to the International Energy Agency and the establishment of international codes and standards through this working relationship.
- Conduct R&D on new structures to satisfy architectural and market-based demands for building-integrated PV systems.
- Produce needed materials for training and education of domestic and international partners in the use of PV technologies.

11 Inverter Testing and Industry Support **R,T**

- Resolve problems/inconsistencies in UL 1741/IEEE 929 testing of inverters.
- Evaluate statistical probability of the existence of islanding conditions.
- Participate in development of standards that encourage use of PV to support distribution-system stability
- Support industry R&D in power electronics through laboratory testing, evaluations of highly accelerated lifetime testing (HALT), high-ambient-temperature tests, and field evaluations of new and existing technologies.
- Develop inverter software models to be used to model behavior in complex situations.
- Conduct long-term inverter testing to assess cost, performance, and reliability of fielded components.

12	**High-Reliability Inverter Initiative** **Phase 1:** • Develop product configuration and architecture that minimizes manufacturing difficulty and increases reliability. • Provide a roadmap indicating how the new product will be developed and demonstrate adherence to performance and safety requirements. • Report on Phase 1 results with three contractors. **Phase 2:** • Initiate Phase 2 with at least two contractors. • Finalize development of new product design, with emphasis on switching technologies and switching devices; manufacturing processes and packaging technologies to be developed; cooling technologies and operating temperatures; surge suppression designs; and physical characteristics. • Assess, test, and validate new product, including characterization criteria for evaluations; component-level tests and analyses; analysis of system performance through simulation tools; validation of packaging technology for increased reliability; and effectiveness of cooling technology. • Conduct prototype evaluations of hardware and software modules. • Validate utility interconnection requirements, compliance with regulating standards (IEEE 929, 519, UL1741, etc). **Phase 3:** • Initiate Phase 3 with two contractors. • Assemble final prototype, maintaining conformity to utility interconnection requirements, performance objectives, and manufacturing objectives. • Conduct testing of final prototype, through laboratory evaluations, HALT testing, environmental testing, and performance evaluations.	**R,S**
13	**Inverter R&D 5-Year Plan** • Conduct inverter workshop and develop 5-year plan based on systems-driven approach • Develop benchmarks for inverter cost, performance, and reliability. • Revise inverter program goals based on progress of 5-year plan.	**R,S**
14	**Charge Controller and Energy Storage Improvements** • Initiate charge-controller contracts to improve algorithms and quality. • Test PV batteries in a laboratory setting to develop a database that will identify specific charging requirements for controllers. • Conduct HALT and laboratory testing to assess new components under development. • Conduct grid-tied PV system battery tests. • Assess fielded charge controllers and batteries.	**U**

4.1.1.5 Schedule and Milestones

Table 4.1.1-7 shows the milestones for the PV Subprogram.

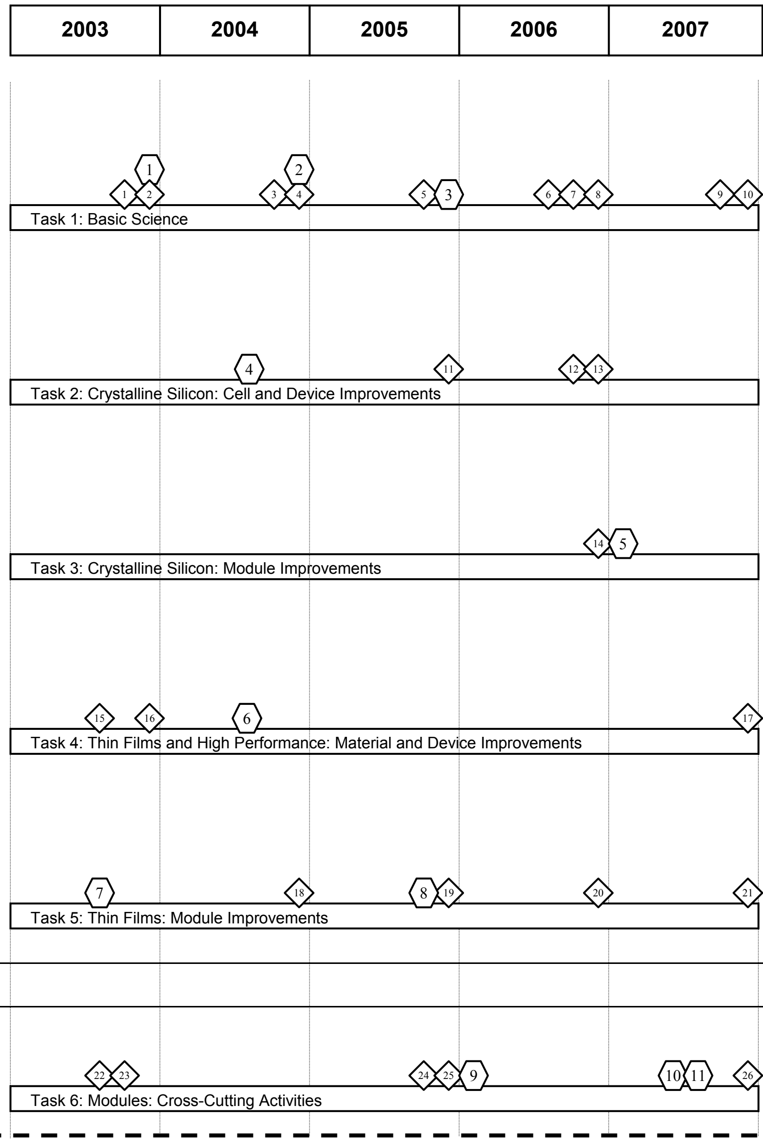
Table 4.1.1-7. Milestones for Flat-Plate PV Subprogram

Milestone	Task	Title	Estimated CY Date Quarter
1	1	Complete installation of a state-of-the-art, high-resolution transmission electron microscope and apply new capabilities to a technologically important problem in silicon.	03 Q4
2	1	Complete Title I design of NREL Science and Technology Facility.	03 Q4
3	1	Start construction of NREL Science and Technology Facility.	04 Q4
4	1	Obtain ISO 17025 accreditation for secondary cell calibration under ASTM and IEC standards.	04 Q4
5	1	Develop characterization platforms that support the NREL Science and Technology Facility process-integration concept.	05 Q4
6	1	Start operations of NREL Science and Technology Facility.	06 Q4
7	1	Assess NCPV research facilities and prepare multi-year capital equipment plan.	06 Q4
8	1	Select university center of excellence for crystalline-silicon PV research and education.	06 Q4
9	1	Demonstrate competitive efficiency and cost potential of thin-crystalline-silicon technologies.	07 Q4
10	1	Demonstrate rapid validation of a next-generation material or cell structure through application of combinatorial research techniques.	07 Q4
11	2	Achieve 13%-efficient thin-crystalline silicon cell (<3 microns) on low-cost substrate.	05 Q4
12	2	Assist industry in demonstrating 19%-efficient, large-area multicrystalline-silicon solar cell using commercial processes.	06 Q4
13	2	Fabricate dual-junction polycrystalline thin-film cell of 15% efficiency.	06 Q4
14	3	Reduce direct module-manufacturing costs to $1.75 and achieve module-manufacturing processes capable of $1.50/watt direct module-manufacturing costs with 500-megawatt production capacity.	06 Q4
15	4	Demonstrate a monolithic, series-connected, multijunction thin-film device and identify critical-loss mechanisms.	03 Q3
16	4	Demonstrate alternative junctions in CIGS and CdTe using process control of carrier concentrations.	03 Q4
17	4	Demonstrate 13%-efficient a-Si cell (stable, total area).	07 Q4
18	5	Demonstrate 10%-efficient commercial CdTe module.	04 Q4
19	5	Complete solutions for device-level issues supporting industry 10-year warranties for CIS and CdTe modules.	05 Q4
20	5	Demonstrate superior control of CIGS growth using process designed to exploit knowledge and control of microstructural mechanisms.	06 Q4
21	5	Complete solutions for device-level issues supporting industry 20-year warranties for CIS and CdTe modules.	07 Q4
22	6	Refine and transfer manufacturing-friendly, electro-optical-based diagnostic to the PV industry.	03 Q3
23	6	Investigate and document dominant factors influencing energy production by PV module technologies.	03 Q3
24	6	Complete next in series of international module-performance inter-comparisons.	05 Q4

Milestone	Task	Title	Estimated CY Date Quarter
25	6	Complete development (achieve manufacturing-line-ready status) for at least three in-line diagnostic processes initiated in FY 2002 awards from In-Line Diagnostic, Intelligent Processing Solicitation.	05 Q4
26	6	Obtain ISO 17025 accreditation for secondary module calibration under ASTM and IEC standards.	07 Q4
27	7	Employ systems-driven approach to assess existing PV analysis tools and identify gaps.	03 Q3
28	7	Incorporate statistical analysis tools into systems-reliability database	03 Q3
29	7	Issue revised DOE PV Program 5-Year Technology Plan.	03 Q4
30	7	Complete an integrated analysis capability for flat-plate PV.	04 Q4
31	7	Review and revise all flat-plate PV milestones based on outputs of systems-driven approach.	05 Q4
32	7	Complete fully populated performance and reliability database of PV systems installed in priority applications.	05 Q4
33	7	Facilitate revision of the *U.S. PV Industry Roadmap* for 2005-2025.	05 Q4
34	7	Issue revised DOE PV Subprogram 5-Year Technology Plan.	05 Q4
35	7	Document 25-year-lifetime systems.	06 Q4
36	7	Assess NCPV contributions toward building PV capacity and expanding markets within the United States, leading to the 20-year *U.S. PV Industry Roadmap* goal of domestic markets gaining parity with burgeoning international markets.	07 Q4
37	7	Issue updated DOE PV Subprogram 5-Year Technology Plan	07 Q4
38	8	Determine formats for all data to be collected for analysis at the systems and component level through field and laboratory exercises.	04 Q2
39	8	Deliver procedures for testing and evaluation of systems to improve performance and reliability.	04 Q2
40	8	Draft inverter test protocol.	04 Q3
41	8	Designate SWRES-SERES virtual lab as a university center of excellence for PV systems studies.	06 Q4
42	9	Document performance-degradation rates of commercial PV modules, and continue effort to quantify array degradation rates.	03 Q4
43	9	Begin formal testing and administration of the National Voluntary Practitioner Certification Program.	04 Q1
44	9	Evolve inverter test protocol into a system test and measurement protocol.	05 Q4
45	9	Update system design and simulation tools to include documented failure and degradation rates at the component level.	07 Q4
46	10	Assess Million Solar Roofs Initiative, documenting successful partnership contracts.	03 Q4
47	10	Develop PV system qualification tests.	04 Q2
48	10	Produce a “best practices” guide regarding safety aspects of designing, installing, and maintaining fielded PV systems and components	04 Q3
49	10	Deliver advanced PV system design tool.	05 Q4
50	10	Document progress toward making PV systems a viable energy option for rural utility applications.	05 Q4
51	10	Establish new BIPV partnerships to develop new opportunities for PV systems.	05 Q4
52	11	Complete inverter model to simulate complex situations.	03 Q4
53	11	Develop long-term inverter test plan.	03 Q4
54	11	Complete statistical study of islanding probability.	04 Q2
55	11	Provide interim levelized inverter cost data from long-term field tests.	05 Q4

Milestone	Task	Title	Estimated CY Date Quarter
56	11	Collect field data and validate performance from inverters installed through the High-Reliability Inverter Initiative.	06 Q4
57	11	Complete long-term evaluations of fielded commercial inverters.	07 Q4
58	12	Develop next-generation inverter to complete Phase 1 of High-Reliability Inverter Initiative.	03 Q2
59	12	Complete Phase 2 (prototype development) of the High-Reliability Inverter Initiative.	04 Q3
60	12	Complete Phase 3 of the High-Reliability Inverter Initiative.	05 Q4
61	13	Develop Inverter R&D 5-year plan based on systems-driven approach.	03 Q4
62	13	Select next steps for inverter testing, modeling, and product development.	05 Q4
63	14	Complete HALT testing on new charge-controller designs.	05 Q4
64	14	Perform field validation of new charge-controller designs.	05 Q4
65	14	Complete database of charge controller/battery configurations.	06 Q4

Fundamental Research; Advanced Materials and Devices



Legend

Milestones-

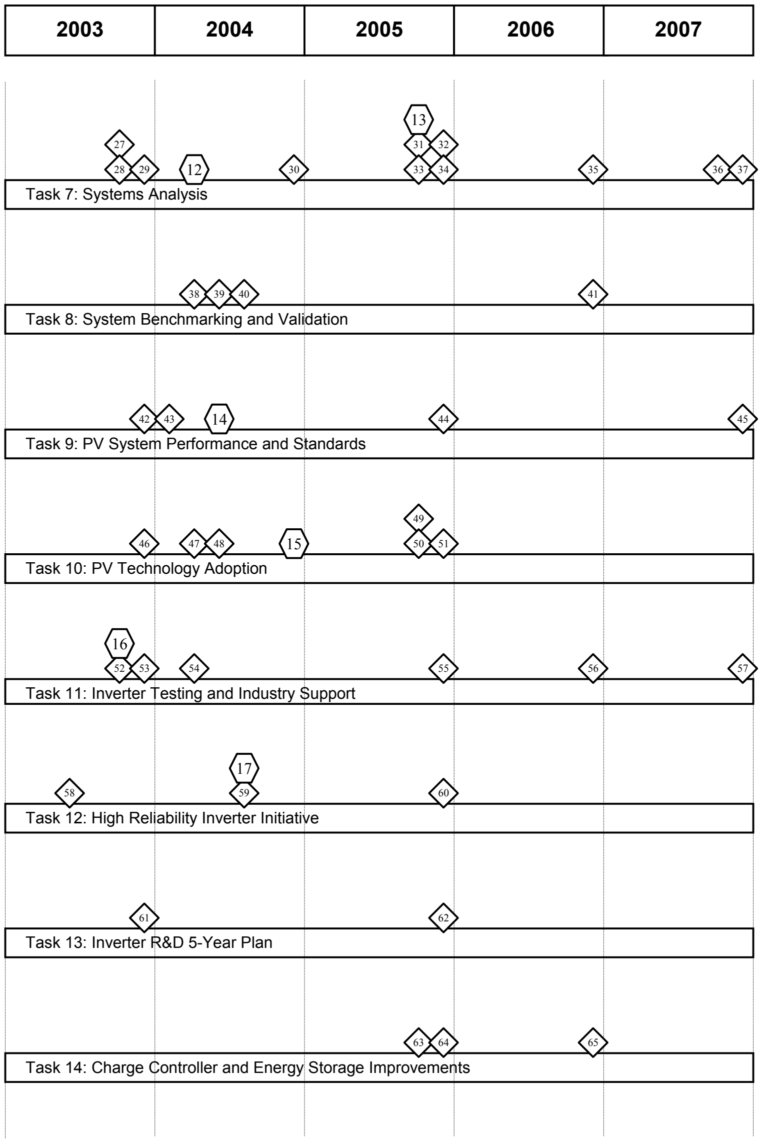
1. Complete installation of a state-of-the-art, high-resolution transmission electron microscope and apply new capabilities to a technologically important problem in silicon.
2. Complete Title I design of NREL Science and Technology Facility.
3. Start construction of NREL Science and Technology Facility.
4. Obtain ISO 17025 accreditation for secondary cell calibration under ASTM and IEC standards.
5. Develop characterization platforms that support the NREL Science and Technology Facility process-integration concept.
6. Start operations of NREL Science and Technology Facility.
7. Assess NCPV research facilities and prepare multi-year capital equipment plan.
8. Select university center of excellence for crystalline-silicon PV research and education.
9. Demonstrate competitive efficiency and cost potential of thin-crystalline-silicon technologies.
10. Demonstrate rapid validation of a next-generation material or cell structure through application of combinatorial research techniques.
11. Achieve 13%-efficient thin-silicon cell (<3 microns) on low-cost substrate.
12. Assist industry in demonstrating 19%-efficient, large-area multicrystalline-silicon solar cell using commercial processes.
13. Fabricate dual-junction polycrystalline thin-film cell of 15% efficiency.
14. Reduce direct module-manufacturing costs to $1.75 and achieve module-manufacturing processes capable of $1.50/watt direct module-manufacturing costs with 500-megawatt production capacity.
15. Demonstrate a monolithic, series-connected, multijunction thin-film device and identify critical-loss mechanisms.
16. Demonstrate alternative junctions in CIGS and CdTe using process control of carrier concentrations.
17. Demonstrate 13%-efficient a-Si cell (stable, total area).
18. Demonstrate 10%-efficient commercial CdTe module.
19. Complete solutions for device-level issues supporting industry 10-year warranties for CIS and CdTe modules.
20. Demonstrate superior control of CIGS growth using process designed to exploit knowledge and control of microstructural mechanisms.
21. Complete solutions for device-level issues supporting industry 20-year warranties for CIS and CdTe modules.
22. Refine and transfer manufacturing-friendly, electro-optical-based diagnostic to the PV industry.
23. Investigate and document dominant factors influencing energy production by PV module technologies.
24. Complete next in series of international module-performance inter-comparisons.
25. Complete development (achieve manufacturing-line-ready status) for at least three in-line diagnostic processes initiated in FY 2002 awards from In-Line Diagnostic, Intelligent Processing Solicitation.
26. Obtain ISO 17025 accreditation for secondary module calibration under ASTM and IEC standards.

9

Go/No Go Decision Points

1. Assess impact and future potential for university collaborations with crystalline silicon companies and determine future research directions.
2. Assess research on exploring pathways to high-efficiency PV and develop plans for implementation phase.
3. Assess contributions of university centers of excellence for PV research and education.
4. Assess potential for thin-silicon technologies and identify areas for increased research emphasis.
5. Assess new opportunities and directions for crystalline silicon technologies.
6. Evaluate optimized cells grown by molecular-beam epitaxy to assess viability of GaInNAs for multijunction cells.
7. Technically assess thin-film system performance.
8. Assess Thin Film PV Partnership, and implement next phase of research activities.
9. Determine need for additional manufacturing R&D, and select areas for elimination or support.
10. Identify commercialization pathways for promising new technologies via university/industrial partnerships.
11. Solicit new manufacturing R&D partnerships as appropriate.

Technology Development



Legend

Milestones-

27. Employ systems-driven approach to assess existing PV analysis tools and identify gaps.
28. Incorporate statistical analysis tools into systems-reliability database
29. Issue revised DOE PV Program 5-Year Technology Plan.
30. Complete an integrated analysis capability for flat-plate PV.
31. Review and revise all flat-plate PV milestones based on outputs of systems-driven approach.
32. Complete fully populated performance and reliability database of PV systems installed in priority applications.
33. Facilitate revision of the *U.S. PV Industry Roadmap* for 2005-2025.
34. Issue revised DOE PV Subprogram 5-Year Technology Plan.
35. Document 25-year-lifetime systems.
36. Assess NCPV contributions toward building PV capacity and expanding markets within the United States, leading to the 20-year *U.S. PV Industry Roadmap* goal of domestic markets gaining parity with burgeoning international markets.
37. Issue updated DOE PV Subprogram 5-Year Technology Plan
38. Determine formats for all data to be collected for analysis at the systems and component level through field and laboratory exercises.
39. Deliver procedures for testing and evaluation of systems to improve performance and reliability.
40. Draft inverter test protocol.
41. Designate SWRES-SERES virtual lab as a university center of excellence for PV systems studies.
42. Document performance-degradation rates of commercial PV modules, and continue effort to quantify array degradation rates.
43. Begin formal testing and administration of the National Voluntary Practitioner Certification Program.
44. Evolve inverter test protocol into a system test and measurement protocol.
45. Update system design and simulation tools to include documented failure and degradation rates at the component level.
46. Assess Million Solar Roofs Initiative, documenting successful partnership contracts.
47. Develop PV system qualification tests.
48. Produce a “best practices” guide regarding safety aspects of designing, installing, and maintaining fielded PV systems and components
49. Deliver advanced PV system design tool.
50. Document progress toward making PV systems a viable energy option for rural utility applications.
51. Establish new BIPV partnerships to develop new opportunities for PV systems.
52. Complete inverter model to simulate complex situations.
53. Develop long-term inverter test plan.
54. Complete statistical study of islanding probability.
55. Provide interim levelized inverter cost data from long-term field tests.
56. Collect field data and validate performance from inverters installed through the High-Reliability Inverter Initiative.
57. Complete long-term evaluations of fielded commercial inverters.
58. Develop next-generation inverter to complete Phase 1 of High-Reliability Inverter Initiative.
59. Complete Phase 2 (prototype development) of the High-Reliability Inverter Initiative.
60. Complete Phase 3 of the High-Reliability Inverter Initiative.
61. Develop Inverter R&D 5-year plan based on systems-driven approach.
62. Select next steps for inverter testing, modeling, and product development.
63. Complete HALT testing on new charge-controller designs.
64. Perform field validation of new charge-controller designs.
65. Complete database of charge controller/battery configurations.

9 Go/No Go Decision Points

12. Identify priority markets to complete integrated analysis capability
13. Re-orient PV milestones based on systems analysis outputs.
14. Hand-off practitioner certification program to private sector.
15. Select partners for BIPV structures/designs
16. Select inverters for long-term testing.
17. Down-select partners for Phase 3 of High Reliability Inverter Initiative

4.1.2 Concentrator Photovoltaic Systems

4.1.2.1 Technology System Status

The fundamental distinction between concentrator and flat-plate photovoltaic technologies is the amount of sunlight incident on the solar cells within each system. It is common to refer to the standard solar irradiance at the Earth's surface—1 kW/m^2—as "one sun," which is the amount of sunlight incident on flat-plate systems. Concentrator systems have more than one sun—as much as hundreds of suns—incident on the solar cell. The number of suns is also termed the concentration ratio. The system's array (Figure 4.1.2-1) must point toward and follow the sun throughout the day to maintain the sun's focus on the cell, and good heat-transfer design is needed to limit the cell's temperature. Tracking the sun's movement benefits the concentrator photovoltaic (CPV) system because it produces more than 30% additional energy, measured in kWh/kW, than a non-tracking flat-plate system. If the cost of the CPV system is low enough, an opportunity exists to produce low-cost electricity from sunlight using relatively high cost/area, high-efficiency solar cells.

Concentrator photovoltaic systems need the highest-efficiency solar cells to improve their cost effectiveness for producing low-cost electricity. In a targeted research effort during the early 1980s, researchers in crystalline-silicon solar cells reduced—one by one—many of the loss mechanisms and increased solar-cell efficiencies from 18% to 20% and then to 22% in 1988. These higher efficiencies rekindled interest and efforts in CPV. The efficiency increases required numerous expensive processing techniques that were too costly for the solar cells to be used in large-area, flat-plate photovoltaic (PV) modules, but not too costly for CPV. Even today, the efficiencies of typical, screen-printed solar cells in flat-plate *modules* are 15%—far below today's world record of 24% for a small-area crystalline silicon *cell* that can be used in a CPV system. Small-area, high-efficiency solar cells are ideal for CPV systems such as one using an optical element that focuses sunlight onto a small (e.g., 1-cm x 1-cm) solar cell, much like a magnifying glass that produces a spot of sunlight bright enough and hot enough to burn a piece of paper. Figure 4.1.2-1 is a schematic for a CPV system consisting of an array connected to an electric utility network. Array details, such as the lenses, solar cells, wiring, and heat spreaders are shown in Figure 4.1.2-2.

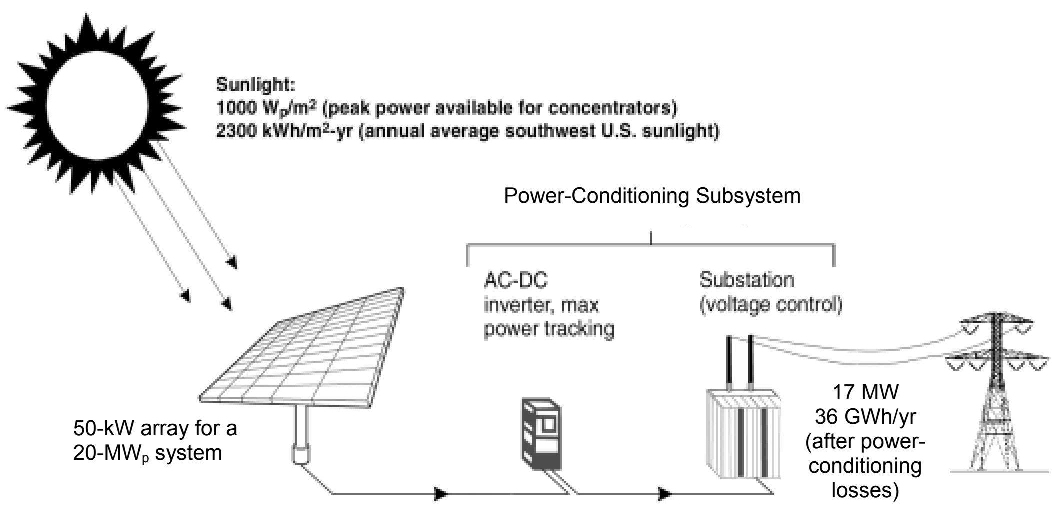


Figure 4.1.2-1. A CPV system connected as a distributed-generation source.

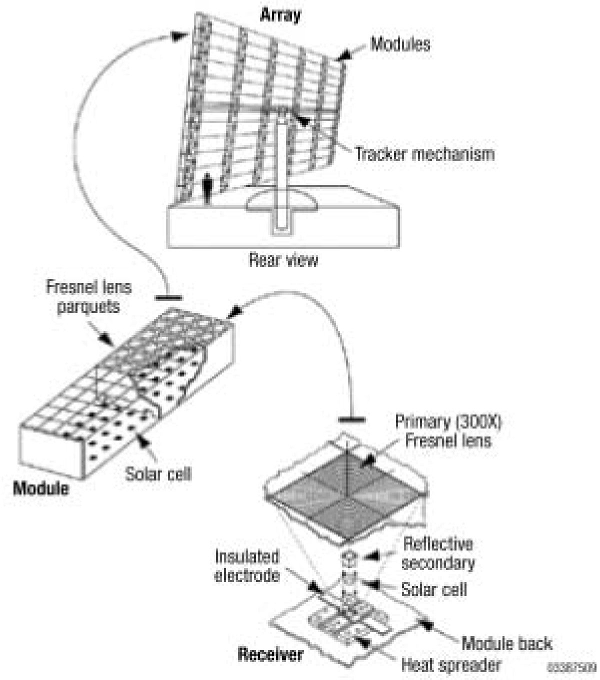


Figure 4.1.2-2. Schematic of a point-focus Fresnel lens concentrator.

Efficiency increases didn't stop with the new world records for crystalline silicon. As a result of R&D successes in the 1990s, the world's highest-performance solar cells are now made principally from elements in columns III and V of the Periodic Table. These so-called "III-V" solar cells now have conversion efficiencies greater than 28% in production, with a world record of more than 36% under concentration. The efficiencies of III-V solar cells are about one-third higher than the efficiencies of the crystalline-silicon solar cells used in today's commercial CPV systems. Over the years, systems analyses have invariably concluded that higher-efficiency solar cells improve the likelihood that CPV systems will be cost effective. Although the III-V cells are more expensive than silicon cells, their cost has been reduced by mass production installed to meet the space-satellite market and can be reduced further by developing lower-cost substrates or by further increasing the concentration ratio. The remainder of the concentrator-system cost results from materials that are much less expensive than the solar cell materials, such as steel and plastic. Recognizing that CPV systems are fabricated primarily of steel and plastic, a Japanese automaker in the late 1990s began to develop its own CPV technology because of strong similarities in the manufacture of cars and CPV systems. Although they decided CPV systems would be quite easy to manufacture, they did not continue CPV development because of market-entry uncertainties.

Concentrator PV systems are not common in the world marketplace, with less than 1% of the PV systems sold in 2001 being concentrators. A CPV array is large, 100 m^2 for 20 kW, so they are suitable for larger, distributed generation such as community energy parks, industrial or commercial facilities, and remote hybrid systems. On taller support structures, it is easy to imagine CPV competing in a recent market identified for large flat-plate PV systems installed over parking areas. The challenge today is to incorporate the development triumphs of the 1990s into CPV systems to produce cost-effective electricity for terrestrial market opportunities as they are identified.

There are a variety of concepts for concentrating sunlight onto PV cells. The most common concentrating concepts are linear concentrators and point-focus concentrators. For each of these concepts, solar concentration can employ reflection or refraction (typically using Fresnel lens systems) of the sun's rays. If, for example, the concentration ratio is 300 suns, the system is usually described as a "300x system." Typical linear concentrator systems operate at 10x to 20x, whereas point-focus concepts work at 200x to 1000x or more. The lower-concentration systems have an apparent advantage in that, with minor changes, they can use lower-efficiency, one-sun solar cells, whereas higher-concentration systems use solar cells designed for very high efficiency and highly concentrated sunlight. Systems analyses conducted to date suggest that higher-concentration CPV systems, above 500x, will take more development, but will ultimately produce less-expensive electricity.

The collective configuration of the solar cells, heat-dissipation components, secondary optical components, and electrodes constitutes the "receiver" within a concentrator module. Figures 4.1.2-2 through 4.1.2-4 show a point-focus Fresnel lens concentrator system, linear-focus Fresnel lens concentrator, and point-focus dish concentrator, respectively.

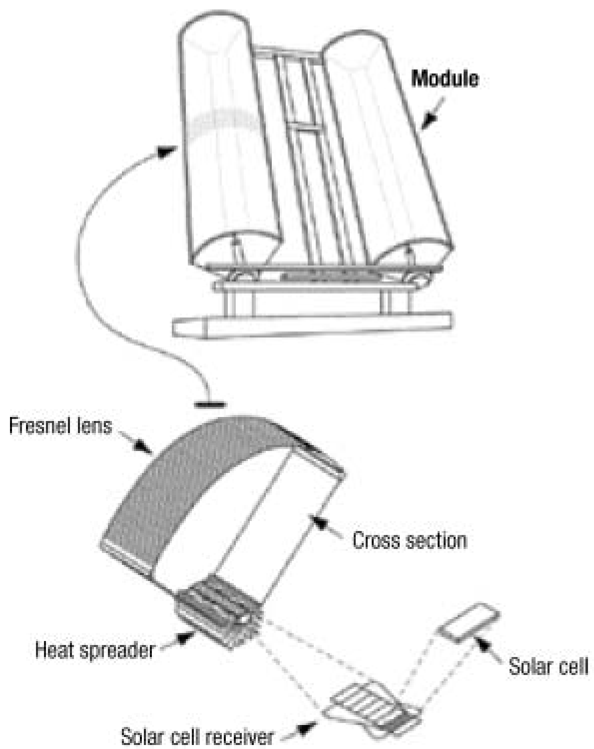


Figure 4.1.2-3. Schematic of a linear-focus Fresnel lens concentrator PV system.

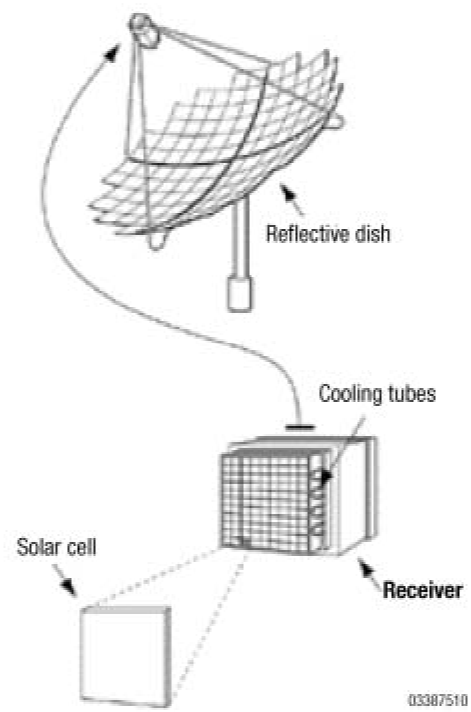


Figure 4.1.2-4. Schematic of a point-focus dish concentrator PV system.

