SOLAR ENERGY TECHNOLOGIES PROGRAM

SOLAR AMERICA INITIATIVE

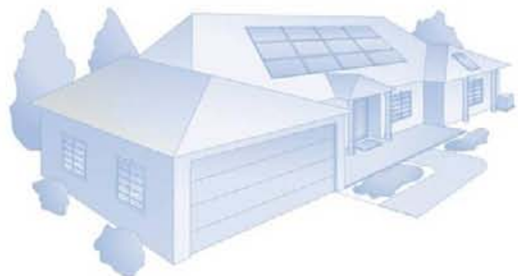
A Plan for the Integrated Research, Development, and Market Transformation of Solar Energy Technologies

SETP-2006-0010

DRAFT

February 5, 2007

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



"Tonight, I announce the **Advanced Energy Initiative**—a 22 percent increase in clean-energy research—at the Department of Energy, to push for breakthroughs in two vital areas. To change how we power our homes and offices, we will invest more in zero-emission coal-fired plants, revolutionary solar and wind technologies, and clean, safe nuclear energy…We must also change how we power our automobiles. We will increase our research in better batteries for hybrid and electric cars, and in pollution-free cars that run on hydrogen. We'll also fund additional research in cutting-edge methods of producing ethanol, not just from corn, but from wood chips and stalks, or switch grass. Our goal is to make this new kind of ethanol practical and competitive within six years"

- **President George W. Bush**
State of the Union 2006 Address
January 31, 2006

The Administration will work to diversify energy sources for American homes and businesses. Accelerating research in clean coal technologies, clean and safe nuclear energy, and revolutionary solar and wind technologies will reduce overall demand for natural gas and lead to lower energy costs.

- **The Advanced Energy Initiative**
White House National Economic Council
February 2006

"To safeguard our future economic health as well as our national security, we must move aggressively to diversify our energy sources. Every time we visit the gas pump these days, we are reminded that there is no time to waste. "

- **Secretary Samuel Bodman**
Golden, CO
July 7, 2006

"I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait till [sic] oil and coal run out before we tackle that."

- **Thomas Edison**

Table of Contents

1.0 Introduction 4

2.0 Markets 12

3.0 Technology Overview 18

4.0 Technology Development Strategy 21

5.0 Program Activities 28

- Systems Analysis 28
- Photovoltaic Systems 32
- Concentrating Solar Power Systems 34
- Technology Evaluation 35
- Market Transformation 36
- Program Activities Chart 38

Appendix A. Acronyms 40

Appendix B. Contacts, Resources, and Weblinks 42

1.0 Introduction

Energy is essential to our Nation and our lives; we use energy to power homes and businesses and to transport people and goods, making it an important component of our economy. Reliable, clean and affordable energy is critical to energy security and our economy. We can reduce our dependence on foreign sources of energy by diversifying our energy mix using domestic resources.

The U.S. Department of Energy (the Department) is committed to "discovering the solutions to power and secure America's future,"[1] which include clean energy technologies that not only enhance energy independence but also can reduce greenhouse gas emissions and criteria air pollutants. To address the need for increased focus on developing advanced energy technologies and increasing our Nation's focus on building the workforce of tomorrow, in 2006 President Bush launched two important initiatives - the American Competitiveness Initiative (ACI) and the Advanced Energy Initiative (AEI).

Department of Energy Releases its Strategic Plan

In 2006, the Department released its DOE Strategic Plan, which outlines DOE goals. These included the following strategic goals, which the Department's solar-related activities address.

- **Energy Strategic Goal:** Promoting America's energy security through reliable, clean, and affordable energy.
  - Goal 1.1. Energy Diversity:
    - Increase our energy options and reduce dependence on oil, thereby reducing vulnerability to disruption and increasing the flexibility of the market to meet U.S. needs
  - Goal 1.2 Environmental Impacts of Energy:
    - Improve the quality of the environment by reducing greenhouse gas emissions and environmental impacts to land, water, and air from energy production and use
  - Goal 1.3 Energy Infrastructure:
    - Create a more flexible, more reliable, and higher capacity U.S. energy infrastructure

- **Science Strategic Goal:** Strengthening U.S. scientific discovery, economic competitiveness, and improving quality of life through innovations in science and technology.
  - Goal 3.1 Scientific breakthroughs:
    - Achieve the major scientific discoveries that will drive U.S. competitiveness, inspire America, and revolutionize approaches to the Nation's energy, national security, and environmental quality challenges
  - Goal 3.2 Foundations of Science:
    - Deliver the scientific facilities, train the next generation of scientists and engineers, and provide the laboratory capabilities and infrastructure required for U.S. scientific primacy.
  - Goal 3.3 Research Integration:
    - Integrate basic and applied research to accelerate innovation and to create transformational solutions for energy and other U.S. needs.

One of the renewable resources of focus in the AEI is solar energy, and in support of the development of solar energy technologies, the President in 2006 launched the Solar America Initiative (SAI). Solar energy is a clean, abundant, widespread and renewable energy source that can be used to increase electricity generating capacity. Electricity produced from solar energy will not only reduce demand for natural gas – which is increasingly imported – but will also reduce the greenhouse gas emissions from traditional combustion-driven electricity generation. Various technologies can capture solar energy and convert it into other useful forms of energy, such as electricity and heat.

The Department's robust activities to support the development of solar energy technologies include applied research in support of the Solar America Initiative in the Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Program as well as important exploratory research in the Office of Science. The President's Solar America Initiative supports the goals of the DOE 2006 Strategic Plan, which identifies the strategic themes of energy security and scientific discovery and innovation, both of which are key drivers of the DOE solar activities. SAI also aligns with the solar-related research and development provisions and broad energy goals outlined in the National Energy Policy and the Energy Policy Act of 2005 (EPACT 2005). In EPACT 2005, Congress expressed strong support for decreasing dependence on foreign energy sources and the cost of renewable energy generation and delivery. The support of Congress, as well as incentives and support from state governments, will be critical to achieving the SAI goals.

Advanced Energy Initiative
The Advanced Energy Initiative provides for a 22% increase in funding for clean-energy technology research at the U.S. Department of Energy. The AEI is an integrated plan to improve America's energy independence by changing how we power our homes and offices by generating more electricity from clean coal, advanced nuclear power, and renewable resources such as solar and wind, and by developing more efficient vehicles that are powered by electricity, biofuels and hydrogen.

Advanced Energy Initiative Goals – Changing How We Power Our Homes and Businesses

- Complete the President's commitment to $2 billion in clean coal technology research funding, and move the resulting innovations into the marketplace.
- Develop a new Global Nuclear Energy Partnership (GNEP) to address spent nuclear fuel, eliminate proliferation risks, and expand the promise of clean, reliable, and affordable nuclear energy.
- Reduce the cost of solar photovoltaic technologies so that they become cost-competitive by 2015, and expand access to wind energy through technology.

Advanced Energy Initiative Goals – Fueling Our Vehicles

- Develop advanced battery technologies that allow a plug-in hybrid-electric vehicle to have a 40-mile range operating solely on battery charge
- Foster the breakthrough technologies needed to make cellulosic ethanol cost-competitive with corn-based ethanol by 2012.
- Accelerate progress towards the President's goal of enabling large numbers of Americans to choose hydrogen fuel cell vehicles by 2020.

This plan describes the Solar America Initiative and details the efforts through 2015 that the Department will undertake to spur widespread commercialization, acceptance and adoption of clean solar technologies across the United States.

The Department has developed a coordinated strategy for accomplishing the goals of the Solar America Initiative which will include:

- Conducting accelerated research and development to improve the materials performance and reduce the cost of advanced photovoltaic (PV) systems
- Developing new manufacturing technology to lower process costs and increase throughput for enabling expanded U.S. manufacturing capability

Energy Policy Act of 2005

In July of 2005, Congress passed the first comprehensive energy legislation in over a decade. The Energy Policy Act of 2005 (P.L. No: 109-058) was signed into law by President Bush on August 8, 2005. The law supports many of the objectives outlined by President Bush in the launch of the Advanced Energy Initiative— strengthening our nation's energy security and infrastructure; reducing our dependence on foreign oil; and expanding the use of clean renewable energy. Title IX, subtitle C of the bill focuses on renewable energy research, development and demonstration. Specifically, section 931(A) states that "[t]he Secretary shall conduct a program of research, development, demonstration, and commercial application for solar energy" to accomplish the high-level objectives supported by Congress.

- Providing technical expertise and building stakeholder consensus to resolve regulatory, institutional, infrastructure, and education-related barriers to technology acceptance
- Accelerating deployment of new solar technologies through promoting demonstrations and early adopter activities consistent with the Energy Policy Act of 2005
- Supporting the demonstration and deployment of energy technologies through collaborative efforts with the private sector and public sector entities

The Solar America Initiative at a Glance

- The SAI will boost research and development (R&D) on the manufacturing processes and product designs that have the best chance of making PV systems less expensive, more efficient, and highly reliable.
- The President's fiscal year (FY) 2007 request of $148.4 million for SAI-related activities represents a more than $66 million increase over FY 2006 funding for solar energy R&D.
    - The FY 2007 budget request for PV-related activities was $139.8 million.
    - The FY 2007 budget request for concentrating solar power (CSP)-related activities was $8.9 million, representing a 20% increase over the FY 2006 appropriation.
- The Department will conduct research and development to reduce cost and expand production of PV by funding industry-led teams collaborating across the value chain. These projects will expand U.S. annual domestic PV manufacturing capacity and also focus on reducing the cost of electricity from PV.
- The Department will also support early-stage companies as they take promising prototype PV cells from laboratory benches into commercial pilot production, leveraging DOE funding and technical assistance from the National Renewable Energy Laboratory (NREL) and Sandia to bring the next generation of PV technologies to market after 2011.
- The Department will also address non-technological barriers to widespread deployment of solar technologies such as codes, standards, certification, and technical training.
    - The Department will establish partnerships with States and utilities to catalyze collaboration in the design of regulations and incentives that promote adoption of solar technologies.
    - Solar "showcase" projects will demonstrate novel large-scale market applications of PV, thereby retiring risk and allowing future private financing of similar projects.
    - The Department will work with city governments that are combining regulation, training, and other measures on route to becoming desirable locations for establishing solar businesses and marketing solar products.
    - The Department will establish Energy Star labeling for solar hot water heaters to ensure product performance.

- The Department will facilitate cost reductions in CSP systems by addressing three factors: further technology development, volume production, and scale-up in plant or project size.

Accomplishing the goals of AEI, and more specifically SAI, will require greater understanding of solar energy technologies than can be gained through basic science research. The "use-inspired" research being sponsored by the DOE Office of Science (OS) may lead to some of the breakthroughs needed for the SAI to be successful, as well as revolutionary concepts that will be useful beyond the 2015 timeframe. The applied research in the Office of Energy Efficiency and Renewable Energy (EERE) includes furthering technology advancements in performance, cost, and reliability, scaling up of manufacturing facilities, reducing infrastructure barriers to deploying the technology, and innovative partnerships between government, industry, national laboratories, non-profit organizations, and universities.

SAI Targets

In support of the SAI, the Department has established performance and cost stretch targets for PV systems in three target markets: grid-connected residential, commercial, and utility applications. As the SAI stretch targets are met, significant market penetrations are forecast to occur across all market segments. The cost of electricity is assessed by the kilowatt-hour, so DOE's targets for PV and CSP systems are based on the *Levelized Cost of Energy* (LCOE) delivered by these systems. LCOE is a measure of total costs of a system (over its expected lifetime) divided by the expected energy output (over its useful lifetime), with appropriate adjustments for time, value of money, etc. The overall cost goals for SAI are shown in Figures 1-1 and 1-2. These targets are based on Energy Information Administration (EIA) projections of relatively flat electricity prices (in real terms).

