International Energy Agency

CO-OPERATIVE PROGRAMME ON PHOTOVOLTAIC POWER SYSTEMS

Task I
Exchange and Dissemination of Information on PV Power Systems

NATIONAL SURVEY REPORT OF PV POWER APPLICATIONS IN THE UNITED STATES OF AMERICA
2006

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i Foreword

The International Energy Agency (IEA), founded in November 1974, is an autonomous body within the framework of the Organisation for Economic Co-operation and Development (OECD), which carries out a comprehensive programme of energy co-operation among its 23 member countries. The European Commission also participates in the work of the Agency.

The IEA Photovoltaic Power Systems Programme (IEA-PVPS) is one of the collaborative research and development (R&D) agreements established within the IEA. Since 1993, its participants have conducted a variety of joint projects in the applications of photovoltaic (PV) conversion of solar energy into electricity.

The 19 participating countries are Australia (AUS), Austria (AUT), Canada (CAN), Denmark (DNK), France (FRA), Germany (DEU), Israel (ISR), Italy (ITA), Japan (JPN), Korea (KOR), Mexico (MEX), The Netherlands (NLD), Norway (NOR), Portugal (PRT), Spain (ESP), Sweden (SWE), Switzerland (CHE), The United Kingdom (GBR), and The United States of America (USA). The European Commission and the European Photovoltaic Industry Association are also members.

The overall programme is headed by an Executive Committee composed of one representative from each participating country, while the management of individual research projects (tasks) is the responsibility of Operating Agents. Ten tasks have been established and six are currently active. Information about these tasks can be found on the public Web site www.iea-pvps.org. A new task concerning PV environmental safety and health is now being developed.

The objective of Task 1 is to promote and facilitate the exchange and dissemination of information on the technical, economic, environmental, and social aspects of photovoltaic power systems.

ii Introduction

The objective of Task 1 of the IEA Photovoltaic Power Systems Program (PVPS) is to facilitate the exchange and dissemination of information on the technical, economic, environmental and social aspects of photovoltaic power systems. An important deliverable of Task 1 is the annual International Survey Report on photovoltaic power applications. This report gives information on trends in photovoltaic power applications in the 19 member countries and is based on the information provided in the National Survey Reports, which are produced annually by each Task 1 participant. The public PVPS Web site also plays an important role in disseminating information arising from the program, including national information.

1 *Executive summary*

The United States' National Survey Report (NSR) summarizes some of the key indicators of the national photovoltaic (PV) industry's progress. These indicators include manufacturing and installation data, policy developments, and national progress in research and development (R&D). However, the U.S. NSR does not cover the global progress being made in the PV industry. The International Energy Agency (IEA) Photovoltaic Power Systems Programme (PVPS) *Trends in Photovoltaic Applications* provides an overview of applications and markets for PV power systems in the reporting countries at the end of 2006 and analyzes trends in implementing PV power systems. Please visit www.iea-pvps.org to obtain an electronic copy of the report.

In 2006, the United States' PV industry witnessed significant progress on the following fronts:

- The implementation of new and aggressive R&D efforts between the U.S. Department of Energy (DOE) Solar Energy Technologies Program, industry, and university partners through the Solar America Initiative (SAI) (www.eere.energy/gov/solar/solar_america/), which is part of the President's Advanced Energy Initiative.

- Increased interest in educational efforts by non-governmental organisations (NGOs) and for-profit organisations to support the market acceptance of solar technologies.

- Increased interest by the investment community in solar energy technologies as part of the clean technology investment movement.

- Expansion of U.S. manufacturing capacity by many PV manufacturers to meet the ongoing global demand for PV.

- Growing political interest in alternative energy sources, such as PV, as a way to hedge against volatile fuel prices, protect the environment, and diversify energy sources. As a result of growing concerns, more local and state governments are enacting policies to promote renewable energy applications.

A summary of 2006 progress follows:

Cell and Module Production

U.S. global cell production increased 30.9 % to 201.6 MW_{dc} in 2006, from 154.0 MW_{dc} in 2005. As the numbers will indicate in this year's NSR, U.S. solar cell producers had a difficult year in 2006 due to the limited access to polysilicon feedstock. Nearly all of the increase in U.S. cell production in 2006 came from First Solar, with 60 MW of thin-film PV.

Module production increased 31 % to 202 MW. U.S. PV cell and module production totaled 202 MW in 2006—a 31 % increase from 2005. Merger and acquisition activity and increased debt financing allowed several companies to expand cell and module production capacity in the United States.