Current Activities: The DOE Solar Program is funding research at the National Renewable Energy Laboratory (NREL) for higher-efficiency III-V solar cells, at several universities as part of the DOE/NREL Fundamental and Exploratory Research Project, and on concentrator cells and receivers as part of the DOE/NREL High-Performance PV Project. The Concentrating Solar Power subprogram has recently provided some funding to integrate III-V cells into a dish concentrator previously designed for a Stirling engine receiver. NREL served as the primary driver for the development of the first CPV qualification standard, completed in 2001, and now leads the international CPV standards effort. There are several small U.S. companies working on CPV designs and systems. One company has deployed 500 kW of their fifth-generation CPV systems, most of them in Arizona. Another company had sold terrestrial systems in the 1980s, but most of their recent work has been the development of CPV systems for use in space projects funded by NASA. Besides the United States, the countries of Australia, Spain, United Kingdom, Italy, Germany, Japan, and Czechoslovakia have interest in CPV as demonstrated by their participation in developing international CPV standards.

Program Coordination and Implementation: CPV companies in the United States participated in developing the U.S. PV industry roadmap, the primary means used by the PV Subprogram to coordinate and implement all PV activities with those of the companies. Unlike the flat-plate PV technologies, CPV systems don't have easily identifiable high-value, niche markets that enable penetration into more difficult ones, such as the electric utility markets identified in the roadmap. CPV companies believe that this market conundrum will be more easily resolved with higher-efficiency solar cells and successful demonstration of recently deployed systems. One important coordination activity led by the PV Subprogram is the development of qualification standards by committees with representatives from CPV companies, research laboratories, and purchasers of CPV systems. This activity touches on most aspects of CPV technology development, including CPV system design, manufacturing, testing, and operation in different market applications. This activity acquired a higher priority for the companies in the late 1990s as they started answering questions from possible customers about safety, reliability, and certification of their product to a standard.

Coordination with Related Programs: In the late 1990s, a joint meeting was held for the U.S. CPV companies and U.S. companies developing Stirling engines for dish concentrators funded under the DOE Solar Program. The DOE Solar Program has subsequently funded an innovative CPV concept—the cavity solar converter—under development for use in a dish concentrator. The Interagency Advanced Power Group serves as a means to coordinate with other U.S. agency programs, especially NASA, Air Force, and the Naval Research Laboratory efforts to develop higher-efficiency space solar cells. The International Electrotechnical Commission (IEC) serves as the principal means to coordinate CPV standards activities in other countries as U.S. CPV companies explore international markets where international standards will be needed. NREL plans and leads the IEC CPV standards activities in its role as convenor of the IEC CPV standards working group.

4.1.2.2 Technology and Component Goals and Objectives

Technology and Component Goals

Goal. The Program goal is to develop viable concentrator photovoltaic technologies for application in a wide range of electrical markets, particularly for the distributed generation and larger bulk electric utility markets. The target electricity cost is 4 to 6 cents/kWh by 2020. There are three subordinate technology goals for CPV components.

- Develop higher-efficiency III-V solar cells and improve their viability by reducing their cost.
- Reduce the cost of all remaining components of the CPV system.
- Ensure the reliability of concentrator PV components through the joint development with manufacturers and users of appropriate stress tests for temperature, humidity, voltage, safety, and other issues that might affect the installed longevity of CPV systems and components.

Objectives. The 2003 baseline technology is a 1-MW plant with a Fresnel lens, point-focus concentrator using silicon solar cells:

- Silicon solar-cell efficiency is 25%
- Silicon solar-cell cost is $2/cm^2
- Concentrator module cost is $160/m^2
- Tracker component cost is $70/m^2

- The CPV system efficiency is 15%
- The concentration ratio is 250x
- The levelized electricity cost (LEC) is between about 25 and 40 cents/kWh and depends on financial and solar resource assumptions.

The 2007 objectives for a 10-MW plant are:

- Reduce the cost of III-V solar cells to $3/cm^2
- Reduce the cost of concentrator modules to $100/m^2
- Reduce the cost of tracker components to $40/m^2
- Reduce operation and maintenance costs to 1 cent/kWh
- Achieve greater than 33% (production) solar-cell efficiency in III-V devices suitable for high solar concentrations such as 400x
- Achieve greater than 22% system efficiency for a CPV technology
- Achieve an LEC of 20 cents/kWh for a solar resource of 2,400 kWh/m^2-yr.

The 2020 objectives for an 80-MW plant are:

- Achieve greater than 40% (production) solar-cell efficiency in III-V devices suitable for high solar concentrations
- Achieve greater than 33% system efficiency at 1000x for a CPV technology
- Reduce the cost of solar cells to $1.50/cm^2
- Reduce the cost of concentrator modules to $80/m^2
- Reduce the cost of tracker components to $25/m^2
- Reduce operation and maintenance costs to 0.5 cent/kWh
- Achieve an LEC of 4-6 cents/kWh for a solar resource of 2,400 kWh/m^2-yr.

Discussion of Analysis and Assumptions for these Cost Objectives

In December 1997, the Electric Power Research Institute (EPRI) and the DOE's Office of Energy Efficiency and Renewable Energy (EERE) completed a systems-analysis characterization of all major renewable energy technologies, including CPV systems (*Renewable Energy Technology Characterizations,* EPRI TR-109496). The characterization developed potential component costs and performance for a variety of CPV system and solar-cell technologies and listed them, beginning with a CPV baseline system in 1996, for intervals ending in 2030. The analysis was not based on detailed (and expensive) engineering design conceptual analyses, but rather, on a consensus review of present and future CPV systems. The cost uncertainties in the study's total system costs ranged from ±10% in the near term to ±50% for long-term estimates. Although the analysis could be considered optimistic, the report's authors and review panel provided oversight for the consensus reviews to have the same degree of optimism among all the renewable energy technologies. Within the analysis uncertainties, this technology characterization showed that CPV systems are just as capable of achieving the same low cost of energy (COE) as those resulting from the analyses for flat-plate crystalline silicon and flat-plate thin-film PV technologies. The above list of costs, goals, and objectives is based on the results in this technology-characterization report. Specifically, the COE goals for concentrator PV systems are 10 cents/kWh by 2010 and 4-6 cents/kWh by 2025. Within analysis uncertainties, the DOE/NREL High-Performance PV project has a similar near-term (2012) goal of $1.50/peak watt ($W_p$) for the price of an alternating-current (AC) system producing electricity at 6 cent/kWh.

A key advantage of concentrator PV systems is the potential to reduce cell costs within the entire system through the use of optical elements. Part of the long-term goal for CPV systems is to have the solar-cell cost accounting for 5% to 10% of the total CPV system cost. Nevertheless, the remaining component costs, other than solar-cell cost, also need to be reduced during this time period because today's component costs are twice those associated with the 2007 objectives, partly because today's systems are in extremely limited production, well below 1 MW per year. There is, therefore, an assumption that large-scale production is needed to achieve the cost objectives listed above. Within the DOE-EPRI Technology Characterization, the system and plant size increased over the 34-year planning period to 80 MW, whereas the baseline plant size was only 20 kW.

4.1.2.3 Key Technical Challenges

The key technical challenges are to:

- Increase the performance of high-efficiency solar cells by identifying new materials and cell design
- Lower the cost impact of high-efficiency solar cells by reducing cell costs and/or by developing higher-concentration PV systems approaching 1000 suns
- Develop receivers meeting flux uniformity, cell packaging, electrical insulation, heat transfer, and other requirements needed for long-term reliability
- Lower the cost of the concentrator structure through design improvements that reduce the amount of steel and other structural materials
- Lower the system cost through manufacturing R&D
- Complete international test standards to prevent reliability problems and reduce operations and maintenance costs for deployed CPV systems and components.

Technical Targets

The technical targets for CPV technologies are shown in the table below:

Table 4.1.2-1. Technical Targets for CPV Technologies

System Element	Units	2003 (baseline)	2007	2025
Solar resource	kWh/m^2-yr	2400	2400	2400
Plant size	MW	1	10	80
(Production) solar cell efficiency	%	25	33	40
Optical efficiency	%	80	85	90
Cell cost per cell area	$\$/cm^2$	2 (silicon)	3 (III-V)	1.50 (III-V)
System efficiency	%	15	22	33
Capacity factor	%	32	32	32
CPV module cost	$\$/m^2$	160	90	80
Tracking cost	$\$/m^2$	70	35	25
Power-related balance-of-systems	$\$/W_p$	0.6	0.3	0.15
Area-related BOS other than land	$\$/m^2$	140	70	50
Indirect costs (% added to all above costs, not including land, to account for marketing and other indirect costs)	%	20	15	10
Annual O&M costs	$/kWh-yr	.02	.01	.005
Total capital cost per AC W_p	$\$/W_p$	9.00	5.0	1.0

The LEC associated with these technical targets needs to be determined using consistent financial and solar-resource assumptions. Nevertheless, the LEC for the 2003 baseline is almost 40 cents/kWh for a 1-MW plant (which hasn't been built yet), whereas the 2007 target has an LEC of 20 cents/kWh for a much larger (10 MW) plant size and the 2025 goal LEC is 4-6 cents/kWh—again, for an even larger plant of 80 MW.

Technical Barriers

These technical barriers listed below are associated with the need for improved performance, lower cost, and demonstrated reliability for a CPV system and its components. The receiver does not have an exact analog in flat-plate PV technologies. It encompasses the solar cell, heat-transfer elements, secondary optical elements, and electrodes within a concentrator PV module. Figure 4.1.2-1 is a sketch of a CPV system connected as a distributed-generation source.

CPV Cells

- **A.** Today's CPV systems use 25%-efficient crystalline-silicon solar cells because they are available at low cost and have shown excellent reliability. Higher efficiencies are needed. III-V solar cells have already demonstrated 35% efficiency under concentration and have a potential for efficiencies above 40%—the performance needed for a CPV system producing electricity at 4-6 cents/kWh. In surmounting this barrier, exploratory research may lead to breakthroughs because specialists in this area calculate theoretical efficiency limits above 80%, with practical efficiency limits above 60%.
- **B.** Today's crystalline silicon CPV solar cells cost about $2/cm^2. III-V solar cells presently cost $10/cm^2 or more, and their cost needs to be reduced to about $1.50/cm^2 in the long-term while maintaining their high performance.
- **C.** CPV cell standards is an area where solar-cell research has gotten ahead of validation since only recently have measurements and characterization experts begun to establish testing protocols, including appropriate solar spectra, for III-V solar cells under concentration.

CPV Receivers

- **D.** Today's CPV optical-receiver elements need to maintain high performance for decades, while costing as little as possible. Today's CPV optical elements transmit about 80% of the light. Improved Fresnel lens design is needed to improve flux uniformity (a more critical issue for III-V cells than for crystalline silicon), transmission, and lifetime.
- **E.** CPV receivers often contain secondary optical elements, solar-cell voltage and current leads and electrical insulation, cell bypass diode protection, and heat-transfer elements to keep the CPV solar cells at reasonable operating temperatures. Receiver performance, lifetime, and cost become an integral part of CPV module performance, lifetime, and cost.
- **F.** Development of qualifications standards for CPV receivers and modules using III-V solar cells so they can have the same longevity as these early-generation CPV systems.

CPV Modules

- **G.** Conduct design and manufacturing studies to identify lower-cost, lighter-weight CPV modules that will still survive extreme conditions such as extreme winds at a particular site. CPV module costs need to decrease from today's values of $160/m^2 to $80/m^2.
- **H.** CPV trackers to track the sun accurately during the day to maximize energy capture, including the need to quickly "stow" the module to a horizontal position, in less than half a minute, in case of exposure to sudden wind gusts.
- **I.** Complete a qualification standard for CPV receivers and modules for the United States, as well as for international CPV markets.

CPV Systems

- **J.** System modeling and analysis is needed to provide an understanding of the performance, reliability, manufacturing costs, installed costs, and LECs from a wide variety of CPV system configurations and applications. A key function of this modeling and analysis is to delineate the relative influences of various concentrator PV module and balance-of-system (BOS) technology options on the installed cost (e.g., $/W$_p$ or kg/W$_p$ using a mass surrogate) of the total system and on the levelized cost of electricity over the lifetime of the system.
- **K.** New systems integration will be designed and optimized based on present and other possible markets. In addition, design methodologies will be established that will facilitate the correct integration of components into system designs.
- **L.** Reliability, testing, and validation are needed to collect data from new technologies as they are developed, from existing components and from systems in laboratory and field tests, and fielded systems over time. The data collected will be fed back into the modeling and analysis activities to validate and improve existing tools, conduct trade-off studies by varying different real parameters, and assess overall system cost and lifetime issues.

M. Codes, standards, and certification activities will be undertaken to support the development of qualification and test standards, because these are the ones critical to market entry of a new technology.

4.1.2.4 Technology Approach and Tasks

The technology approach is to improve efficiency, lower cost, and ensure long-term reliability of future CPV systems through the following tasks. Tasks listed below with dates are taken from the recently revised five-year photovoltaics plan milestone schedule and can be considered as part of the FY 2003 Solar Program. Note that the majority of the CPV tasks funded by the FY 2003 Solar Program budget support CPV cell research and development.

Table 4.1.2-2. Tasks for CPV Technology R&D

Task	Title	Barriers
1	**CPV Cell Research and Development**	
	• "Keep the door open" for the exploration and development of a third-generation solar cell approach for efficiencies approaching 60%. Select university research teams for third-generation PV technologies targeting very high efficiency and very low cost.	**A**
	• Evaluate optimized cell grown by molecular-beam epitaxy to assess the viability of GaInNAs for multijunction cells.	**A**
	• Assess research on exploring pathways to high-efficiency PV and develop plans for implementation phase.	**A**
	• Begin implementation efforts of Phase II, addressing cell materials, design, and receiver components for High-Performance PV.	**A**
	• Demonstrate 37% cell efficiency under concentration.	**A**
	• Demonstrate the feasibility of third-generation PV devices such as hot-carrier and impact-ionization concepts.	**A**
	• Demonstrate 39% cell efficiency under concentration.	**A**
	• Investigate methods to increase efficiency and reduce cell cost through film transfer, wafer bonding, or buffer layer.	**C**
	• Develop testing protocol for III-V solar cells under concentration.	**A**
	• Assess implementation efforts of Phase II, leading to the initiation of Phase III of High-Performance PV implementing CPV advances.	**A**
2	**CPV Receiver Research and Development**	
	• Assess R&D needs for CPV optical elements.	**D**
	• Assess issues of operating a high-efficiency multijunction cell under a high-concentration Fresnel lens.	**E**
	• Test high-efficiency (35%) concentrator cell receiver in concentrating-solar-power dish system.	**E**
	• Assess need to develop integrated receiver packaging to resolve issues of thermal management, flux uniformity, and cell protection.	**E**
	• Develop international qualification standard for CPV receivers with III-V solar cells.	**F**
	• Address the operating issues assessed for high-efficiency multijunction cells under a Fresnel lens.	**E**

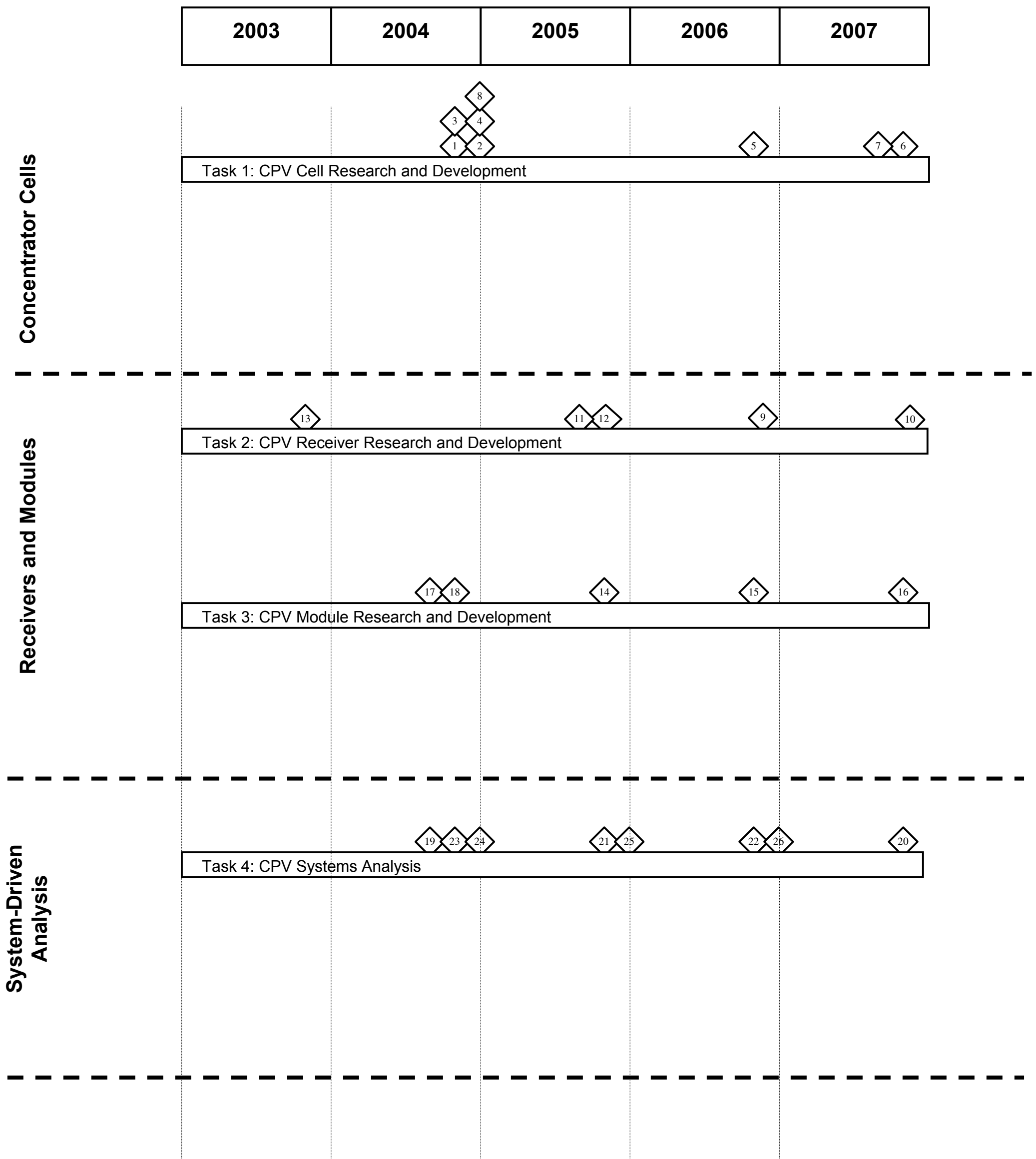
Task	Title	Barriers
3	**CPV Module Research and Development**	
	• Assess need for new system designs having reduced weight as measured in terms of kg/kW or kg/m^2, while meeting structural and wind-loading requirements.	**G**
	• Assess need to develop lower-cost manufacturing processes through plant layout, supply specification, component design, or system design.	**G**
	• Design a conceptual CPV system targeting 33% system efficiency and meeting 2025 LEC goals	**G**
	• Assess needs for low-cost, high-accuracy, stable tracker concepts.	**H**
	• Develop a modified international version of IEEE 1513-2001 to qualify III-V solar cells in a CPV system.	**I**
4	**System Analysis**	
	• Conduct complete CPV systems analysis using the systems-driven approach to verify and prioritize target barriers.	**J**
	• Conduct complete CPV systems analysis to identify and verify appropriate CPV markets and to identify CPV systems interface issues.	**K**
	• Track field operation of CPV systems deployed by other organizations.	**L**
	• Support CPV stakeholders in the development of other (international) standards needed for CPV components and for systems integration.	**M**

4.1.2.5 Schedule and Milestones

Table 4.1.2-3. Schedule and Milestones for CPV

Milestones	Task	Title	Estimated CY Date
1.	1	Exploration and development of a myriad of third-generation solar-cell approaches for efficiency of 60%; select university research teams.	04 Q4
2.	1	Evaluate optimized cell grown by molecular-beam epitaxy to assess the viability of GaInNAs for multijunction cells.	04 Q4
3.	1	Assess research on exploring pathways to high-efficiency PV and develop plans for implementation phase.	04 Q4
4.	1	Demonstrate 37% cell efficiency under concentration.	05 Q4
5.	1	Demonstrate the feasibility of third-generation PV devices such as hot-carrier and impact-ionization concepts.	06 Q4
6.	1	Demonstrate 39% cell efficiency under concentration.	07 Q4
7.	1	Explore film transfer, wafer bonding, or buffer layer technologies as a means to increase cell performance and reduce cost.	07 Q4
8.	1	Develop testing protocol for III-V solar cells under concentration.	04 Q4
9.	1	Begin Implementation efforts of Phase II, High-Performance PV, addressing critical cell and receiver components.	06 Q4
10.	1	Assess implementation efforts of Phase II, leading to the initiation of Phase III of High Performance PV implementing CPV advances.	07 Q4

Milestones	Task	Title	Estimated CY Date
11.	1, 2, 3	Complete capability to evaluate multijunction concentrator cells and modules to 1000x with lowest practical uncertainty.	05 Q4
12.	2	Assess R&D needs for CPV optical elements.	05 Q4
13.	2	Assess issues of operating a high-efficiency multijunction cell under a high-concentration Fresnel lens.	03 Q4
14.	2	Address the operating issues assessed for high-efficiency multijunction cells under a Fresnel lens.	05 Q4
15.	2	Test high-efficiency (35%) concentrator cell receiver in concentrating-solar-power dish system.	06 Q4
16.	2	Develop integrated receiver packaging to resolve thermal management, flux uniformity, and cell protection issues.	07 Q4
17.	2	Develop international qualification standard for CPV receivers with III-V solar cells.	04 Q4
18.	3	Assess need for new system designs having reduced weight as measured in terms of kg/kW or kg/m^2, while meeting structural and wind-loading requirements.	04 Q4
19.	3	Assess need to develop lower-cost manufacturing processes through plant layout, supply specification, component design, or system design.	04 Q4
20.	3	Design a conceptual CPV system targeting 33% system efficiency and meeting 2025 LEC goals.	07 Q4
21.	3	Assess needs for low-cost, high-accuracy, stable tracker concepts.	05 Q4
22.	3	Develop a modified international version of IEEE 1513-2001 to qualify III-V solar cells in a concentrator PV system.	06 Q4
23.	4	Conduct complete CPV systems analysis using the systems-driven approach to verify and prioritize target barriers.	04 Q4
24.	4	Conduct complete CPV systems analysis to identify and verify appropriate CPV markets and to identify CPV systems interface issues.	04 Q4
25.	4	Track field operation of CPV systems deployed by other organizations.	05 Q4
26.	4	Support CPV stakeholders in the development of other (international) standards needed for CPV components and for systems integration.	06 Q4



Legend

◇ Milestones

1. Exploration and development of a myriad of third-generation solar cell approaches for efficiency of 60%; select university research teams.
2. Evaluate optimized cell grown by molecular-beam epitaxy (MBE) to assess the viability of GaInNAs for multijunction cells.
3. Assess research on exploring pathways to high-efficiency PV and develop plans for implementation phase.
4. Demonstrate 37% efficiency under concentration.
5. Demonstrate the feasibility of third-generation PV devices such as hot-carrier and impact-ionization concepts.
6. Demonstrate 39% cell efficiency under concentration.
7. Reduce III-V cell cost substantially through film transfer, wafer bonding, or buffer layer technologies while maintaining or increasing cell performance.
8. Develop testing protocol for III-V solar cells under concentration
9. Begin implementation efforts of Phase II, High Performance PV addressing CPV cell components
10. Assess implementation efforts of Phase II, leading to the initiation of Phase III of High Performance PV implementing CPV cell advances
11. Complete capability to evaluate multijunction concentrator cells and modules to 1000x with lowest practical uncertainty
12. Assess R&D needs for CPV optical elements
13. Assess issues of operating a high-efficiency multijunction cell under a high-concentration Fresnel lens.
14. Address the operating issues assessed for high-efficiency multijunction cells under a Fresnel lens
15. Test high-efficiency (35%) concentrator cell receiver in concentrating solar power dish system.
16. Assess need to develop integrated receiver packaging to resolve thermal management, flux uniformity, and cell protection issues.
17. Develop international qualification standard for CPV receivers with III-V solar cells
18. Assess need for new system designs having reduced weight as measured in terms of kg/kW or kg/m^2, while meeting structural and wind loading requirements.
19. Assess need to develop lower-cost manufacturing processes through plant layout, supply specification, component design, or system design
20. Design a conceptual concentrator PV system targeting 33% system efficiency and meeting 2025 levelized cost of energy goals
21. Assess needs for low-cost, high-accuracy, stable tracker concepts
22. Develop a modified international version of IEEE 1513-2001 to qualify III-V solar cells in a concentrator PV system.
23. Conduct complete CPV systems analysis using the systems driven approach to verify and prioritize target barriers
24. Conduct complete CPV systems analysis to identify and verify appropriate CPV markets and to identify CPV systems interface issues
25. Track field operation of concentrator PV systems deployed by other organizations
26. Support concentrator PV stakeholders in the development of other (international) standards needed for CPV components and for systems integration

4.2 Concentrating Solar Power Systems

As introduced in Section 2, concentrating solar power (CSP) systems include three distinct technologies: parabolic troughs, power towers, and dish-Stirling systems.

4.2.1 Technology Systems Status

Parabolic-trough solar technology has been demonstrated by the nine large utility-scale solar power plants that are operating in California's Mojave Desert. These plants, developed by Luz International Limited and referred to as Solar Electric Generating Systems (SEGS), range in size from 14 to 80 MW and represent 354 MW of installed electric-generating capacity. More than 2 million square meters of parabolic-trough collector technology have been operating daily for as long as 18 years, and, as the year 2002 ended, these plants had accumulated 135 plant-years of operational experience. By virtue of the SEGS experience, parabolic-trough technology has proven to be a robust and reliable power technology in an industrial-utility operating environment. Its key advantages are proven performance, manufacturing simplicity, use of standard equipment and materials, improvement in cost effectiveness via incremental steps, and low technical or financial risk to the investor. Figure 4.2-1 is a schematic of a parabolic-trough system.

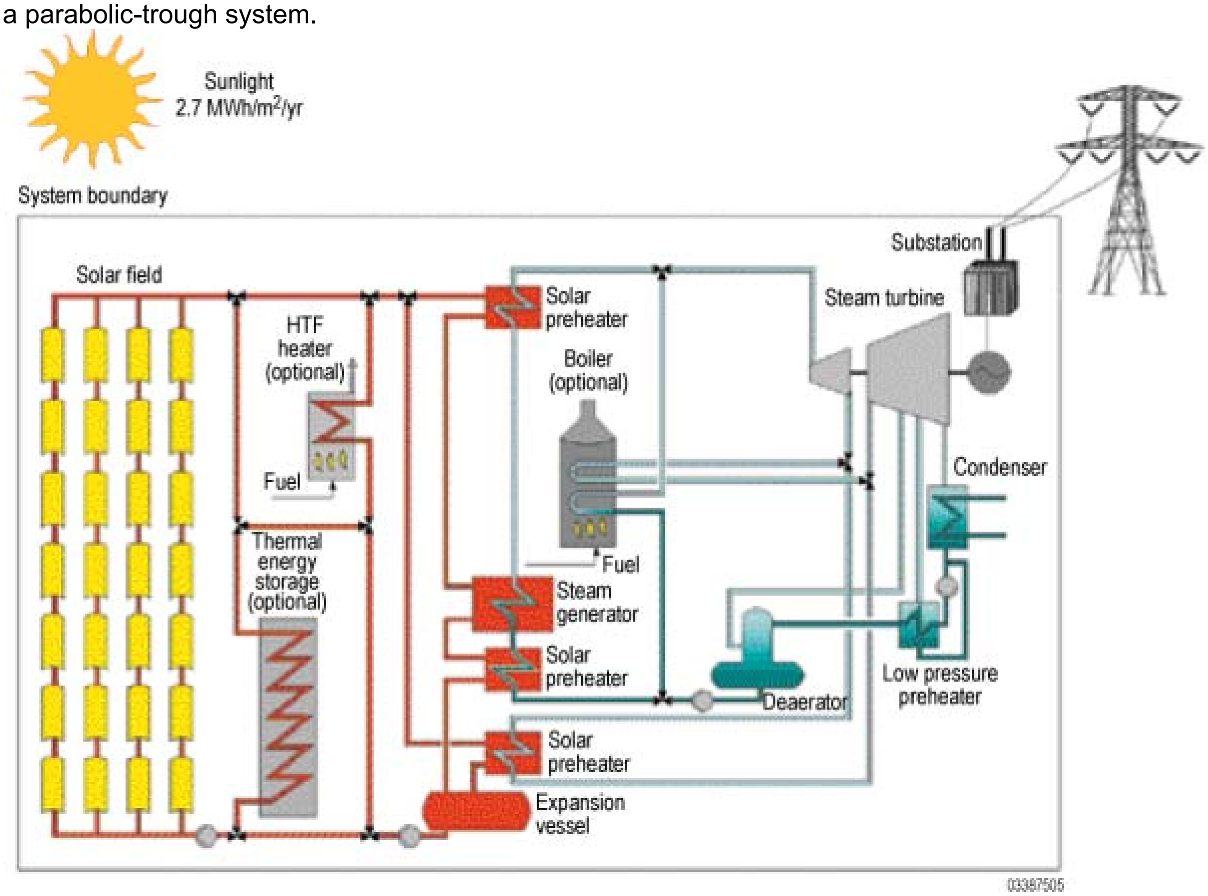


Figure 4.2-1. Schematic of a parabolic-trough system

Current power-tower technology takes the form of utility-scale, grid-connected plants providing electricity to the wholesale market. Numerous working fluids have been tested or considered for use in power-tower plants, including water/steam, air, sodium, and molten salt. The DOE Solar Program has narrowed R&D efforts to focus on the use of molten salt, because it offers very low-cost thermal storage that enables a plant to "dispatch" and produce electricity when it is desired, not just when the sun shines, and to achieve a high capacity factor. Molten-salt power-tower technology was demonstrated at the 10-MWe Solar Two project that operated from 1996 to 1999, but has not yet been deployed commercially. However, a number of opportunities have surfaced recently that could result in the deployment of commercial power-tower technology. A schematic of a solar power tower is shown in Figure 4.2-2.