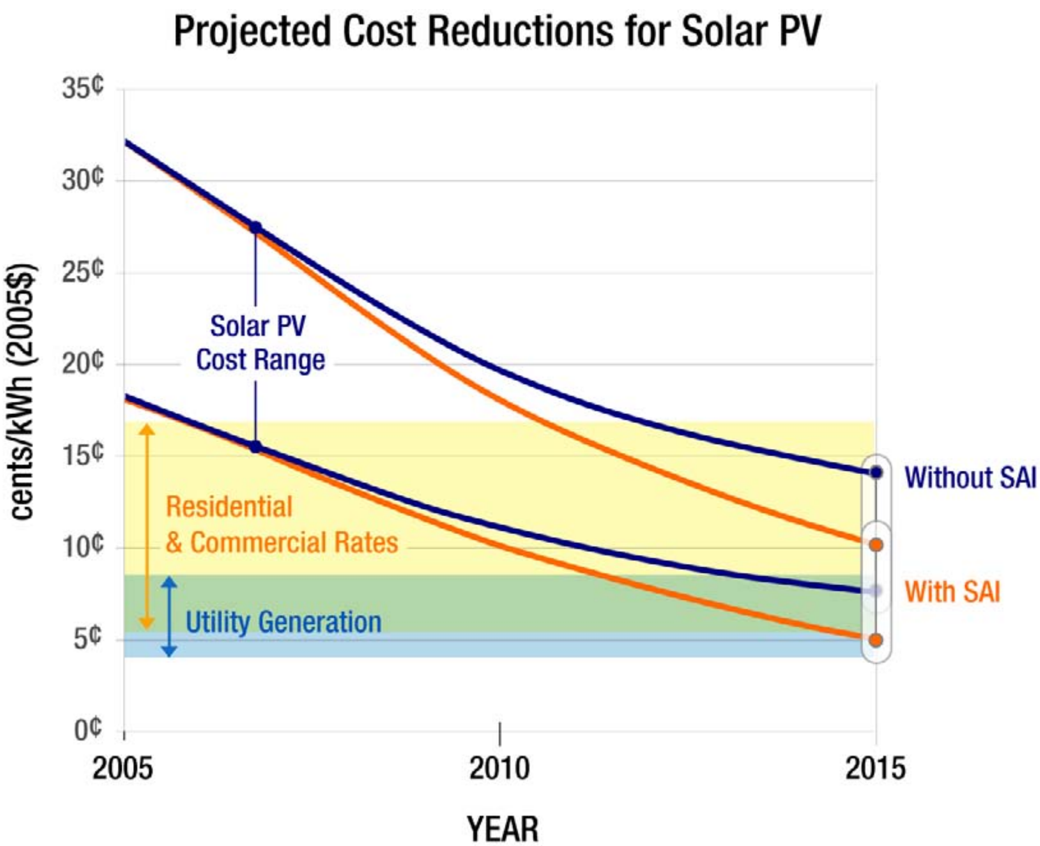


Figure 1-1. Projected PV Cost Reductions across All Market Sectors within SAI

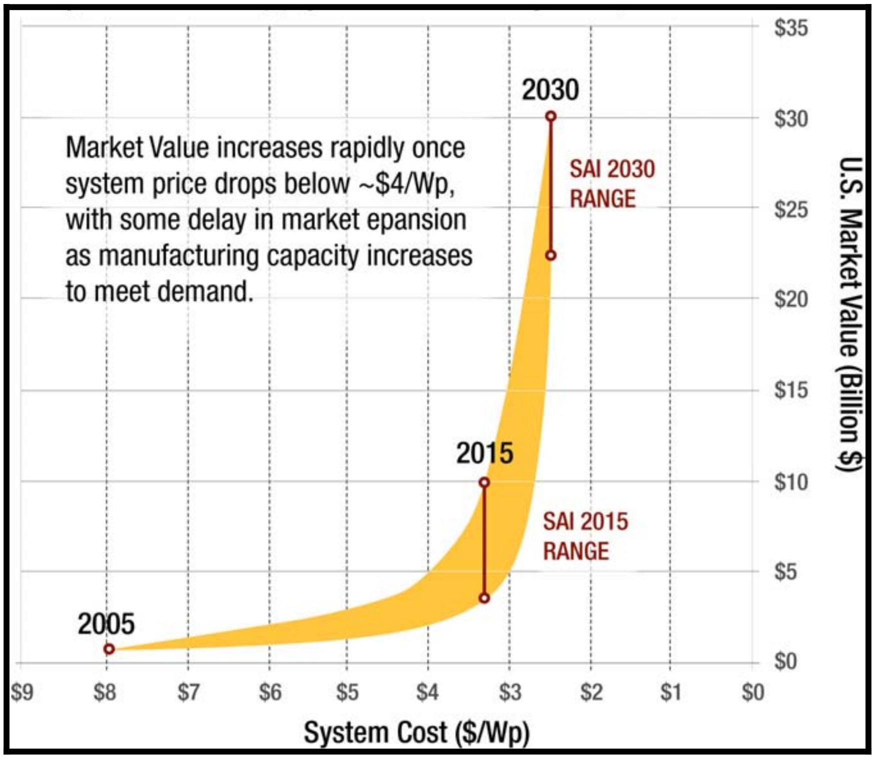


Figure 1-2. Projected Market Value for PV Systems, 2005-2030

The Benefits of the SAI

Displacing a significant amount of conventional electricity production with new energy technologies is a major challenge. The U.S. electric generation system is enormous, with roughly 1,000 GW of generating capacity currently in place.[2] In contrast, in 2005, the total U.S. installed PV capacity was 0.44 GW,[3] i.e., less than 0.1% of total U.S. generating capacity. Yet, solar energy is available in all regions of the country and can provide significant amounts of energy in places like New York and Minnesota, not just places like Texas and California. In fact, according to National Renewable Energy Laboratory projections, if every single-family home in America had a 3 kilowatt (kW) photovoltaic (PV) system on its roof, these combined homes could generate more than 420 billion kilowatt-hours (kWh) of electricity–more than 35% of the entire residential electricity demand for the United States.[4]

Solar energy technologies can improve energy independence by supplementing current electricity generation capacity. In recent years, natural gas combined-cycle power plants have made up the majority of new generating capacity. As a result, demand for natural gas in the power sector has increased steadily over the past 15 years, even in the face of dramatically higher prices. The tight balance between natural gas supply and demand has led to a more volatile market, which can respond dramatically to weather-related events and geopolitical developments. At present, 85% of U.S. natural gas demand is met through domestic production.[5] Natural gas consumption, however, is projected to grow to 74 billion cubic feet per day by 2025,[6] up from 61 billion cubic feet per day in 2004.[7] Diversifying our energy mix with solar technologies can help to mitigate the effects of fluctuating natural gas prices.

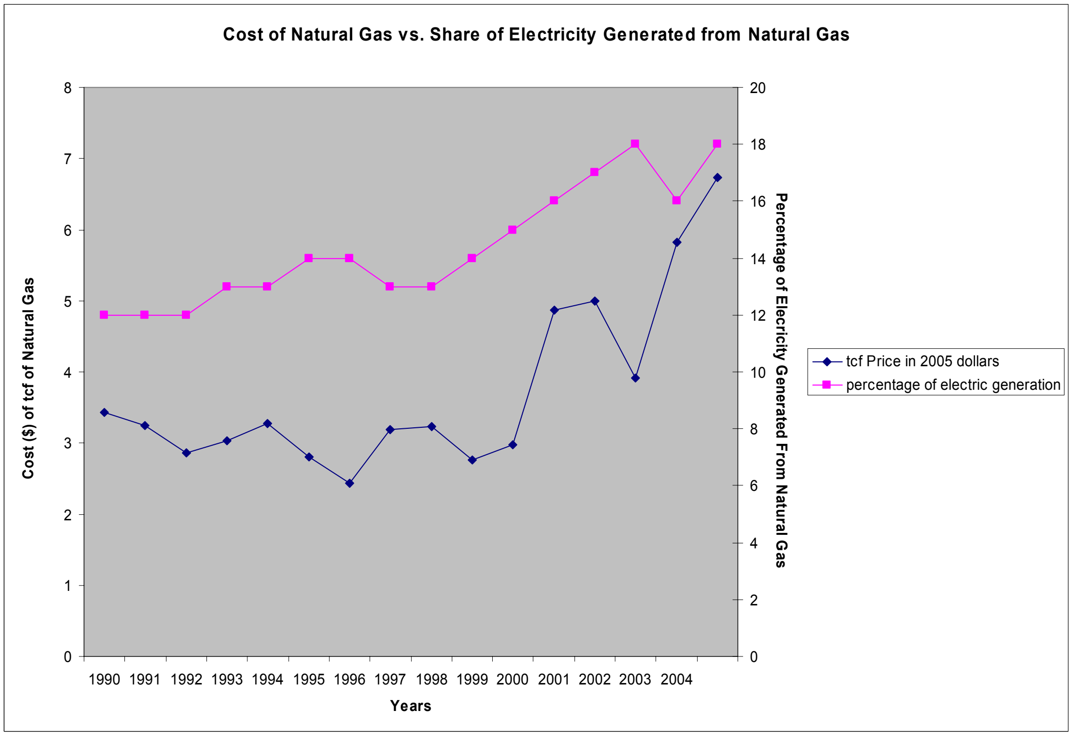


Figure 1-3. Cost of Natural Gas vs. Share of Electricity Generated from Natural Gas

Under the SAI, distributed PV can play a significant role in displacing the need for new electricity generation capacity. Assuming that for every MW of PV installed, 0.6 MW of new capacity is displaced (a reasonable average for the United States), various scenarios show that PV could displace 10-25% of new capacity additions in 2015, and up to 40% of new capacity additions in 2030. Projections for baseline, moderate, and high *cumulative* capacity additions scenarios by 2030 are depicted in the following figure.[8]

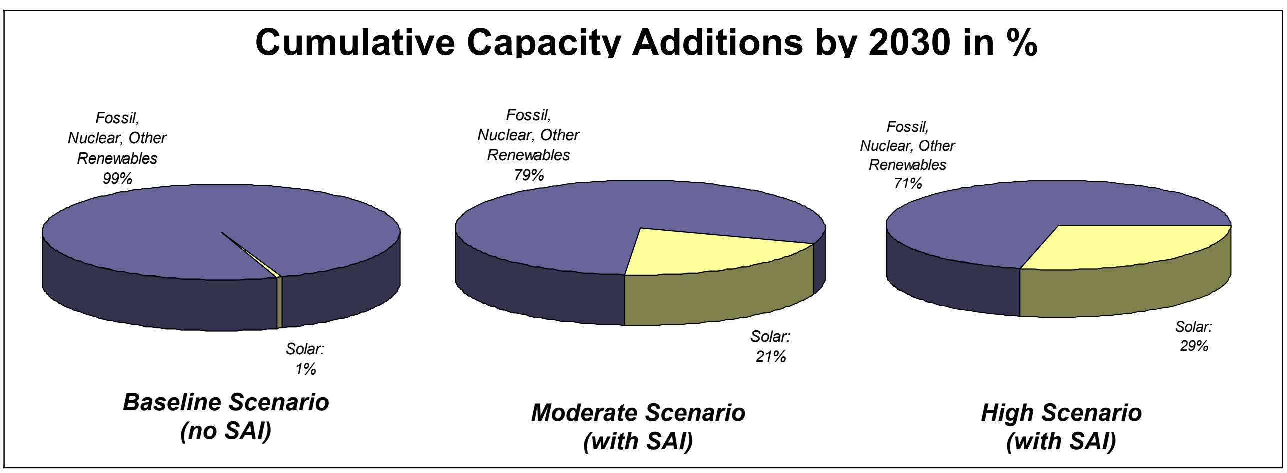


Figure 1-4. Solar as Part of New Capacity Additions 2030 (Baseline, Low and High Scenario)

In addition to benefiting our National Security by increasing energy independence, solar energy also serves to make the electric grid more secure and less susceptible to terrorist attack. Use of decentralized photovoltaics will enhance the reliability of our aging electric grid by reducing the demand placed on it, as well as reducing the impact of a potential terrorist attack on our centralized electricity infrastructure.

Electricity produced from solar energy will also reduce greenhouse gas emissions in the United States. Electricity generation using natural gas combined-cycle power plants or conventional coal combustion technology generates both criteria pollutant and greenhouse gas emissions. Many electricity generating processes also require significant quantities of water for cooling. Solar electricity, by contrast, emits no pollutants or greenhouse gases into the air, and requires very little water. Using solar energy technologies in the place of conventional methods to produce 100MW of electricity would result in a reduction of 191,000 tons/yr of CO_2, 7.4 tons/yr of NOx, and 4.5 tons/yr of CO. [9] Based on this data, DOE estimates that the deployment of new solar technology installations under SAI will triple the amount of carbon emissions avoided by 2015.

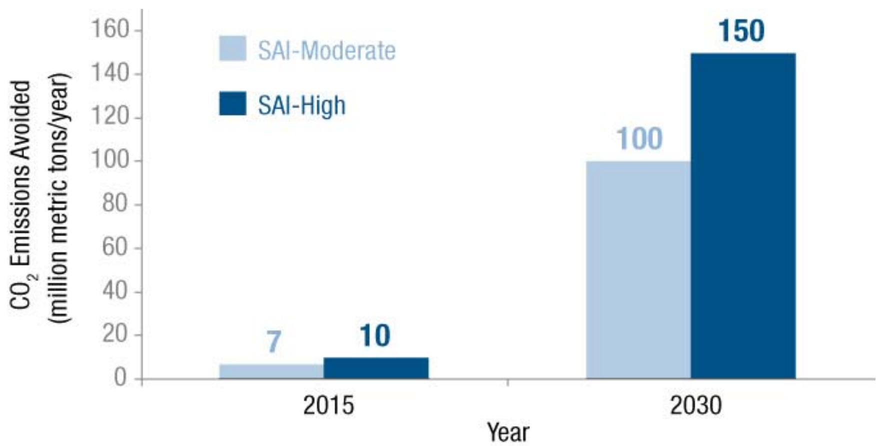


Figure 1-5. The SAI accelerates greenhouse gas reductions by avoiding CO_2 emissions. By 2030 the SAI is projected to avoid 100-150 million more metric tons of CO_2 annually than the baseline.