Installations

Installations in the United States increased 40 %, from 105 MW in 2005 to 145 MW in 2006. Most of the growth occurred in the grid-connected sector—from 70 MW in 2005 to more than 106 MW in 2006.

Costs and Prices

The installed cost of grid-connected PV systems remained nearly constant at $7.00–8.00 / W_{ac} U.S. dollars (USD). This was the case despite the fact that module costs increased from 3.60 / W_{ac} USD in 2005 to 3.75 / W_{ac} USD in 2006. Reductions in installed costs to compensate for higher module costs were made possible by volume discounts, reduced labor costs owing to increased volume of installations and module efficiency increases, and reduced profits.

Budgets for PV R&D and Installations

The DOE Solar Energy Technologies Program (Solar Program) provides the primary leadership for research in advanced material and devices, device performance and reliability, and deployment of PV. The federal budget for PV R&D was 81.8 million USD for fiscal year (FY) 2006—a 24 % increase over FY 2005 research funding. About 60 million USD was approved for research and engineering. Under the President's Advanced Energy Initiative, the FY 2007 budget to initiate the new Solar America Initiative amounted to about 150 million USD.

In 2006, state tax credits for PV systems totaled more than 300 million USD and are expected to increase. Nearly 60 % of the state support came from California, which installed nearly 80 % of the U.S. grid-connected systems in 2006.

The following sections of the U.S. NSR provide detailed information and data about the progress of the U.S. PV industry, including cumulative installed power, manufacturing and technology data, R&D news, and policy advancements.

2 The implementation of PV systems

The PV power market is defined as the market of all nationally installed (terrestrial) PV applications with a PV capacity of 40 W or more. A PV system consists of modules, inverters, batteries, and all installation and control components for modules, inverters, and batteries.

2.1 Applications for photovoltaics

PV applications of more than 40 W in the United States grew 33 %, from 105 MW in 2005 to 145 MW in 2006. Applications of PV cover virtually all sectors, from off-grid to on-grid and from commercial / industrial to consumer. In spite of this diversity, grid-connected applications did not begin their high growth rate until 1999 and 2000, when state subsidies became more common.

The sectors are described below:

Off-grid Consumer Sector: Off-grid consumer-sector installations amounted to more than 14 MW in the United States in 2006. This sector consists predominantly of remote PV applications. Specifically, it includes PV for remote residences, boats, motor homes, travel trailers, vacation cottages, and farms where connecting to the electricity grid is not feasible or practical. Most systems are rated at less than 1 kW, have several days of battery storage, and usually serve dc loads. Some larger systems use stand-alone inverters to power ac loads and may include a diesel generator as backup.

Off-grid Commercial / Industrial Sector: This is the second-largest sector of the U.S. PV market, amounting to 23 MW installed in 2006. Telecommunications encompass a wide range of applications, from remote repeaters and amplifiers for all modes of communication, including fiber optics, satellite links, and cable links, as well as small data-link stations via phone, TV, and secure communications throughout the country. Remote PV power systems also serve as sensor power sources and data communication power for a broad range of applications including weather / storm warning; seismic, radiation, and pollution monitors; security phones on highways and parking lots; and traffic monitors. Remote lighting and signals are ubiquitous, with applications ranging from bus stops, remote shelters, parking-lot lights, billboards, highway information / construction signs (replacing small-engine generators), intercoastal navigation aides, and supplemental lighting sources for environmentally friendly corporate headquarters.

Government Sector: PV serves a broad array of applications for local, state, and federal government. These include large PV / diesel hybrid power stations where grid connections are not practical, as well as smaller systems for the types of applications mentioned above. The U.S. Department of Defense funds the installation of about 0.5 MW / year, resulting in more than 5 MW of installed PV systems in the last decade.

In the past, the federal government, in partnership with the Utility Photovoltaic Group (UPVG)—now known as the Solar Electric Power Association (SEPA)—directed thousands of utility installations that amounted to more than 9 MW in 5 years. Several thousand applications have been installed that are “nearly economical” applications. The DOE subsidized these early utility-partnered applications, with an average of 25 % of the project funding coming from federal sources. No SEPA / federal partnered systems were installed after 2002. This early work to develop solar demonstration projects by utilities has been replaced by funding / deployment mechanisms such as state-mandated renewable portfolio standards (RPS) and set-aside funding schemes that voters approve on a state-by-state basis. Typically, a small portion of a customer’s utility payment is directed to a set-aside fund to support the installation of renewable energy systems, e.g., wind or solar systems. Other federal and state programs fund the installation of small, grid-connected systems in schools for education and applications for emergency power production.