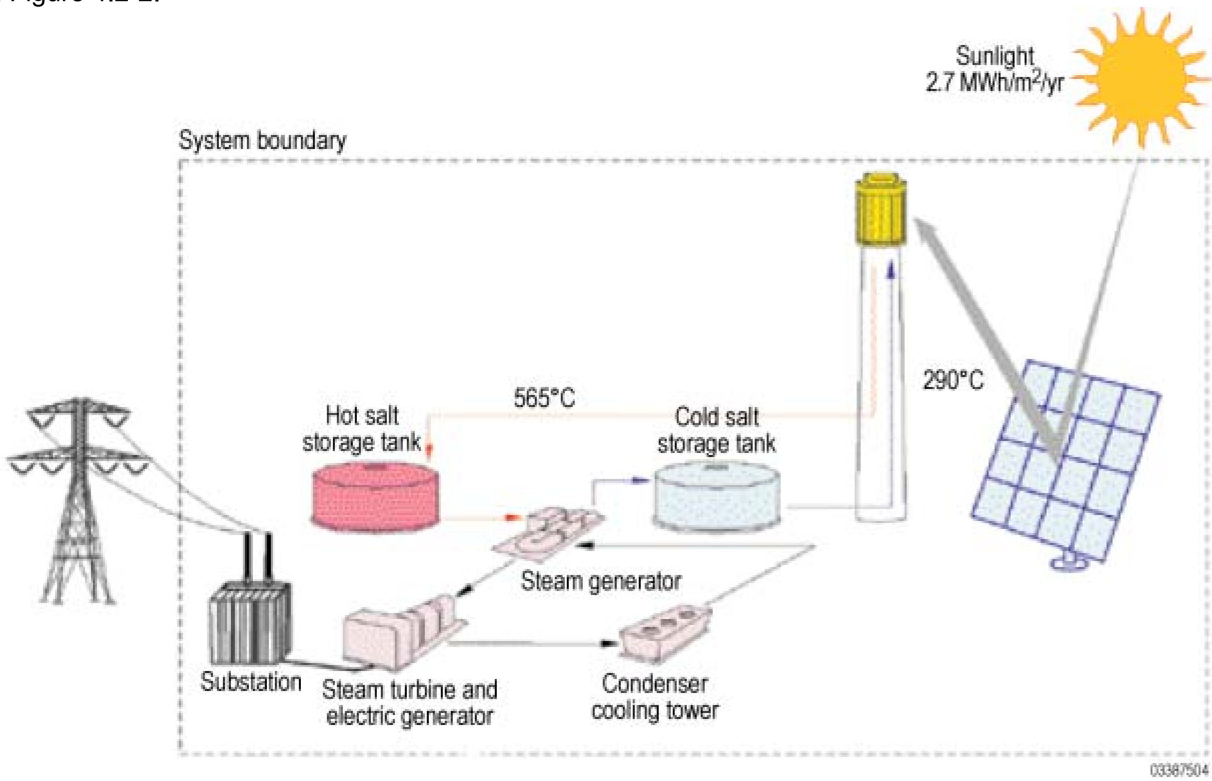


Figure 4.2-2. Schematic of a solar power tower system

Four dish-engine systems are under development today: two are 25-kW and two are 10-kW units. Three of these units are located in the United States and one is in Germany. About 23 units of these systems have been built during the last 10 years. All of the current systems use kinematic Stirling engines. Stirling engines are used because of their high efficiencies, high power density, tolerance of non-uniform flux distributions, and potential for long-term, low-maintenance operation. An existing dish-Stirling system has demonstrated a peak, instantaneous, net solar-to-electric conversion efficiency of nearly 30%. Concentrating PV and other converters are also being considered for use in dish systems. Figure 4.2-3 is a schematic of a dish/engine system.

Current Activities. Trough R&D activities focus on improved concentrator designs, advances to the trough receiver, improved reflectors, development of thermal storage, and advances in power-cycle integration. These R&D efforts are supporting the development of new trough plants currently in development or under consideration in Sun Belt countries around the globe.

Recent power-tower activities have included assisting industry incorporate the lessons learned from the Solar Two demonstration project into the baseline design for the next commercial plant and supporting industry with technology-development activities.

Current activities related to dish-Stirling systems focus on reliability improvement and potential deployment of dish-Stirling systems in southern Nevada. Reliability improvement focuses on operating systems and collecting data on component failures (severity and type of failure), identifying root causes, initiating repairs, and implementing design changes or upgrades to fix the problem. This approach has proved very useful on three systems currently being tested and will be expanded to a third unit from another manufacturer.

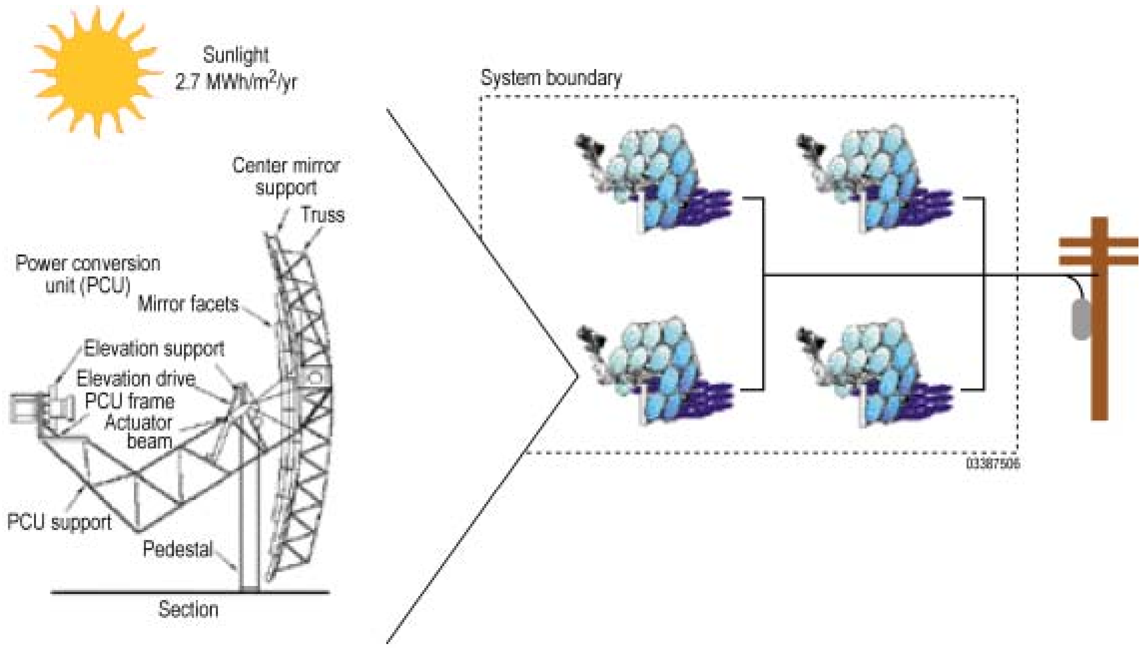


Figure 4.2-3. Dish/engine system schematic. The combination of four 25-kWe units shown here is representative of a village power application.

4.2.2 Technology and Component Goals and Objectives

The following goals and objectives are planned over the 5-year time horizon, based on the long-term goal of being directly competitive with fossil-power-generated electricity within a 10- to 15-year horizon, assuming Energy Information Agency (EIA) fossil fuel and electricity-cost forecasts.

Goals

- Develop parabolic-trough power plant technologies capable of competing on a cost-competitive basis with conventional fossil power technologies as dispatchable intermediate-load generation in the wholesale intermediate-power market (levelized energy cost [LEC] \$0.04 to \$0.06/kWh).
- Develop power tower technologies that will be cost competitive with conventional fossil power technologies as dispatchable intermediate-to-baseload generation in the wholesale bulk-power market (\$0.04–\$0.06/kWh).
- Develop dish-Stirling systems capable of competing in niche areas of distributed generation (short-term competition is diesel generators), grid support, remote and village power markets. Intermediate-power generation may also be a market for these systems.

Objectives[1,2]

Troughs

The 2003 technology baseline is a 50-MWe trough plant with no thermal storage, a net solar-to-electric efficiency of about 11% to 13%, and an LEC of about $0.12/kWh in solar resource regions of 2940 kWh/m^2-yr. Objectives for future years follow.

- By 2005, develop and validate 100-MWe trough-plant technology that uses thermal storage technologies that provide up to 6 hours of storage, costs less than $30/kWht, has 95% round-trip efficiency, and achieves an LEC of less than $0.10/kWh in solar resource regions of 2940 kWh/m^2-yr.
- By 2007, develop and validate 100-MWe trough plants that demonstrate solar-to-electric efficiencies greater than 16%, use thermal storage technologies that provide up to 12 hours of storage, cost less than $15/kWht, have 98% round-trip efficiency, and achieve an LEC of less than $0.07/kWh in solar resource regions of 2940 kWh/m^2-yr.
- By 2012, develop and validate 200-MWe trough plants that demonstrate solar-to-electric efficiencies greater than 16.5%, use thermal storage technologies that provide up to 12 hours of storage, cost about $10/kWht, have greater than 99% efficiency, and achieve an LEC of less than $0.05/kWh (in volume production) in solar resource regions of 2940 kWh/m^2-yr.

Power Towers

The 2003 technology baseline is a 13.7-MWe plant using molten salt as the heat transfer fluid, 13 hours of thermal storage, an annual solar-to-electric efficiency of 13.7%, and an LEC of about $0.15/kWh in solar-resource regions of 2940 kWh/m^2-yr.

- Support deployment of the first commercial molten-salt power tower.
- By 2007, demonstrate power tower technology capable of achieving an LEC of less than $0.06/kWh when deployed at 2940 kWh/m^2-yr solar resource level.
- By 2018, demonstrate power-tower technology capable of achieving LEC of $0.04/kWh when deployed at 2940 kWh/m^2-yr solar resource level.
- By 2025, demonstrate power-tower technology capable of powering Brayton and combined cycle plants as well as thermochemical reactors to create hydrogen or other fuels.

Dishes

For 2003, the technology baseline is a solar-only 25 kW dish-Stirling system with net annual solar-to-electric generation efficiency of about 20%, solar-only system operation, and a cost of energy (not including O&M cost) of about $.40 per kWh. Objectives for future years follow.

- By 2007, validate 25-kW dish-Stirling systems that requires half the capital cost of current systems as a result of production and improved concentrator and power control unit (PCU) designs, demonstrate improved reliability with greatly reduced O&M costs, operate with an annual net solar-to-electric conversion efficiency of 23%, and achieve a cost of energy of less than $.20/kWh.

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[1] The technology baseline and future technology objectives for troughs and towers are based on the Sargent & Lundy Report, "Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts - Draft 3." Prepared for the U.S. Department of Energy and the National Renewable Energy Laboratory, Sargent & Lundy, Chicago, Illinois, October 2002.

[2] Levelized energy cost (LEC) is based on the DOE methodology in which LEC is shown in constant 2003 dollars (i.e., the effects of inflation are removed). Nominal input assumptions come from the S&L report and include independent power producer project finance with 30-year project life at 14% return for equity holders, 20-year debt at 8.5% interest with a minimum 135% debt coverage ratio, 0.5% annual insurance, and 0.5% property tax. Debt/equity ratio, initial energy price, and energy price escalation are selected to minimize LEC. The existing 10% investment tax credit and 5-year accelerated depreciation are included. This is equivalent to an approximately 8.8% real fixed-charge rate.

- By 2025, develop advanced dish-engine systems that include advanced concentrator designs, using materials that cost less, advanced converters such as microturbines and PV devices, hybrid operation to increase capacity factor to 50%, and achieve a cost of energy of less than $.06/kWh.

4.2.3 Key Technical Challenges

The key technical challenges for parabolic-trough technology are reducing the LEC and developing a low-cost and thermally efficient thermal energy storage that will allow dispatching power to meet the system peak load and that will increase the plant capacity factor. The LEC can be reduced by increasing the plant output, increasing plant efficiency, reducing capital cost, reducing O&M costs, reducing development costs, and reducing technology risk that affects the cost of capital required to invest in the project.

Technology improvements are required for power-tower technology to develop further, but these would be evolutionary changes in the technology rather than revolutionary breakthroughs. LEC reductions resulting from scale effects are large on a relative basis, because so far only small-sized plants (in utility terms) have been built. However, scale effects, technology improvements, and volume-production cost reductions are all likely necessary to reach the full market competitiveness that will encourage widespread deployments and can measurably impact societal issues of global warming and energy security. R&D supports scale-up of the solar field and the development of technology advances. DOE manufacturing R&D would also aid cost reductions related to volume production, but much of this benefit is expected to result from industry-funded efforts. R&D in support of the transition from the Solar Two demonstration plant to the next commercial plant will result in a substantial reduction in LEC to about $0.12/kWh if located at a premium solar site.

Short-term technical challenges for dishes are dominated by improving the reliability of current systems through systematic operation, root-cause analysis of failures, and improvement of component design and/or operation of the system. This process leads to incremental improvements in existing technologies while, at the same time, developing and incorporating new technologies into the units under study. Long-term technical challenges include reducing the capital and O&M costs for these systems. A major focus of the activity will be to develop and engineer robust components that are capable of operating for long periods of time between failures and scheduled maintenance. The first “key” activity in this plan is to assess the markets for these systems, to further define the market entry requirements and the potential of these systems to meet these requirements.

The sections below address the technical targets and key technical barriers facing parabolic trough, power tower, and dish technologies.

Technical Targets

The following tables (4.2-1 through 4.2-3) highlight the technical targets for each technology. The metrics shown in the tables relate to the specific plant configurations assumed in future years. The LEC is based on sites with a premium solar resource. Trough and tower plants shown are solar only to clarify the progression of technology targets, although hybrid plants may also be deployed commercially.

Table 4.2-1. Technical Targets: Parabolic Trough Power
(Solar-only operation at premium solar site)

Plant Characteristics	Unit	Calendar Year			
		2003	2005	2007	2012
Solar Resource: Kramer Junction, CA	kWh/m^2-yr	2940	2940	2940	2940
Plant Size	MWe	50	100	100	200
Thermal Storage	hours	0	6	12	12
Solar Field Size (aperture area)	km^2	0.32	0.87	1.03	2.00
Land Area	km^2	1.09	2.9	3.5	6.8
Plant Capacity Factor	%	28	39	56	56
Electricity per Square Kilometer of Land	GWh/km^2	113	127	140	149
Net Solar-Electric Efficiency	%	13.0	13.2	16.2	16.7
Total Capital Cost	$/kWe	2805	3556	3422	2920
Solar Field (Collectors + field piping)	$\$/m^2_{coll}$	245	221	180	160
Storage System Cost	$\$/kWh_t$	NA	31	14	13
Steam Generation + Power Cycle + BOP	$\$/kW_e$	850	690	690	550
O&M Cost	$/kWh	0.0248	0.0148	0.0099	.0072
LEC With technology R&D	**$/kWh**	**0.113**	**0.096**	**0.064**	**0.054**
With volume production					**0.046**

Table 4.2-2. Technical Targets: Power Tower

Plant Characteristics	Unit	Calendar Year			
		2003	2005	2007	2018
Solar Resource	kWh/m^2-yr	2940	2940	2940	2940
Net Electric Power	MW_e	13.7	50	100	220
Gross Thermal Power	MW_t	100	350	700	1400
Solar Field Mirror Area	km^2	0.23	0.72	1.32	2.65
Land Area	km^2	1.1	3.4	6.6	14
Receiver Area	m^2	280	710	1110	1990
Operating Temperature	°C	565	565	565	650
Thermal Storage	hours	13	13	13	13
Peak Net Solar-Electric Efficiency	%	19.5	21.6	22	24
Annual Net Solar-Electric Efficiency	%	13.7	15.7	16.5	17.8
Capacity Factor	%	78	75	73	72
Capital Cost	$\$/kW_e$	6800	4100	3500	2500
Solar Collection System (heliostats + tower + receiver)	$\$/m^2_{field}$	240	170	140	100
Storage System Cost	$\$/kWh_t$	10.2	9.1	8.7	6.6
Steam Generation + Power Cycle + BOP	$\$/kW_e$	960	670	550	500
O&M Cost	$/kWh	0.036	0.012	0.008	0.005
LEC @ 8.8% FCR	**$/kWh**	**0.12**	**0.066**	**0.057**	**0.04**
w/ Heavy Deployments				**0.054**	**0.037**

Table 4.2-3. Technical Targets: Dishes

Plant Characteristics	Units	Calendar year 2003	2007	2025
Solar Resource: Daggett, CA	kWh/m^2-yr	2800	2800	2800
Solar Collector				
Solar Aperture Area	m^2	91	91	88
Projected Glass Area	m^2	88	88	85
Reflectivity	%	92	94	95
Intercept Factor	%	95	97	99
Concentrator Weight	kg/m^2	75	65	30
Power Conversion Unit				
Receiver Type		DIR	DIR	ADV*
Receiver Efficiency	%	90	90	95
Engine Type		KSE	KSE	ADV
Engine Efficiency	%	32	35	42
System Performance Parameters				
Capacity Factor				
Annual Solar Energy Production	kWh/m^2	575	627	754
Annual Total Energy Production	KWh/m^2	575	627	1095
Annual Solar Efficiency Net	%	20	23	26
Annual Capacity Factor	%	24	24	50
Levelized Energy Cost	$/KWh	0.40	0.20	0.06

Considerations:
Hybrid receiver in 2025.

4.2.4 Technical Barriers

These technical barriers apply to all three CSP systems.

- **A. Capital Cost**. The high capital cost of CSP technologies leads to high LEC and also makes project financing more difficult compared to technologies that are fuel-cost intensive.
- **B. Reliability**. Reliability issues vary by technology, but improved reliability is desirable or necessary in all cases.
- **C. Performance.** Improved system performance (efficiency) reduces the required quantity of solar hardware to produce a given amount of power.
- **D. O&M Cost.** Historically, small plant sizes and low capacity factors have led to O&M costs for troughs and towers that are significantly higher than their competition. O&M costs for developmental dishes have been very high and must be reduced to be competitive in both distributed and, especially, remote markets.
- **E. Technology Risk**. New technologies that have never been deployed commercially first need to be sufficiently demonstrated to help reduce the uncertainty in cost, performance, and reliability.
- **F. Market Entry**. All CSP technologies face market-entry obstacles related to the aforementioned barriers. In addition, they face the hurdles of any new technology trying to penetrate markets. This can include difficulties in financing projects and finding customers willing to try something new. It is important to identify and understand these types of market-entry barriers so that solutions (technical, policy, or other) can be developed. For example, the hybridization of CSP technologies with fossil fuels may provide a market “on-ramp” wherein cost and/or risk are reduced, thereby easing the transition to larger or solar-only deployments.

4.2.5 Approach and Tasks

4.2.5.1 Trough Technology Approach and Tasks

Although parabolic-trough solar technology is not economically competitive in today's energy market, it appears to have significant potential for cost reduction. Key advantages of the technology are its simplicity and use of standard equipment and materials. Based on extensive commercial operating experience, parabolic-trough technology is considered to have a lower technical risk than many technologies and, thus, a lower financial risk. The technology R&D plan attempts to build on these strengths through the following key tasks:

I. Developing less costly and more efficient parabolic trough solar field technology.

To achieve long-term goals, the cost of the solar collector technology needs to be reduced by half, from about $250/m^2 to $125/m^2, and the annual solar field efficiency needs to increase from 37% at current plants to about 52% at future plants. At the same time, the peak operating temperature will be increased from 390º to 500ºC. The key to reducing costs is reducing the cost of the structure, mirrors, and receivers. Near-term efforts focus on optimizing the structure of current steel/thick-glass concentrators and increasing the concentrator size (relative to the LS-2 parabolic collector). This effort is expected to reduce costs to the $180 to $200/m^2 range without any reduction in mirror or receiver cost. Volume production and increased competition should help reduce prices even further. In the longer term, further cost reduction can be achieved 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 and higher performing selective coating. Advanced concentrator designs that use integrated structural reflectors are expected to allow significant reductions in the cost of the structure and reflectors.

II. Developing efficient and lower-cost thermal energy storage (TES) technologies.

The integration of thermal storage is needed to boost overall plant capacity factors for solar-only operation from about 25% in current plants without thermal storage to more than 50% in the future. This will enable dispatching and increase the value of the power. A near-term TES option has been developed that uses molten nitrate salt as the storage medium in a two-tank system and 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 $30 to $40/kWht depending on storage capacity. Substantial cost reduction, by a factor of three or more, is required to meet longer-term TES cost goals. The approach being taken to reduce future TES costs is to (1) go from an indirect system that requires a heat exchanger to one that uses the same fluid in the solar field and storage system, (2) move from a two-tank system to a single-tank thermocline storage system, and (3) increase the hot and cold temperature differential in the storage system. The key here is to find a heat-transfer fluid (HTF) that is suitable for both the solar field and the storage system. Two HTF approaches are currently being pursued. The first option looks at using an inorganic molten nitrate salt. The key technical issues with inorganic molten-nitrate salt are the relatively high freeze point of the salt (120ºC and up) and the need to develop appropriate valve and ball-joint packing materials that survive the high temperatures (450º to 500ºC). The R&D plan for this type of HTF focuses on resolving the freeze protection and packing issues, developing reliable collector-interconnect piping, demonstrating the lifetime of the TES filler material, and demonstrating the system elements in the field. The second HTF option under consideration is to use an organic salt. Organic salts offer many of the same advantages of inorganic molten salts, but many also have the added benefit of being liquid at ambient temperatures. The primary issue with organic salts is to find one that is thermally stable at the high temperature and is not too expensive.

III. Developing optimized solar power plants.
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. Alternative power cycles (combined cycle and organic Rankine cycles) will be considered for niche applications. Power plant O&M costs will be reduced primarily through scaling up plant size and increasing capacity factor. Improvements in receiver and mirror reliability and mirror-washing techniques will help reduce solar-field O&M requirements. Developing 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.

IV. Developing the design and systems integration tools for solar power plant optimization.
This activity focuses on developing systems-integration tools to evaluate trough technologies and assess program activities. Metrics, and a methodology for tracking them, to support the Solar Program systems-driven approach and to support technical evaluation of program R&D efforts will be developed. Many of the existing models used for technical and economic analysis of parabolic-trough solar power plant technologies need to be updated and validated. This includes 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. The development of testing standards, facilities, and data-reporting requirements for key solar-field components, systems, and power plants will be implemented. The EERE Troughnet Website (http://www.eere.energy.gov/troughnet) will be updated to improve technology transfer to stakeholders.

Table 4.2-4. Tasks for Parabolic Trough Technology R&D

Task	Title	Barriers
I	**Parabolic Trough Solar Field Technology**	
1	**Advanced Trough Receiver**	
	• Develop improved receiver glass-to-metal seal	**All**
	• Develop higher-temperature selective coating	**B,C**
	• Develop low-cost receiver	**A,D**
	• Develop industry-accepted receiver testing standards	**E**
2	**Next-Generation Parabolic Trough Concentrator**	
	• Develop structure optimized for optical accuracy and cost	**A,B,C**
	• Develop updated control systems that use modern electronics and communications technologies	**All**
	• Conduct full-scale wind force tests to compare with wind tunnel results	**A,B,C**
	• Field test new designs to reduce technical and financial risk	**E**
3	**Develop advanced linear concentrator collector technology**	
	• Develop advanced linear-concentrator concepts	**A,C,D**
	• Develop front-surface reflector	**All**
	• Develop prototype collectors and field test designs	**B,C**
II	**Thermal Energy Storage Technology**	
4	**Near-term thermal storage options**	
	• Design optimization of indirect molten-salt, two-tank TES	**A,C,F**
	• Evaluate thermocline storage options	**A**
	• Test prototype near-term thermocline storage configurations	**E**

Task	Title	Barriers
5	**Inorganic Molten Salt Heat Transfer Fluid/Thermal Energy Storage**	
	• Test molten-salt and thermocline filler material	A,B,E
	• Develop collector-interconnect technology for molten-salt HTF	B,D
	• Identify and test appropriate salt valve and instrumentation	B,D,E
	• Develop freeze-protection and freeze-recovery technologies	B,D
	• Develop thermocline storage system	A
	• Develop detailed O&M methods for use with molten-salt HTF	D
	• Field demonstration	E
6	**Advanced Heat-Transfer Fluid Development**	
	• Identify candidate fluids that meet process requirements	A,C
	• Prototype fluid synthesis and laboratory testing	B
	• Fluid scale-up and testing	B
	• Field demonstration testing	E
7	**Advanced TES Concepts**	
	• Coordinate U.S./European TES activities	All
	• Identify alternative TES concepts (direct salt, phase-change, chemical, other)	All
	• Develop advanced TES concept.	All
III	**Solar Power Plant Technology**	
8	**Power Cycle Integration Activities**	
	• Optimize steam-cycle power plant design (gross cycle efficiency and parasitics)	A,C
	• Integrate trough solar field with combined-cycle power plant	A,C,F
	• Develop optimized trough organic Rankine cycles (ORC)	A,C,F
	• Assess direct steam generation	A,C
9	**Water Reduction**	
	• Develop hybrid wet/dry and dry cooling designs for trough power plants	A,C,D
	• Reduce water requirements for mirror washing	D
	• Develop steam cycle designs that conserve water	D,F
10	**Operation & Maintenance Technology**	
	• Develop specialized O&M tools (improved mirror-wash technology, reflectivity monitoring, alignment, receiver vacuum-monitoring methods, solar radiation forecasting)	D
	• Develop advanced automation and controls	A,C,D
	• Develop improved information systems for O&M (reliability tracking, electronic logs, solar-field maintenance)	D
	• Develop improved O&M procedures	D
IV	**System Integration**	
11	**Trough System Simulation and Analysis**	
	• Develop detailed 5-year-plan metrics, 10-year and 25-year goals; develop metric tracking for systems-integrated approach	All
	• Perform trade-offs and analyses to compare candidate trough/subsystem combinations with respect to cost and performance	All

Task	Title	Barriers
12	**Tools for Design Integration**	
	• Develop integrated parabolic-trough systems model for systems-integrated approach that includes performance, capital cost, O&M costs, and financial analysis	**All**
	• Develop and update design tools for parabolic-trough components (receiver, concentrator, solar field, TES, power cycle, cooling, O&M, financial)	**A,C,D**
	• Continually update and refine trough-system-component models as data become available from Solar Program projects and other sources	**A.C,D**
13	**Standards, Testing, and Technology Transfer**	
	• Develop testing standards for solar-field components, systems, and plants	**E**
	• Develop laboratory test facilities to support R&D program (coatings, reflector, concentrator, storage)	**A,B,C**
	• Develop mechanism for technology transfer to stakeholders	**All**

4.2.5.2 Tower Technology Approach and Tasks

Molten-salt power tower technology has excellent potential with its low-cost integral storage and large cost reductions possible through scale-up. Large-scale deployment of this technology occurred in the Solar Two demonstration project; the next step is deployment in a commercial plant. Many of the tasks in this area are related to assisting with near-term commercialization and scale-up of this technology, including providing technical assistance to industry and reducing the technical and financial risks. The task plan also includes many items aimed at achieving long-term competitiveness with fossil fuels, because technical innovations will be required to reach this goal.

I. Developing less costly and higher performance heliostats.

Heliostat performance varies with time and location in the field, impacting annual plant performance and optimal design. Testing and modeling standards are needed to insure prototype tests permit accurate annual performance estimates. The heliostats must be aimed to maximize energy collection, but avoid damaging the receiver. Improved flux management and monitoring systems are needed to protect the receiver from possible damage. Allowing for 30-year peak winds normally drives heliostat structural design, but lower-speed winds also affect performance. The combination of turbulence, bluff-body aerodynamics, heliostat structural dynamics, site variability, and temporal variability has led to expensive conservatism in heliostat design. An improved fundamental understanding of wind loads and development of risk-based design tools are needed. The heliostats' open-loop control systems are susceptible to numerous error sources that can reduce performance. Improved, error-correcting control methodology must be developed and tested. An improved understanding of the influence of structural stiffness and drive backlash on tracking accuracy is required to optimize heliostat and system design. Heliostat beam quality is a complex phenomenon influenced by many factors that vary with location, and time, in the field. One factor is structural stiffness, which is directly tied to heliostat cost. In the long term, higher receiver flux levels will require improved heliostat tracking accuracy and beam quality because the relative target size will decrease.

II. Developing low-cost and reliable salt systems.

Very large reductions in LEC are possible by increasing the size of the solar plant because unit ($/kWh) capital and O&M costs decrease when power-cycle size and capacity-factor increase. One key R&D activity is supporting industry with the scale-up of salt-system technologies through analysis and testing. Stress corrosion cracking that was observed in some Solar Two piping must be addressed by validating and using materials, installation practices, and/or operational procedures that provide resistance. Additional work is needed to validate improved receiver and oven-cover designs that prevent salt freezing during high-wind drain-and-fill operations. More reliable, cost-effective valves and instruments must be proven for use in molten salt. Also, plant designs must be simplified to reduce values, instruments, and O&M costs. For example, long-shafted pumps mounted directly on the storage tanks eliminate pump sumps and valves and reduce failure modes. Likewise, the elimination of the outlet vessel and valves from the downcomer (outlet) piping reduces complexity and cost. These concepts need to be tested further. Higher receiver flux levels reduce the receiver's required size and cost, while simultaneously increasing efficiency. Additional analysis and testing of receivers will be required, as will improved heliostat accuracy, flux monitoring, and feedback systems. Increased annual receiver absorptivity will reduce LEC and can be achieved by both increasing the as-new absorptivity and increasing durability. In the long term, operating temperatures of 600º–650ºC will be required if higher efficiency, supercritical Rankine cycles are used. "Solar salt" has been kept stable at 650ºC in prototype testing. In the next 5 years, work is needed on salt stability, containment materials, and receiver designs to determine if this approach is worth pursuing. If successful, additional development and testing would be required to prove the concept at larger scale.

III. Developing higher-efficiency power cycles and improving balance-of-plant technologies.

Molten-salt power tower plants use commercial Rankine-cycle steam turbines to generate electricity. However, additional work is needed to improve O&M procedures, refine plant controls, and reduce parasitic losses. Some markets may have water-supply constraints, so lower-consumption dry or hybrid wet/dry cooling technologies will be needed. The power industry is developing large, high-efficiency, supercritical Rankine cycles for use with conventional fuels. Work is needed to evaluate the use of increased operating temperature power-tower technology with these cycles.

IV. Performing system integration and analysis.

The design of a power-tower plant is a complex optimization involving the size, cost, and performance of the many subsystems. Optimal designs provide lower energy costs, and updated design tools are needed to achieve this potential. Also needed is an integrated analysis tool that simplifies case studies and additional work in assessing market issues, such as the value of storage or impact of public policy, and identifies market-entry opportunities. Improved solar resource data are needed for performance predictions in potential markets. Support of industry in deploying commercial projects is critical and offers very high return on investment, because significant reductions in LEC are projected from the rapidly increasing scale (size) of the initial commercial deployments.