Investment in the solar industry through SAI will also ensure that the U.S. solar industry is able to capture an increased market share of the anticipated global and domestic demand for solar technology, supporting more jobs for skilled workers in manufacturing, production, and installation. Under the SAI, direct PV-related employment is projected to result in the creation of 10,000–30,000 jobs by 2015 and 67,000–89,000 jobs by 2030.[10]

2.0 Markets

PV has often been the power source of choice for remote applications, based on cost and proven reliability. However, lower costs and recent advances in PV efficiencies have enabled the PV market to broaden rapidly to include utility, distributed generation, and building-integrated applications. A major milestone in the evolution of PV markets occurred in 2002 when sales for grid-connected PV applications decisively surpassed sales for remote applications.[11]

- The PV industry has been expanding rapidly during the last decade. Much of this growth has been driven by PV-targeted subsidies in Germany, Japan, and a number of U.S. states (e.g., California, Arizona, and New Jersey).
- Global PV production increased from about 60 MW in 1994 to almost 1.8GW in 2005. 2006 production is estimated to be 2400 MW.
- During this period, the most rapidly growing PV markets were for grid-connected PV systems installed on residential and commercial buildings.
- Although solar is one of the fastest-growing high-tech industries, the U.S. solar industry faces strong and growing challenges from competitors in Europe and Asia.
- After decades of global leadership in PV market share, the United States has fallen behind other countries in the manufacturing of PV (see Figure 2-1), such as Japan and Germany. China, Korea, and India are now also investing heavily in PV research and development to solidify their respective market positions.
- Similarly, the United States' lead in Concentrating Solar Power (CSP) technology is being challenged by Germany, Spain, and Israel.[12] These and other countries have captured growing global market share through dedicated federal investments in technology R&D and market incentives.[13]

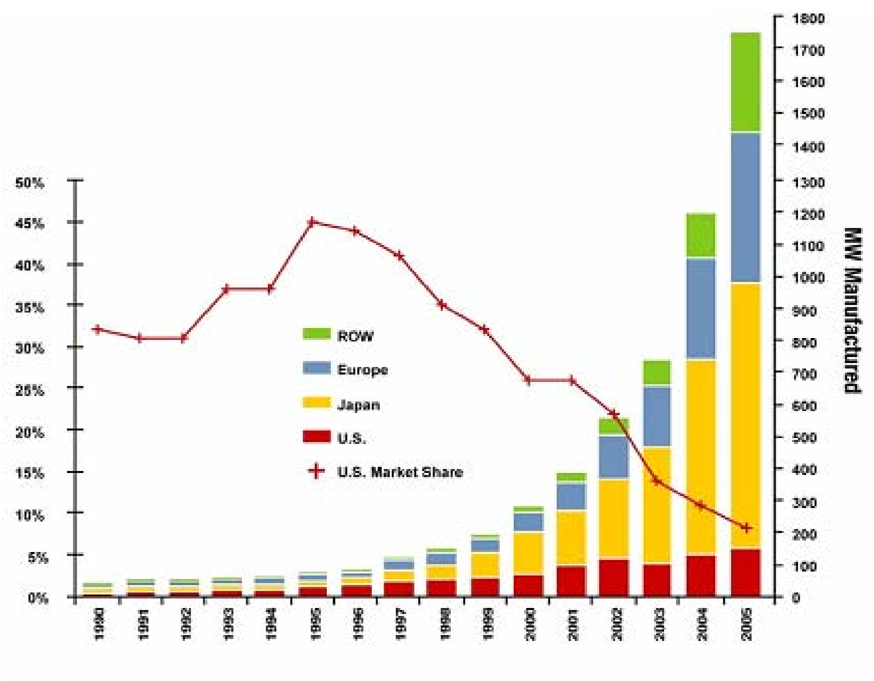


Figure 2-1. Global PV Market Share by Country

The global PV market is expected to continue its rapid growth through the next decade (see Figure 2-2), and grid-tied residential and commercial markets are expected to be the primary drivers of this growth. According to the recent U.S. PV Industry Roadmap, the domestic PV industry is expected to parallel the global growth of the global PV industry during this time with California leading the way, followed by New Jersey and other states that have aggressive solar programs.[14]

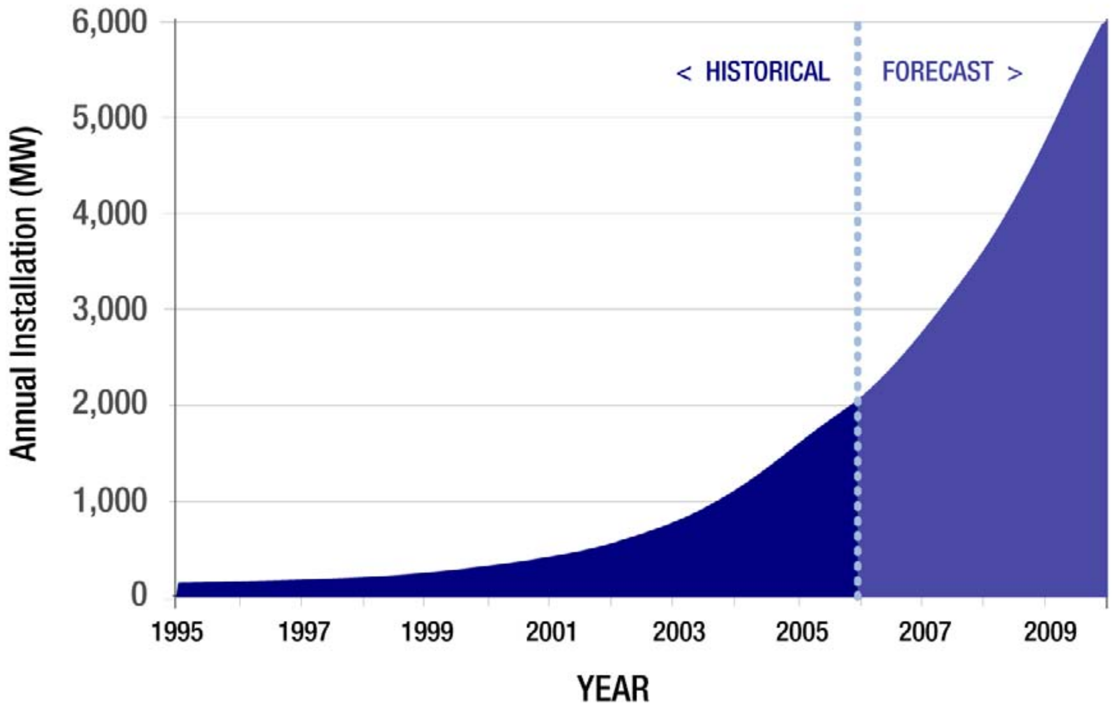


Figure 2-2. Global PV Installation Forecast

The U.S. Department of Energy will address these shortfalls of the U.S. PV industry using the market-driven approach of the SAI, minimizing the time between laboratory developments and product deployment. This will facilitate cost reductions at a rate that otherwise could not be achieved.

One consequence of this rapid growth has been the emergence of a supply shortage of solar-grade silicon. Solar-grade silicon is a key input for crystalline PV cells/modules, the dominant PV technology in the marketplace today. This supply shortage, which is most likely temporary with new supplies coming on line between 2007 and 2009, has created an opportunity for thin-film PV and concentrator technologies, which use little-to-no polysilicon feedstock, to accelerate their move from pilot production into manufacturing and large-scale production.[15]

The silicon shortage coupled with the high demand for solar products will likely keep PV prices higher over the next two years as demand continues to outpace supply.[16] The SAI is targeting manufacturing and process improvements that will lower the production cost for PV technologies. Ultimately, prices will fall to reflect the lower production cost as PV production capacity and silicon feedstock production increase to meet demand.

While the U.S. has fallen behind in the PV market, technology improvements and various State-funded incentives are stimulating domestic demand for solar systems. Although the prospects for continued growth in the global PV industry are significant, many factors could influence how rapidly U.S. markets expand.

Federal and State PV Incentives

- There is a need to significantly reduce the cost of PV systems via research to improve performance and lower materials, manufacturing, and installation costs.
- Increases in market opportunities will be realized through the reduction of institutional barriers, including the lack of interconnection standards and net-metering provisions for distributed energy
- **Residential Solar and Fuel Cell Tax Credit:** The Energy Policy Act of 2005 establishes a 30% tax credit capped at $2,000 for the purchase and installation of residential PV property.
- **Commercial Solar and Fuel Cell Tax Credit:** EPAct 2005 also establishes a 30% tax credit for the purchase and installation of PV systems on commercial property (no cap).

In addition, several States have solar incentives in place. Among California's many solar programs are:

- **California Solar Initiative**: The goal of this $2.8 billion, 10-year program is to create 3,000 megawatts of new solar capacity by 2016.
- **Property Tax Exemptions for Solar Systems**: This is a property tax exemption for certain types of solar energy systems installed by December 31, 2009.
- **Zero Energy New Home Program:** This program develops new home designs that will optimize energy efficiency and onsite solar generation to decrease household energy bills.

New Jersey also has many solar programs, including:

- **Clean Energy Financing for Local Schools and Governments:** The New Jersey Board of Public Utilities offers local governments and schools a low-interest, long-term financing program to combine energy efficiency and renewable energy incentive programs.
- **Solar and Wind Energy Systems Exemption:** New Jersey offers a full exemption from the State's 6% sales tax for all solar and wind-energy equipment.

The Concentrating Solar Power Market and SAI Potential

Concentrating Solar Power technologies are most often applied in centralized power production. Although power from CSP currently costs more than other renewable options such as wind, utilities are becoming more aware of the potential economic benefits of CSP deployment. There are several reasons for utility interest in CSP. CSP power production aligns closely with their periods of peak demand. The problems of solar intermittency can be overcome with thermal storage or hybridization with natural gas, allowing plants to dispatch power to the line when it is needed. In some regions, such as the Southwest, the widespread availability of solar energy provides flexibility in locating CSP power plants near existing or planned transmission lines.

Parabolic trough technologies have had the most commercial success in the CSP market so far.

- Solar Electric Generating Stations (SEGS) projects in California have reached a capacity of 354 MW.
- The first SEGS plant was completed in 1985, and all nine plants continue operating today.
- There has also been a recent renewal of commercial CSP activity in the US and Spain. A 1 MW trough plant began operation in Arizona in 2006 and a 64 MW plant is scheduled to begin operation in Nevada in 2007.[17]
- The cost of power from a new CSP trough plant built today is estimated to be 12-14¢/kWh.[18]

Significant progress has been made on reducing both component costs and O&M expenses associated with trough plants in the last several years. For example, advances in thermal storage, using molten salt have made it possible to provide the dispatchable power desired by the electric power industry. This ability to store solar energy makes the technology particularly attractive to utilities because it gives them the option of using the power when they need it most.

Since the late 1970's *parabolic dish-engine* technologies have seen several demonstrations and pre-commercial deployments, but there are currently no commercial dish systems in operation. A prototype six-dish, 150 kW power plant built with private funds is now operating at the National Solar Thermal Test Facility at Sandia National Laboratories. The experience gained from the prototype plant has been helpful in reducing the capital cost of these systems, and the operational experience will improve reliability and reduce O&M costs.

Markets for CSP are being driven by new policy incentives and technology improvements, and this is resulting in renewed worldwide market interest. Favorable power purchase agreements are leading to commercial projects in Spain, and European suppliers are in competition with American suppliers for these markets.[19] Recent market activity suggests that large deployments of dish-Stirling systems will soon be a reality in the U.S. as well.

- On August 10, 2005, Stirling Energy Systems (SES) and Southern California Edison announced a 20-year power purchase agreement that will result in the construction of a 4,500 acre, 20,000 dish plant in the Mojave Desert. The plant is slated to have an output of 500MW, and the agreement provides for possible expansion to 800MW.[20]

- San Diego Gas & Electric announced that it had also signed an agreement with SES, and intends to purchase all of the output from a 300MW, 12,000 dish plant for a period of 20-years. The deal contains provisions for the plant, which is to be located in Southern California's Imperial Valley, to be expanded by as much as 600MW in the future.[21]

There are a number of factors that determine the cost of power from CSP plants, such as the intensity of solar insolation, interest rates, and the cost of commodity materials such as glass and steel. The size of the plant is also important, with plants greater than 200 MW often providing the lowest cost power.[22]

SAI will facilitate cost reductions in CSP by addressing three factors: further technology development, volume production, and scale-up in plant or project size. Technology development includes evolution in the performance and reliability of specific technology components (receivers, concentrators, reflectors, and balance of solar field), improvements in construction techniques and reductions in O&M costs due to learning experience as more projects are installed. Volume production brings significant cost reductions due to decreases in manufacturing cost, material procurement costs, standardized engineering, and project development costs. Large power plant sizes or multiple plants in a single project invoke economies of scale in equipment and systems.

An example of the expected cost reduction in CSP is illustrated in Figures 2-3 and 2-4. Estimates are given for 2015 deployment levels up to 4 GW. This represents a development and deployment plan for the relatively mature parabolic trough technology, which is also a reasonable scenario for the other CSP technologies.

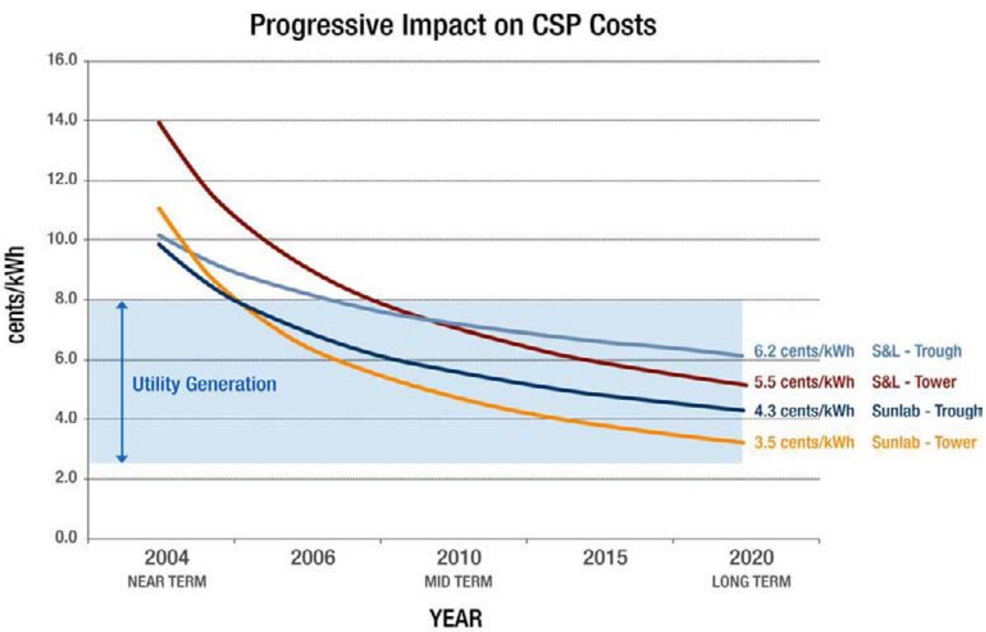


Figure 2-3. Sargent & Lundy CSP Cost Reductions Projections[23]