Table 4.2-5. Tasks for Power-Tower Technology R&D

Task	Title	Barriers
I	**Heliostat Technology**	
1	**Improve Heliostat Optical Performance and Reduce Cost**	
	• Develop and validate error-correcting control methodology	**C,E**
	• Improve method for collecting tracking-error data during installation and operation	**C,D,E**
	• Develop a lower-cost, pedestal-mounted drive	**A,E**
	• Develop improved field flux management and monitoring systems	**C,D,E**
2	**Improve Heliostat Testing, Modeling and Design Optimization**	
	• Develop heliostat optical performance and drive testing standards	**A,B,C**
	• Develop a heliostat drive cost/performance database	**A,C**
	• Improve models of heliostat/field performance	**C**
	• Perform optimization studies on heliostat performance/cost trade-offs	**A,C**

3	**Address Heliostat Wind Loading** • Develop risk-based design tools for wind survival • Improve fundamental understanding and modeling of wind loads on heliostats • Evaluate approaches to wind-load reduction and structural damping	 **A,B,D** **A,C** **A,C**
4	**Advanced Heliostat Design** • Identify promising advanced, low-cost heliostat design concepts • Develop and test prototypes of promising concepts	 **A,C,D** **E**
II	**Salt Systems**	
5	**Receiver Technology** • Improve receiver fill/drain performance in high winds • Increase receiver flux limits • Scale up receiver size • Improve receiver absorptivity and thermal performance	 **B,E** **A,C** **A,E** **C**
6	**Salt Storage, Valves, and Instruments** • Address stress corrosion cracking • Improve salt valve and instrument performance, cost, and reliability • Demonstrate long-shafted pump design at commercial scale • Refine salt-system design to improve reliability and reduce initial and recurring costs (e.g., valveless downcomer)	 **B** **B,D,E** **B,E** **A,D**
7	**Increase System Operating Temperature** • Evaluate options to increase operating temperature • Identify and characterize materials needed • Demonstrate HTF temperature stability	 **C** **A,B,E** **B,C,E**
III	**Power Cycle and Balance of Plant**	
8	**Power Cycle Integration** • Evaluate integration of power towers into supercritical Rankine cycles	 **A,C**
9	**Water Reduction** • Analyze market requirements for water use • Develop hybrid wet/dry and dry cooling designs • Reduce water requirements for mirror washing	 **F** **F** **D,F**
10	**Operation & Maintenance Technology** • Develop specialized O&M information tools (improved mirror-wash scheduling, reflectivity monitoring, equipment-reliability tracking and maintenance scheduling, solar radiation forecasting) • Develop advanced plant automation and controls • Develop improved O&M procedures that reduce parasitic power use and improve reliability	 **C,D** **C,D** **C,D**

IV	System Integration and Analysis	
11	**Power-Tower System Simulation and Analysis**	
	• Develop/update detailed 5-year-plan metrics, 10-year and 25-year goals; develop metric tracking for systems-integrated approach.	**F**
	• Identify novel power-tower designs and market opportunities	**F**
	• Evaluate impact of atmospheric attenuation limits using updated resource assessment data and analyze alternative approaches	**C**
12	**Tools for Design Integration**	
	• Update and improve power tower design tools	**A,C**
	• Develop an integrated analysis tool	**All**
	• Validate models	**All**
	• Continually update and refine models with new data	**All**
13	**Support Commercial-Plant Deployment Opportunities**	
	• Identify relevant markets and policy issues	**F**
	• Test components to reduce risk	**E**
	• Provide technical support with project development, detailed design, construction, and operation	**E,F**
	• Evaluate hybrid operation and hardware required for solar/fossil integration	**A,C, F**
14	**Monitor Commercial-Plant Performance**	
	• Support an active test and evaluation program	**B,C,D**
	• Collect data for model validation and improvement	**All**
	• Support analysis of lessons learned	**All**

4.2.5.3 Dish Technology Approach and Tasks

To address the barriers facing the deployment of dish-Stirling systems that were identified in the preceding section of this plan, we will pursue the following tasks. The first-and-foremost activity for dish-Stirling systems is to better identify and quantify the markets and market requirements for these systems and to expand on existing models and develop new ones for dish-Stirling-system performance and cost. In parallel with this activity, we will continue to measure and improve on reliability and to develop robust components and advanced systems that will improve performance. The dish-Stirling tasks for the next 5 years are described in the following activities and table and the milestone chart of this section.

I. Performing systems analysis.

Systems analysis is needed to identify in more detail the markets and market requirements for dish systems in distributed generation, remote power, and, potentially (as identified by some system developers), in bulk-power markets. Emerging distributed-generation markets are not currently well understood or characterized, and the requirements of systems to be deployed in those markets are not known. Some of these markets will be on the “wholesale” side of the meter, having characteristics of utility-like power generation, and others will be on the “customer” side of the meter and command a higher value for the power they generate. In both cases, we need to know the size of the markets and their requirements for systems deployment. Existing models will be expanded and new ones developed for dish-Stirling systems. They will be used to evaluate the impact of R&D improvements and designs on the performance and cost of power, similar to the due-diligence activity that has been done for solar-trough and power-tower systems.

II. Improving system performance and reliability.

This activity involves three main tasks: (1) collecting data on the operation of systems, (2) continuing to develop the models and tools required to track and analyze O&M data, and (3) operating and improving systems performance at the laboratories by systematically identifying root causes, initiating repairs, and, where possible, implementing design changes or upgrades to fix the problem.

III. Developing and testing advanced components.

A major barrier to the deployment of these systems is their cost. Developing advanced concentrators, receivers, and solar energy converters are key activities to reduce the cost of electricity from dish-engine systems. The development of hybrid receivers is of special importance, because this not only increases the operating time for the system but also increases the value of power because it makes the power dispatchable.

IV. Supporting deployment by industry.

Support of industry deployment of systems is crucial, not only because it supports DOE's goal of increasing the use of solar energy, but for other reasons, as well. First, deployment of systems provides additional opportunities to gather data for reliability improvement and test beds for evaluation of new system components. Second, it is critical that deployed systems operate the "best that they possibly can" so that users and potential users will have a good picture of what the potential of this technology really is. Laboratory support and technical assistance for deployed systems is absolutely necessary to achieve this objective.

Table 4.2-6 lists a number of general tasks associated with these four main activities. Also listed in the table are the barriers that each activity addresses. Not listed in the table is the benefit—the reduction in the LEC—that will accrue with the successful completion of the task. The reason the benefit is not listed is that our models are not sufficiently complete at this time to estimate the benefit. We do not have a good set of market requirements and complete models of system costs to complete the analysis. The first milestone of Activity I above addresses this issue.

Table 4.2-6. Tasks for Dish-Engine/Converter Technology R&D

Task	Title	Barriers
I	**Perform Systems Analysis**	
1	**Evaluate Markets for Dish Systems**	
	• Evaluate DER, remote, and village power market requirements	**F**
	• Develop consistent financial parameters and assumptions for modeling costs	**F**
2	**Develop Models of Dish-System Components**	
	• Develop integrated-model architecture	**All**
	• Develop individual-component models	**All**
	• Establish consistent economic models	**All**
3	**Integrate Component Models in a Systems Model**	
	• Evaluate model inputs/outputs and revise	**All**
II	**Improve System Performance and Reliability**	
4	**Monitor and Track Operating Systems**	
	• Identify and track existing systems	**B,C**
	• Implement data-tracking activities with new system installations	**B,C**

5	**Operate, Monitor, and Repair Systems**	
	• Operate industry systems at the laboratory (Advanced Dish Development System, Stirling Energy Systems, etc.)	**B,C**
6	**Upgrade and Coordinate Reliability Database**	
	• Evaluate and upgrade reliability database	**B,C**
	• Compare with PV database and evaluate consolidation	**B**
	• Train users to enter data and extract information	**B,C**
III	**Develop and Test Advanced Components**	
7	**Solar Concentrator**	
	• Develop lower-cost drives	**A**
	• Evaluate alternative reflector materials	**A,B**
	• Start to evaluate advanced concentrator concepts	**A**
8	**Power Conversion Unit**	
	• Evaluate and test PV inverters	**A,B**
	• Assess the potential of micro-turbine converter	**A,B**
	• Develop advanced hybrid receiver	**C,F**
IV	**Promote/Support Deployment by Industry**	
9	**Help Promote Industry Deployment Projects**	
	• Nevada 1-MW project	**A,B,F**
	• Support SW 1000-MW deployment	**F**
10	**Support Industry with Design Assistance**	
	• Evaluation of components	**A,B,C,D**
	• Design assistance to solve O&M problems	**D**

4.2.6 Schedule and Milestones

The milestones listed in the following tables were developed assuming a stable CSP budget during the planning period of about $15 million.

Table 4.2-7. Trough Technology Development Milestones

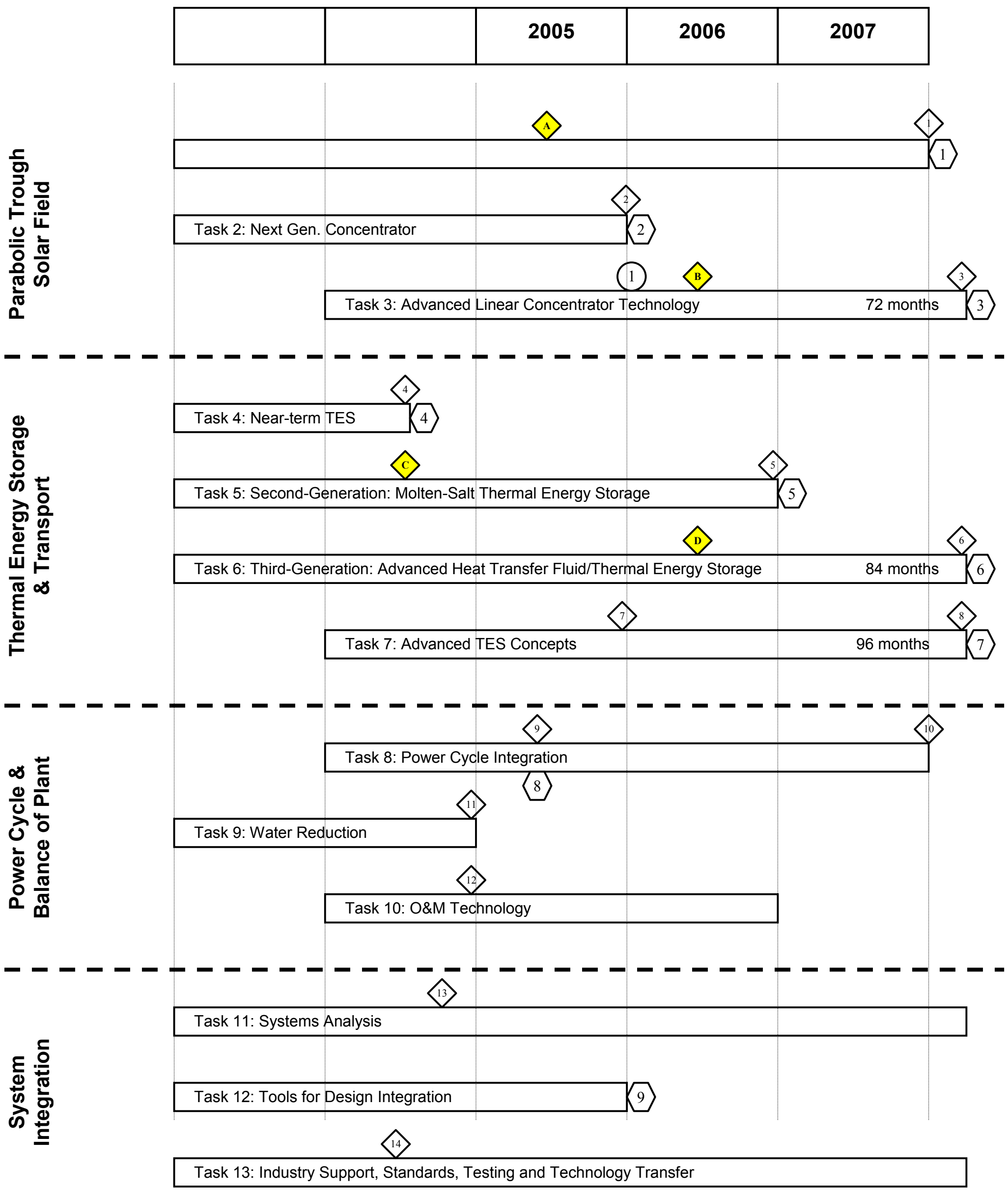
Milestones	Task	Title	Estimated CY Date Quarter
1.	1	Advanced trough receiver demonstrated	07 Q4
2.	2	Next-generation parabolic trough concentrator demonstrated	05 Q4
3.	3	Advanced linear-concentrator design prototype	09 Q4
4.	4	Complete near-term TES design optimization	04 Q2
5.	5	Validate inorganic molten-salt HTF/TES for 450ºC	06 Q4
6.	6	Validate organic molten-salt HTF for 450ºC	09 Q4
7.	7	Identify advanced TES concepts for 550ºC and direct salt	05 Q4
8.	7	Demonstrate advanced TES concepts	11 Q4
9.	8	Demonstrate optimized trough organic Rankine-cycle engine	05 Q2
10.	8	Decide whether to pursue direct steam generation.	05 Q4
11.	9	Identify reduced-water design options.	04 Q4
12.	10	Validate field of concentrator-alignment assessment tools	04 Q4
13.	11	Solar Advisor trough model available	04 Q3
14.	13	Identify industry testing and data standards	04 Q2

Table 4.2-8. Power Tower Technology Development Milestones

Milestones	Task	Title	Estimated CY Date Quarter
1.	1	Error-correcting heliostat control methodology validated	04 Q4
2.	1	Improved tracking-error data collection demonstrated	05 Q4
3.	2	Improved heliostat/field models	05 Q4
4.	3	Improved wind-loading model developed	07 Q4
5.	4	Prototype advanced heliostat design tested	07 Q2
6.	5	Improved receiver oven-cover design tested	04 Q2
7.	5	Peak flux levels of 1.4 MW/m^2	07 Q2
8.	6	Improved salt valves and instruments tested	04 Q4
9.	7	Evaluate options to increase operating temperature	06 Q4
10.	8	Report on integration of towers into supercritical Rankine cycles	06 Q2
11.	9	Reduced water-use cycle design options identified	04 Q4
12.	10	Advanced O&M information systems implemented	07 Q4
13.	11	Atmospheric attenuation limitations and solutions reported	06 Q4
14.	12	2^{nd}-generation integrated tower model available	06 Q4

Table 4.2-9. Dish Technology Development Milestones

Milestones	Task	Title	Estimated CY Date Quarter
1.	1	Complete market-requirements evaluation	04 Q2
2.	1	Review previous market evaluation	07 Q4
3.	2	Complete dish-Stirling components models	05 Q2
4.	3	Integrate/validate new component models	05 Q2
5.	4	Complete upgrade of tracking system	04 Q2
6.	4	Implement tracking of 1-MW systems	05 Q1
7.	4	Implement tracking of new project systems	07 Q1
8.	5	Start testing of next-generation DS System	05 Q1
9.	5	Start testing of next advanced system	05 Q4
10.	6	Upgrade reliability methodology	04 Q1
11.	7	Start evaluation of advanced concentrators	06 Q4
12.	8	Test a PV converter on a dish	03 Q4
13.	8	Start evaluation of micro-turbine converter	07 Q4
14.	8	Start hybrid receiver development	07 Q4
15.	9	Place 1-MW Nevada contract	03 Q4
16.	2	Develop an integrated solar system model	04 Q4
17.	7	Develop drives for heliostat and dish	05 Q1



Legend

Milestones

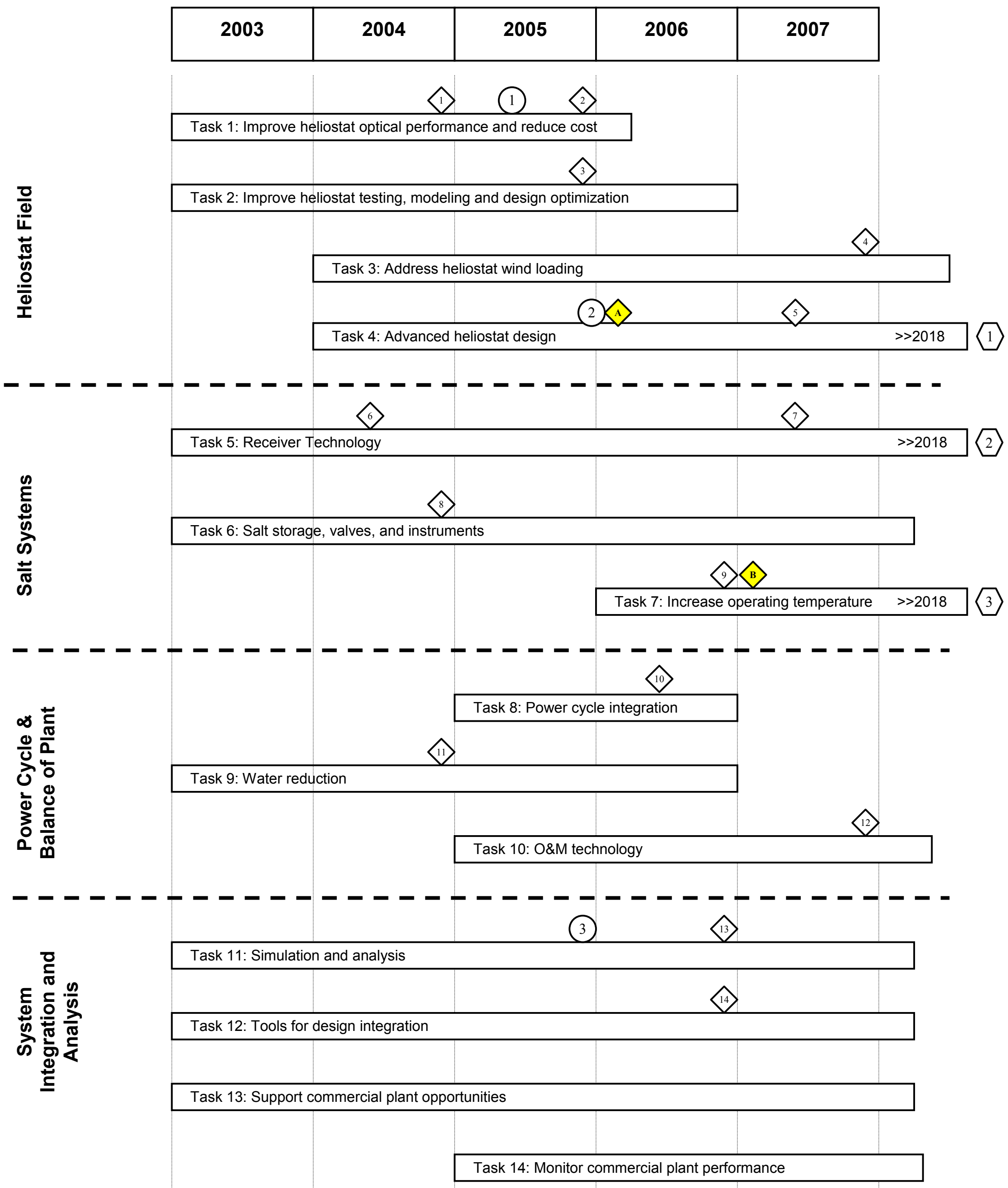
15. Advanced trough receiver demonstrated.
16. Next-generation parabolic trough concentrator demonstrated.
17. Advanced linear concentrator design prototype
18. Complete near-term TES design optimization.
19. Validate inorganic molten-salt HTF/TES for 450ºC.
20. Validate organic molten-salt HTF for 450ºC.
21. Identify advanced TES concepts for 550ºC and DSG.
22. Demonstrate advanced TES concepts
23. Demonstrate optimized trough organic Rankine cycle engine.
24. Decide whether to pursue direct steam generation.
25. Identify reduced water design options.
26. Validate concentrator alignment assessment tools field.
27. Solar Advisor trough model available.
28. Identify industry testing and data standards.

Go/No Go Decision Milestones

E. Select advanced receiver technology/decision to proceed
F. Decision to proceed on advanced generation concentrator
G. Decision to proceed on molten-salt HTF/TES
H. Down select fluids/decision to proceed on advanced HTF

Technology

10. Advanced high temperature receiver available
11. Next generation concentrator available
12. Advanced low-cost concentrator available
13. Indirect 2-tank molten-salt TES available
14. 450C Inorganic molten-salt HTF/thermocline TES available
15. 450C Organic molten-salt HTF/thermocline TES available
16. 550C Advanced TES technology available
17. 100 kWe ORC engine available
18. Validated design and modeling tools available.



Legend

Milestones

1 Error-correcting heliostat control methodology validated
2. Improved tracking error data collection demonstrated
3. Improved heliostat/field models.
4. Improved wind loading model developed.
5. Prototype advanced heliostat design tested.
6. Improved receiver oven cover design tested.
7. Peak flux levels increased to 1.4 MW/m^2.
8. Improved salt valves and instruments tested.
9. Evaluate options to increase operating temperature
10. Report on integration of towers into supercritical Rankine cycles.
11. Reduced water use cycle design options identified.
12. Advanced O&M information systems implemented.
13. Atmospheric attenuation limiations & solutions reported.
14. 2nd-generation integrated tower model available.

Go/No Go Decision Milestones

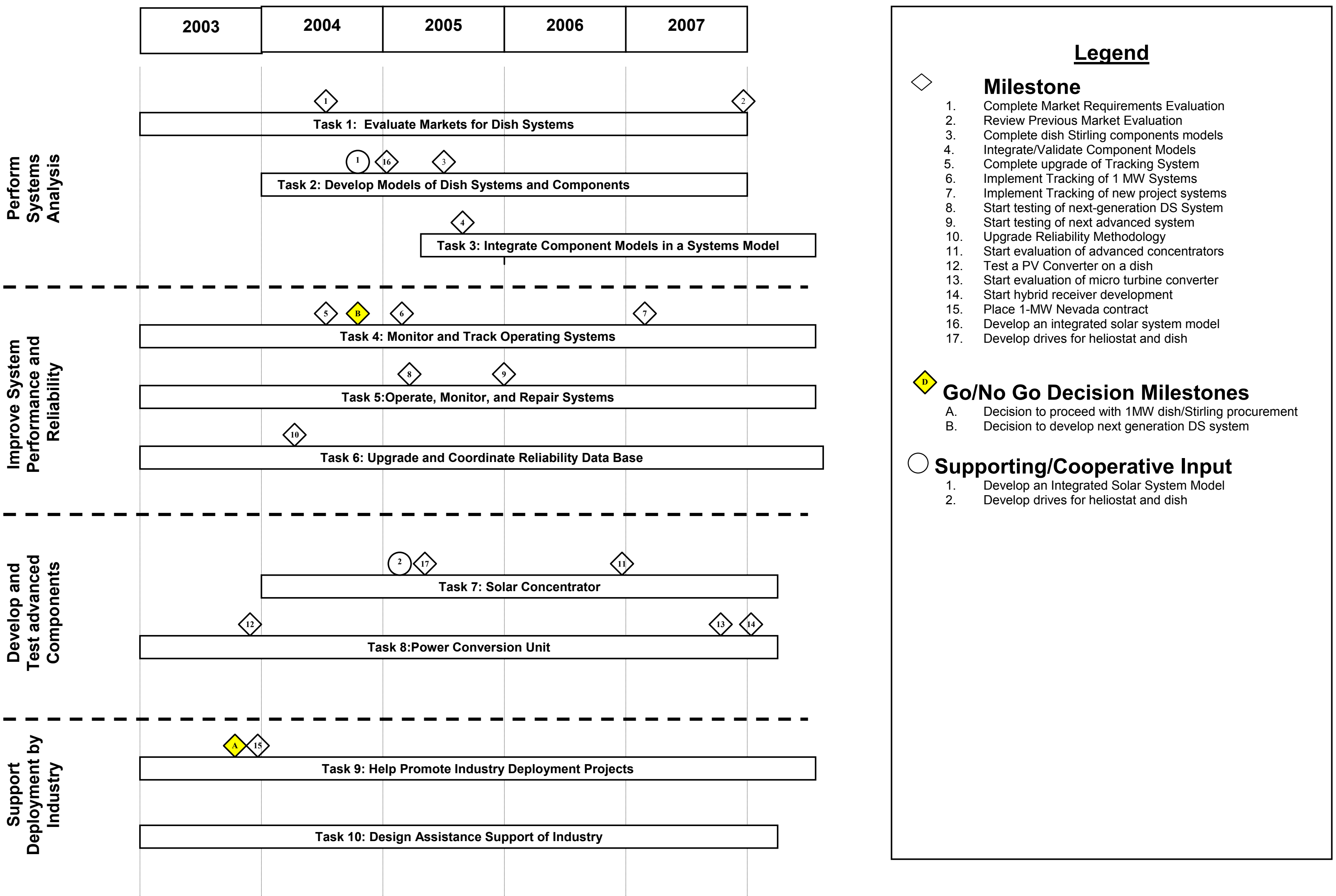
A. Select advanced heliostat concepts worthy of prototype (if any)
B. Increase operating temperatures for supercritical cycles

Technology

1. Advanced heliostat with 20% lower costs in volume production
2. Peak receiver flux levels increased to 1.6 MW/m^2.
3. System with increased operational temperature (600º–650ºC).

Supporting Input

1. Heliostat and dish drive development.
2. Evaluate alternate reflector materials.
3. Atmospheric attenuation data from resource assessment program.


2003
2004
2005
2006
2007
Perform Systems Analysis
Task 1: Evaluate Markets for Dish Systems
Task 2: Develop Models of Dish Systems and Components
Task 3: Integrate Component Models in a Systems Model
Improve System Performance and Reliability
Task 4: Monitor and Track Operating Systems
Task 5:Operate, Monitor, and Repair Systems
Task 6: Upgrade and Coordinate Reliability Data Base
Develop and Test advanced Components
Task 7: Solar Concentrator
Task 8:Power Conversion Unit
Support Deployment by Industry
Task 9: Help Promote Industry Deployment Projects
Task 10: Design Assistance Support of Industry
Legend
Milestone
1. Complete Market Requirements Evaluation
2. Review Previous Market Evaluation
3. Complete dish Stirling components models
4. Integrate/Validate Component Models
5. Complete upgrade of Tracking System
6. Implement Tracking of 1 MW Systems
7. Implement Tracking of new project systems
8. Start testing of next-generation DS System
9. Start testing of next advanced system
10. Upgrade Reliability Methodology
11. Start evaluation of advanced concentrators
12. Test a PV Converter on a dish
13. Start evaluation of micro turbine converter
14. Start hybrid receiver development
15. Place 1-MW Nevada contract
16. Develop an integrated solar system model
17. Develop drives for heliostat and dish
Go/No Go Decision Milestones
A. Decision to proceed with 1MW dish/Stirling procurement
B. Decision to develop next generation DS system
Supporting/Cooperative Input
1. Develop an Integrated Solar System Model
2. Develop drives for heliostat and dish

4.3 Solar Heating and Lighting

Solar collectors can provide thermal energy for direct use in the form of hot water for domestic water heating, space heating, and process heat, as well as in the form of hot air for space heating and process heat. Higher-temperature collectors can drive absorption and desiccant air-conditioning systems and can provide low-temperature steam. Current program focus is on lowering the cost of solar water-heating systems, with future active solar R&D to also address building heating and cooling loads. Solar collectors used for hybrid solar lighting, on the other hand, track the sun and concentrate sunlight onto flexible optical fibers that "route" the sunlight inside the building to illuminate interiors. This is a relatively new concept, and research is focused on developing the system and understanding its potential benefits.

Two distinct types of systems are used for solar water heating. 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. An integral-collector-storage (ICS) system is shown in Figure 4.3-1. A second type of passive system is the thermosiphon. 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.

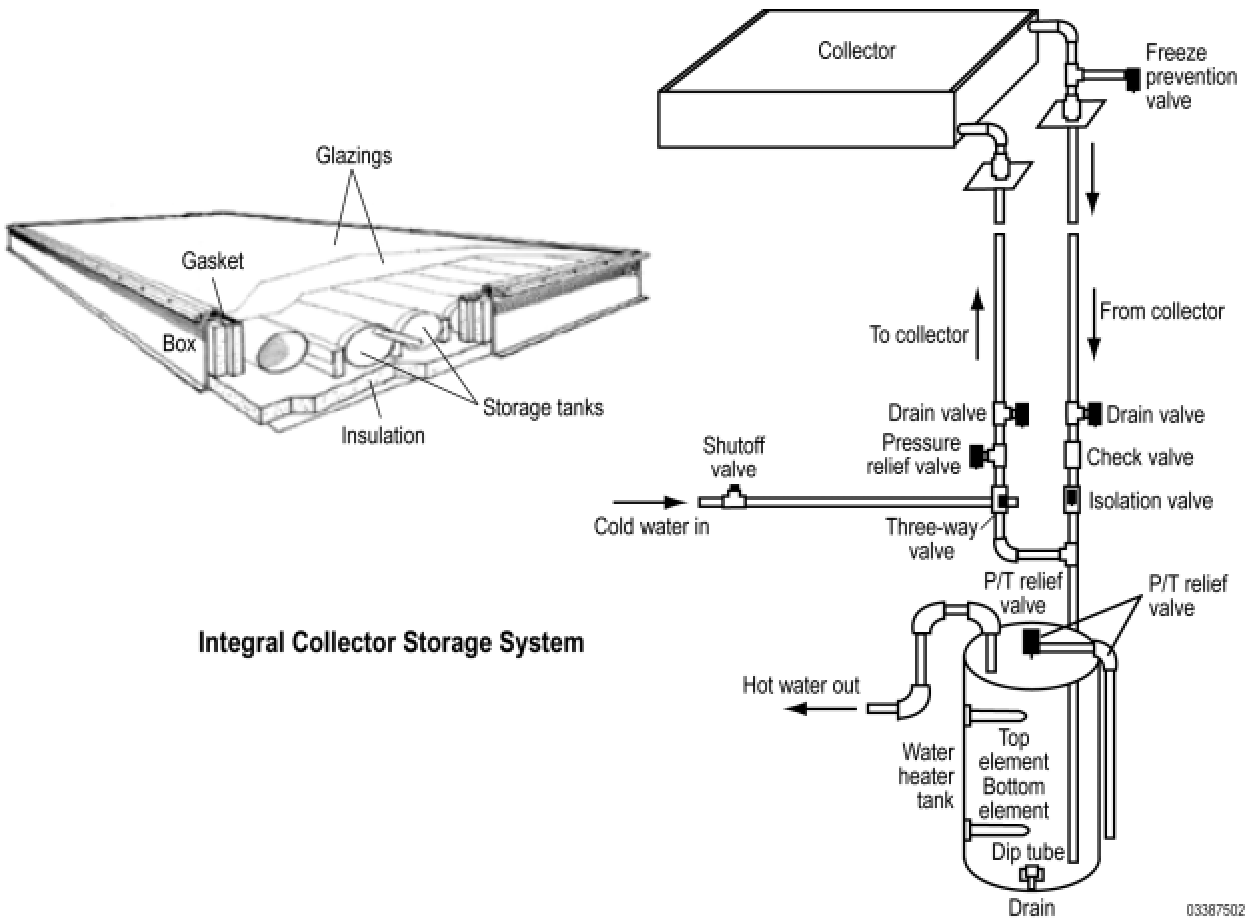


Figure 4.3-1. Passive integral-collector-storage system for warm climates.

Active systems circulate a heat transfer fluid through the collector, transferring heat to storage (Figure 4.3-2). These 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 (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 (drainback system). In addition to providing hot water, active systems can also be sized to provide space heat.

To improve aesthetics, current solar water-heating systems are installed at the roof angle; this results in only minimally lower energy production. Some systems are designed to mount directly to the roof deck, with the roofing material applied around them, as with skylights. These systems do not need to be removed during reroofing, so out-year maintenance costs are reduced.