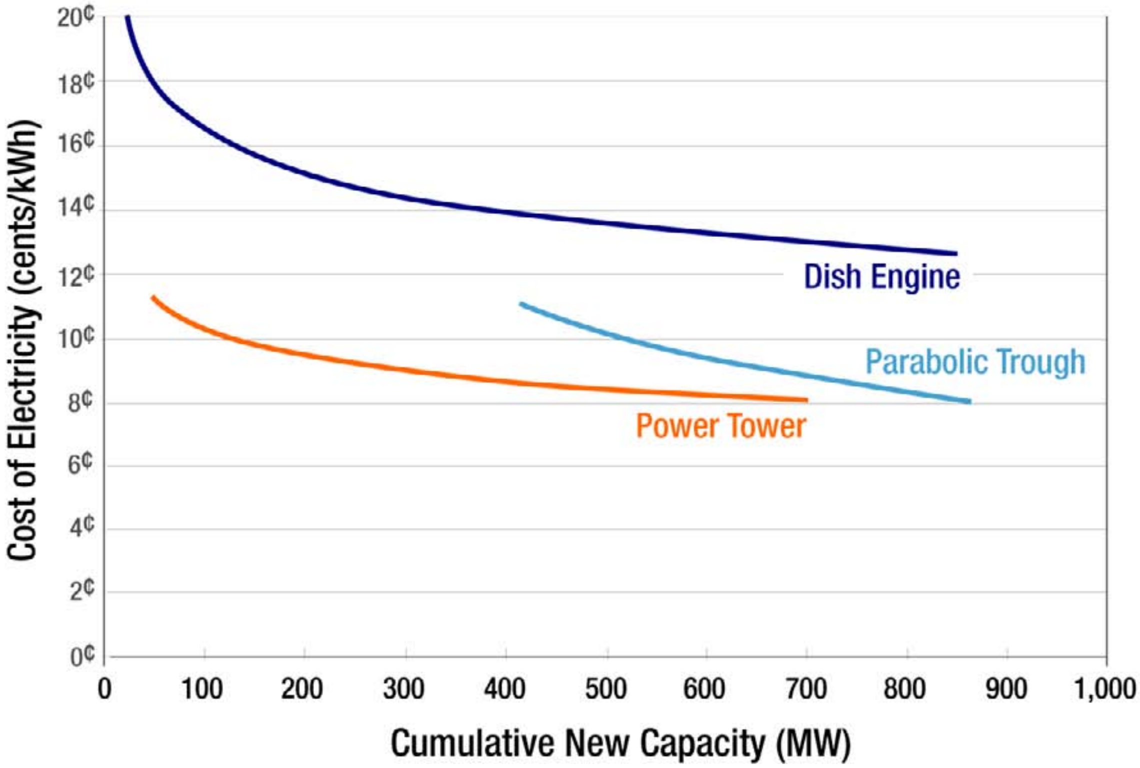


Figure 2-4: Platts/NREL Estimated CSP cost reductions[24]

SAI's Market-Driven Approach

The goals of the SAI are directly market-oriented, in terms of cost, so all R&D activities initiated under SAI will be guided by a systems-based approach. Because the SAI is structured to have an impact on markets in the near-term, the approach will emphasize industry leadership of R&D projects to assure that development planning is driven by commercial business strategies and requirements. Under the SAI, industry-led Technology Pathway Partnerships (TPPs) with universities, component suppliers, and National Laboratories will be established to conduct R&D on all PV system components with a common goal of producing fully-integrated PV systems optimized for U.S. markets.

3.0 Technology Overview

Photovoltaics

Photovoltaic-based solar cells convert sunlight directly into electricity. They are made of semiconducting materials similar to those used in computer chips. When sunlight is absorbed by these materials, the solar energy knocks electrons loose from their atoms, allowing the electrons to flow through the material to produce electricity. The process of converting light to electricity is called the *photovoltaic effect*.

Conventional crystalline silicon PV cells are typically combined into modules that hold about 40 cells; about 10 of these modules are mounted in PV arrays, or panels, that can measure up to several meters on a side. These *flat-plate* PV arrays can be mounted at a fixed angle facing south, or they can be mounted on a tracking device that follows the sun, allowing them to capture the most sunlight over the course of a day. About 10 to 20 PV arrays can provide enough power for a household; for large electric utility or industrial applications, hundreds of arrays can be interconnected to form a single, large PV system. Sunlight can also be focused onto PV panels using lenses or mirrors; such systems are referred to as Concentrating Photovoltaic (CPV), and are far more efficient than their regular PV counterparts.

Zero Energy Home with Roof Mounted PV and Solar Water Heating Systems

Energy efficiency and solar energy technologies can result in zero net energy consumption from nonrenewable sources. During times of peak demand, a near zero energy home generates more power than it uses and reduces power demand on the utility provider. In a Florida study, a prototype near zero energy home outperforms a conventional model by providing most of its own power needs throughout the year.

Thin film solar cells use layers of semiconductor materials only a few micrometers thick. Thin film technology has made it possible for solar cells to now serve in building-integrated applications such as rooftop shingles, roof tiles, building facades, or the glazing for skylights or atria. The solar cell version of items such as shingles offer the same protection and durability as ordinary asphalt shingles.

Photovoltaic panels produce direct-current (DC) electricity. Although a number of applications use the direct current from the modules, the fastest-growing markets for PV integrate the panels into systems with power-conditioning equipment that converts the DC electricity to alternating current (AC) electricity. These systems are then interconnected to the utility grid and are referred to as grid-tied systems. Grid-tied and simple DC PV system configurations are illustrated in Figure 3-1 below.

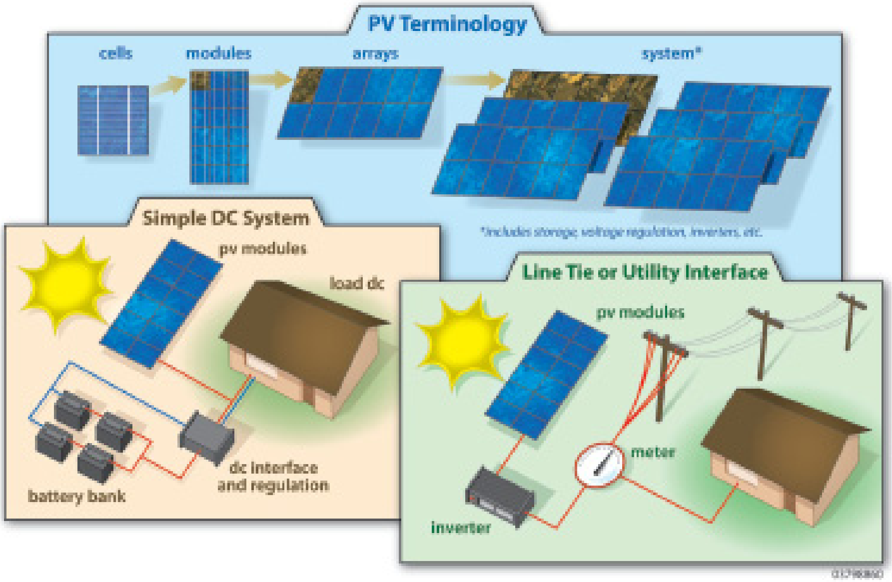


Figure 3-1. Graphical Depiction of PV Systems with Common Terms Illustrated-Source NREL

CSP Technology

Concentrating Solar Power (CSP) technology does not rely on the photovoltaic effect to create electricity. Instead, CSP systems use mirrors to convert the sun's energy into heat, which in turn is then converted into electricity. Figure 3-2 gives a graphical depiction of *parabolic trough* and *parabolic dish-engine* CSP systems, which are described below.

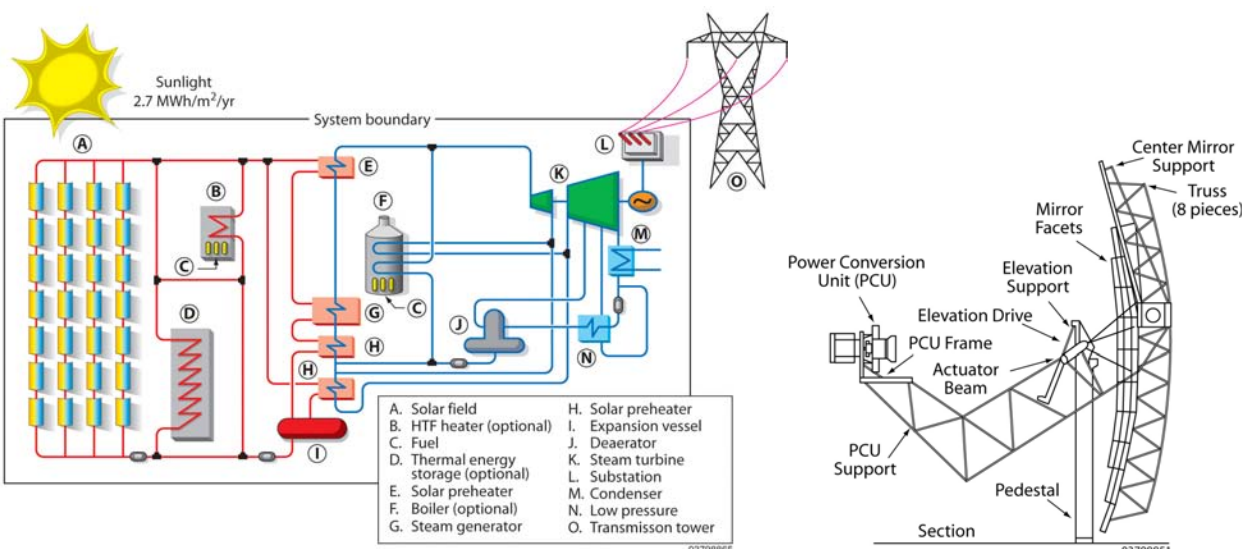


Figure 3-2. Graphical Depiction of CSP Trough (left); Graphical Depiction of CSP Dish-Engine (Right)-Source NREL

Parabolic trough systems are the most common form of CSP. They use single-axis-tracking, parabolic trough-shaped reflectors to concentrate sunlight onto an absorber pipe located at the focal line of the parabolic surface. A high temperature heat transfer fluid flowing through the absorber absorbs the thermal energy from the sunlight. Heat in the fluid is then used to make steam in a steam generator. The steam drives a conventional steam-Rankine power cycle to generate electricity. A collector field contains many parallel rows of troughs connected in series. Rows are typically placed on a north-south axis, allowing the single-axis troughs to track the sun from east to west during the day. Trough systems are best suited for large-scale plants, with their extensive arrays of mirrors and large turbine generators.

Parabolic dish-engine CSP systems comprise a solar concentrator and the power conversion unit (PCU). The concentrator consists of mirror facets which form a parabolic dish which redirects sunlight to a receiver mounted on a boom at the dish's focal point. The system uses a two-axis tracker so the concentrator continuously points at the sun. The PCU includes the thermal receiver and the engine-generator. In the thermal receiver, radiant solar energy is converted to heat in a closed hydrogen loop. The heated hydrogen drives the Stirling engine-generator. Because PCUs are air cooled, cooling water is not required, as it is for the large, central power blocks associated with CSP parabolic trough technology. A parabolic dish-engine system using an efficient Stirling engine is shown in the figure above. The modular nature of dish systems allows for them to be deployed in either distributed or remote generation applications, and in large arrays of hundreds or thousands of dishes to produce power on a utility scale.

4.0 Technology Development Strategy

Accomplishing the goals of the SAI will require a multi-tiered, multi-phased program that addresses the near-, mid-, and long-term technological and scientific advances for improved performance, lower cost, and improved reliability of PV system components and installed systems. Figure 4-1 below illustrates, at the highest level, the multi-tiered approach of SAI.

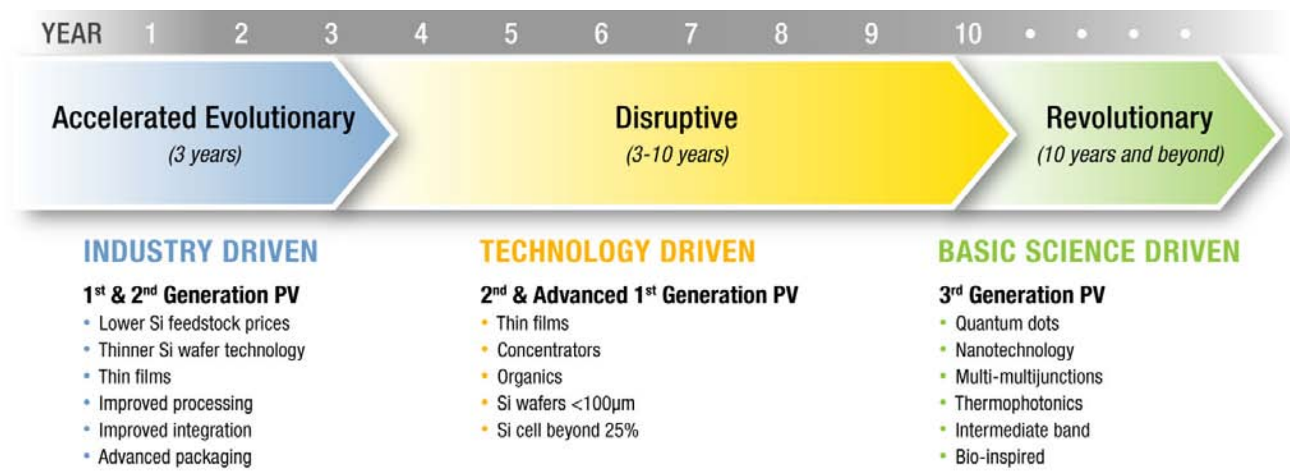


Figure 4-1. Multi-tiered Approach of SAI

Figure 4-2 shows the solar technology development pipeline and the research and development activities associated with the various stages in the pipeline process.

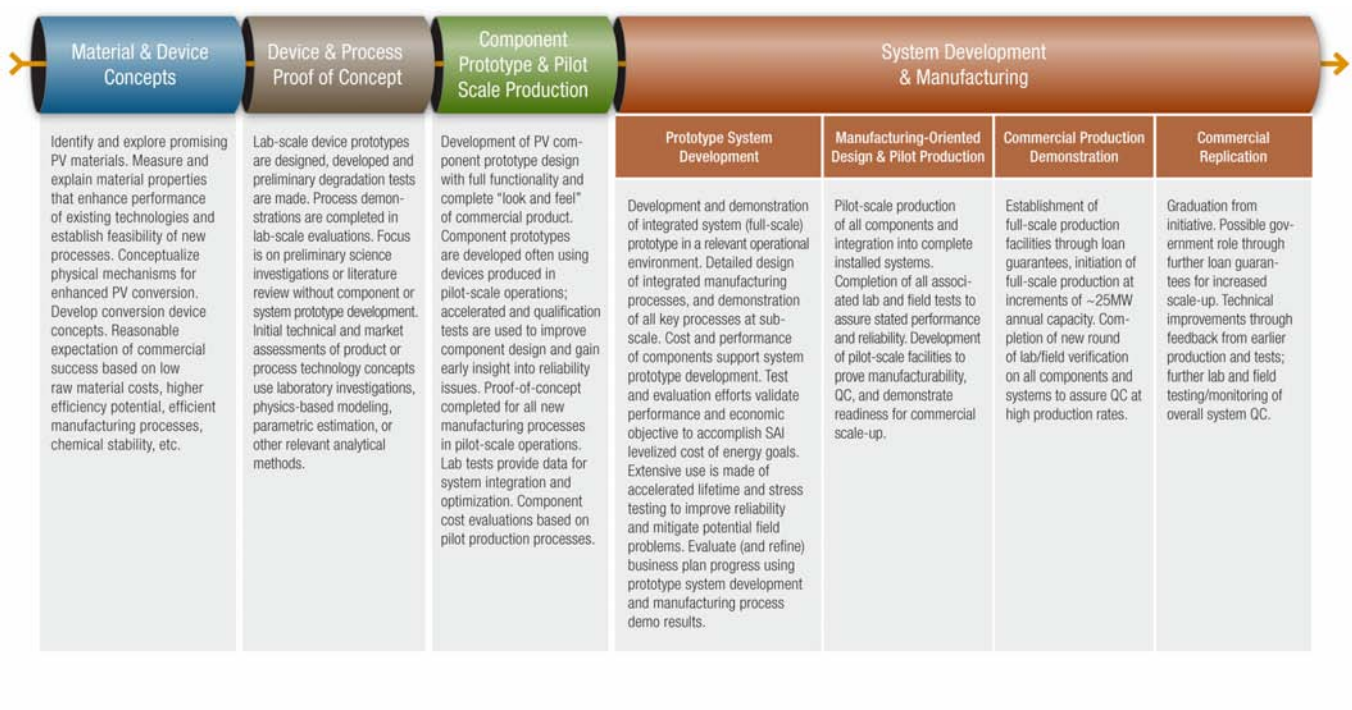


Figure 4-2. Solar Technology Development Pipeline

In the development of advanced PV products, the Solar Program provides numerous technology development opportunities. These opportunities range from research on basic science properties of new materials and processes to the development of new, fully-integrated energy systems ready for mass production. These opportunities are depicted in Figure 4-3 below; specific information about the solicitations can be found on the Solar Program Web site: http://www.eere.energy.gov/solar/

PHASES	Material & Device Concepts	Device & Process Proof of Concept	Component Prototype & Pilot Scale Production	System Development & Manufacturing	
SOLICITATION	Solar Energy Utilization	Future Generation PV Devices & Processes	PV Component / System Incubator	University Product & Process Development Support	Technology Pathway Partnerships
FUNDING SOURCE	DOE/O/S, BES	DOE / SETP	DOE / SETP	DOE SETP	DOE / SETP
DESCRIPTION	New materials and pathways for solar to electric conversion	Novel devices or processes with potentially significant performance or cost advantages	Prototype PV components or systems produced at pilot-scale with demonstrated cost, reliability, or performance advantages	Universities perform targeted materials science and process engineering research in support of industry-led teams developing new PV systems for commercialization in 2010-2015.	PV systems and components ready for mass production delivering energy at target costs
PROJECT LIFECYCLE	3 years	2 years	1.5 years w 9 mo. On/Off Ramp	3 Years	3 years
ANNUAL FUNDING LEVEL	$ 0.3 - 1.5 M	$ 0.3 - 1 M	$ 1 - 2 M	Up to $300K/YR	$ 2 - 7 M
TEAM LEADS	Universities or Laboratories*	Small Businesses, Universities, or Laboratories*	U.S. Commercial Entity	Universities	U.S. Commercial Entity
ELIGIBLE PARTICIPANTS	All	All	Universities / Laboratories*	Universities	Universities / Laboratories
ENTRANCE CRITERION	Basic science properties conceived/simulated	Materials systhesized; properties observed	Coupon-scale PV cell; process demonstrated in lab; proof of concept demo	Identification of manufacturing process or component improvements possible through targeted research investigations.	Prototype components; pilot production demo; business case established
EXIT CRITERION	Materials synthesized; properties observed	Coupon-scale PV cell; process demonstrated in lab; proof of concept demo	Prototype components; pilot production demo; business case established	Incorporation of research results into commercial manufacturing operations or product designs.	Commercial PV systems and subsystems; scaled production demonstrated >25MW
TOPICS	• Single-crystal, polycrystalline, amorphous, and nanostructured inorganic and organic materials • Electronic structure • Single or multiple junction solar cells	• New devices and structures using materials such as thin-film silicon, microcrystalline/amorphous silicon, polycrystalline metal chalcogenides and oxides, nanocrystalline materials, biomimetic concepts, organic materials, photoelectrochemical cells, dye-sensitized materials, materials with low-dimensionsal quantum structures • Very-high efficiency epitaxial solar cells or other concepts	• Modules: multiple technologies (including CPV) seeking efficient material use, better performance, or improved manufacturing • BOS Components: higher reliability inverters, CPV trackers, rapid installation features, storage systems • Systems: controls and smart monitoring, integration of components, factory diagnostics	Identifying and developing: • Fabrication processes to improve material properties during manufacture • Improved solar cell materials • Innovative device designs to improve solar cell efficiency • Simpler, lower cost manufacturing processes • New electrical contacting techniques for improved efficiency and reliability • Diagnostic techniques to identify properties and quality of solar cells materials during manufacturing • Improved materials utilization processes • Understanding of chemistry between encapsulants and solar cell materials • Providing careful long-term field testing of modules and systems in support of product improvement	• Partnerships with U.S. industry for projects that focus on development, testing, demonstration, validation, and interconnection of new PV components, systems, and manufacturing equipment • Technology improvements in PV system and component design, integration, and installation will be a focus • Cost reductions, performance enhancements, and reliability improvements are sought for all aspects of PV systems

NOTE: The NREL and SNL teams that are part of the SETP program will continue to provide technical support for these activities through the SETP but will not be direct participants

Figure 4-3. Technology Development Opportunities

The Office of Science and the Office of Basic Energy Sciences, through the "Solar Energy Utilization" Solicitation, focus on novel technologies that are far from commercialization, such as nanostructured inorganic and organic materials, and multijunction cells. These new and novel materials and pathways for solar to electric conversion are identified, synthesized, and observed. Technologies targeted by this solicitation include single-crystal, polycrystalline, amorphous, and nanostructured inorganic and organic materials as well as single or multiple junction solar cells.

The Solar Energy Technologies Program takes over when a technology is ready for prototype system development/proof of concept. The "Future Generation PV Devices & Processes" solicitation focuses on slightly more mature technologies. These include thin-film silicon, nanocrystalline materials, biomimetic concepts, organic materials, photoelectrochemical cells, dye-sensitized materials, and very-high efficiency epitaxial solar cells, among other concepts.

The "PV Component/System Incubator" solicitation will involve small businesses and non-university research institutes. This solicitation is designed for technologies/processes that have successfully demonstrated a proof of concept/process in a lab, but are not yet mature enough for large-scale commercial production, and the emphasis will be on the barriers to entry towards 2010 commercialization. Prototypes of these PV systems and components will be produced on a pilot-scale in a relevant operational environment with their demonstrated cost, reliability, or performance advantages. PV and CSP modules, components, and systems are all targeted in this phase of the technology development pipeline with the goals that include the more efficient use of materials, better performance, higher reliability, storage systems, and improved manufacturing.

The "University Product and Process Development Support" focuses on targeted materials science and process engineering research in support of industry-led teams developing new PV systems for commercialization in 2010-2015. This research will be conducted by universities.

The last stage of the technology pipeline before commercial replication and graduation from the initiative is targeted by the DOE/SETP's "Technology Pathway Partnerships" (TPPs). These partnerships with US Industry, national laboratories, and universities focus on the development, testing, and demonstration of new PV components, systems, and manufacturing equipment ready for mass production delivering energy at targeted costs.

Industry-Led Technology Pathway Partnerships

The TPP element of the program will establish industry-led teams and provide them the opportunity to apply entrepreneurial creativity and the best industry practices towards the development of innovative technology solutions.

The high-level concept behind the TPP approach is to fund industry-led teams that are comprised of industry members that address the R&D and engineering requirements of much or all of the PV system's value chain.

- The industry-led Technology Pathway Partnerships (TPPs) focus on the near-term, "accelerated evolution" aspects of their technologies, as well as on some of the technical improvements needed in the mid-term for "disruptive" advances toward meeting the 2015 goals. Underlying both the near- and mid-term research is improved scientific understanding of materials, devices, and processes, which can also result in "revolutionary" advances in the longer term (post 2015).

- The driving philosophy of SAI project management will be to ensure maximum value for the DOE/taxpayer investment in solar energy technologies by requiring TPPs to pursue aggressive but realistic technical and production goals, and then holding them accountable to reaching those goals as a condition of continued funding.
- Another key aspect to the TPP approach is the inclusion of two classes of participation. Larger companies/technologies can fully capitalize on their market position and drive those technologies to competitiveness more quickly, while providing emerging companies/technologies the opportunity to vastly accelerate their ability to scale up production and impact the market.

NREL Core Program

The SAI's NREL Core Program will complement the aforementioned TPPs, and is critical to meeting the 2015 goals of the Initiative and facilitating post-2015 technological and global market leadership for the Nation. In the near-and mid-term, the National laboratories and universities will support the TPPs with specific research tasks identified by the individual companies selected. In addition, the NREL Core Program will conduct cross-cutting research that will benefit several companies and technologies by working on fundamental materials, device, and processing issues. Providing measurements and characterization support to industry is one important aspect of this support. Another key element is to support research that keeps the pipeline of innovation full in order to achieve the progress needed to accomplish the 2015 goals, as well as facilitate post-2015 global competitiveness for U.S. PV technologies. Traditionally, this research has often been performed by researchers at National laboratories and universities, as well as by new corporate start-ups (small and large businesses) that are a few years away from qualifying as a TPP participant, but have excellent prospects for meeting the longer-term and post-2015 goals.

The teamed collaboration and technical integration that results among in-house researchers and university and industry subcontractors has been the hallmark of successful programs such as NREL's Thin Film PV Partnership. This has resulted in today's U.S. global leadership position for thin-film technologies in laboratory and the marketplace.

Science and Technology Facility (S&TF)
located at the National Renewable Energy Laboratory in Golden, CO

The centerpiece of the building is the Process Development and Integration Laboratory (PDIL), specifically designed to accommodate a new class of crystalline silicon and thin-film PV processing and characterization tools. The basic concept of the PDIL is to allow researchers to pass samples between equipment and processing steps in a controlled way, avoiding contamination from the air. The PDIL will also allow a scientist to integrate control systems and databases in such a way that someone who is growing a sample can see the results of a measurement and vice versa. The S&TF will include nine advanced materials synthesis, characterization, and general support laboratories.

As part of its Core Program, NREL has the Electronic Materials and Devices (EM&D) project that performs research in semiconductor, dielectric, conductor, encapsulant materials, and device properties. For Silicon Materials and Devices, NREL will develop and transfer technology to enable processing of high-performance crystalline and thin-film devices. In regards to Thin-Film Polycrystalline Compounds, NREL seeks to Adapt high efficiency CIGS (Copper Indium Gallium Diselenide) and CdTe (Cadmium Telluride) solar cell materials systems to implementation in low-cost manufacturing and durable performance. NREL will also work to develop a suite of processes and processing tools that operate rapidly at atmospheric pressure and low temperature. By 2015, NREL will have also developed and transferred technology for production of 40%-efficient concentrator cells that are manufacturable at competitive costs. Work will also continue involving cell and module stability and reliability, with a goal of elucidating the factors that contribute to cell and module degradation in order to develop models that predict service life at the prototype cell and module stage by 2015. In collaboration with the DOE Office of Science, the program will also conduct basic research to target breakthroughs in key areas such as ultra-high efficiency and/or ultra-low cost materials and devices, and solar-hydrogen conversion and storage technologies.[25]

Coordination with the Office of Basic Energy Sciences

The solar energy utilization research supported by the Office of Basic Energy Sciences is focused on advancing fundamental understanding of atomic/molecular level interactions and reactions associated with the conversion of solar energy into electricity and chemically stored energy. To ensure the success of SAI, the program is developing linkages in order to leverage these activities through collaboration and coordination – for example, workshops, planning, and joint support actions. Starting in FY07, new research activities will be initiated through recent solicitations for awards in the following areas:

For *solar to electric energy conversion*, the major emphases will be on the synthesis and discovery of new materials to efficiently absorb sunlight and new techniques to harness the full spectrum of wavelengths in solar radiation. The major activities include:

- Recent advances in the design and synthesis of nanostructured architectures offer great promise to revolutionize the technology used to produce solar electricity. Major solar electricity research activities will be initiated in the following areas:
  - Exploiting thin films, organic semiconductors, dye sensitization, and quantum dots for cheaper, more efficient, and longer-lasting solar PV cells.
  - Synthesis and fabrication of nanoscale architectures by novel top-down and bottom-up techniques.
  - Nanoscale characterization using electron, neutron, and X-ray scattering and spectroscopy with an emphasis on ultrafast tools.
  - Simulations of electronic and molecular behavior in nanoscale semiconductor assemblies using density functional theory.
- These activities are aimed at paving the foundation to drive a revolution in the way that solar cells are conceived, designed, implemented, and manufactured.