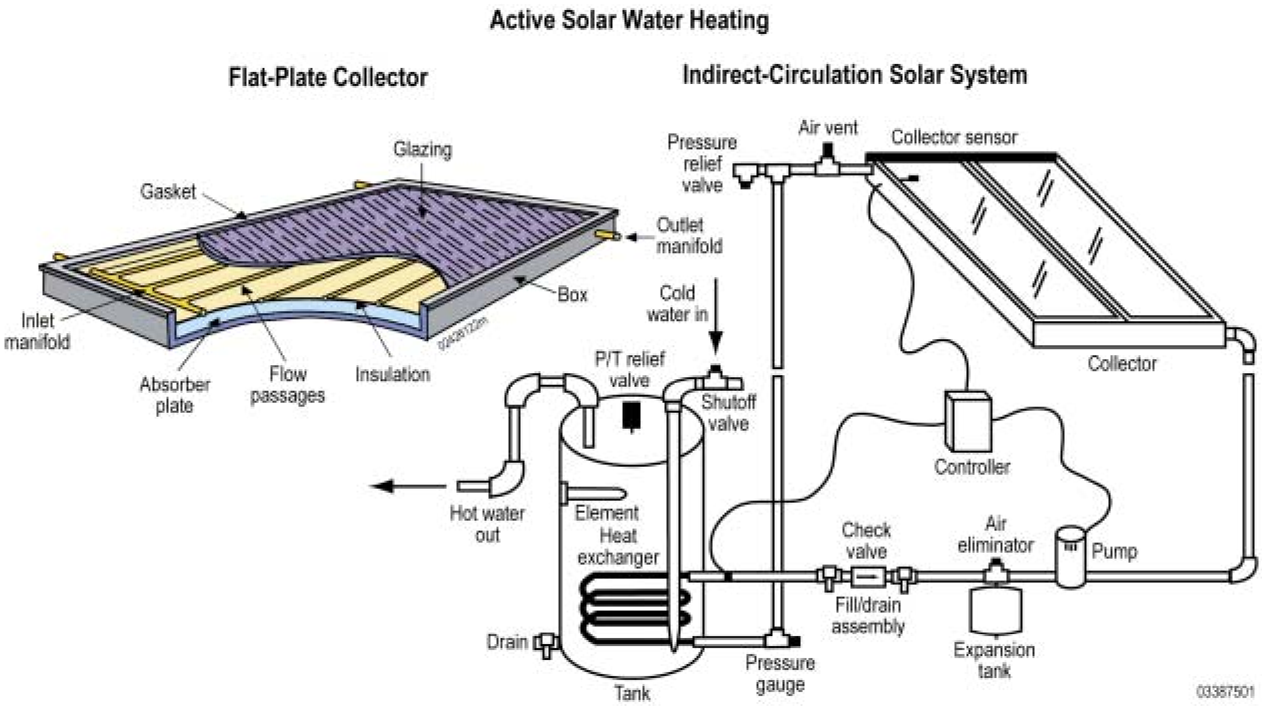
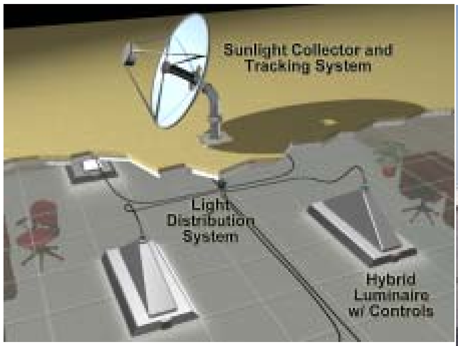


Figure 4.3-2. Active glycol solar water-heating system.

Hybrid solar lighting (HSL) uses parabolic collectors to focus a large amount of sunlight onto the ends of optical fibers. Sunlight is routed into buildings through a small roof penetration, where it is combined with electric light in “hybrid” light fixtures to illuminate building interiors. Daylight-harvesting control systems automatically adjust the level of fluorescent lighting using dimmable ballasts to maintain a constant illumination level, compensating for variations in the sky condition and sunlight levels. HSL specifically targets the largest consumer of electricity in commercial buildings (i.e., electric lighting, which consumes between 30% and 35% of the electricity in a typical school, retail store, or office building). Figure 4.3-3 shows an actual HSL system located at Oak Ridge National Laboratory’s (ORNL’s) National Transportation Research Center (NTRC).



Basic HSL System


Prototype HSL collector mounted on ORNL's NTRC building


Photo of HSL laboratory being illuminated by distributed sunlight (left) and standard fluorescent lamps (right)

Figure 4.3-3. Schematic (upper left) and photos of actual installation of hybrid solar lighting system.

4.3.1 Technology Systems and Status

Current Activities

R&D efforts are centered on the development of low-cost passive solar water-heating systems. Conceptual and engineering development has been completed and the systems are in the final stage of product development. Two manufacturers are working on complementary designs, each with goal of $1,000 installed cost. Initial prototypes and production will utilize copper heat exchangers until the lower-cost polymer heat exchangers that are under development are available. Full-scale prototypes are being assembled for field-testing in FY 2003–-2004. A roof-integrated thermosiphon (RITH) system, with a goal of $1,500 installed cost, is also being developed through a heavily cost-shared cooperative research and development agreement (CRADA) with industry and a utility. The RITH system has a very low profile, comparable to a skylight, and is being made from corrosion-resistant materials to be compatible with various groundwater conditions. Prototype RITH systems are being tested (see Figure 4.3-4).

Figure 4.3-4. Roof-integrated thermosiphon (RITH) solar water-heating system.

These passive systems, however, can be used only in mild Sun Belt climates where the danger of freezing is minimal. Active solar water-heating systems are needed for hard-freeze climates, and active-system R&D will ramp up as the passive-system R&D ramps down. R&D efforts on active systems for cold climates are just beginning in FY 2003.

The first HSL systems were built in 2003. These systems are being evaluated in a laboratory setting and improvements to the design are being developed. A second-generation system is expected to be complete in 2004–2005.

The program also assists industry efforts to lower cost, improve performance, and ensure the quality of solar heating or lighting products. It does this by applying the technical expertise of the national laboratories to problems industry is unable to solve on its own.

The Solar Heating and Lighting Subprogram works closely with other programs to overcome barriers to acceptance of solar thermal technologies and to increase deployment. A key target of support is DOE’s Buildings Technologies (BT) Program. Solar water-heating systems are being installed by some of the home-building teams participating in the BT Zero Energy Buildings Subprogram and in the BT Building America Subprogram. These teams have been supplying invaluable feedback on the product specifications, including price points, aesthetics, and installation procedures. This interaction will continue. Through hybrid solar lighting, cooperative research is also under way with the Energy Efficiency Science Initiative and the DOE Fossil Energy Program.

4.3.2 Technology and Component Goals and Objectives

The following goals and objectives are planned over the 5-year time period, based on the long-term goal of solar water heating, space heating, and lighting becoming competitive with electric or gas alternatives within a 10-year horizon. As with all solar-driven technologies, performance depends on solar incidence and is location-dependent; cost goals are stated for an average climate within the target market.

Goals

- Develop low-cost passive solar water heaters for warm climates that will be cost-competitive with conventional technologies, with levelized energy cost (LEC) of 4-6¢/kWh. This represents a 25%–50% reduction.
- Develop low-cost active solar systems for solar water heating in cold climates and for combined building heating and cooling that have LEC of 6¢/kWh. This represents a 50%–-70% cost reduction, depending on application.
- Develop a low-cost hybrid solar lighting system that has LEC of 12¢/kWh, a reduction of 70% from the current cost estimate of the first system.

Objectives

Water and Space Heating

- During 2003, obtain SRCC (Solar Rating and Certification Corporation) certification and rating for the RITH system, and verify its installed cost of $1,500/unit. Install full-scale prototypes of polymer ICS systems.
- By 2004, obtain SRCC certification and ratings for polymer ICS Systems and design manufacturing processes for 10,000 systems/year.
- By 2005, develop and evaluate active water-heating concepts for cold climates and for combined solar heating and cooling systems; develop RITH systems that combine electric water heating and rooftop solar hot water storage in a single unit.
- By 2007, field-test active cold-climate solar water heater prototypes and combined solar heating and cooling system prototypes, and assist industry in implementing new concepts in integrated roof/hot water systems.
- By 2009, complete code approval of active cold-climate solar water heaters and combined solar heating and cooling systems.
- By 2012, solar water heaters 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.
- In all years, provide technical assistance to industry to reduce manufacturing and installation costs, increase throughput, improve quality, and increase material lifetime.

Hybrid Solar Lighting

- During 2003, develop improved “alpha” HSL system designs.
- By 2005, develop “beta” HSL.
- By 2007, field-test HSL system at several commercial sites.

4.3.3 Key Technical Challenges

The key technical challenges for solar heating and hybrid lighting systems are to reduce installed system cost and to ensure that product reliability is at the level necessary for wide-scale adoption by builders.

The strategy for cost reduction for solar heating is to use low-cost materials and manufacturing methods, such as developed in the polymer industry. New materials introduced by the polymer ICS system, however, have unknown durability in this new application. Continued exposure testing is needed to determine the projected lifetime of UV-protected polycarbonates. The polymer absorber materials lack the higher-temperature data needed to insure against premature failures from stagnation events. At the system level, pipe-freezing of the supply/return pipes has always been an issue for passive systems. Cost of manufacturing is another key element of collector cost. The development of a low-cost 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. Laser-welding processes for the RITH system, demonstrated on production equipment in the laboratory, must be transferred to the industrial partner. Current solar water-heating systems are typically backed up by conventional water heaters, which adds to system cost. Incorporating the backup heating function as part of the solar system can reduce cost.

Key technical challenges for hybrid solar lighting include reducing system complexity while improving efficiency, and determining the tangible economic- and productivity-related benefits of sunlight brought indoors. Collectors/concentrators must be developed that are easier to assemble, align, calibrate, and maintain with less complex secondary mirror- and fiber-mounting arrangements and lower-cost, lightweight, and more easily manufactured components (mirrors, motors, and mounts). The number of connectors and splitters must be minimized or eliminated. There must be a better match of the chromaticity of distributed sunlight with that of co-located electric lamps. Research done by numerous organizations outside the Solar Program has indicated there are benefits of sunlight on worker and student health and performance, as well as ancillary benefits related to product sales. This research will be analyzed to identify tangible benefits and methods will be developed to credibly quantify the impact of these benefits using human-factors-based studies at alpha and or beta demonstration sites.

Technical Targets

Table 4.3-1 has technical targets for passive solar water-heating technology for warm climates. The LEC is based on the climate of San Diego, California, a site with an average solar resource for the Sun Belt market.

Table 4.3-1 Technical Targets[a] — Passive Solar Water Heating

Characteristics	Unit	Conv. ICS[b]	RITH[b]	Polymer ICS[b]
		2003	2004	2005
System Description & Goals				
Collector size	ft^2	32	32	40
Thermal storage	gals	40	40	50
Annual efficiency[c]	%	33	40	29
Builder cost (hardware + inst)	$	1800	1500	800
Customer cost (+ mrkt/sales)	$	2300	1900	1000
Total cost (+ O&M)	$	2600	2200	1300
LEC[d]	¢/kWh	10.4	7.2	4.7
Component Goals				
Collector/storage unit	$	900	900	300
Balance of system	$	300	300	200
Installation	$	600	400	300
Marketing and sales[e]	$	500	400	200
O&M (present value)	$	$300	$300	$300

a: Costs are to nearest $100; "new construction" install; mrkt./sales = 25% of bldr. cost; 5% discount rate; 20-yr. analysis period; present worth factor (PWF) = 12.5 yr.
b: Production volume of 10,000 units/year assumed for conventional and polymer ICS, and 1000 units/year for RITH.
c: Annual efficiency η_{ann} derived by simulation, $\eta_{ann}=Q_{saved,annual}/Q_{incident,annual}$
d: Radiation is for average Sun Belt city of San Diego, CA, at a tilt of (latitude-15); I_{col} = 5.6 kWh/ m^2-day; LEC = (total cost)/(η_{ann}* I_{col}*A_{col}*365*PWF).
e: Marketing and sales cost is taken as 25% of the builder's cost.

Table 4.3-2 highlights technical targets for active solar technology. There are two technologies: cold-climate solar water heating (SWH) and building heating and cooling (Htg & Clg). LEC is based on sites with average solar resource for the target markets.

Table 4.3-2. Technical Targets[a] — Active Solar

Characteristics	Unit	SWH[b]		Htg & Clg[c]	
		2003	2009	2003[d]	2009[e]
System Description/Goals					
Collector size	ft^2	40	40	200	400
Annual efficiency*	%	40	40	14	(6+2)
Builder cost (hardware + install)	$	2200	1100	8000	4000
Customer cost (+ mrkt./sales)	$	2800	1400	9200	4600
Total cost (+ O&M)	$	4000	2000	11600	5400
LEC	¢/kWh	12.6	6.3	17.8	7.3
Component Description/Goals					
Collector: Lifetime	years	25	20	25	20
Weight	lbs/ft^2	3	1	3	1
Unit area cost	$\$/ft^2$	12	5	12	3
Storage: Lifetime	years	12	20	15	20
Capacity	gal	80	80	800	800
Unit cost	$/gal	3	1	2.5	0.75
Balance of system	$	500	400	1200	800
Installation	$	900	400	2400	1400
Marketing cost[f]	$	600	300	1200	600
O&M cost (present value)	$	1200	600	2400	800

a: Costs are to nearest $100; "new construction" install; 5% discount rate; 20-yr. analysis period.
b: Typical "hard-freeze" climate, I_{col} = 4.7 kWh/m^2-day; assume Washington, D.C., at tilt of (lat-15°).
c: Htg/Clg system assumed in a southwest Sun Belt climate; assume Sacramento, CA, with I_{col} = 5.5 kWh/m^2-day, at tilt of (lat-15°).
d: Glazed system: space heating and DHW only, no cooling.
e: Unglazed system, with space heating, DHW, and space cooling (radiative/convective heat rejection at night); ~6% net heating efficiency increased to 8% to account for the cooling savings.
f: Marketing cost taken as 25% of builder cost for SWH, and 15% of cost for space htg/clg system.

Table 4.3-3 shows the technical targets for hybrid solar lighting. The 2003 status is based on proof-of-concept prototypes that have been developed, and associated costs are based on custom-designed and fabricated components rather than actual products. Economic analyses based on current prototype designs have been completed and are reflected in the 2007 goals, based on production-level quantities of the current prototype system. System-cost benchmarking is based on estimated rather than actual data.

Table 4.3-3 Technical Targets — Hybrid Solar Lighting

Characteristics	2003 status	2007 goal
Energy displacement efficiency	52%–250%	70%–315%
Projected installed $/W$_p$	$10/W$_p$	$2.00/W$_p$
Projected payback period (Sun Belt)	20 years	4 years
Projected relative lifecycle cost	$20,000	$5,000
Projected LEC savings	$0.41/kWh	$0.12/kWh
Projected system cost/m^2 of collector area	$10,000/m^2	2,000/m^2
Delivered lumens/m^2 collector area	40,000 lum	50,000 lum
Projected cost of delivered lumens (peak)	$0.16/lum$_p$	$0.035/lum$_p$

Note: Energy displacement efficiency is the amount of electrical power displaced per unit incident solar power available.

4.3.4 Technical Barriers

4.3.4.1 Passive Solar Water Heating

Durability. Passive ICS collectors are appropriate for warm climates, but polymer ICS systems include materials that are new to the building market.

- **A.** Continued exposure testing is needed to show that properly UV-protected polycarbonates and acrylics do not yellow or fail mechanically.
- **B.** 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.
- **C.** Heat exchangers—whether first-generation copper tubing or polymer tubing under development—can fail under high temperature and pressure, because of chlorine damage and scale accumulation (which blocks passageways).
- **D.** 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.
- **E.** Current systems are backed up by conventional water heaters, adding to system cost.

Building codes. Code bodies routinely approve metal-glass thermosiphon systems, and it is unlikely major concerns will arise with the RITH. On the other hand, the new materials introduced in the polymer integral collector storage (PICS) systems raise several questions.

- **F.** SWH code bodies (SRCC and others) must conduct certification testing of solar collectors.
- **G.** Polymer collector materials and system designs must be accepted by building code officials.
- **H.** Appropriate methods for rating unpressurized ICS with immersed load-side heat exchangers are required.

Manufacturing. For the roto-molded PICS, the tank and glazing production will likely be outsourced initially, and there are no serious challenges. Manufacturing for the other collector types will be in dedicated facilities.

- **I.** Laser-welding processes for the RITH system, demonstrated on production equipment in the laboratory, must be transferred to the industrial partner. Coating and other fabrication processes must be integrated into a 1000-unit/yr production line.
- **J.** Manufacturing processes for the tank for the extruded PICS must be developed, building on techniques of extrusion and manifold welding that are well proven for similar polymer pool collectors (over one million collectors have been made by one U.S. manufacturer).
- **K.** The 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.

4.3.4.2 Active Cold-Climate Solar Water Heating and Solar Heating and Cooling

Collector

- **A.** Cost: Reduce current FOB cost from \$110-170/m^2 (\$10-15/ft^2) to ~\$54/m^2 (\$5/ft^2) for active solar water heating and ~\$22/m^2 (\$2/ft^2) for active combined heating and cooling (CHC) systems.
- **B.** High temperatures: Collectors must withstand stagnation temperatures of ~250-450^{o}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 a key generally only for polymer-based absorbers.
- **C.** Installation: Today's metal-glass collectors weigh about 3 lb/ft^2, which is heavier than desirable for efficient installation.
- **D.** Durability/reliability: Lifetime of polymer collectors is expected to be less than that for metal-glass collectors.

Storage

- **E.** Cost: For active systems with storage separate from the collector, storage is a major cost component. Today's pressurized storage tanks start at ~\$3/gallon, or ~\$250 for an 80-gallon storage tank. Costs increase drastically if a heat exchanger is included in the storage.
- **F.** 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. Balance of system includes pump/controls and piping/valving.

- **G.** 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, being estimated at \$450.
- **H.** Reliability: ΔT-controller-pump failures contribute about \$300 to O&M present value cost. Plumbing valves and other components have been identified individually as the cause of most installation errors and a significant contributor to reduced reliability.

4.3.4.3 Active Solar Combined Heating and Cooling

- **A.** Collector: To supply the same amount of space heating saving as SWH savings, the glazing devoted to space heating must be larger (lower incidence, lower ambient temperatures and efficiencies). For an unglazed system, the collector area is roughly twice that required for a glazed system for equivalent savings.
- **B.** Storage: Compared to SWH, space heating requires larger ratios of storage volume per unit of collector area, because energy must be stored for a longer time. The optimal storage size range is not yet well established.
- **C.** 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.

D. System integration: System control is more complex with CHC systems. For unglazed systems collecting both heat and coolness, there will likely be a separate SWH and space-conditioning (heating and cooling) tank. Control of flow of heat to SWH and space-heating storage must be managed optimally.

4.3.4.4 Hybrid Solar Lighting

A. Collectors: The method of collecting the solar energy through the primary and secondary mirrors must be simplified and made less expensive. The cost of this component is too high.
B. Fiber optics: The bundle of fibers must be packed more efficiently so that less solar energy falls between the fibers.
C. Balance of plant: The system is too complicated and too expensive. The tracking system must be improved, as must the control system. The system must also be integrated into the conventional lighting system within the building.
D. System integration and analysis. This technology is very immature. The R&D has only gone as far as a proof of concept. The system design must be refined. A more detailed analysis of the costs must be done as well as an analysis of the potential benefits of the technology.

4.3.5 Technical Approach and Tasks

Passive Solar Water Heating

Key objectives are to establish durability of the PICS, complete the polymer heat exchanger development, certify the systems, and assist in implementing novel manufacturing processes. These activities are heavily cost-shared.

1. Durability. Pipe-freezing limits the market for warm-climate systems. Clearer definition of geographical limitations based on the potential for pipe-freezing must be established for all passive system types, including those using extensible polymer piping and freeze-protection valves. For the RITH system, existing field installations will continue to be monitored. For the PICS, a dual-level approach using both materials testing and system testing is optimal for building confidence at the lowest cost.

2. Materials testing. Accelerated materials testing is the most efficient way to project material lifetimes. Polycarbonate glazings are subject primarily to UV degradation (yellowing, cracking, and eventually mechanical failure). UV degradation testing using three complementary approaches (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©. Korad©-coated polycarbonates have not shown *any* optical degradation at the 8-year-equivalent dose point, reached in FY 2002. 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.

3. System testing. There are two types of system tests: torture tests that focus on high-stress situations like hail impact, high winds, high/low temperature performance, and mechanical abuse; and field tests that verify performance and durability under normal conditions. Both types of testing will be continued through FY 2004.

4. Building codes. The RITH system will be submitted for rating and certification by SRCC. Problems are not anticipated. The PICS systems are being 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.

5. Manufacturing. Design and implementation of manufacturing will be funded mostly by the industry partners. Assistance will be provided for those aspects that are novel and necessary to achieve the low-cost goals. For RITH, assistance will be provided on laser welding of fin-tube assembly and a new absorber coating line. For the rotomolded PICS, manufacturing support is minimal. For the extruded PICS, assistance will be provided for development of the tank manifold welding and the heat exchanger fabrication.

Table 4.3-4. Technology R&D Tasks — Passive Solar Water Heating for Warm Climates

Task	Title	Barriers
1	**Durability**	
	Materials Testing	
	• Continue glazing testing.	**A**
	• Initiate absorber high-temperature testing.	**B**
	• Measure mechanical properties and creep of candidate glazing/absorber materials.	**A, B**
	• Determine chlorine resistance of heat-exchanger (HX) tubing materials.	**C**
	• Characterize scaling in polymer tubing.	**C**
	Systems Testing	
	• Extend freeze-based market definition to polymer piping and freeze-protection valves.	**A**
	• Complete prototype torture testing: dry/wet stagnation, freeze chamber, and others.	**B,D**
	• Initiate field-testing of PICS.	**A,B,C**
	• Continue field-testing of RITH.	**E**
	• Develop 1-tank roof-integrated thermosiphon system.	**E**
2	**Building Codes**	
	• Submit RITH and PICS designs to SRCC.	**F**
	• Submit polymer ICS designs to ICC-ES for code-compliance assessment.	**G**
	• Initiate work on roof weight.	**G**
	• Validate a test-and-rate process on PICS.	**H**
	• Support SRCC testing for polymer systems.	**F,H**
3	**Manufacturing**	
	• Support implementation of novel manufacturing technology.	**I,K**
	• RITH: laser welding, coating line	**I**
	• Roto-molded PICS: heat exchanger fabrication	**J,K**
	• Extruded PICS: welding (tank and HX) and HX weaving machines	**J,K**
	• Assist industry in reducing manufacturing and installation costs.	**I,J**

Active Cold-Climate Solar Water Heating and Solar Heating and Cooling

As with passive systems, the technology development approach involves three phases, moving from initial concepts through engineering development to final product and manufacturing development. Descriptions of specific technical issues and tasks follow. Approaches proven successful in the PICS work will lower development costs. Unit-area system cost should be reduced at least 50% for SWH and at least 80% for Htg/Clg (including roofing credits). The tasks are first described for SWH followed by tasks unique to combined Htg/Clg. Similarly, the task tables are first displayed for SWH (Table 4.3-5), followed by tasks unique to Htg/Clg (Table 4.3-6).

Cold-Climate Solar Water Heating

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

<u>*Collector configuration.*</u> When using polymer materials, overheating of the absorber under dry stagnation becomes a potential issue, because polymers generally have relatively low melting temperatures and a reduction in strength 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 insure reliability while minimizing materials.

<u>*Glazings.*</u> UV-degradation testing of coated polycarbonate sheets has been ongoing, as described in Section 4.3.3. Thin-film glazings (e.g., fluorocarbons like Tefzel™) are also known to weather well. They are harder to mount and maintain than sheet materials, but could be the least-cost option.

<u>*Absorbers.*</u> Based on their low thermal conductivity (3 orders of magnitude lower than 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.

<u>*Container/insulation.*</u> It has proven cost-effective with the PICS 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.

<u>*Mounting.*</u> Experience in the low-cost PICS development indicates that if the collector bottom is corrugated, roof-drying is adequate when mounting the collector flat upon the roof. This simplifies the mounting procedure.

2. Storage. For active systems with storage separate from the collector, storage is a major cost component. Storage cost can be reduced significantly 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 (roto-molded 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, and materials must be tested, prototypes built, and manufacturing optimized.

3. Balance of System

<u>*Heat exchangers:*</u> Solar-side heat exchangers (used with pressurized storage) are smaller than load-side heat exchangers (used with unpressurized storage). Depending on 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 under development prove successful, a load-side heat exchanger could be priced at ~$50, or ~$0.60/gallon. Nylon and polybutylene heat-exchanger development are under way for PICS 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, and will be a key item to be developed 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, wherein 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%.

4. System Integration

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 IR transmission).

Combined Heating and Cooling

The most fundamental dilemma for space heating is that the need/load is highest when the resource/irradiance is lowest. Collectors for htg/clg will likely be integrated into the roof, which implies high-beam incidence angles, a further challenge. In energy-efficient new construction, it can be assumed that good envelope design minimizes or eliminates space-heating load on sunny days. This implies a relatively larger storage volume is needed compared to solar domestic hot water, 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 (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).

1. Collector. To supply the same amount of space-heating saving as SWH savings, the glazing devoted to space heating must be larger (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**.**

2. Storage. Storage is usually envisioned as water, but schemes employing the ground beneath the building have appeal, especially for cooling where 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.

3. Balance of System. System control is more complex with htg/clg 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 a natural gas supply, at temperatures higher than is practical for flat-plate solar systems. However, absorption chillers designed to operate at temperatures more suitable for low-cost solar thermal systems are now under development in Europe and China. Liquid desiccant systems that work well temperatures lower than 80^{o}C may become available.

4. System Integration. System thermal-performance modeling capability 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 RFP has been 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 4.3-5. Technology R&D Tasks — Active Cold-Climate Solar Water Heating

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

Table 4.3-6. Technology R&D Tasks — Active Solar Combined Heating and Cooling
(Note: Tasks are the same as for Active Solar Water Heating, plus the following.)

Task	Title	Barriers
1	**Collector**	
	• Evaluate unglazed collectors.	**B**
	• Evaluate/develop roof-integrated collector options.	**B,D**
2	**Storage**	
	• Evaluate/develop alternative large-capacity storage options.	**C**
3	**Balance of System**	
	• Evaluate/develop distribution subsystems.	**D,H**
	• Evaluate/develop controls.	**H**
4	**System Integration**	
	• Evaluate/develop system models.	**H**
	• Develop goals, optimal designs.	**Overall**

Hybrid Solar Lighting

Key objectives are to establish a more refined HSL system based on the data obtained from the proof of concept (alpha) systems evaluated during FY 2003. This should lead to a second-generation system (beta) that is much less complicated, more efficient, and less expensive.

1. Collectors. Develop a collector/concentrator design that is easier to assemble, align, calibrate, and maintain, with less complex secondary mirror- and fiber-mounting arrangements and is also lower in cost, lightweight, and more easily manufactured.

2. Fiber Optics. Develop a better match to the chromaticity of distributed sunlight with co-located electric lamps, eliminate glare associated with existing solar lighting sunlight diffusing rods.

3. Balance of Plant. Develop hybrid-compatible daylight-harvesting control systems that match the rapid-intensity variations associated with solar lighting, and improve the luminaire efficacy of distributed sunlight without impacting the luminaire efficacy of co-located electric lamps. Develop systems-level communication methodologies; diagnostics, data acquisition, and control systems; a user-friendly HSL user interface; simple, low-cost methods of installing HSL hardware in commercial buildings, including required building modifications, methods of installing the collector/concentrator, routing of the optical fibers, terminating the fibers efficiently at the luminaries, and commissioning the daylight-harvesting system; and low-cost, preferably automated, maintenance methodologies.

4. System Integration and Analysis. Develop hybrid-compatible daylight-harvesting control systems that match the rapid-intensity variations associated with solar lighting, and improve the luminaire efficacy of distributed sunlight without impacting the luminaire efficacy of co-located electric lamps. Assuming that tangible benefits are identified, develop and implement methods to credibly quantify the impact of these benefits using human-factors-based studies at alpha and/or beta demonstration sites.

Table 4.3-7. Technology R&D Tasks — Hybrid Solar Lighting

Task	Title	Barriers
1	**Collector**	
	• Develop a collector/concentrator design that is easier to assemble, align, calibrate, and maintain, with less complex secondary mirror- and fiber-mounting arrangements and lower-cost, lightweight, and more easily manufactured components (mirrors, motors, and mounts).	**A**
	• Develop light-distribution systems that eliminate the need for connectors and splitters in HSL system designs, develop fiber bundles with thermally compressed end-faces to reduce packing fraction losses, and increase the light-carrying capacity and temperature range of polymer large-core optical fibers.	**A**
2	**Fiber Optics**	
	• Develop a better match for the chromaticity of distributed sunlight with co-located electric lamps, eliminate glare associated with existing solar lighting sunlight-diffusing rods.	**B**

3	Balance of System	
	• Develop tracker controllers that can be quickly calibrated (and are capable of periodic self-calibration) with a centralized high-level control system that operates from a centralized network (PC) and simultaneously controls several small roof-mounted collector/concentrators to reduce the per-unit controller costs.	**C**
	• Develop a series of large-scale beta HSL systems. Several systems will be installed and monitored to assess energy savings, functionality, and performance of systems-level communication methodologies, diagnostics, data acquisition, control systems, user interfaces, and installation and maintenance methodologies.	**C**

4	System Integration and Analysis	
	• Analyze previous research on the benefits of sunlight to determine the tangible benefits of distributed sunlight on worker and student health and performance, as well as ancillary benefits related to product sales.	**D**
	• Tools: Develop integrated systems models (performance and costs).	**D**
	• Standards: Develop testing standards and supporting facilities for solar components and systems.	**D**

4.3.6 Schedule and Milestones

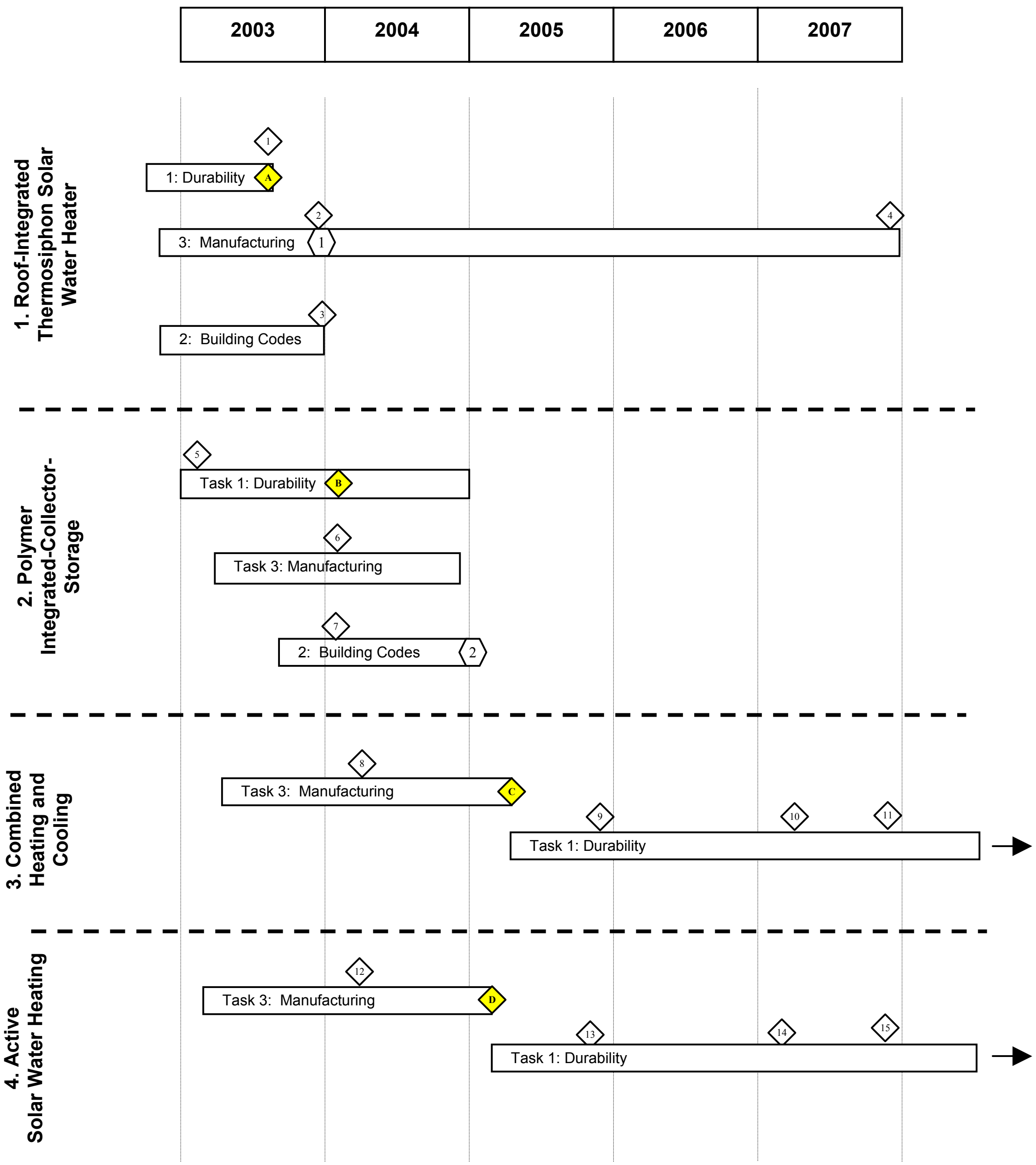
The following tables (4.3-8 and 4.3-9) contain the schedule and milestones for solar water heating and hybrid solar lighting, respectively. They were developed with the assumption of a stable solar heating and lighting budget during the planning period of about $4 million.