For *solar fuels research*, the major activities include:

- Application of the revolutionary advances in biology and biotechnology to the design of plants and organisms that are more efficient energy conversion "machines," and
- Design of highly efficient, all-artificial, molecular-level energy conversion machines exploiting the principles of natural photosynthesis.

A key element in both approaches is the continued elucidation—by means of structural biology, genome sequencing, and proteomics—of the structure and dynamics involved in the biological conversion of solar radiation to sugars and carbohydrates. The disclosure of these long-held secrets of natural solar conversion by means of cutting-edge experimentation and theory will enable a host of exciting new approaches to direct solar fuel production.

Artificial nanoscale assemblies of new organic and inorganic materials and morphologies, replacing natural plants or algae, will be synthesized to use sunlight to directly produce H_2 by splitting water and hydrocarbons via reduction of atmospheric CO_2. The main emphasis of this activity is to develop approaches and systems to bridge the vast knowledge gap in generating durable, cheap, and efficient artificial molecular machines to convert sunlight to chemically stored energy.

In solar thermal systems, the main research activities focus on novel thermal storage materials with an embedded phase transition to offer the potential of high thermal storage capacity and long release times, bridging the diurnal cycle. Nanostructured thermoelectric materials, in the form of nanowires or quantum dot arrays, will also be investigated for direct electricity production from temperature differentials with efficiencies of 20-30% over a temperature differential of a few hundred degrees Celsius. The much larger differentials in solar thermal reactors make even higher efficiencies possible. New low-cost, high-performance reflective materials for the focusing systems are needed to optimize the cost effectiveness and continued improvement of all concentrated solar thermal technologies.

Defense Advance Research Project Agency (DARPA) Advances Solar Technologies
Outside of DOE, the Defense Advanced Research Projects Agency (DARPA) within the Department of Defense recently began an ambitious project to develop a 50% efficient solar electric device in four years for use in recharging batteries for critical information technology systems under battlefield conditions.

In February 2005, the Defense Advance Research Projects Agency's (DARPA) Advanced Technology Office issued a solicitation for up to $53 million for the Very High Efficiency Solar Cell (VHESC) program.

The objective of this program is to demonstrate at least 50% efficiency in a PV device. The program requires that teams be formed to comprehensively address all aspects of the high-efficiency PV problem including the development of fabrication processes that are scaleable to industrial manufacturing and an affordable product.

A broad consortium led by the University of Delaware–including 15 universities, corporations, and laboratories–was selected.

DOE is collaborating with DARPA in its selection of contractors and a technology portfolio, its creation of workshops, exchanges, and requirements for systems analysis. NREL is a DARPA contractor on this program.

5.0 Program Activities

Systems Analysis

The Systems Analysis element of the DOE's Solar Energy Technologies Program will devote its resources to evaluating all program activities to ensure a well-managed, market-based technology research, development and deployment organization. The establishment and tracking of milestones will serve the Solar Program as it works to achieve its goals.

The Solar Program will partner with the U.S. PV and CSP industries to improve and advance the deployment of systems design tools, component and systems performance databases, systems performance prediction tools, and market penetration models. The Systems Analysis activities will take full advantage of relationships and access to information offered by the monitoring of selected SAI Technical Pathway Partnerships, and other solicitations.

The Solar Program has developed a set of Technical Improvement Opportunities (TIOs) that generate a framework for the TPPs to identify the technical requirements that they need to pursue in order to meet program objectives. The TIO framework is depicted in Figure 5-1 below with Tier 1 TIOs consisting of Modules; Inverters and Balance of Systems (BOS); Systems Engineering and Integration; and Deployment Facilitation.

TIOs		Metrics			
TIER 1 TIOs	TIER 2 TIOs	Performance Efficiency	Cost	O&M	Reliability
Modules	Module	red	red	white	yellow
	Absorber	red	red	white	white
	Cells and Contacts	red	red	white	yellow
	Interconnects	white	white	white	yellow
	Packaging	white	yellow	white	red
	Manufacturing	yellow	red	white	yellow
Inverter & BOS	Inverter	yellow	yellow	yellow	red
	Inverter Software	yellow	white	yellow	white
	Inverter Components/Design	white	yellow	yellow	red
	Inverter Packaging/Manufacturing	white	white	yellow	red
	Inverter Integration	yellow	white	white	yellow
	Other BOS	yellow	yellow	yellow	yellow
Systems Engineering & Integration	System Engr. & Integration	white	red	yellow	yellow
	System Manufacturing/Assembly	white	yellow	yellow	red
	Installation & Maintenance	white	red	red	yellow
Deployment Facilitation		white	white	yellow	white

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Figure 5-1. Technology Improvement Opportunities. PV Color boxes indicate degree of impact that TIO has on each metric and overall levelized cost of energy. (red-high, yellow-medium, white-low)

The Solar Program will continue to use the Levelized Cost of Electricity (LCOE) as the SAI's primary metric. The LCOE incorporates all of the critical technical elements of a PV system related to performance and reliability, while also capturing manufacturing costs. The LCOE is an elegant metric in that it allows applicants to pursue a variety of innovative combinations of improved performance, reliability, and cost that will reach LCOE targets. Many of the technology pathways and improvements to realize SAI LCOE targets have been addressed or demonstrated at the laboratory level. The challenge of the SAI is to more quickly move laboratory findings into commercially available products.

The Systems Analysis activities will include two main elements:

- Program Evaluation and Stage Gate Reviews
- Benchmarking & Design Support Tools

Program Evaluation & Stage Gate Reviews

The Stage Gate process (see Figure 5-2) is a means of making focused, goal-oriented disciplined research and development decisions at all stages along a product development cycle. The Stage Gate process is being used throughout the Solar Program.

The basic approach is as follows: project development takes place in a series of sequential "stages" and the reviews of the projects are done at "gates." The "development cycle" for a project can go from applied research investigations through technical activities that support massive production.[26] Increasing rigor, industry involvement, and expenditure are expected as development moves through successive stages. This approach is applied across varying levels of development and integration of new solar systems, from new subcomponents to fully integrated systems.

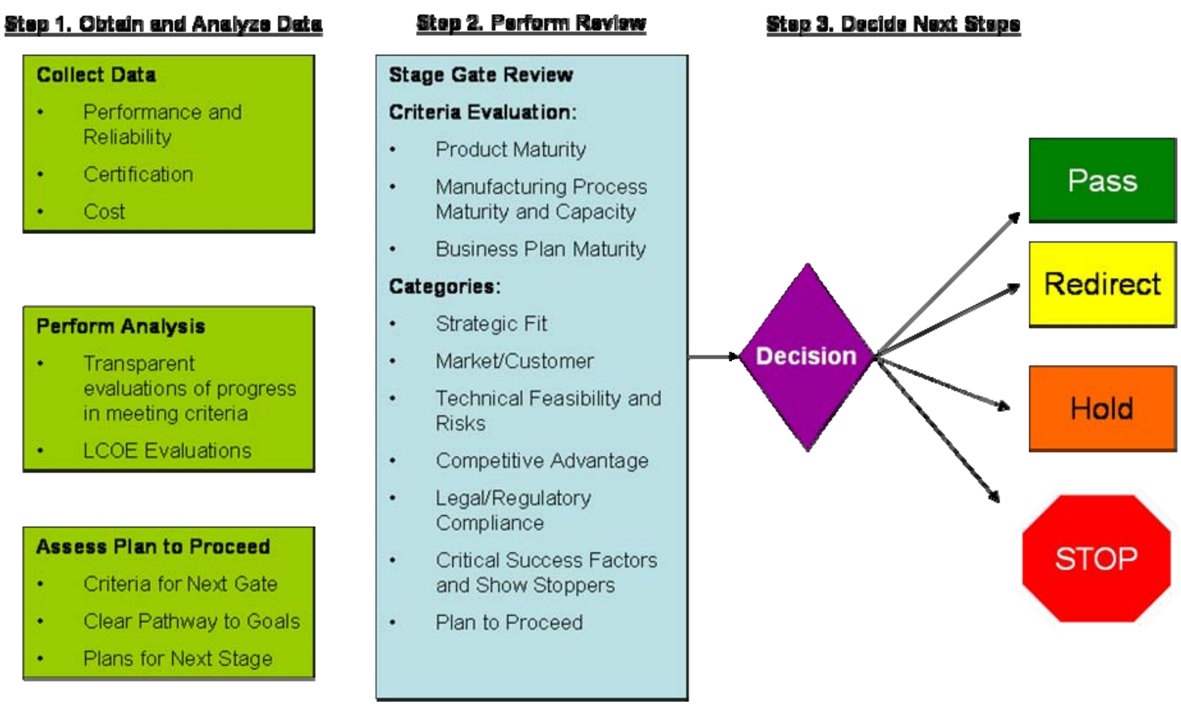


Figure 5-2. Stage Gate Review Process

Implementation of the Stage Gate process is allowing the Solar Program to achieve important improvements in several principal areas of R&D portfolio management:

- Strategic Alignment: R&D activities are directly relevant to the overall goals and strategy of the solar program
- High Value: R&D portfolio positioned to make the largest potential impact on the solar energy industry
- Balance: Technical activities can be expected to produce cost, reliability, and performance improvements in all important areas of solar systems development.
- Accountability and Transparency: allows program to establish accountability for progress in meeting quantified, integrated goals, which can be readily seen and assessed by stakeholders

Current and future market considerations, quantification of the impact of technical improvement opportunities, and prioritization of program activities are combined in a dynamic decision-making process wherein the list of active projects is continually revised.

Benchmarking and Design Support Tools

Benchmarking capabilities and design support tools are key to program, and ultimately, industry success. The program must track its progress towards key targets, especially the SAI Stretch Targets. Benchmarking component and system cost, performance, and reliability and using these data in models is necessary to verify progress. The ongoing analysis of technology, market, and cost trends will help us understand and continually incorporate improvements that can be expected to occur by 2015 as a result of program activities. Industry also requires these capabilities because as solar industry technologies mature in the market, customer expectations for performance, cost, and reliability of systems are increasing rapidly.

- The primary objective of the benchmarking activity is to document historical and current cost, reliability and performance metrics for fielded systems and components.
- Benchmarked data will be used to support the model development and analysis, to help evaluate project proposals and progress under the SAI solicitations, and to assist in Solar program planning (input to multi-year plans, etc.).

In PV, for example, there is a strong trend away from capacity-based specifications to performance-based guarantees over extended periods. The ability to readily and accurately predict a system's performance and LCOE is becoming critical in ensuring a company's viability/profitability. Additionally, a shift away from component-based program planning to more of a systems perspective demands a comprehensive set of predictive modeling tools that allow for a variety of parametric/sensitivity studies. Systems perspective helps to sort out component development needs, priorities, and informs R&D decision making.

SDA Modeling and Analysis

Over the last three years the Solar Program has developed and employed a Systems-Driven approach (SDA) to program management, which uses empirical data to assess the relative marketplace impacts of different research and development directions. This approach applies throughout the solar system value chain, from fundamental research on materials to improved components and integrated solar systems. The Stage Gate methodology, the modeling and analysis work, and the collection of sound empirical data through testing and evaluation, are interconnected efforts employed as part of the Systems-Driven Approach.

SAM Model

A DOE/NREL/Sandia team has developed the Solar Advisor Model (SAM) to provide a common platform for calculating LCOE and to conduct TIO sensitivity studies on overall system LCOE. The SAM Model is currently undergoing validation, user-testing and refinement. The model allows analysts to investigate the impact of variations in performance, cost, and financial parameters on key figures of merit. The model is intended for use by DOE, laboratory management, and research staff for program planning purposes. The model may also be used by members of the solar industry to inform their internal R&D direction and to estimate systems cost and performance.

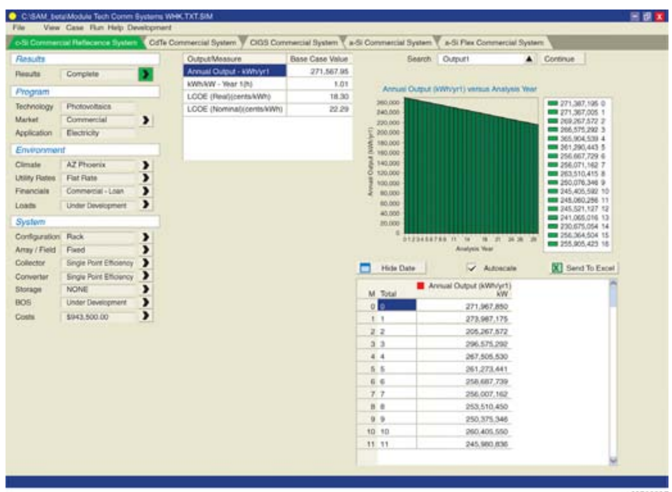


Figure 5-3. SAM Model Screen Shot

Photovoltaic Systems

Increasing PV system efficiency and lowering manufacturing costs are essential for the success of the Solar America Initiative. Program activities will focus on bringing emerging technologies and manufacturing processes out of the laboratory and to market. Ongoing and planned R&D includes the following activities:

PV Cell Technologies

- Develop and demonstrate fabrication of high-efficiency crystalline silicon, thin film, III-V multijunction, and future-generation cells. The specific efficiency milestones for the various cell technologies are reflected in the Gantt chart.
- Develop novel c-Si cell-contacting schemes.
- Engage in efforts to transfer laboratory cell performance to production modules.
- Assess and verify durability and reliability of future-generation solar cells.

PV Module Technologies

- Pursue innovations to improve manufacturability of c-Si cells and interconnects.
- Develop and fabricate amorphous silicon, CIGS, and CdTe modules that have increased solar-to-electric efficiencies.
- Pursue innovations in thin film module design leading to reduced active-area losses through edge and interconnect scribes.