Table 4.3-8. Technology Development Schedule and Milestones — Solar Water Heating

Milestones	Task	Title	Estimated CY Date Quarter
1.	1	Complete one-year field-testing of 2-tank RITH	03 Q3
2.	3	Complete manufacturing line for 2-tank RITH, 1 K/yr	03 Q4
3.	2	Two-tank RITH certified	03 Q4
4.	3	Complete one-tank RITH improvement	07 Q4
5.	1	Install prototypes for field and torture testing	03 Q1
6.	3	Complete design modifications based on test/codes	04 Q1
7.	2	Systems certified	04 Q4
8.	3	Issue focused RFP for low-cost concepts (4-8 awards)	04 Q2
9.	1	Complete testing of small-scale prototypes/redesign	04 Q2
10.	1	Complete fabrication of full-scale prototype	07 Q2
11.	1	Field and torture tests under way	07 Q4
12.	3	Issue focused RFP for low-cost concepts (4-8 awards)	04 Q2
13.	1	Complete testing of small-scale prototypes/redesign	05 Q4
14.	1	Complete fabrication of full-scale prototype	07 Q2
15.	1	Field and torture tests under way.	07 Q4

Table 4.3-9. Technology Development Schedule and Milestones — Hybrid Solar Lighting

Milestones	Task	Title	Estimated CY Date Quarter
1.	1	Completion of Generation 2 dish-based collector development and balance of system components	05 Q1
2.	1	Completion of alternate designs	07 Q1
3.	4	Completion of systems-level HSL control systems	06 Q1
4.	4	Completion of Alpha demonstrations	06 Q4
5.	3	HSL product entry	07 Q1
6.	3	Completion of large-scale beta demonstrations.	07 Q4



Legend

Milestones

Roof-integrated thermosiphon (RITH)
1. Complete one-year field-testing of 2-tank RITH.
2. Complete manufacturing line for 2-tank RITH, 1K/yr.
3. Two-tank RITH certified.
4. Complete one-tank RITH improvement

Polymer ICS (2 systems: roto-molded and extruded)

5. Install prototypes for field+torture testing.
6. Complete design mods based on test/codes feedback.
7. Systems certified

Combined Solar Heating and Cooling

8. Issue focused RFP for low-cost concepts (4-8 awards)
9. Complete testing of small-scale prototypes/redesign
10. Complete fabrication of full-scale prototypes
11. Field+torture tests underway

Active Solar Water Heating

12. Issue focused RFP for low-cost concepts (4-8 awards)
13. Complete testing of small-scale prototypes/redesign
14. Complete fabrication of full-scale prototypes
15. Field+torture tests underway

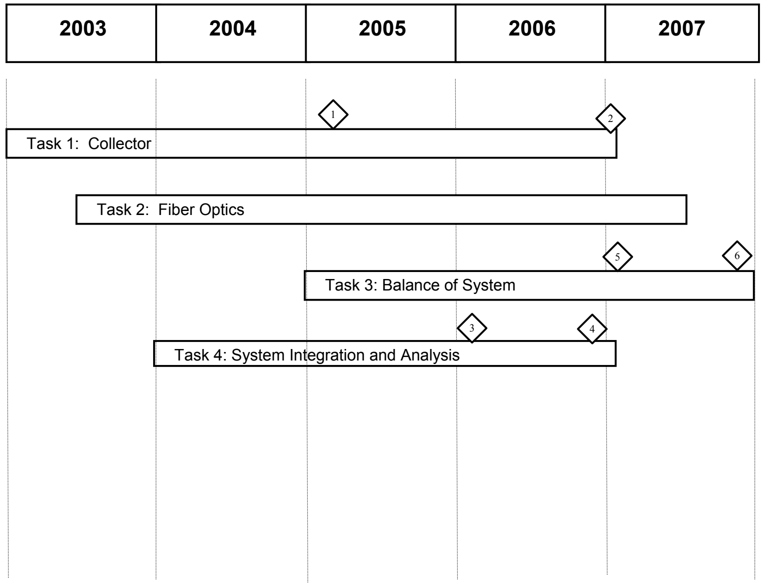
Go/No Go Decision Milestones

A. A. Proceed with basic system design , submit to SRCC.
B. Decision on proceeding with manufacturing/certification.
C. Downselect most promising Combined Heating and Cooling concepts for engineering development (1-3 awards)
D. Downselect most promising Active SWH concepts for engineering development (1-3 awards)

Technology

1. Two-tank RITH system available to the market.
2. 2 polymer ICS Systems final design/manufacturing processes

Hybrid Solar Lighting



Legend

◇ **Milestones**

1) Completion of Generation 2 dish-based collector development and balance of system components
2) Completion of alternate designs
3) Completion of systems-level HSL control system
4) Completion of HSL alpha demonstrations
5) HSL product entry
6) Completion of large-scale beta demonstrations

4.4 New Concepts

The DOE Solar Energy Technologies Program recognizes that the technology approaches that it is helping to develop must provide solar energy options that are relevant in a constantly changing environment. This environment may change for a number of reasons, such as national security, economics, natural environmental quality, competing technologies, new market applications, and personal choice. For these and other reasons, today's solutions may not be appropriate for tomorrow's problems.

4.4.1 The Solar Technology Incubator

The Solar Program, as part of its "systems-driven approach" to define and manage its activities, continually evaluates the environment in which its technologies are intended to function. Through ongoing analyses and interactions with its stakeholder community, the Solar Program seeks to establish new directions for its technology development priorities that reflect likely changes in the markets that the technologies are intended to serve. It also seeks input from other governmental programs, both within and outside of the DOE that may have overlapping and/or complementary interests. Technologies under development by other EERE programs are expected to provide especially attractive opportunities for hybrid combinations with the suite of Solar Program technologies.

In addition, the Solar Program periodically issues solicitations looking for innovative approaches to meeting its goals. These solicitations favor universities and small businesses, because these two sectors traditionally are the most fruitful in discovering new ideas and technologies. For example, the PV Subprogram is currently examining two groups of promising PV cell designs (described below) that were proposed in response to two separate competitive solicitations of this nature. Two well-established programs designed to take advantage of the potential offered by small businesses are the Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR) Programs. Following are three examples of the types of impacts that encouraging small business participation have had on the state of the U.S. photovoltaics industry.

- Support for development of a novel silicon wafer slicer to GTI enabled this company to eventually become a world-class supplier of PV manufacturing equipment to the U.S. and the rest of the world.
- Initial support was given to develop large utility-scale concentrating PV systems that are designed for use by investor owned utilities.
- The precursor to First Solar received support to develop an environmentally friendly process for recycling cadmium telluride PV modules, thereby answering criticisms about next-generation thin film technologies having offsetting negative environmental effects.

These activities are structured with well-defined selection criteria and metrics for monitoring the progress of technology development. If the new technologies show sufficient progress, they may be moved into the mainstream of the appropriate Solar Program subprogram. If progress is not meeting expectations, the Program then discontinues supporting them.

In the following sections, several new technologies and concepts that the Solar Program is pursuing are described in terms of their promise, the challenges that their development face, their developmental status, and near-term development activities. None of these activities are presently along any of the Program's critical paths. They generally fall into the following three categories.

Beyond the Horizon and Future Generation Photovoltaics: About one-half the cost of a PV solar-electric system is due to the PV module itself. The PV Subprogram is presently examining four new approaches to solar cells that promise, in the long term, to dramatically reduce the cost of this component in PV systems: organic, dye-sensitized, nanotechnology, and "third-generation" solar cells.

Advanced Building Integrated Concepts: With one-third of the total U.S. energy consumption due to building energy requirements and the ubiquitous nature of solar energy in the United States, building-related solar-energy technologies could potentially have an enormous impact on the country's energy supply. Two novel approaches for achieving this potential are discussed. The first is the AC Building Block for supplying solar electricity, and the second is a device that produces both electricity and useful thermal energy. Another opportunity exists that could leverage Solar Program resources from DOE's Building Technologies Program and access large additional markets. This opportunity lies in advanced lighting development. The physics of the leading advanced lighting technologies presently being considered are shared with the physics of certain advanced PV cells.

Advanced Solar Conversion: The third category is in the area of solar or solar-assisted hydrogen production. As the country moves toward a hydrogen energy future, methods are being sought for cleanly producing this fuel through renewable energy. Several solar energy technologies could provide cost-effective methods for accomplishing this. Both solar-thermal and direct-conversion approaches will be described.

4.4.2 New Technologies and Concepts

4.4.2.1 Beyond the Horizon and Future Generation Photovoltaics

These two titles highlighted DOE-funded efforts in the late 1990s to explore new PV technologies and to support fundamental research on mature PV technologies. The Future Generation PV request for proposals in the late 1990s led to new research projects at 18 U.S. universities. Soon thereafter, the Beyond the Horizon request for proposals resulted in 15 more efforts at 4 companies and 11 universities. They were all the result of recognition by the PV Subprogram for providing some support for high-risk, high-payoff PV ideas requiring long-term research, development, and innovation. Sometimes the new concepts haven't really been new; their origins can frequently be traced back to the early days of solar cell research in the 1950s and 1960s. However, they may have lacked critical enabling technologies or breakthroughs that have since appeared on the scene, inviting a fresh look at their potential.

At present, there are four nonconventional PV technologies in today's spotlight—organic solar cells, dye-sensitized solar cells, solar cells based on nanotechnology materials, and third-generation concepts. Their status and challenges are highlighted in the sections below, along with the research approaches and tasks needed for their development. Fundamental research is a fifth area for conventional PV technologies, specifically thin films and crystalline silicon.

4.4.2.1.1 Organic Solar Cells

Technology System Status

The Nobel Prize for chemistry in 2001 highlighted the promise of organic solar cells because the award recognized discoveries in organic semiconductors—the building blocks for organic electronics, displays, and solar cells. During the 1990s, organic semiconductors demonstrated incredible progress in display technologies, with many small and large companies developing display products for commercial and defense applications. Organic displays are more efficient than incandescent light bulbs and are quickly approaching the efficiency of fluorescent lighting. Displays are, however, based on the inverse process of solar cell operation wherein light produces electricity instead of electricity generating light in a display. The relationship between the two processes is close enough that success in display technologies will likely provide research and development benefits for organic solar cell technologies. We can therefore expect a leveraging effect because a small investment in organic PV R&D is likely to have a larger impact as a result of the huge R&D investments made to penetrate the more lucrative organic display markets.

Several of these nonconventional PV technologies, including organic solar cells, work through a fundamentally different process for generating electricity. Conventional PV technologies are based on light creating separate electrons and holes that are swept away by an internal electric field produced by a p-n semiconductor junction. In an organic solar cell, light creates a bound electron-hole pair, called an exciton, that separates into an electron on one side and a hole on the other side of a material interface within the device. This distinction means that much of conventional PV technology is not applicable to organic solar cell development. One result of this distinctly different photovoltaic process is that organic solar cells are typically 10 times thinner than thin-film solar cells, which are already some 100 times thinner than crystalline-silicon solar cells. Although we can expect reduced materials costs for organic solar cells, there will likely be more stringent thickness and uniformity requirements.

There are also two types of organic solar cells: those based on small-molecules with molecular weights less than 10,000, and those based on polymers with molecular weights in the millions. The small-molecule organic solar cells tend to be more efficient, perhaps over 4% conversion efficiency, whereas, the polymer solar cell may be closer to 3% efficient. The small-molecule technology uses vacuum deposition techniques, whereas, the polymer technologies rely on preparation in beakers and flasks with simple coating techniques related to printing technologies. For both types of organic cells, considerable R&D will be required to realize their promise.

Current Activities: NREL has a small internal research effort focusing on polymer solar cells. Research will continue at several universities on organic solar cell projects begun almost 2 years ago under the Beyond the Horizon PV funding. These include heterojunction small-molecule solar cells at Princeton, liquid-crystal (small-molecule) cells at the University of Arizona, polymer cells at University of California Santa Cruz and NREL, and small molecular chromophore cells under development jointly at Johns Hopkins and North Carolina State University. Each of these projects is funded at low levels (between $120,000 to $150,000 per year) and typically supports one or two graduate students per year for periods of 3 years so that total funding is about $700,000 in FY 2003.

Program Coordination and Implementation: Sharing of research information through research publications and at research conferences is critically important for both coordination and implementation. There have been three conferences sponsored by DOE and NREL—*Future Generation Photovoltaics* and *Photovoltaics for the 21st Century I and II*—that have permitted reviews of DOE-funded projects, as well as presentations from internationally recognized experts. Peer reviews of research results are especially important for effective project implementation to ensure high quality and identify performance problems.

Coordination with Related Programs: Coordination with industry efforts to develop organic displays or organic lighting can help leverage research to improve solar cell efficiency and stability. Spin-off companies working on organic displays, as well as organic solar cells, have been established around the Princeton and Johns Hopkins/NCSU research. In these cases, the coordination is implicit. Because of considerable industry support to universities for organic displays, several universities found themselves well positioned to write excellent proposals for the Beyond the Horizon solicitation. To date, there has been no coordination with other government agency activities in organic electronics. This could be a topic for a future Interagency Advanced Power Group meeting.

Technology and Component Goals and Objectives

Goal: The goal of this research effort is to create new solar cell options that can meet long-term goals for producing solar electricity at low cost.

Objectives: The 2003 baseline for organic solar cell technology is:

- Polymer solar cell efficiency claimed to be between 1% and 2%
- Small-molecule cell efficiency claimed to be between 3% and 4%
- Lifetime is unknown, although organic display lifetimes are measured in tens of thousands of hours
- Cost is unknown, although the basic elements (e.g., C, O, H) are considered low cost.

The 2007 objectives for organic solar cell technology are:

- Demonstrate polymer solar cell efficiency of 5%
- Demonstrate small-molecule cell efficiency of 7%
- Based on research progress, reassess the potential of organic solar cells for continued support.

The 2025 objective is:

- Assuming this technology survives go/no go decision points, achieve a levelized cost of electricity competitive in an appropriate market.

Key Technical Challenges

The success of organic solar cells relies on:

- Improving their conversion efficiencies by a factor of 10 or more
- Developing low-cost manufacturing processes
- Exhibiting reliable, long-term operation under the environmental extremes encountered in PV applications.

Technical Targets

System Element	Unit	2003 (baseline)	2007	2025
Polymer-Cell Efficiency	%	2%	5%	TBD
Small-Molecule Efficiency	%	4%	7%	TBD

Technical Barriers

Organic Solar Cells

A. New knowledge is needed to identify pathway options for higher-efficiency cells

B. New knowledge is needed to ascertain or improve organic cell stability in an outdoor environment.

Technology Approaches and Tasks

Task 1, Organic Solar Cells: Near-term organic solar cell activities will necessarily focus on improving the efficiency of both polymer and small-molecule solar cells. (These milestones are part of the recently revised Five-Year Photovoltaics Subprogram Plan.) Nevertheless, applying the systems-driven approach might provide market insights that could expedite research progress toward a commercialization pathway. Just as conventional PV once targeted the utility market but found a more accessible buildings market, organic photovoltaics may be more suited to a totally different market. Some startup organic solar cell companies have openly said they are targeting solar cell materials such as fibers or flexible materials that can be worn on clothing to power cell phones, personal data assistants, or high-capacity personal music systems.

- Initiate theoretical studies for doping organic materials
- Conduct peer review of “Beyond the Horizon PV” (organic) projects
- Determine operational characteristics of excitonic solar cells using biomimetic, organic and nanotechnology concepts
- Assess efficiency potential, stability and reliability of organic polymer and small-molecule solar cells
- Identify commercialization pathways for promising new technologies via university/industrial partnerships

Schedule and Milestones (Refer to Table 4.4-2)

4.4.2.1.2 Dye-Sensitized Solar Cells

Technology System Status

The dye-sensitized solar cell, an inorganic/organic material concept, appeared as a breakthrough in fundamental solar cell research with the appearance of a publication in *Nature* in 1991 authored by Swiss researchers. Dye solar cells had been studied since the early 1970s, but the efficiencies had been extremely low prior to the discovery that flat oxide films can be replaced with a large-surface-area nanocrystalline form of titanium oxide (about 80 m^2/g) and a new organic dye that was well matched to the oxide and did not degrade. Excitons created by sunlight on the dye were able to transfer electrons extremely rapidly into the titanium dioxide, and dye cell conversion efficiency demonstrated a quantum leap; the present world record approaches 11%. A liquid electrolyte is needed to complete the cell’s electrical circuit, but titanium dioxide is a robust material in the presence of the electrolyte and laboratory lifetime tests for the dye cell are suggesting years of stable operation. This extraordinarily high efficiency for a new solar cell concept and the low cost of the porous titanium dioxide matrix have generated considerable interest. The promise of this technology is also demonstrated in the simplicity of its manufacturing process, which involves no vacuum or high-temperature processing. The dye solar cell has been a major subject in the field of photochemistry, and thousands of research publications have appeared in scientific journals or in the proceedings of international photochemistry conferences. The research foundation for this concept is quite solid, but the key intellectual property resides with the Swiss research laboratory that discovered it. In summary, the promise of the dye solar cell is the result of low-cost materials; good, stable solar conversion efficiency; and a simple, low-cost manufacturing process.

Current Activities: The Solar Program has funded NREL researchers with about $225,000 per year for much of the past decade. Caltech receives about $120,000 per year from a Beyond the Horizon contract, so that total DOE Solar Program funding is about $350,000 annually.

Program Coordination and Implementation: The Solar Program funds researchers for dye cell research so that coordination is limited to sharing research information through visits or research conferences. The most recent *Photovoltaics for the 21st Century II* conference hosted more than a dozen of the world’s best dye solar cell scientists to provide data for the published dye solar cell assessment prepared to meet a FY 2001 milestone. Peer reviews are important for effective project implementation to ensure high-quality research is taking place.

Coordination with Related Programs: DOE’s Office of Basic Energy Sciences (BES) funds considerable fundamental research related to the dye solar cell. An international photochemistry conference in 2001 had more than 70 presentations on the dye solar cell. BES funded the basic research for many of the presentations. The best presenters were invited to participate in the DOE/NREL dye solar cell session at the *Photovoltaics for the 21st Century II* conference.

Technology and Component Goals and Objectives

Goal: The goal of this research effort is to create new solar cell options that can meet long-term goals for producing solar electricity at low cost

Objectives: The 2003 baseline for dye solar cell technology is:

- An NREL-verified solar cell efficiency approaching 11%
- Module efficiencies claimed to be 5%-7%
- Reliability in the laboratory appears excellent
- Cost is unknown, although the primary component, titanium dioxide, is low cost.

The 2007 objectives for dye solar cell technology are:

- Demonstrate dye solar cell efficiency of 12%
- Identify reliability limits for dye cell modules either in outdoor tests or through qualifications standards, suitably modified for the dye cell modules.

The 2025 objective is:

- Assuming this technology survives go/no go decision points, achieve a levelized energy cost (LEC) of $0.06/kWh.

Key Technical Challenges

The success of dye-sensitized solar cells relies on:

- Developing a solid alternative to the liquid electrolyte in this cell or developing a liquid electrolyte that can withstand high temperatures
- Demonstrating adequately high efficiencies for modules in production
- Developing a low-temperature procedure for annealing oxide films on plastic substrates
- Developing a thermal plastic sealant for the dye cell with a liquid electrolyte that can withstand temperatures above 100°C
- Demonstrating adequate reliability for dye solar modules
- Reducing the cost of the organic dye
- Identifying options for making higher-efficiency dye solar cells.

Technical Targets

System Element	Unit	2003 (baseline)	2007	2025
Dye-Cell Efficiency	%	2%	5%	TBD
Small-Molecule Efficiency	%	4%	7%	TBD
System LEC	$/kWh			$0.06

Technical Barriers°

Dye-Sensitized Solar Cells

C. New knowledge is needed to identify pathway options for higher efficiency cells

D. New knowledge is needed to determine and meet reliability requirements in an outdoor environment.

Technology Approaches and Tasks

Task 2, Dye-Sensitized Solar Cells: Near-term dye solar cell activities will focus on assessments for improving the efficiency and determining the reliability issues of dye solar cells and modules. Employing the systems-driven approach in performing these assessments will be important in identifying technology or market options that could move the dye solar cell onto a commercialization pathway.

- Assess efficiency potential, stability, and reliability of inorganic/organic solar cells
- Assess dye-sensitized solar cell options involving solid-state electrolytes.

Schedule and Milestones (Refer to Table 4.4-2)

4.4.2.1.3 Nanotechnology Solar Cells

Technology System Status

Solar cells based on nanotechnology receive almost as much publicity as organic solar cells. One reason for excitement about nanotechnology materials is that their optical and electronic properties can be altered in particles having nanometer dimensions. Nanospheres are called quantum dots, and they suffer, in the case of solar cells, from charge-transport limitations within, for example, an organic-polymer medium surrounding the quantum dots. Despite charge-transport limitations, there is a potential for leveraging other nanotechnology research because the U.S. government has several nanotechnology research initiatives with significant funding. Like other excitonic solar cell concepts, nanostructured solar cells are likely to be extremely thin. They may also be easy to manufacture when the nanoparticles are produced by means of chemical solution.

Current Activities: At the moment, there are no Solar Program contracts funding nanotechnology solar cells. University of California Berkeley, Vanderbilt, and the University of West Virginia each had a Future Generation PV contract to develop nanotechnology solar cells. The contract funding ended in 2002. Plans to recompete the Future Generation PV projects in 2002 were delayed due to budget uncertainties. NREL has a small (less than $200,000) internal Beyond the Horizon PV project exploring the use of nanotechnologies for Third-Generation PV concepts described below.

Program Coordination and Implementation: As in the case of organic and dye solar cells, the principal means of program coordination has been the DOE/NREL conferences on *Photovoltaics for the 21st Century I and II*. Peer reviews at these or NCPV review meetings support the program implementation.

Coordination with Related Programs: There may be an opportunity to coordinate with the U.S. government's National Technology Initiative, but so far, there has been little interaction with other government agencies exploring nanotechnologies for other applications or trying to increase scientific knowledge about nanotechnologies. Nanotechnologies are also considered for some display concepts and, as in the case of organic solar cells, there may be opportunities to coordinate or leverage nanotechnology display concepts. The principal investigator at UC Berkeley, along with Harvard and MIT professors, provides intellectual property to a company developing several nanotechnologies including displays, as well as organic/nanotechnology solar cells.

Technology and Component Goals and Objectives

Goal: The goal of this research effort is to create new solar cell options that can meet long-term goals for producing solar electricity at low cost.

Objectives: The 2003 baseline for nanotechnology solar cells is:

- A nanotechnology/polymer solar cell efficiency claimed to be almost 3%
- Cell stability seems to be good in the laboratory.

The 2007 objectives for nanotechnology solar cells are:

- Demonstrate nanotechnology solar cell efficiency of 5%
- Identify non-cadmium nanoparticles suitable for solar cells.

The 2025 objective is:

- Assuming this technology survives go/no go decision points, achieve a levelized energy cost of less than $0.06/kWh.

Key Technical Challenges

The success of nanotechnology solar cells relies on:

- Improving charge transport from the quantum particles to the electrodes in nanotechnology solar cells
- Improved nanotechnology solar cell efficiencies
- Non-cadmium-containing materials identified.

Technical Targets

System Element	Unit	2003 (baseline)	2007	2025
Nanotechnology Cell Efficiency	%	3%	5%	TBD
System LEC	$/kWh			$0.06

Technical Barriers

Nanotechnology Solar Cells

E. New knowledge is needed to identify pathway options for higher efficiency cells
F. New knowledge is needed to determine and meet reliability requirements in an outdoor environment.

Technology Approaches and Tasks

Task 3, Nanotechnology Solar Cells: The UC Berkeley, Vanderbilt, and West Virginia University projects funded through the Future Generation PV program came to an end last year, while a (Third-Generation) quantum dot project at NREL continues at a level of about $200,000 per year. The UC Berkeley work is likely to continue at about $120,000 annually since it consistently scored at the top or near the top of two peer reviews conducted during the Future Generation PV program. UC Berkeley would be a likely candidate to propose under the “core” university science initiative.

- Renew most-promising “Future Generation PV” nanotechnology contracts
- Determine operational characteristics of excitonic solar cells using nanotechnology concepts—including biomimetic concepts mimicking a solar biological process.

Schedule and Milestones (Refer to Table 4.4-2)

4.4.2.1.4 Third-Generation Technologies

Technology System Status

The thermodynamic limit for the efficiency of conversion of sunlight to electricity is 93%, although the route to such high efficiency is presently unknown. In the 1950s and 1960s, there were many publications on solar cells involving fundamentally different approaches to converting sunlight into electricity. Researchers of that period determined that most of these approaches were impractical because many enabling technologies weren't available. Several of the approaches have been labeled as "third-generation" solar cells by Australian researchers pioneering these efforts; first- and second-generation technologies are crystalline silicon and thin film solar cells, respectively. As an example, a fundamental loss mechanism in conventional solar cells is that electrons given too much energy by sunlight lose that energy as heat as the electrons thermalize to the bottom of the conduction band. So-called "hot-carrier" solar cells would use quantum dots (i.e., nanoparticles) to confine electrons long enough so that they could be extracted to do work before their energy dissipates as heat.

Nanotechnologies and other alternative approaches are very important for third-generation technologies. Another concept—impact ionization—would produce two electrons, instead of just one, for sun light with sufficient energy. Yet another concept explores the use of minibands in a superlattice structure to mimic a multijunction solar cell. These third-generation concepts are targeting much higher efficiencies—60% and higher—while conserving the potential for extremely low-cost manufacturing.

Current Activities: The University of New South Wales in Australia is the world's leading explorer for third-generation concepts. There are also small research projects at the Polytechnic University of Madrid, Imperial College in London, and at NREL. The University of New South Wales has a 10-year funding horizon to develop third-generation concepts. NREL's in-house Beyond the Horizon project is funded at less than $200K per year. The "Core" university science initiative, if funded in FY 2004, could support several large university projects exploring new PV concepts, including third-generation concepts.

Program Coordination and Implementation: There is no DOE Solar Program in this area to coordinate because there is only one in-house project at NREL.

Coordination with Related Programs: The University of New South Wales has held several small workshops for the very small set of universities and laboratories looking at third-generation concepts. NREL's Senior Research Fellow has participated in these workshops. All of the participants in the workshops have given presentations at the DOE/NREL *Future Generation Photovoltaics* and *Photovoltaics for the 21st Century* conferences.

Technology and Component Goals and Objectives

Goal: The goal is to identify and verify, both theoretically and experimentally, third-generation concepts leading to very high-efficiency and very low-cost options for producing solar electricity at very low cost.

Objectives: The 2003 baseline for third-generation concepts is:

- Several concepts for third-generation solar cells have been proposed
- None of the concepts have been shown to work.

The 2007 objectives for third-generation concepts are:

- Demonstrate that one of these third-generation concepts works.

The 2025 objective is:

- Assuming this technology survives go/no go decision points, achieve a levelized energy cost of less than $0.06 /kWh.

Key Technical Challenges

- Identifying enabling technologies that could make a third-generation solar cell feasible
- Demonstrating that a third-generation process, such as one involving hot carriers, actually results in solar conversion to electricity.

Technical Targets

System Element	Unit	2003 (baseline)	2007	2025
Third-Generation Cell Efficiency	%	0%	>0%	TBD
System LEC	$/kWh			TBD

Technical Barriers

Third-Generation Solar Cells

G. New knowledge is needed to identify pathway options for third-generation solar cells
H. A demonstration is needed for at least one third-generation process.

Technology Approaches and Tasks

Task 4, Third-Generation Solar Cells: NREL has an internal project exploring the theoretical and experimental justifications for third-generation technologies. Soliciting proposals from highly qualified research groups, under the DOE Solar Program "Core" University science initiative, will lead to totally new efforts to achieve such aggressive goals.

- Select university research teams for third-generation PV technologies targeting very high efficiency and very low cost
- Demonstrate feasibility of third-generation PV devices such as hot-carrier and impact-ionization concepts
- Assess potential of nanotechnologies for achieving third-generation goals of very high efficiency and very low cost.

Schedule and Milestones (Refer to Table 4.4-2)

4.4.2.2 Advanced Building-Integrated Concepts

Technology Status and Challenges

Buildings account for roughly a third of total energy consumption in the United States. Given the ubiquity of incident solar radiation in our country and our national goal of energy independence, a tremendous potential exists for the solar energy technologies to make a large impact on reaching that goal. Building energy loads are generally heating, cooling, lighting, and others that are typically met through "plug power" (electricity). Solar energy has already demonstrated that it can address all of these loads. Active solar-thermal space and water heating systems have long been available and successfully compete with fossil- and electrically driven technologies in many markets. Thermally driven cooling systems exist that can use solar energy in place of fossil energy sources. Solar daylighting complements electrically driven artificial lighting, and can largely displace it in buildings whose duty cycles are primarily daytime. Plug power from central plants built using the concentrating solar power technologies have been operating reliably since the 1980s. Plug power from point-of-use sited solar photovoltaic systems has been in use for many years.

The primary challenges facing greater use of the solar energy technologies in building applications generally fall into one or both of the following categories. First, they need to better compete economically with conventional building energy technologies. Second, building community stakeholders (e.g., builders, buyers, operators, financiers, code officials) need to be better informed about those solar technologies that presently compete in today's marketplace.

The economics of the building-integrated solar technologies begin by roughly mirroring those of the same technologies used in non-integrated applications, but can significantly improve from those levels by taking advantage of whole-building opportunities. The first of these opportunities is due to the solar technologies being able to perform more widely than as energy producers. For example, transparent PV panels can also serve as glazing, thereby permitting some of the PV cost to be offset by avoiding the purchase of the windows that they replace. A similar situation exists for roofing. Available in markets today are combination PV modules/roofing shingles. Also, large commercial and institutional buildings today are being fitted with roof systems that insulate, prevent moisture intrusion, and provide simplified means of installation, as well as produce solar electricity. One solar-thermal heating technology that doubles as a building's external cladding has been performing well for many years.

A second opportunity follows when tradeoffs between energy conservation and energy production are considered. Frequently, modest expenditures made in reducing building energy usage can lead to much larger savings in energy production costs. Therefore, it often costs less to save a kilowatt-hour than it does to generate one.

Better outreach at keeping the building stakeholder community informed about the relative benefits of building integrated solar technologies should also accelerate the diffusion of these technologies into the marketplace. The fact that life-cycle costs of solar technologies relative to conventional ones are lower can appeal to owner-operators of buildings who procure these buildings and operate them over long periods. Examples of these owner-operators are housing authorities, military housing entities, and those that are responsible for institutional (e.g., health, corrections, government administration) buildings.

The Solar Program has long recognized the large potential impact that solar energy can have in this sector. Its recent PV:BONUS competitive solicitations and subsequent awards have produced building-specific solar technologies into the marketplace. In addition, the Solar Program's Building-Integrated Photovoltaics (BIPV) activity has been a formal element of the PV Subprogram for the past several years.