PV Manufacturing R&D Program

- Work with industry partners on improved manufacturing processes.
- Implement fully the Science and Technology Facility (S&TF) tool suites to facilitate laboratory/industry interaction in developing manufacturing technologies and accelerating technology transfer to industry.
- Identify commercialization pathways for promising new technologies via university/industrial partnerships.

PV Inverter Technologies

- Work with industry partners via Technology Pathway Partnerships, and specifically with GE and Xantrex through the High Reliability Inverter Initiative.

PV Systems Development

In the early stages of solar energy R&D, the Solar Program has necessarily been focused on system components (primarily PV cells and modules), but under the SAI, the focus will be on solar energy systems development. This will ensure the most direct path to the marketplace for system and technology advances. Under this portion of the SAI, TPPs will be focused initially on photovoltaic systems and the PV industry. It is anticipated, however, that teams will also include university partners and other laboratory expertise that capitalizes on the Solar Program's historic investment in the U.S. solar energy R&D infrastructure.

To integrate the program into the current industry structure and status, the following program phasing will be pursued:

Phase 1: Demonstrate Pilot Production of Lower Cost Systems

- R&D Project Duration of 3 Years (2007-2009)
- Two classes (Systems and Subsystems) give companies the flexibility to align projects with their targeted business model, technical capabilities, and product/process maturity
  - Systems Class: Development of Turnkey Systems
    - DOE Support for Awards limited to $20 million over the three-year period ($10 million/yr ceiling for DOE Award Support + 50% minimum Cost Share; 4-10 Awards expected)
  - Subsystems Class: System-driven R&D on Components
    - DOE Support for Awards limited to $8 million over the three-year period (Up to $4 million/yr ceiling for DOE Award Support + minimum 50% Cost Share, 10-15 Awards expected)
- Down-select following intermediate Stage Gate (After 16-18 Months)

Phase 2: Demonstrate Replication of Low Cost Pilot Production

- R&D Project Duration of 3 Years (2010-2012), with new entrants eligible.
- Classes and requirements TBD based on Phase 1 program experiences.
- Possible use of different procurement instruments (e.g. Loan Guarantees), depending on maturity of technology and business models

Phase 3: Develop Supply Chain & Distribution Infrastructure

- Reduce capital expenditure intensity of manufacturing scale-up, through targeted investments in equipment/feedstock suppliers, distribution channels, etc.

Concentrating Solar Power Systems

In parallel to the PV R&D efforts, the Solar Program will continue to pursue advances in driving CSP to be cost competitive. Projections for CSP cost trends are shown in Figure 5-4.

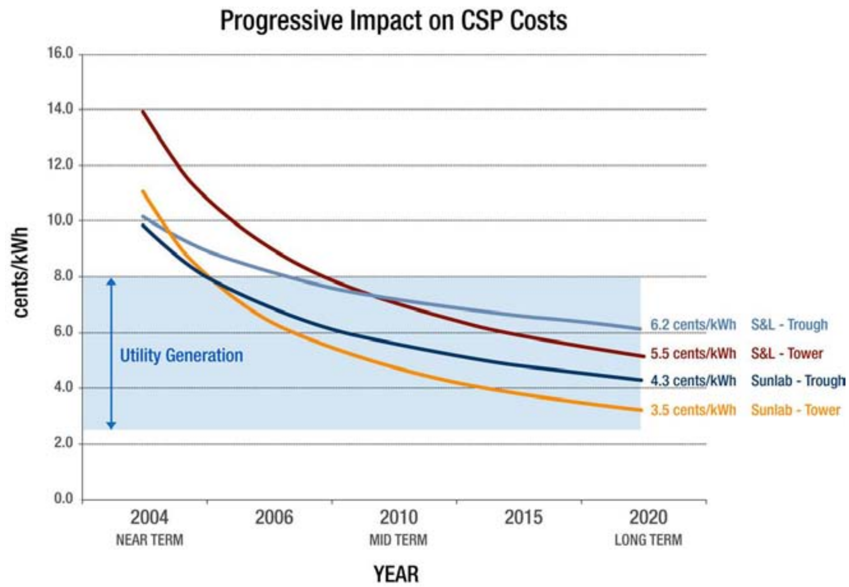


Figure 5-4. Projections for LCOE Cost Reductions for CSP by Sergeant and Lundy and DOE's SunLab[27]

Until the CSP budget enables additional contracts that augment core R&D lab activities, the Solar Program will focus on the following opportunities:

Troughs

- Provide technical support for CSP projects in the Southwest, including optical testing to optimize receiver and concentrator designs
- Begin development of next-generation system capable of operating at 450° Celsius
- Develop improved receiver testing capabilities, advanced selective coatings, receiver maintenance systems, and optical characterization tools

Dish/Engines

- Work with industry on the six-dish mini-plant at the industry/laboratory test facility in New Mexico to test dishes in a power plant configuration
- Focus on engineering solutions to Stirling engine reliability issues
- Work with industry to improve dish manufacturability and any necessary component upgrades or redesigns
- Assist industry in the design of the 1.0 MW demonstration project in California and subsequent projects

Storage

- Identify a heat transfer fluid suitable for both the solar field and storage system at temperatures up to 450°C; the fluid must have a high thermal capacity, low vapor pressure, and remains liquid at ambient temperatures.
- Conduct research, lab tests and field demonstrations of thermal energy storage systems that may offer a near-term, low-cost storage option for industrial trough projects

Technology Evaluation

The Technology evaluation (TE) activities within the Solar Program are focused upon collaboration and cooperation with industry and on obtaining data that quantify performance improvements within the industry and the Solar Program. The PV TE staffs currently obtain "hardware" from a variety of sources (U.S. and global manufacturers, system integrators, and university/internal researchers) and will obtain both prototype and commercial hardware from TPP teams. Testing equipment is very expensive and can be cost prohibitive, but through the SAI's TE activities, DOE is ensuring that companies do not have to make investments in such equipment and can instead focus their resources elsewhere.

- TE activities will include several different types of tests on systems, components, or devices. These evaluations produce performance parameters, validated data base entries, data reports and analyses, test protocols, and data analysis methodologies.
- In addition, in-line diagnostics for use in product improvement or process understanding are developed.
- Specialty measurements can be performed to support evaluation of new system or component concepts; often the insights gained in these evaluations lead to improvements in test protocols.
- Access is provided for direct industry use of "one of a kind" test facilities, such as the new Science and Technology facility at NREL or the PV Systems Optimization Lab at Sandia.
- All results are used in direct support of component and manufacturing process improvement, integration of systems, stage gate evaluations, benchmarking, codes and standards development, and performance modeling. Results are also valuable in planning and evaluating Solar Program technical activities.

Supporting these Solar Program technology evaluation efforts are the personnel, processes, capabilities, and facilities at several National Laboratories (National Center for Photovoltaics: National Renewable Energy Laboratory and Sandia National Laboratories) and the Solar Energy Technology Program's Regional Experiment Stations (SW, Southwest Technology Development Institute and SE, Florida Solar Energy Center). This work is complementary to and supportive of the capabilities of many private entities and standards and codes organizations that also support the PV industry. TE support for CSP is centered at the National Solar Thermal Test Facility located in Albuquerque, NM at the Sandia National Laboratories.[28]Technology evaluation results are fully documented for integrity and transparency, with a formal protocol for product delivery, testing, and dissemination of results. Proprietary data are routinely handled without compromise.

Market Transformation

Market Transformation is the set of SAI activities that aims to reduce market barriers and promote deployment assistance for solar energy technologies through non-R&D activities. Funded through separate solicitations in parallel to the Technical Pathway Partnerships, these activities will augment the R&D efforts of industry, National Laboratories, and universities.

The SAI goal of achieving cost-competitiveness of solar energy technologies by 2015 across all market sectors is an aggressive one, and will require both technologically-based solutions and consideration of non-R&D barriers to full-scale market penetration. As the previous chapters have discussed, there are many pathways for improving solar energy technologies using R&D, manufacturing engineering or other technical solutions. These technologically-based approaches offer opportunities for substantial progress in reducing the cost of solar technologies.

Yet the picture is incomplete without consideration of the non-R&D or institutional barriers that prevent full-scale market penetration of solar technologies. Inability to easily connect to the electric grid, lack of net-metering regulations, or the forced-purchasing of liability insurance by a utility, can all prevent the installation of a PV system, even one that is highly-efficient at a low-cost. In that case, despite the significant gains realized through R&D, our Nation will not accrue any energy, security, nor environmental benefits. It is therefore critical to address infrastructure-related market barriers to solar technologies in addition to R&D work.

Market Transformation Planned Activities

In conclusion, the Market Transformation element will work in parallel to the SAI TPPs to reach a broad spectrum of industry and stakeholders. Market Transformation and Technology Pathway Partnerships will help ensure success for the SAI by covering a wide range of technical and non-technical barriers.

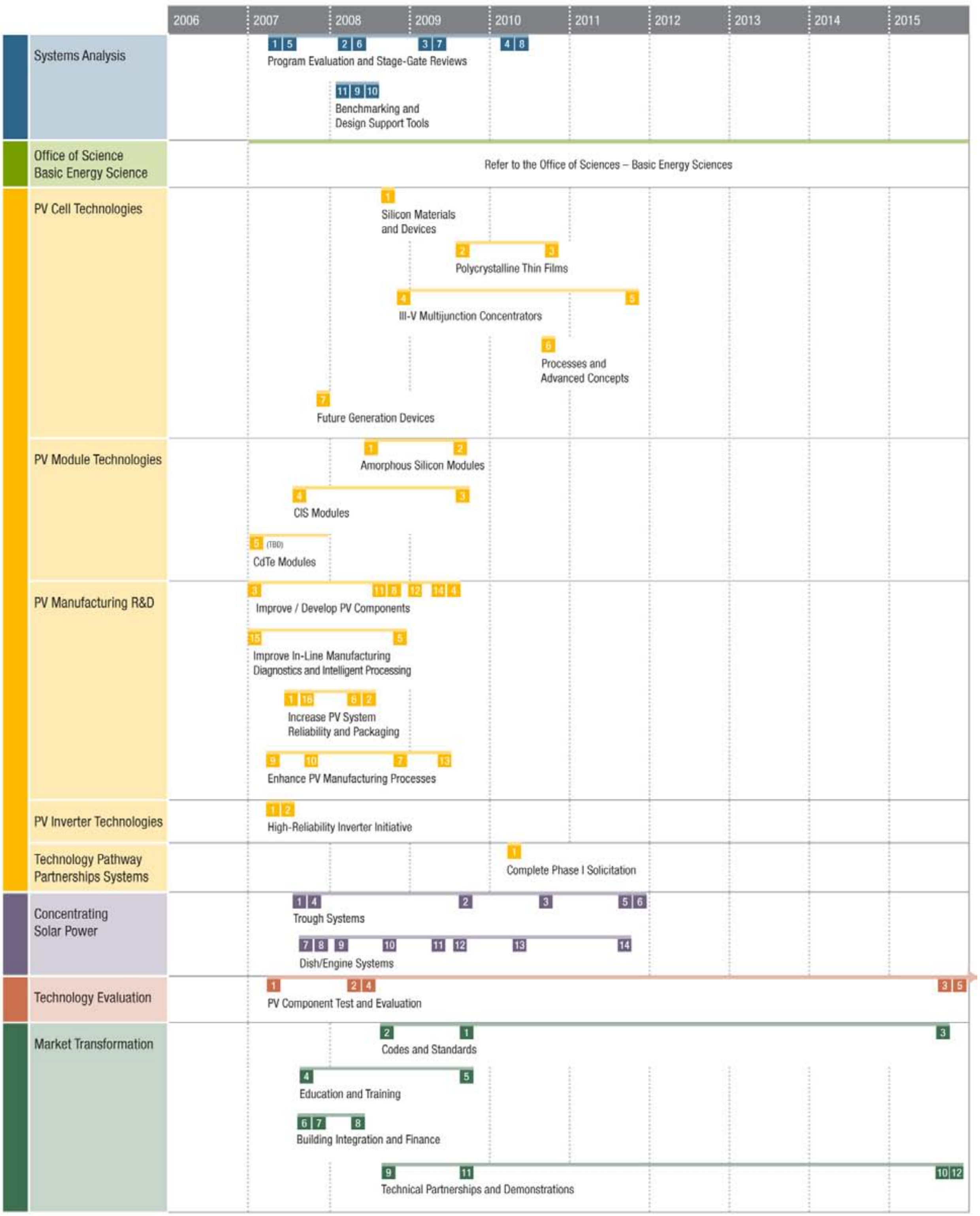
Figure 5-5 shows the various Funding Opportunity Announcements (FOA's) for the Market Transformation activities of the Solar America Initiative.