Technology Approaches and Tasks

4.4.2.2.1 AC Building Block

Status: A proposed new concept, an "AC Photovoltaic Building Block," can revolutionize the PV industry. The building block modules are fully integrated with mounting hardware as approved electrical conduit, inverter, interconnect busses, surge protection, and safety devices to become a plug-and-play system. Goals for the proposed new project are to reduce balance-of-systems (BOS) costs by 50% and improve reliability and ease of installation. This project opens vast opportunities to enhance cooperative national laboratory/industry work through a broad range of technology transfer. The revolutionary advances for the photovoltaic industry allow U.S. technology to lead once again by providing power conversion methodologies and system designs that are extremely rugged and reliable.

The project involves development of an extremely rugged and reliable DC-AC inverter/system that is compatible with utility interconnections and the full range of energy sources. The project incorporates packaging methodologies, interconnecting devices, and thermal management already used in space and weapons applications at Sandia National Laboratories, but not yet brought to the commercial market. Additionally, the automotive and telecommunications markets are using proven technologies that should be applied to this AC PV building block.

Key Technical Challenges

The success of the project relies on:

- **I.** Mass production of quality products using the latest technology
- **J.** All of the elements coming together into a rugged, reliable, and proven package.

The development of this concept is based on mass production of consumer products, just as in the cellular telephone, personal computer, and automotive industries.

Technology Approaches and Tasks

Task 5, AC Building Block: Near-term work will include a first-year feasibility development for a system to demonstrate elements of power density, packaging, and preliminary thermal management. It will be pursued with key knowledgeable and experienced manufacturers through competitive, contracting and will be collaborative with key organizations at Sandia National Laboratories to tap technologies developed for space and weapons components for the commercial PV industry; specifically, provide proof of concept related to the microinverter, its power density, calculated mean-time-to-failure, and layout with a first-design prototype package. Additionally, the first year will focus on providing a report on materials study, lamination methods, and thermal management for the power bar.

4.4.2.2.2 Photovoltaic/Thermal Hybrid

Status: Today, separate collector technologies (PV modules and flat-plate solar-thermal collectors) are used to produce electricity and thermal energy. With increased interest in zero-energy buildings, it is becoming more common for PV and thermal collectors to be installed on the same building, side-by-side on the roof. Because PV modules typically convert only 5% to 15% of the incident solar radiation to electricity, an obvious question is whether a combined PV/thermal collector would make sense.

Potential advantages of PV/thermal collectors include: (1) cost savings due to dual use of components and labor, (2) reduced roof-space requirements, (3) fewer roof penetrations, and (4) integrated appearance. With lower-cost PV cells in the future, it becomes increasingly important to reduce the cost of other components in the PV module/array (e.g., superstrate/substrate, frame, mounting hardware, installation labor), and the beneficial impact of cost-sharing dual use in a PV/thermal collector increasing market. Beyond cost, there are practical advantages and the market appeal (to architects, sellers, installers, and consumers) of a single product that provides both electricity and thermal energy for applications such as zero-energy buildings.

Challenges: Significant technical challenges must be overcome to develop practical PV/thermal collectors. Currently, few or no PV/thermal products are commercially available despite R&D efforts (some of which simply combined existing PV and solar-thermal collector designs). Potential problems include:

- **K.** Reduced PV efficiency due to elevated temperatures and optical losses
- **L.** Energy, temperature, and seasonality matching of PV waste heat with thermal end-uses

M. Multiple plumbing connections between modules
N. Differential thermal expansion
O. Overall system complexity, especially compared to a PV-only system.

Technology Approaches and Tasks

Task 6, PV/Thermal Hybrid: The technology development approach involves three phases, moving from initial concepts to marketable products. Concept development (Phase I) involves researchers and multiple industry partners developing/evaluating multiple technology approaches/concepts for a particular application, e.g., cold-climate solar water heating. Engineering development (Phase II) involves down-selected industry partners further developing the most-promising concepts into practical designs. Product development (Phase III) involves final testing, redesign, and certification. In each phase, the approach is collaborative, typically with industry partners developing the technology and government laboratories and subcontract consultants providing technical support. Industry partners are selected through competitive solicitations based on the merits of their proposed technical concepts and their capabilities to develop technology from initial concept to marketable product.

Technical options include various combinations of the following: thermal end-uses, liquid/air-based systems, glazed/unglazed collectors, module designs, direct/heat-pump systems, thermal distribution systems, and roof integration. The first step will be a thorough literature search. An iterative analytical/experimental approach will be used. Component concepts will be developed, optimized, and evaluated using computational heat-transfer analysis. System performance will be predicted in detailed systems analysis using hour-by-hour annual simulations and weather data for a range of climates. Promising component/system concepts will be prototyped and tested, as necessary, to characterize their performance. Experiments will proceed from laboratory testing of small prototypes to field monitoring of full-scale prototypes under typical operating conditions.

The approach will emphasize simple, practical, roof-integrated systems and preserved/improved PV efficiency based on innovative thermal designs. Exploratory analysis and optimization may well lead to unorthodox designs. For example, low cell temperatures and increased PV output may be achieved for crystalline-silicon PV by using it in a low-efficiency, unglazed, large-area thermal collector. Special attention will be paid to effective extraction of heat and avoidance of nonuniform cell/module temperatures that can limit PV current and output. The design approach will also consider roof-integrated technologies and hydronic heating technologies.

4.4.2.3 Other Advanced Solar Conversion

Technology Status and Challenges

As the country moves toward a hydrogen energy future, methods for cleanly and economically producing this fuel are being sought. The solar energy technologies could provide methods for accomplishing both of these objectives. In all cases, production costs are key, and a systems-driven approach will be followed in evaluating these methods.

Approaches that use natural gas as a consumable feedstock will not be followed. Increasing domestic consumption, decreasing domestic production, and increasing imports of this relatively clean “transitional” fossil fuel suggest that its use in hydrogen production is likely not in the nation’s best interest.

Approaches and Tasks

4.4.2.3.1 Solar-Thermal Hydrogen

Status: Solar thermochemical hydrogen production is based on concentrated solar thermal energy driving chemical reactions. Most of the research has employed point focus-dish or central-receiver concepts. Hydrogen can also be processed using solar energy to “split” water via direct photochemical methods. This effort will evaluate solar hydrogen production concepts in concert with DOE’s Hydrogen Program.

Challenges: The systems-driven approach is ideal for evaluating the possibilities.

- **P.** Identify a solar-driven hydrogen production process that is cost effective when compared with renewable and nonrenewable options.

Technology Approaches and Tasks

Task 7, Solar-Thermal Hydrogen:

- Establish a system-driven framework for identifying and comparing cost-effective methods for the production of hydrogen from solar thermal energy

4.4.2.3.2 Direct Conversion

Status: Direct conversion of solar energy into hydrogen is typically associated with water splitting using photovoltaic or thermochemical processes. This is a high-risk project that could yield large payoff benefits because hydrogen could be produced without carbon dioxide release. These approaches are technically feasible; conversion efficiencies for producing hydrogen increased significantly during the 1990s to values above 12%.

It is appropriate to work in concert with DOE’s Hydrogen Program to evaluate the production of hydrogen through electrolysis powered by solar electricity. These approaches are also promising for other inexpensive renewable electricity sources, such as hydroelectricity, geothermal, or wind-generated electricity. It appears appropriate to review the possibilities, in light of progress made over the past decade and in terms of the High-Performance PV Project goals, for very-high-efficiency concentrator PV systems that have the potential for a more rapid reduction in the cost of electricity as production capacity increases and a potential for electricity costs approaching wind-generated electricity costs.

Challenges: Direct conversion faces the following challenges:

- **Q.** Identify solar cell devices with appropriate voltages for generating hydrogen, while mitigating corrosion effects either through device design or protective coatings
- **R.** Employ a systems-driven approach to identify opportunities and barriers for cost-effective direct conversion of solar energy into hydrogen.

Technology Approaches and Tasks

Task 8, Direct Conversion:

- Establish a systems-driven framework for identifying limitations and opportunities for the direct conversion of solar energy to hydrogen through enabling PV technologies
- Assess innovative approaches for mitigating corrosion effects in direct conversion of solar to hydrogen
- Assess the potential for concentrating PV or hybrid concentrator/electrolyzer/fuel cell systems to produce cost-effective hydrogen.

Schedule and Milestones (Refer to Table 4.4-2).

4.4.2.3.3 Thermochemical Transport and Storage

Status: The ultimate potential of solar energy, especially for non-electric applications such as process heat and transportation fuels, could be greatly expanded if efficient and cost-effective means of converting solar energy to chemical energy for storage and transport at large scale existed. This would overcome both the intermittent nature of the resource and its lack of coincidence with major load centers. One such mechanism offering this potential is closed-loop thermochemical heat-pipe transport and storage. In this technology, a gas mixture (typically methane[1] and carbon dioxide) is reformed in a high-temperature (800°C) catalytic solar reactor (a power tower, for example, or, for smaller applications, a dish system), to produce syngas (hydrogen and carbon monoxide) according to the reaction:

$$CH_4 + CO_2 \leftrightarrow 2H_2 + 2CO.$$

The syngas (containing the original solar energy as chemical energy) can then be economically transported over distances of several hundred kilometers or stored for an extended period of time (its energy content is equivalent to about half that of natural gas). When the energy is needed, the syngas is processed in a conventional methanation reactor, converting the gas back to the original products reversibly, and releasing the original stored energy at temperatures up to 700°C. The methane/carbon dioxide gas can then be recycled through the process indefinitely. For example, solar energy could be collected on a large -scale, year-round in the Mojave desert, with seasonal storage and conventional gas pipelines then supplying the energy to the Los Angeles area for zero-emission process heat or power generation on a 24/7 basis.

Although part of the beauty of the process described above is its completely closed-loop nature (which is perfect for the described application), the reactor designs and chemistry are similar to those that might be used for hydrogen and fuels production as well.

Proof-of-concept experimental solar reactors have been successfully demonstrated. These efforts have shown moderate efficiency and lifetimes and have validated the potential of the technology. Lifetime of the volumetric receiver/reactor materials and window materials need to be substantially improved, as do catalyst materials and their incorporation in the system. Scaled-up designs suitable for large-scale use remain to be developed.

Challenges: Reforming reactions and methanation reactions and reactors are well understood, as are all the conventional elements of the system. However, challenges remain in the:

- **S.** Design, development, testing, and scale-up of solar reactor, including
- **T.** Volumetric catalytic receiver designs; windows for the receivers; catalyst adaptations for the solar environment; engineering for durability, reliability, and efficiency; extensive testing; and scale-up demonstrations.

Technology Approaches and Tasks

Task 9, Thermochemical Transport and Storage: Initial activities will include reviewing the international literature and international programs (most of which are regularly reported through SolarPACES) to better understand progress made in the past few years. Systems analyses will be developed and updated to identify markets, quantify the potential, and identify key areas of development need. Initial experimental programs will likely focus on catalytic absorber development and small-scale testing in solar simulator and solar dish or furnace environments.

Schedule and Milestones (Refer to Table 4.4-2).

[1] Natural gas usage here is as a working substance. It is not consumed in this reversible, closed-loop process.

Table 4.4-1. Tasks for New Concept Development

Task	Title	Barriers
I	***Beyond the Horizon* and *Future Generation PV***	
1	**Organic Solar Cells** • Initiate theoretical studies for doping organic materials • Conduct peer review of “Beyond the Horizon PV” (organic) projects • Determine operational characteristics of excitonic solar cells using biomimetic, organic, and nanotechnology concepts • Assess efficiency potential, stability, and reliability of organic polymer and small-molecule solar cells • Identify commercialization pathways for promising new technologies via university/industrial partnerships.	**A,B**
2	**Dye-Sensitized Solar Cells** • Assess efficiency potential, stability, and reliability of inorganic/organic solar cells • Assess dye-sensitized solar cell options involving solid-state electrolytes.	**C,D**
3	**Nanostructure Solar Cells** • Renew most-promising “Future Generation PV” nanotechnology contracts • Determine operational characteristics of excitonic solar cells using nanotechnology concepts—including biomimetic concepts mimicking a solar biological process.	**E,F**
4	**Third-Generation Technologies** • Select university research teams for third-generation PV technologies targeting very high efficiency and very low cost • Demonstrate feasibility of third-generation PV devices such as hot-carrier and impact-ionization concepts • Assess potential of nanotechnologies for achieving third-generation goals of very high efficiency and very low cost.	**G,H**
II	**Advanced Building-Integrated Concepts**	
5	**AC Building Block** • Conduct a first-year feasibility development • Research materials and develop lamination methods for the double insulation design that reduces AC-side for ground-fault protection • Provide a report on materials, lamination methods, and thermal management for the power bar • Develop and select the best inverter technology applicable to best practices in mass production and the best compromise of cost, performance, reliability, and necessary form factor for all applications	**I,J**

Task	Title	Barriers
	• Develop a permanent PV module to inverter link in collaboration with Sandia National Laboratories, module manufacturers, and inverter manufacturers • Begin forward-looking, long-term concepts using made-to-order power electronics and controls to take advantage of large-scale integration, decrease numbers of interconnects and parts. • Develop best solutions for simple communications to report status of each AC Building Block • Develop the AC bus construction methods complete with permanent internal connections and connectable but corrosion-resistant, long-lived interconnect links and final interconnects to the utility or other AC connections • Develop the frame or rail to be compatible with the wide range of PV modules, to provide low-stress protection for the PV modules, while providing long-life, corrosion-proof DC and AC interconnects • Collaborate with the PV module industry and electronic/packaging industry to fully integrate the plug-and-play package • Collaborative work with multiple synergistic industries such as automotive or electric lighting to develop best-effort approach and to leverage influence on electronic power semiconductor industry for made-to-order electronics • Take best-effort and most-promising design to final testing, redesign, listing, and certification.	
6	**Photovoltaic/Thermal Hybrid** • With multiple industry partners, develop/evaluate multiple approaches/concepts for chosen applications • With down-selected industry partners, further develop the most-promising concepts into practical designs • Complete final testing, redesign, and certification.	**K,L,M,N,O**
III	**Advanced Solar Conversion**	
7	**Solar-Thermal Hydrogen** • Establish a systems-driven framework for identifying and comparing cost-effective methods for the production of hydrogen from solar-thermal energy.	**P**
8	**Direct Conversion** • Establish a systems-driven framework for identifying limitations and opportunities for the direct conversion of solar energy to hydrogen through enabling PV technologies. • Assess innovative approaches for mitigating corrosion effects in direct conversion of solar to hydrogen • Assess the potential for concentrating PV or hybrid concentrator/electrolyzer/fuel cell systems to produce cost-effective hydrogen.	**Q,R**

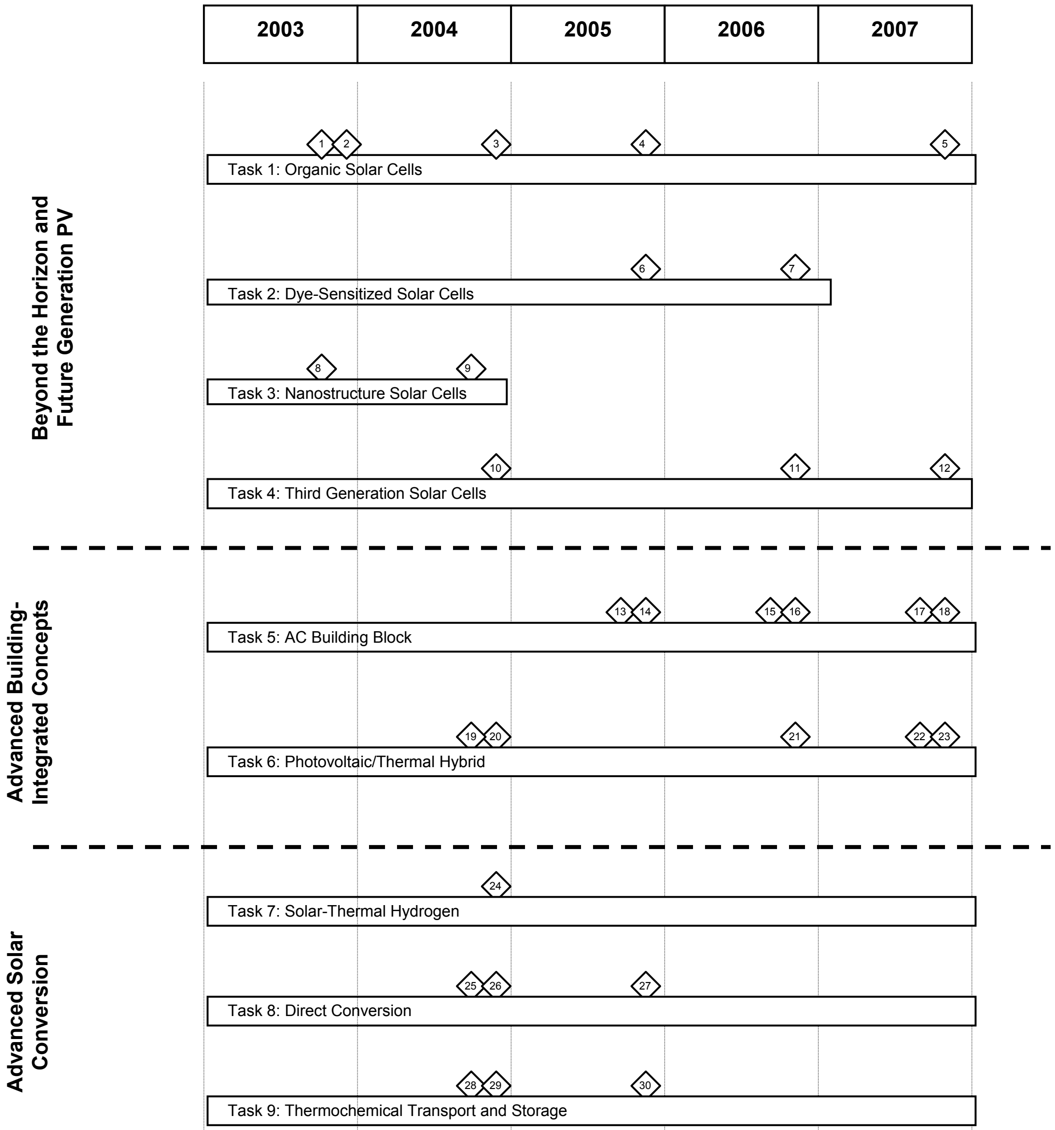
9	**Thermochemical Transport and Storage** • Review the international literature and international programs • Develop and update systems analyses to identify markets, quantify the potential, and identify key areas of development need • Conduct initial experimental programs focusing on catalytic absorber development and small-scale testing.	**S,T**

4.4.3 Schedule and Milestones

Table 4.4-2. New Concept Development Milestones

Milestones	Task	Title	Estimated CY Date Quarter
1.	1	Initiate theoretical studies for doping organic materials	03 Q4
2.	1	Conduct peer review of "Beyond the Horizon PV" (organic) projects	03 Q4
3.	1	Determine operational characteristics of excitonic solar cells using biomimetic, organic, and nanotechnology concepts	04 Q4
4.	1	Assess efficiency potential, stability, and reliability of organic polymer and small-molecule solar cells	05 Q4
5.	1	Identify commercialization pathways for promising new technologies via university/industrial partnerships	07 Q4
6.	2	Assess efficiency potential, stability, and reliability of inorganic/organic solar cells	05 Q4
7.	2	Assess dye-sensitized solar cell options involving solid-state electrolytes	06 Q4
8.	3	Renew most-promising "Future Generation PV" nanotechnology contracts	03 Q4
9.	3	Determine operational characteristics of excitonic solar cells using nanotechnology concepts—including biomimetic concepts mimicking a solar biological process	04 Q4
10.	4	Select university research teams for third-generation PV technologies targeting very high efficiency and very low cost	04 Q4
11.	4	Demonstrate feasibility of third generation PV devices such as hot-carrier and impact-ionization concepts	06 Q4
12.	4	Assess potential of nanotechnologies for achieving third-generation goals of very high efficiency and very low cost	07 Q4
13.	5	Rudimentary proof of concept (inverter packaging and initial thermal characterization)	05 Q4
14.	5	Complete initial materials studies for laminations, bus, links, interconnects, thermal management, mounting	05 Q4
15.	5	Complete inverter topology, design, and layout to accommodate at least 200-W capabilities	06 Q4
16.	5	Issue contracts to fully integrate the AC PV Building Block Package	06 Q4
17.	5	Complete full-scale prototype to include power processing, communications, interface with the utility, and interface with a variety of PV modules	07 Q4
18.	5	Begin optimization process for integrating all electronics using made-to-order power switches, drive modules and controls	07 Q4
19.	6	Roadmapping meeting for PV/thermal hybrid	04 Q4
20.	6	Issue-focused RFP for most promising concepts	04 Q4
21.	6	Complete testing of small-scale prototypes	06 Q4
22.	6	Complete fabrication of full-scale prototypes	07 Q4
23.	6	Field and torture tests under way	07 Q4
24.	7	Systems-driven framework complete	04 Q4
25.	8	Systems-driven framework complete	04 Q4
26.	8	Innovative approaches assessed	04 Q4
27.	8	Potential for CPV or hybrid concentrator/electrolyzer/fuel cell systems to produce cost effective hydrogen assessed	05 Q4

Milestones	Task	Title	Estimated CY Date Quarter
28.	9	International literature and international programs reviewed	04 Q4
29.	9	Systems analyses updated	04 Q4
30.	9	Initial experimental programs completed.	05 Q4



Legend

Milestones

1. Initiate theoretical studies for doping organic materials
2. Conduct peer review of "Beyond the Horizon PV" (organic) projects
3. Determine operational characteristics of exaction solar cells using biomimetic, organic and nanotechnology concepts
4. Assess efficiency potential, stability and reliability of organic polymer and small-molecule solar cells
5. Identify commercialization pathways for promising new technologies via university/industrial partnerships
6. Assess efficiency potential, stability and reliability of inorganic/organic solar cells
7. Assess dye-sensitized solar cell options involving solid-state electrolytes
8. Renew most promising "Future Generation PV" nanotechnology contracts
9. Determine operational characteristics of excitonic solar cells using nanotechnology concepts---including biomimetic concepts mimicking a solar biological process
10. Select university research teams for third generation PV technologies targeting very high efficiency and very low cost
11. Demonstrate feasibility of third generation PV devices such as hot carrier and impact ionization concepts
12. Assess potential of nanotechnologies for achieving third generation goals of very high efficiency and very low cost
13. Rudimentary Proof of Concept (Inverter Packaging and Initial Thermal Characterization
14. Complete Initial Materials Studies for Laminations, Bus, Links, Interconnects, thermal management, mounting
15. Complete inverter topology, design and layout to accommodate at least 200 W capabilities
16. Issue contracts to fully integrate the AC PV Building Block Package
17. Complete full scale prototype to include power aprocessing, communications, interface with the utility and interface with a variety of PV Modules
18. Begin optimization process for integrating all electronics using made to order power switches, drive modules and controls
19. Roadmapping meeting for hybrid
20. Issue-focused RFP for most promising concepts
21. Complete testing of small-scale prototypes
22. Complete fabrication of full-scale prototypes
23. Field+torture tests underway
24. Systems-driven framework complete
25. Systems-driven framework complete
26. Innovative approaches assessed
27. Potential for CPV or hybrid concentrator/electrolyzer/fuel cell systems to produce cost effective hydrogen assessed
28. International literature and international programs reviewed
29. Systems analyses updated
30. Initial experimental programs completed

5.0 Managing the Solar Energy Technologies Program

The management of the DOE Solar Energy Technologies Program seeks to emphasize results and implement successful private-public partnerships. In the *President's Management Agenda*, the Bush Administration outlined a renewed spirit of accountability that emphasizes results-driven—rather than process-oriented—government management. A key aspect is establishing measurable program metrics as benchmarks to evaluate progress. DOE is committed to following the Administration's directives concerning reforming the business of government.

In July 2002, leaders of EERE recognized the need to change the way the office did business and implemented a new structure that created a streamlined, integrated, and focused alignment that emphasizes strong program management for better performance. The structure is built on 11 technology programs by which EERE accomplishes its goals and a business administration office that supports the programs. EERE's new structure is recognized as a front-runner for:

- Implementing the *President's Management Agenda*
- Improving organizational efficiency
- Enhancing fiscal accountability
- Empowering program managers (thereby establishing greater accountability)
- Focusing on results rather than processes
- Integrating performance planning and budgeting.

EERE has also implemented a Strategic Management System (SMS) that will aid in incorporating Office of Management and Budget (OMB) Applied R&D investment criteria into its planning and budget formulation activities. SMS effectively integrates planning, budget formulation, program implementation, and program evaluation and provides the framework for the EERE portfolio management approach. Data in the SMS include major milestones and technology status and can be used annually and throughout the year to assess partners' performance, adjust funding, and realign R&D portfolios. This Multi-Year Technical Plan is a cornerstone of the SMS process, and the entire process is depicted in Figure 5-1.

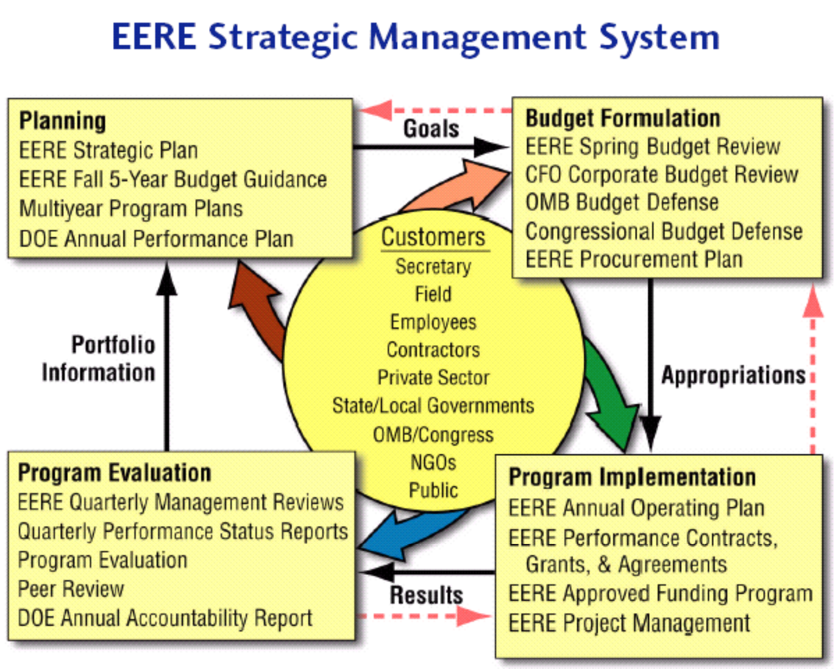


Figure 5-1. Schematic of the EERE strategic management system, showing the four key activities and their relationship to customers and to one another.

To ensure that SMS has accurate and up-to-date information, the Solar Program implemented a Web-based project management database in 2003. The database includes the following information on each solar project: objectives, background, approach, recipient, location, milestones, status, amount of funding, and program priority. The database is kept current by national laboratory researchers or contract managers responsible for the project. Financial information such as the program spend plan is entered by DOE technology managers. The database provides lab and DOE managers immediate access to the most recent information on all program activities. It also adds efficiency to the planning process, in that tasks for the coming year are developed in the database and become the program's annual operating plan. Information from this database is downloaded directly into the SMS.

EERE is in the process of implementing a single Web-based project management database that will cover all 11 of the energy efficiency and renewable energy programs. Once implemented, the Solar Program will upload data from the solar database into the new EERE-wide database.

5.1 Program R&D Portfolio

The Solar Program maintains its goal-oriented R&D portfolio, which incorporates a balance of short-, mid-, and long-term research. The portfolio is balanced to ensure support for high-risk, high-payoff research that is unlikely to be supported outside the Federal government, combined with research that has lower risks and near-term benefits that attracts partners in industry and in state and local governments. This strategy provides a "pipeline" of research advances with the potential to "leapfrog" the limits of current technologies and applications that could dramatically increase the use of solar energy in the United States.

However, the Solar Program must direct its limited resources wisely and leverage private-sector funding to achieve its goals. Solar technologies can deliver energy to many applications, ranging from calculators powered by milliwatts up to power plants that generate hundreds of megawatts. Solar technology has established niche markets for remote applications where there is no electric grid (e.g., emergency highway phones, village power, portable sign boards) or where it is less expensive than fossil-fueled alternatives (e.g., pool heaters). It is also entering markets in applications (e.g., water heaters and PV systems on buildings) where it is still more expensive than competing options. These uses make sense where there are tax incentives or rebates and where policy makers understand that solar energy benefits society at large. Utilities are also encouraged through renewable portfolio standards or other policy incentives to use solar energy.

To achieve its vision of a future where solar energy is widely used, the Solar Program must continually reassess its portfolio of technologies. The portfolio must take into account various factors: the balance of mid- and long-term research; the pursuit of all solar-electric and solar-thermal markets; diverse research by national laboratories, industry, and universities; and technical and policy issues. This complexity has, in the face of Federal resource constraints, driven the Solar Program to establish a systems-driven approach (SDA) for making critical decisions.

The solar portfolio is managed by a Program Manger and a staff organized in three teams: Photovoltaics R&D, Solar Thermal R&D, and Systems Integration and Coordination.

5.1.1 Photovoltaics and Solar Thermal R&D

All PV and Solar Thermal R&D is coordinated by the respective DOE management team. Each team is responsible for providing technical direction to the national laboratories, as well as budget development and technology strategy and planning. In addition, the respective teams serve as communication and coordination points with industry partners (e.g., solar industry, utilities).

5.1.2 Systems Integration and Coordination

To carry out crosscutting and decision-making activities within the Solar Program, a System Integration and Coordination (SINC) Team has been created to manage independent analytical and decision-making processes. The responsibilities of SINC include:

- Conducting systems-driven analyses and processes to provide the Solar Program and EERE management with solid technology costs and market data from which to base programmatic decisions.
- Implementing communication, education, and outreach activities that promote solar energy to new and emerging customers.
- Coordinating among related DOE, Federal agency, and international programs and providing information about the latest advances in solar energy technologies.

Thus, SINC is responsible for implementing critical non-R&D, crosscutting activities that form the foundation for successful project management as outlined in the following sections.

5.2 Analytical Activities

A computer-modeling platform is being developed that will allow users to conduct trade-off and impact studies of various technology options in different market sectors. Thus, the SDA will be a rigorous analytical process by which technology development efforts are driven by well-defined and well-documented requirements based on analyses of present and potential markets, technology trade-off studies, and R&D reviews.

An early outcome of the SDA process is that the Solar Program has elected to use levelized energy cost (LEC) as its overall programmatic metric. This measure of delivered energy cost takes into account the capital cost, operating costs, and all financial parameters used to measure all solar technologies versus other competitive energy options. Long-term goals have been established for each market segment:

- Distributed retail electricity using PV at \$0.06/kWh (\$1/W)
- Utility-scale electricity using concentrating solar power at \$0.04–0.06/kWh (50% capacity factor)
- Building thermal energy using solar hot water at \$0.04–0.06/kWh (\$1,000 installed).

The LEC metric will also allow for a measure of success for the Solar Program by determining where specific technologies or R&D activities can be left to the private sector. Thus, through the SINC Team, the Solar Program has implemented effective, results-based program management that will accelerate the development and deployment of solar energy technologies.

5.2.1 Decision-Making Using Systems-Driven Analysis

Consistent with EERE’s new business approach, the Solar Program has chosen the systems-driven approach as the fundamental program philosophy. The SINC Team has been given the responsibility to implement a systems-driven approach to determine priorities, such as:

- Identifying key market sectors in which solar technologies can have significant impacts
- Determining critical R&D to address technology barriers related to those markets
- Developing a standardized means of data collection and analysis to ensure that fielded technologies meet targets related to cost, performance, and reliability.

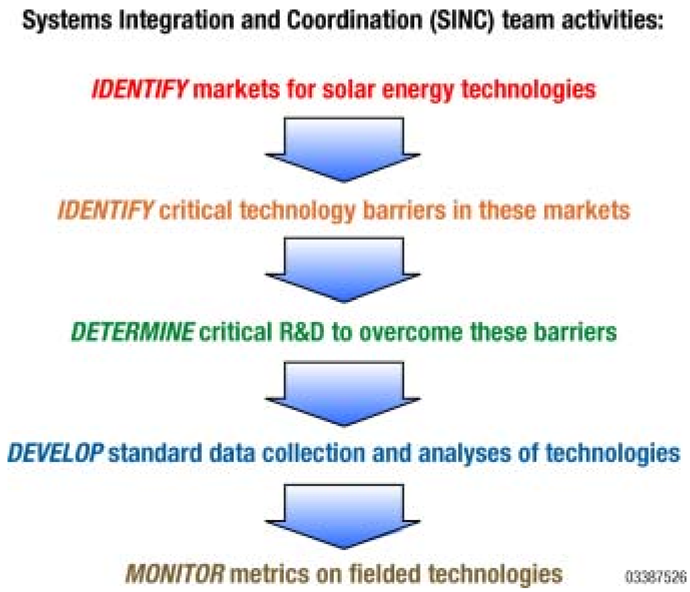


Figure 5-2. Activities performed in concert with the PV and solar thermal teams to implement the systems-driven approach.

The systems-driven approach is defined as follows: a process whereby all technical targets for R&D on the components and systems funded through the Solar Program are derived from a common market perspective and national energy goals, and the resultant technologies are tested and validated in the context of established criteria for each market. A standard framework is being developed in the Solar Program to analyze each program technology. By developing and using a systems-driven approach, a standard configuration will enable rigorous target-setting and decision-making at the program level.

5.2.2 Resource Assessment

Understanding the solar resource is fundamental to understanding how much energy a solar energy system can produce. The Solar Program supports activities that gather and interpret weather data from thousands of ground locations. These data provide a historical perspective of weather patterns that can be used to predict future solar insolation. The program also supports the gathering of solar insolation data from satellites, which provides the potential for predictions that can be very site specific—a capability considered crucial to industry decisions on siting large solar power plants.

5.2.3 Environmental Safety and Health

A number of environmental benefits are associated with solar energy. Because the development of 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.

5.3 Communications and Outreach

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 and decision-makers in business and government need 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.

The Solar Energy Technologies Program is developing an integrated communications and outreach plan that streamlines processes for all program activities, ensuring stronger coordination of efforts and leveraging of resources. This is being accomplished by first identifying communications goals and objectives, identifying key target audiences and their needs, developing targeted messages, and determining the best approaches for reaching those audiences. With this framework established, the next step will be to develop resources to meet the needs of the audiences and establish mechanisms for delivering those resources. The communications and outreach plan will serve as a guide for the development of appropriate communications materials throughout the fiscal year. It will be updated annually to ensure that the communications and outreach processes in place are accomplishing their intended goals and objectives, and will be flexible enough to accommodate changes in strategic direction. The Solar Program communications and outreach liaison will maintain dialogue with the corporate EERE Office of Communication and Outreach to keep it abreast of the needs and achievements of the Solar Program, and to ensure that it complies with EERE's communications standards. The solar communications and outreach plan is expected to be completed by March 2004.

The communications and outreach plan will put solar energy technologies in context with other energy systems, in a way that has meaning for the businesses and end-users who will build, sell, and purchase solar technologies. The solar communications and outreach plan will:

- Communicate to all relevant stakeholders the major expectations in the Solar Program's communications effort over the next year.
- Identify Solar Program communications goals, objectives, target audiences, strategy and rationale, and tactics and evaluation tied to goals and objectives.
- Suggest the implementation of new approaches to reach target audiences and ways to communicate successes, results, and status of all R&D projects and initiatives.
- Promote the development and distribution of training and education materials about solar energy, establish delivery mechanisms, and identify and allocate sufficient funding and other resources for doing so.
- Focus initially on printed materials such as descriptive brochures, fact sheets, and briefing materials.
- Marshall and target solar communications resources within and outside the Federal government.
- Promote a wide range of communications and outreach activities tied to upcoming national events such as the Solar Decathlon and the American Solar Challenge.
- Highlight a revision of the Solar Program Web site and the coordination of events and trade show exhibits.
- Include activities related to the Million Solar Roofs Initiative, which promotes the installation of solar energy systems on one million homes and commercial/institutional buildings.
- Identify opportunities to coordinate communications activities with other EERE programs to build awareness of the importance and synergies of energy efficiency and renewable energy.

5.4 Program Coordination

The bulk of the Solar Program's activities are carried out using the exceptional and unique capabilities of DOE's multi-program national laboratories. The Solar Program has established two primary research centers: the National Renewable Energy Laboratory (NREL) in Golden, Colorado, and Sandia National Laboratories (SNL) in Albuquerque, New Mexico. Oak Ridge National Laboratory (ORNL) and Brookhaven National Laboratories (BNL) also contribute their expertise to perform specific tasks. The DOE Golden Field Office and Albuquerque Service Center help DOE headquarters administer and manage contracting activities not assigned to the laboratories. Finally, the Solar Program works with the six EERE Regional Offices in Boston, Philadelphia, Atlanta, Seattle, Denver, and Chicago for outreach and deployment activities such as the Million Solar Roofs Initiative.

5.4.1 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 has created several solar-specific user and test facilities, including the extensive measurements and characterization facilities for photovoltaic cells, modules, and systems; the National Solar Thermal Test Facility for testing concentrating solar power technologies; and the Thermal Test Facility for testing active solar, passive solar, and ventilation technologies. These facilities must continually be outfitted with the most advanced equipment to conduct effective research in materials science, electrochemistry, thermal sciences, and other disciplines.

5.4.2 DOE Energy Efficiency and Renewable Energy Programs

The Solar Program coordinates its activities with several other EERE programs, as well as Federal, state, and local agencies, that can benefit by incorporating solar energy to enhance overall value for end-users. These programs include the following:

- *Hydrogen, Fuel Cells, and Infrastructure.* These technologies can incorporate solar energy systems into the production of hydrogen as a fuel.
- *Distributed Energy Resources.* Technologies such as combined heat and power, microturbines, and engines can be hybridized with solar into clean, reliable energy systems.
- *Buildings.* This area includes energy efficiency programs that can incorporate solar systems into building envelopes, critical to its *Zero Energy Buildings* program goal.
- *Federal Energy Management Program.* This program has helped promote and make available solar energy systems to the Federal government, which is the largest energy user in the United States.
- *Weatherization and Intergovernmental Programs.* These programs have helped promote and deploy solar energy via contacts in state, regional, and local organizations. They also support international projects and the renewable energy component of bilateral and trilateral energy agreements.
- *Small Business Innovative Research/Small Business Technology Transfer Research (SBIR/STTR) Programs.* These programs were created to stimulate opportunities and innovation by setting aside Federal R&D funding for small businesses. The DOE solar programs have contributed more than $10 million in research grants since 1982.
- *Historically Black Colleges and Universities (HBCU) Program*. DOE sponsors a select group of undergraduates from historically black colleges and universities to perform PV research, explore international applications, and fill summer intern positions at the national laboratories.

5.4.3 Other Federal Programs

Many other Federal agencies and programs are interested in solar energy to achieve their missions and objectives. Close coordination has been achieved with the following groups:

- *DOE's Office of Science* supports critical research in materials and fundamental sciences that improve solar energy collectors.
- *Department of Homeland Security/Federal Emergency Management Agency* has worked to accelerate the commercialization of solar products for homeland security and disaster-relief applications, including mobile solar systems that can generate electric power immediately.
- *The Environmental Protection Agency* has been interested in solar energy to help the nation meet air-quality mandates.
- *The Department of Interior* has been tremendously supportive in making public lands available for renewable energy. It also uses solar energy to provide power and thermal energy at many national park facilities.
- *The Department of Defense (DOD)* has supported reducing DOD energy consumption by analyzing the benefits and installing solar energy systems for military housing and facilities.
- *The U.S. Department of Agriculture/Rural Utilities Service* is a staunch supporter of solar energy and encourages PV as an energy supply option of choice in the rural utility community. It has developed incentive programs for rural electric cooperatives that tie long-term financing with new business opportunities for solar-electric customer service.
- *The National Aeronautics and Space Administration (NASA)* is a large user of PV cells for space power. DOE coordinates its R&D activities with key NASA laboratories and contractors.
- *Housing and Urban Development* entered into a collaborative effort to educate appraisers and buyers of homes on the merits of residential solar energy systems.
- *Interagency Advanced Power Group (IAPG)* is a Federal coordinating organization that shares research, development, demonstration, and deployment information among Federal agencies responsible for advanced power sources, including batteries, fuel cells, PV, and superconducting devices.
- *U.S. Agency for International Development (USAID)* has partnered with the Solar Program through Interagency Agreements and Participating Agency Support Agreements to further the achievement of common renewable energy deployment and market-preparation goals.

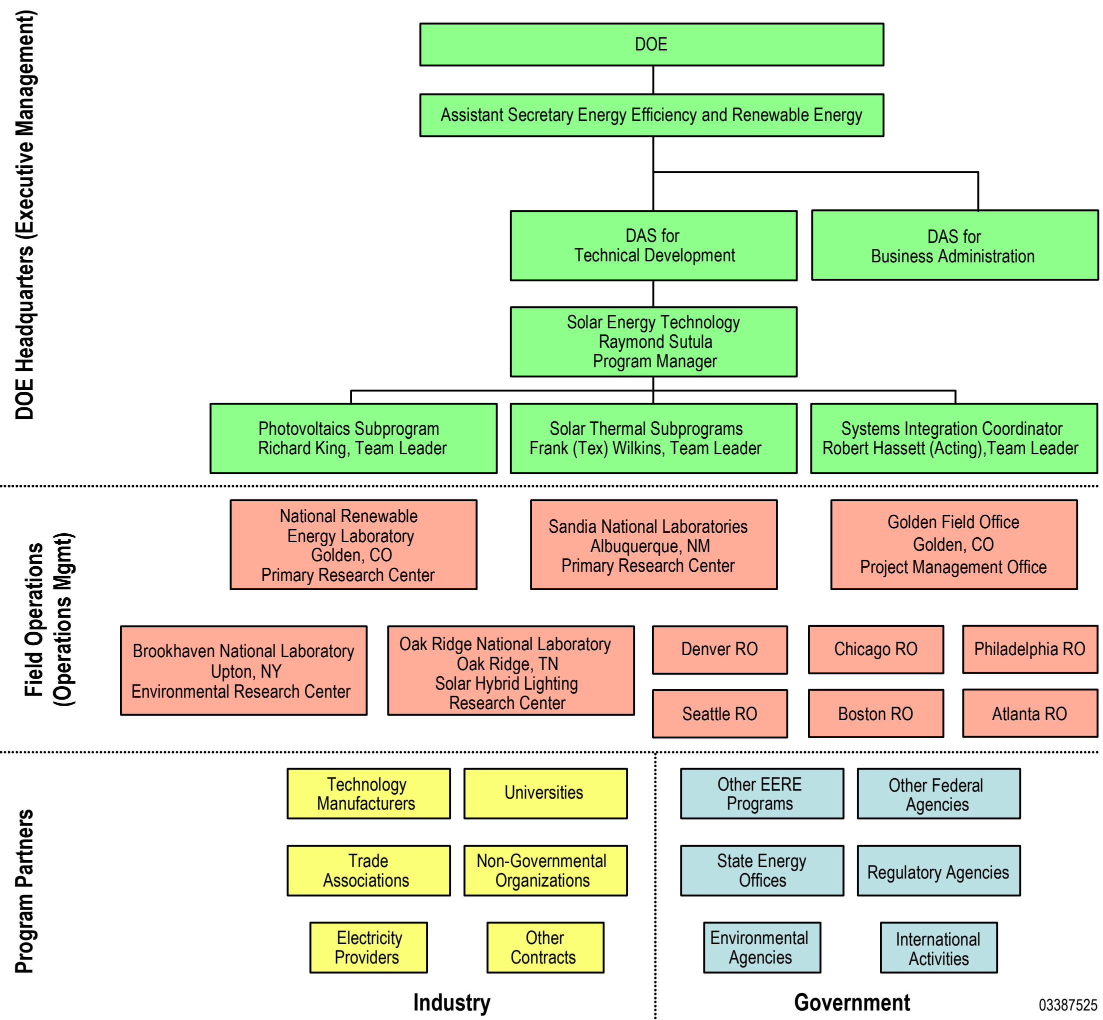


Figure 5-3. Organizational chart for the Solar Energy Technologies Program, showing its DOE Headquarters executive management, operations management in the field, and program partners.

5.4.4 State Programs

State energy programs work with local and regional governments to educate customers and stimulate the deployment of solar energy. Although consumers today have more energy choices than ever, their choices are heavily influenced by policies at the state and local levels. States play an increasingly important role in setting R&D priorities for solar and renewable energy, and in the funding of research, development, and demonstration projects. State laws and regulations that define the terms of utility restructuring and the choices consumers can make regarding their electricity supplies are critical to the success of solar energy in the marketplace. DOE uses its six regional offices for effective coordination with state and local organizations and has also established communications with several organizations:

- *The Western Governors' Association* has taken a proactive interest in analyzing the economic and environmental benefits of solar power to states in the Southwest.

- *The National Association of State Energy Organizations* represents state energy officials and has been instrumental in establishing partnerships in 32 states and 48 cities for the Million Solar Roofs activity.
- *The American Society of State Energy Research and Technology Transfer Institutes* provides state funding for R&D and incubation of technology companies through organizations such as the *California Energy Commission* and the *New York State Energy Research and Development Authority*.
- *The National Council of State Legislatures* is interested in the benefits of solar energy to determine whether state legislation should provide incentives for the adoption of solar energy.
- *The National Association of Regulatory Utility Commissioners* has reviewed and enacted policy drivers such as tax rebates and system-benefits charges to stimulate solar energy research, development, and deployment.

5.4.5 Industry Trade and Professional Associations

The organizations that represent the manufacturers, marketers, installers, customers, component suppliers, and consumers of solar energy provide keen insight to DOE regarding the markets, products, and services for solar energy. DOE maintains an open dialogue with many of these groups, including:

- *The Solar Energy Industries Association* represents the manufacturers, suppliers, and marketers of solar energy.
- *The Solar Electric Power Association* is interested in using solar energy for grid-connected and grid-independent electricity.
- *American Solar Energy Society* members are the professional society of technical researchers, employees, and advocates for solar energy.
- *The North American Board of Certified Energy Practitioners* works to bring certification programs for PV practitioners to the mainstream of the electrical industry.

5.4.6 International and Intergovernmental Programs

The United States is part of the global economy, and its industry competes and cooperates internationally. Indeed, a large part of the solar-energy market is international, as most domestically produced products are shipped overseas. Additionally, several countries have very active solar R&D programs, some even larger than that of the United States. International markets are significant for solar energy and will continue to represent substantial sales in the near term.

The Solar Program international and intergovernmental activities are carried out according to an annual plan that is evaluated to be consistent with current U.S. technology, trade, and foreign policy. International activities are carried out in developing countries chosen for their governments' commitment to renewable energy and the potential of a large market for U.S. products. The Solar Program sponsors more than 50 overseas trips annually for staff participation in international meetings and conferences. The Solar Program partners with USAID and with DOE's Office of Weatherization and Intergovernmental Programs to support the U.S. Clean Energy Initiative and other multilateral and bilateral agreements that support DOE goals.

The Solar Program's international projects support U.S. strategic objectives for international activities, such as:

- Emerging global environmental and energy issues
- Trade and market development

- Energy and environmental security
- Cooperative R&D.

It also supports the following agreements:

- Memorandum of Understanding between the Unites States and India
- Bilateral agreements between the United States and China and the United States and Mexico
- The North American Energy Working Group's United States/Mexico/Canada trilateral activities.

The Solar Program also coordinates with its international solar R&D counterparts by participating in the International Energy Agency (IEA) and communications with its industry partners. Ongoing agreements include the following:

- *The IEA Photovoltaic Power System Implementing Agreement* supports the United States' commitment to the *International Energy Agency Implementing Agreement for a Cooperative Programme on Photovoltaic Power Systems* and brings international perspectives and collaboration on key PV system issues to the U.S. solar industry. This agreement typically includes the following activities:
    - Provides technical assistance
    - Demonstrates the technical feasibility of new technologies and applications
    - Provides training
    - Develops and promotes norms and standards
    - Fosters business development, including and facilitating joint-venture agreements between foreign and U.S. companies.
- *IEA SolarPACES* is an international cooperative organization that brings together teams of experts from around the world to focus on the development and marketing of concentrating-solar-power systems (also known as solar-thermal-power systems). Solar*PACES* focuses on technology development. Its member countries work together on activities aimed at solving the wide range of technical problems associated with commercialization of concentrating solar power technology, including large-scale system tests and the development of advanced technologies, components, instrumentation, and systems-analysis techniques. In addition, market development and building of awareness of the potential of concentrating solar power technologies are key elements of this multilateral effort.
- Furthermore, the Solar Program coordinates its activities with DOE's *Tribal Energy Program*, which provides financial and technical assistance to tribes for feasibility studies and shares the cost of implementing sustainable renewable energy installations that can promote energy self-sufficiency and economic development on tribal lands.

5.5 Program Organization Control and Implementation

The Solar Program uses a number of management tools for planning, budget formulation, program implementation, and program evaluation. Because the Program cannot be effective if it is autonomous, many management activities and hours are spent coordinating with other solar-energy stakeholders. The following is a set of comprehensive and coordinated management functions conducted by the Solar Program.

5.5.1 Program Planning

These activities serve to conceptualize the goals, objectives, rationale, approaches, and specific performance measures to be undertaken by the Solar Program. In addition to ongoing planning activities throughout the year, the Program conducts the following annual activities:

- *Multi-Year Decision Plan*, which is prepared and scrutinized by DOE executives, is a predecessor to the OMB budget review. It requires the Solar Program to strengthen its government rationale, ties to national energy policies, multi-year resource requirement, and quantitative performance/success indicators.

- *Multi-Year Program (Technical) Plan* is the cornerstone that defines the specific objectives and technical activities to be undertaken over the next 5 years. The document also presents the rationale, management approach, and specific performance indicators for the Solar Program. Typically, it incorporates significant input from other industry partners and stakeholders that has been accumulated via formal roadmapping and strategic planning sessions.

5.5.2 Program Budget Formulation

The Federal budget formulation process is undertaken annually by each Federal program and includes preparation in the spring by each Executive Branch agency (the DOE, in the case of the Solar Program); review and approval in the fall by OMB, a branch of the White House (Executive Office of the President); which is submitted to Congress in the winter; and review and approval in the autumn (in most years by October 1, in time to implement new fiscal-year activities) via annual appropriations legislation by Congress. The following represents key activities undertaken by the Solar Program each year.

- *The Spring Budget Review* includes a DOE internal review budget that defines specific activities and resource requirements needed for the prospective fiscal year. An extensive 3-month iterative review process is undertaken before it is approved by DOE executive management.

- *The OMB Budget Defense* is a rigorous 6-month review process undertaken with OMB examiners to defend objectives, rationale, and resource requirements. OMB R&D requirements are applied, and Solar Program managers are required to defend their budget submissions.

- *The Procurement Plan* is implemented following a Congressionally approved budget that is the outcome of the Federal appropriations process. The Solar Program prepares a procurement execution plan that defines resource requirements targeted for national laboratories, universities, industrial competitive contracts, and other recipients of Program funds.

5.5.3 Program Implementation

Implementation activities are prepared annually and include technical, management, and coordination activities. These activities specify the tactics by which the Solar Program is carried out, and they include:

- *The Annual Operating Plan (AOP)* is prepared by the Solar Program and reviewed by DOE management, and it defines the objectives, research, development and deployment activities, management activities, and specific resources to be committed to each area. The AOP is initiated in the spring to anticipate the DOE appropriations request and is typically completed before the beginning of the Federal government fiscal year (October), after the Congressional appropriations process is complete.

- *Competitive Solicitations* are required to attract industrial and other partners to cost-share Program elements. Many Solar Program resources are identified for activities carried out directly by the managers and operating contractors at DOE's national laboratories. However, industry typically receives funding through a series of competitively evaluated topical solicitations. The Program targets more than 90% of its funds to be awarded through competitive processes. A major criterion for these awards is a contractor's ability and willingness to demonstrate commitment to long-term pursuit of the technology, which is demonstrated via cost-share commitments. Another Program target is for 20% cost-share in applied research and 50% cost-share in technology-development activities.

5.5.4 Program Evaluation

Managers take seriously the evaluation function of the Solar Program, as the programmatic portfolio and all activities are critically, regularly, and independently reviewed. Reports on the following regular activities are provided to Solar Program managers for their decisions.

- *Peer Reviews* are intended to provide periodic independent review and confirmation of the technical quality and merit of research activities. Each technical research area is reviewed at least biannually, and a programmatic peer review is scheduled to evaluate the Program portfolio balance and objectives.

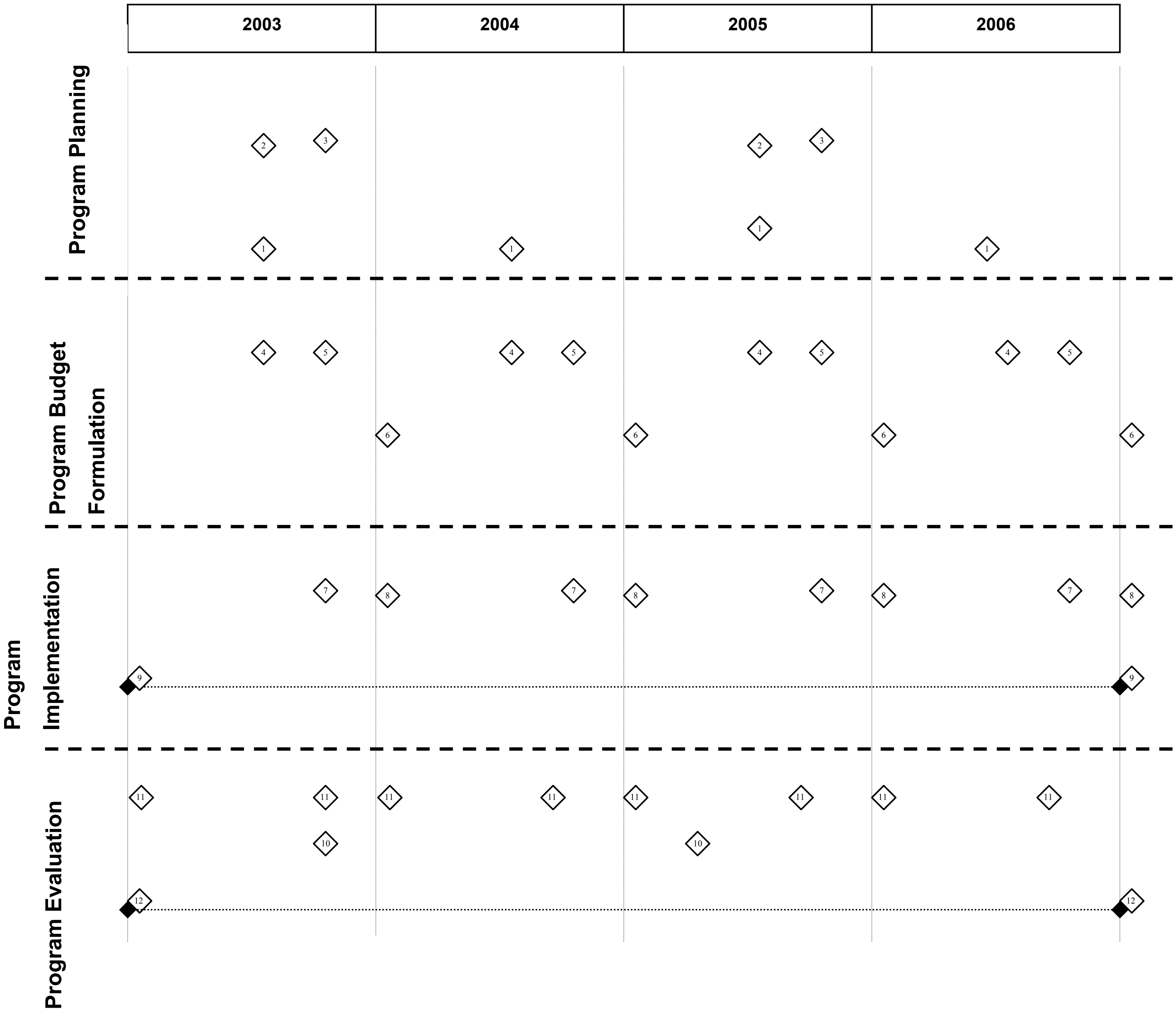
- *Semiannual Program Reviews* are conducted by DOE and national laboratory executive and program managers at least twice each year to review the status, progress, budgets, and issues for the entire Solar Program. Review meetings are scheduled as needed for topical areas requiring more intense scrutiny. Findings from these secondary meetings are communicated to Program managers for key decision-making.

- *Activity Terminations,* or "off ramps," are considered annually as part of rigorous decision-making AOPs and Program/peer reviews are prepared. For example, this plan contains numerous decision points for each activity. Each year, there are several key decision points (typically "go/no-go" decisions) to terminate a specific activity, while new research breakthroughs necessitate new directions. Thus, exit strategies for specific programmatic activities are designed into strategic and operating plans that continually evaluate technical merit compared with their cost and potential impact.

5.5.5 Schedule and Milestones

Table 5-1. Schedule and Milestones: Solar Energy Technologies Management Plan

Milestones	Title	Estimated CY Date Quarter
1.	Complete Multi-Year Decision Plan for Spring Budget Summit.	Annually Q3
2.	Prepare final rough draft for revised Solar Program Multi-Year Technical Plan.	Every 2 years Q3
3.	Publish final Solar Program Multi-Year Technical Plan.	Every 2 years Q4
4.	Prepare Solar Program successive-year budget planning for Spring Budget Review.	Annually Q3
5.	Submit successive-year (FY 2005, FY 2006, and FY 2007) budget request and defend to OMB.	Annually Q4
6.	Complete Procurement Execution Plan for following budget year after Congressional appropriations process.	Annually Q1
7.	Complete draft of successive-year Annual Operating Plan.	Annually Q4
8.	Complete final of current-year Annual Operating Plan.	Annually Q1
9.	Issue competitive solicitations for Program activities (as received).	Annually
10.	Complete documentation of topical program Peer Review.	03 Q4 05 Q2
11.	Complete semiannual Solar Program Review.	Twice a year Q1/Q4
12.	Terminate selected technical program activities (as decided by Solar Program management).	Ongoing



Legend

Milestones

1. Complete Multi-Year Decision Plan for Spring Budget Summit
2. Prepare final rough draft for SET Multi-Year Technical Plan
3. Publish Final SET Multi-Year Technical Plan
4. Prepare SET successive year budget planning for Spring Budget Review
5. Submit successive year (FY 2005, FY 2006 and FY 2007) budget request and defend to OMB
6. Complete Procurement Execution Plan for following budget year after Congressional appropriations process
7. Complete draft of successive year Annual Operating Plan
8. Complete final of current year Annual Operating Plan
9. Issue Competitive Solicitations for program activities (as received)
10. Complete documentation of topical Program peer review
11. Complete semi-annual SET Program Review
12. Terminate selected technical program activities (as decided by SET management)

6.0 Abbreviations and Acronyms

AC	alternating current
ADVISOR	Advanced Vehicle Simulator
AOP	annual operating plan
AR	antireflective
a-Si	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
CdTe	cadmium telluride
CHC	combined heating and cooling
CHP	combined heat and power
CIGS	copper indium gallium diselenide
CIS	copper indium diselenide
COE	cost of energy
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
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
EERE	DOE Office of Energy Efficiency and Renewable Energy
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
FCR	fixed-charge rate
FEMA	Federal Emergency Management Agency
FEMP	Federal Energy Management Program
FOB	free on board
FSEC	Florida Solar Energy Center
FY	fiscal year
GaInNAs	gallium indium nitrogen arsenide
GEF	Global Environment Facility
GO	Golden Field Office
GW	gigawatt
GW_p	peak gigawatt
HALT	highly accelerated lifetime testing
HBCU	Historically Black Colleges and Universities

HCE	heat-collection element
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
IR	infrared
ISO	International Organization for Standardization
kg	kilogram
kWe	kilowatt-electric
kWh	kilowatt-hour
kWht	kilowatt-hour thermal
LCOE	levelized cost of energy
LEC	levelized energy cost
m^2	square meter
MBE	molecular-beam epitaxy
MM Btu	million Btu
MOS	measure of success
MSR	Million Solar Roofs
MYTP	Multi-Year Technical Plan
MW	megawatt
MWe	megawatt-electric
NASA	National Aeronautics and Space Administration
NCPV	National Center for Photovoltaics
NEMS	National Energy Modeling System
NREL	National Renewable Energy Laboratory
NTRC	National Transportation Research Center
O&M	operations and maintenance
OMB	Office of Management and Budget
ORC	organic Rankine cycle
ORNL	Oak Ridge National Laboratory
PCU	power control unit
PICS	polymer integral collector storage
PWF	present worth factor
PV	photovoltaics
PV:BONUS	Photovoltaics Building Opportunities in the United States
PVRES	PV energy-efficient residential building
R&D	research and development
RFP	request for proposal
RITH	roof-integrated thermosiphon
RO	Regional Office
SBIR	Small Business Innovative Research
SET	Solar Energy Technologies
STTR	Small Business Technology Transfer Research
SDA	systems-driven approach
SDHW	solar domestic hot water

SEGS	Solar Electric Generating Systems
SERES	Southeast Region Experiment Station
SET	Solar Energy Technologies Program
SINC	Systems Integration and Coordination (Team)
SMS	Strategic Management System
SNL	Sandia National Laboratories
SolarPACES	Solar Power and Chemical Energy Systems
SRCC	Solar Rating and Certification Corporation
SWH	solar water heating
SWRES	Southwest Region Experiment Station
SWTDI	Southwest Technology Development Institute
TBD	to be determined
TES	thermal energy storage
TCO	transparent conducting oxide
UL	Underwriters Laboratories
UNDP	United Nations Development Programme
UV	ultraviolet
USAID	U.S. Agency for International Development
W	watt
W_p	peak watt
ZEB	Zero Energy Buildings

About the Office of Energy Efficiency and Renewable Energy

A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. By investing in technology breakthroughs today, our nation can look forward to a more resilient economy and secure future.

Far-reaching technology changes will be essential to America's energy future. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a portfolio of energy technologies that will:

- Conserve energy in the residential, commercial, industrial, government, and transportation sectors
- Increase and diversify energy supply, with a focus on renewable domestic sources
- Upgrade our national energy infrastructure
- Facilitate the emergence of hydrogen technologies as vital new "energy carrier's."

The Opportunities

Biomass Program
Using domestic, plant-derived resources to meet our fuel, power, and chemical needs

Building Technologies Program
Homes, schools, and businesses that use less energy, cost less to operate, and ultimately, generate as much power as they use

Distributed Energy & Electric Reliability Program
A more reliable energy infrastructure and reduced need for new power plants

Federal Energy Management Program
Leading by example, saving energy and taxpayer dollars in federal facilities

FreedomCAR & Vehicle Technologies Program
Less dependence on foreign oil, and eventual transition to an emissions-free, petroleum-free vehicle

Geothermal Technologies Program
Tapping the Earth's energy to meet our heat and power needs

Hydrogen, Fuel Cells & Infrastructure Technologies Program
Paving the way toward a hydrogen economy and net-zero carbon energy future

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