MARKET TRANSFORMATION FUNDING OPPORTUNITY ANNOUNCEMENTS (FOA'S)

SOLICITATION	Solar Codes and Standards			State and Utility Solar Technical Outreach		Solar City Strategic Partnerships	Solar America Showcases
TOPIC AREA	Solar Codes and Standards Working Group Leadership	Experience-Based Utility PV Capacity Credits	National Voluntary PV Module Standard	State Solar Technical Outreach	Utility Solar Technical Outreach		
DESCRIPTION	A central body to address, as appropriate, all solar codes and standards issues that are encountered by DOE, DOE contractors, partners, award recipients and stakeholders. The group will assist state and other regulating and inspection bodies in adopting best practices, guiding stakeholders, and in verifying the adequacy of particular equipment and installation methods. It will also work with utilities and state/local jurisdictions to standardize interconnection and installation requirements for grid-connected PV systems.	This Topic Area will support the development and adoption of specific capacity credit values or other utility-approved measures for system benefits of PV. The main deliverable will be a report, paper, software product or other medium that contains the methodology to be used for calculating capacity credit values for PV Systems of widespread use to utilities and other solar stakeholders.	The main focus of this Topic Area is the creation of a national voluntary PV module rating standard, including performance, reliability, safety, anticipated degradations and operational limits and the establishment of testing procedures and protocols for use. The purpose is to increase consumer confidence in PV module performance by bringing actual module performance in line with module nameplate ratings.	Will identify and promote efforts by the relevant decisions makers to accelerate the adoption of solar technologies within their states. Where appropriate, DOE will expect coordination among the various organizations throughout the award period to best address shared solar issues that affect multiple groups of State decision makers.	Will provide targeted solar information, education, and resources to electric utilities. Also will strengthen outreach to utilities who already maintain advanced solar programs and assist such utilities in advancing their acceptance and promotion of solar even further. Aims to foster strong strategic relationships with utilities on solar issues to identify and provide solutions to strategic market barriers to solar energy technology adoption and enable key commercialization activities to promote the SAI.	Support for cities ready to take a comprehensive, systematic, city-wide approach to solar technology that facilitates mainstream adoption and provides a model for other cities. DOE is looking for cities to commit to achieving a sustainable solar infrastructure, not simply a year or two of experimental solar projects. Recipient Cities are expected to develop a city-wide solar implementation plan as a deliverable under this project.	DOE will provide technical assistance to large-scale, high-visibility solar installation projects that have the ability to impact the market for solar technologies through large project size, use of a novel solar technology, and/or use of a novel application for a solar technology. Ideal projects will have a total capacity in excess of 100kw. (Projects may include multiple sites and do not have to be co-located.)
FUNDING CEILING	$4,200,000	$100,000	$3,000,000	$225,000	$900,000	$200,000	$2,700,000 (total FY07 funding)
FUNDING FLOOR	$500,000	$25,000	$500,000	$50,000	$50,000	$80,000	
# OF RECIPIENTS	1-2	1-2	1-2	4-6	1-2	6-10	Up to 25
PROJECT LIFECYCLE	5 years	1 year	3 years	3 years	3 years	24 months	

Figure 5-5. Market Transformation Funding Opportunity Announcements (FOA's)

Program Activities Chart



MILESTONE		DATE
SYSTEMS ANALYSIS		
1	Validate and characterize Technology Pathway Partnership (TPP) targets and metrics	04/05/2007
2	TPP Stage-Gate review and down-selects	02/05/2008
3	TPP Stage-Gate review and down-selects	02/05/2009
4	TPP Stage-Gate review and down-selects	02/05/2010
5	Validate and characterize NREL EM&D targets and metrics	04/05/2007
6	NREL EM&D Stage-Gate review and down-selects	02/05/2008
7	NREL EM&D Stage-Gate review and down-selects	02/05/2009
8	NREL EM&D Stage-Gate review and down-selects	02/05/2010
9	Develop improved PV systems performance and cost model	04/01/2008
10	Develop public-access PV design support database	04/01/2008
11	Develop open-source PV manufacturing cost model	02/01/2008
OFFICE OF SCIENCE BASIC ENERGY SCIENCE		
	Refer to the Office of Sciences – Basic Energy Sciences	
PHOTOVOLTAICS		
PV Cell Technologies		
1	Develop 20% Silicon SHJ Champion cell	10/01/2008
2	Develop 20% CIGS Cell: 17% CdTe cell	09/03/2007
3	Develop 12% dye-sensitized cell	10/02/2009
4	Develop 40% MJ Concentrator	10/06/2008
5	Demonstrate 33% module efficiency with 42% efficient cell	10/03/2011
6	Demonstrate atmospheric processing for CIGS cells	09/30/2010
7	Demonstrate 1% polymer-based solar cell	10/01/2007
PV Module Technoloies		
1	Develop > 11% Cell	08/12/2008
2	Fabricate modules at 25 MW capacity at 10%	08/12/2009
3	Demonstrate 25 % increases in CIGS deposition to 15-in/min	08/12/2009
4	Develop low-cost process for TCO coating	08/13/2007
5	*Milestones to be determined*	*TBD*
PV Manufacturing R&D		
1	Verify 25% reliability increase for 500-kW inverter	5/30/2007
2	Complete protection-system production line scale-up and calibration	6/13/2008
3	Achieve 30% labor reduction in installation with new materials handling tools	1/31/2007
4	Demonstrate 2% module efficiency increase	6/30/2009
5	Implement in-line elipsometer for production process monitoring	12/31/2008
6	Demo 30-yr module reliability and 50% increase in energy production/area	5/14/2008
7	Complete demo of manufacturing methods for 170W 11% Silicon-Film module	12/31/2008
8	Demo Cz-Si module manufacturing <$2/W &>15% efficiency	9/30/2008
9	Develop 25 wafers cut with 20% thinner cutting wire and no yield change	3/30/2007
10	Demo 15% efficient cells manufactured on production line	8/31/2007
11	Complete production-ready controller and drive system for CPV tracker	6/30/2008
12	Complete market study and submit PV roof tile module for UL listing	1/30/2009
13	Complete cell line factory design	5/29/2009
14	Complete qualification and testing of high-voltage module	5/29/2009
15	Complete development of Computer Integrated Manufacturing System	1/15/2007
16	Complete long-term exposure testing of modules w/ thin-film specific encapsulant	6/1/2007
PV Inverter Technologies		
1	Final Report on Inverter Development (GE)	03/30/2007
2	Final Report on Inverter Development (Xantrex)	03/30/2007
Technology Pathway Partnerships Systems		
1	Complete Phase I Activities	02/03/2010

MILESTONE		DATE
CONCENTRATING SOLAR POWER		
1	Performance: Demonstrate 78% thermal efficiency in receiver	09/30/2007
2	Performance: Demonstrate 82% thermal efficiency in receiver	09/30/2009
3	Performance: Demonstrate 70% optical efficiency in collector	09/30/2010
4	Cost: Demonstrate trough system cost @ 11-13¢/kWh	9/28/2007
5	Cost: Demonstrate trough system cost @ 10-12¢/kWh	9/30/2011
6	Cost: Demonstrate thermal storage @ $20/kWh	9/30/2011
7	Integrate/validate component models	9/30/2007
8	Complete market requirements evaluation	12/31/2007
9	Upgrade reliability methodology	3/31/2008
10	Start testing of SES Gen 3 System	9/30/2008
11	Integrate/validate new component models	6/30/2009
12	Develop project operations database	9/30/2009
13	Review and update market evaluation	6/30/2010
14	Start testing of advanced system	9/30/2011
TECHNOLOGY EVALUATION		
1	Develop system performance rating protocol	3/16/2007
2	Demonstrate improved system performance rating protocol	3/17/2008
3	Provide independent testing to TPPs and industry companies	9/30/2016
4	Demonstrate new accelerated test protocols for thin film modules	4/11/2008
5	Provide independent testing to TPPs and industry companies	9/30/2016
MARKET TRANSFORMATION		
1	Complete IEEE/IEC Voluntary Module Performance Testing Standard	9/30/2009
2	Complete study of Utility Solar Capacity Credit Valuations	9/28/2007
3	Complete removal/minimization of all code/standard barriers to PV market penetration	9/30/2015
4	Complete "Train the Trainer" for at least ten trainers	9/28/2007
5	Complete federal involvement in training/certification for PV	9/30/2009
6	Conduct Solar Decathlon 2007	9/28/2007
7	Complete initial finance study	9/28/2007
8	Release financial "Best Practice" and utility/financial institution Solar Pathway instrument guidance	3/28/2008
9	Complete City Strategic Partnership City Energy Plans from Phase I	9/26/2008
10	Complete Solar America City Program	9/30/2015
11	Provide final technical assistance to Solar America Showcases Phase I	9/26/2008
12	Complete Solar America Showcases Program	9/30/2015

Appendix A. Acronyms

AC	alternating current
a-Si	amorphous silicon
a-Si:H	hydrogenated amorphous silicon
BIPV	building-integrated photovoltaics
BNL	Brookhaven National Laboratory
BOP	balance of plant
BOS	balance of systems
Btu	British thermal unit
c-Si	crystalline silicon
CdTe	cadmium telluride
CIGS	copper indium gallium diselenide
CIS	copper indium diselenide
COE	cost of energy
COSE	cost of saved energy
CPV	concentrator photovoltaics
CRADA	cooperative research and development agreement
CSP	concentrating solar power
CY	calendar year
DC	direct current
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
EPAct	Energy Policy Act of 2005
ES&H	environment, safety, and health
FSEC	Florida Solar Energy Center
FY	fiscal year
GaInNAs	gallium indium nitrogen arsenide
GO	Golden Field Office
GPRA	Government Performance Results Act
GW	gigawatt
GWp	peak gigawatt
HALT	highly accelerated lifetime testing
HIT	heterojunction with intrinsic thin layer
HTF	heat-transfer fluid
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronics Engineers
IPP	independent power producer
kW	kilowatt
kg	kilogram
kWe	kilowatt electric
kWh	kilowatt-hour
kWht	kilowatt-hour thermal
LCOE	levelized cost of energy
LEC	levelized energy cost
LED	light-emitting diode
m2	square meter

MMBtu	million Btu
MOS	measure of success
MPPT	maximum power-point tracking
MTBF	mean time between failure
MTBI	mean time between incident
MYPP	Multi-Year Program Plan
MYTP	Multi-Year Technical Plan
MW	megawatt
MWe	megawatt-electric
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NCPV	National Center for Photovoltaics
NEC	National Electrical Code
NEMS	National Energy Modeling System
NRC	National Research Council
NREL	National Renewable Energy Laboratory
NSTTF	National Solar Thermal Test Facility
NTRC	National Transportation Research Center
O&M	operations and maintenance
PDIL	Process Development and Integration Laboratory
PV	photovoltaics
PWF	present worth factor
R&D	research and development
RFP	request for proposal
RPS	renewable portfolio standard
S&TF	Science and Technology Facility
SAM	Solar Advisor Model
SBIR	Small Business Innovative Research
SCADA	supervisory control and data acquisition
SDA	systems-driven approach
SEP	State Energy Program
SERES	Southeast Region Experiment Station
Si	silicon
SINC	Systems Integration and Coordination (Team)
SNL	Sandia National Laboratories
SRCC	Solar Rating and Certification Corporation
STTR	Small Business Technology Transfer Research
SWRES	Southwest Region Experiment Station
SWTDI	Southwest Technology Development Institute
TBD	to be determined
TES	thermal energy storage
TIO	technology improvement opportunity
TMY	typical meteorological year
UV	ultraviolet
W	watt
Wp	peak watt
WGA	Western Governors' Association
ZEB	Zero Energy Buildings
ZEH	zero energy home

Appendix B. Contacts, Resources, and Weblinks

Contacts

Steven Chalk
Acting Program Manager
Solar Energy Technologies Program
DOE Office of Energy Efficiency and Renewable Energy

Craig Cornelius
Solar America Initiative Posture Plan Coordinator
Solar Energy Technologies Program
DOE Office of Energy Efficiency and Renewable Energy

Document Citations

President's Advanced Energy Initiative
www.whitehouse.gov/stateoftheunion/2006/energy

Solar Energy Technologies Multi-Year Program Plan 2007-2011
www.eere.energy.gov/solar/about.html

National Energy Policy
May 2002
www.whitehouse.gov/energy

PV Industry Roadmap
www.seia.org

Web Sites of Relevant DOE Offices

Office of Energy Efficiency and Renewable Energy
www.eere.energy.gov

Solar Energy Technologies Program
www.eere.energy.gov/solar

Solar America Initiative
www1.eere.energy.gov/solar/solar_america

Office of Science
Basic Energy Science
www.science.doe.gov/feature/BES.htm

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[9] Black & Veatch, "Economic Benefits of Concentrating Solar Power in California, Draft Final Report," December, 2005. The quantified potential environmental benefit of solar energy varies depending on the fuel it replaces. The emission reductions were calculated relative to combined-cycle gas plants because a large percentage of the new power plants use natural gas as their energy supply.
[10] "The Solar America Initiative: Energy, Economic, and Environmental Benefits." DRAFT Whitepaper, Roebrt Margolis and the National Renewable Energy Laboratory. September 2006.
[11] "Cumulative installed PV power by application area in IEA reporting countries (MWp)." International Energy Agency. Retrieved on September 29, 2006 from http://www.solarbuzz.com/StatsGrowth.htm
[12] In Spain there are numerous large-scale CSP plants under development and construction. These include the 50MW trough plants Andasol I and Andasol II, and the PS10, PS20 and Solar Tres power towers. www.mileniosolar.com, www.solucar.es, www.solarpaces.org/News/Projects/Spain.htm. German companies such as FLAGSOL and Millenium AG have played large roles in the design and construction of these plants. See www.mileniosolar.com/, www.flagsol.com. Israeli company Solel has become a major CSP producer/service provider, and is involved with CSP projects in Spain, as well as the SEGS plants in California and a new 64MW plant in Nevada. Solel and the Israeli government are also working together to build a 100-500MW CSP plant in the Negev desert. www.solel.com
[13] "Support for PV in Japan and Germany, "Lawrence Berkeley National Laboratory and the Clean Energy Group, 2002.
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[16] *Ibid.*
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17 € cents thereafter. Source: IEA Global Renewable Energy Policies and Measures Database: http://www.iea.org/textbase/pamsdb/detail.aspx?mode=gr&id=2034
Actual text of Royal Decree (in Spanish): http://noticias.juridicas.com/base_datos/Admin/rd436-2004.html

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Stirling Energy Systems Press Release. September 7, 2005. http://www.stirlingenergy.com/news/SES%20Press%20-%20SDGE%20V%203.pdf

[22] "Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts." Sargent and Lundy Consulting Group LLC. SL-5641. Chicago, Il. May 2003.

[23] *Ibid.*

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[28] An inventory of the Solar Program test and evaluation capabilities, along with references to related codes and standards, can be found at: http://www1.eere.energy.gov/solar/solar_america/