On-grid Distributed Sector: Prior to 1999, this sector involved a few early adopters who installed residential and commercial systems connected to the utility grid that amounted to less than 2 MW / year. This sector grew 54 %, from 65 MW in 2005 to more than 100 MW in 2006. PV installation growth was primarily in both the on-grid residential and commercial sectors. The on-grid sector growth is believed to be the result of the growing popularity of state tax credits and rebates, as well as the Federal Tax Credit. California led the way with more than 65 MW of grid-connected systems installed in 2006.

Other important government-related programs and outreach activities included:

- The U.S. PV for Schools program to install PV systems on educational buildings and to increase students' and consumers' awareness about solar energy (federal and state level).

- Renewable energy set-aside programs that allocate funds from customers' utility bills for installing renewable energy systems (state and local level).

Other forms of marketing incentives and deployment techniques included:

- The availability of PV systems as a standard feature for new homes by homebuilders through larger PV system integrators, such as GE Energy, BP Solar, and PowerLight, in certain U.S. home markets.

- Expanded in-store sales of packaged, grid-connected PV systems through big-box retailers such as Home Depot, a major home-improvement retailer.

2.2 Total PV power installed

Table 1 shows the cumulative installed PV power for each sub-market in the United States for 1995 through 2006.

Table 1: Cumulative Installed PV Power in the U.S. by IEA-defined Sub-markets through the End of Each Calendar Year*

Application	'95 MW	'96 MW	'97 MW	'98 MW	'99 MW	'00 MW	'01 MW	'02 MW	'03 MW	'04 MW	'05 MW	'06 MW
Off-grid Domestic	19,3	23,3	27,5	32,0	37,5	43,5	50,5	58,9	67,9	88,0	100,0	114,0
Off-grid Non-Domestic	25,8	30,2	35,0	40,2	46,7	55,2	64,7	77,7	93,7	112,0	133,0	156,0
On-grid Distributed	9,7	11,0	13,7	15,9	21,1	28,1	40,6	63,6	95,6	154,0	219,0	322,0
On-grid Centralized	12,0	12,0	12,0	12,0	12,0	12,0	12,0	12,0	18,0	22,0	27,0	32,0
TOTAL	**66,8**	**76,5**	**88,2**	**100,1**	**117,3**	**138,8**	**167,8**	**212,2**	**275,2**	**376,0**	**479,0**	**624,0**

* IEA sub-markets are categorized for PV power applications above 40 W.

KEY POLICY INITIATIVES

Federal Support of Photovoltaics

President Bush announced the Advanced Energy Initiative in his State of the Union Address in January 2006. He promised more aggressive renewable energy policy and research efforts by the federal government to diversify U.S. energy sources and mitigate climate change, among other goals. In response, the Solar America Initiative (SAI) was created by the DOE to accelerate manufacturing, cost, and commercialization goals for solar energy technologies. The Initiative supports an 80 % increase in funding for PV, from about 82 million USD in FY 2006 to 148 million USD in FY 2007. A majority of the funding is directed at cost-shared research and commercialization efforts with external partners. See Fig. 1 in section 2.5 below to learn more about the aggressive SAI goals. Additionally, federal tax credits for PV went into effect in 2006 and include a 30 % investment tax credit for commercial grid-connected systems and a 30 % tax credit for residential grid-connected PV systems, with an annual cap of 2 000 USD per system.

State Support of Photovoltaics

Because all U.S. electricity generation is an issue of states' rights, all utility policy and regulation comes under state rule. States play an increasingly important role in the deployment of PV. Policy issues related to PV include: restructuring, net metering, on-site generation (residential and commercial), interconnection standards, insurance, taxes, and subsidies. Fourteen states have established clean-energy funds, which are typically funded by a small surcharge on retail electricity rates to promote the development and commercialization of renewable energy technologies. As mentioned previously, many of these subsidies take the form of renewal power set-asides and direct tax credits at local and state levels. In 2006, the total value of these incentives was more than 300 million USD. To learn more about these varied and complex codes, laws, and incentives, visit www.dsireusa.org.

2.3 PV implementation highlights, major projects, demonstration and field test programmes

The Solar America Initiative, announced in 2006, represents the DOE's most comprehensive effort thus far to support PV market development. The two-pronged approach to accelerating markets and bringing the cost of PV to grid parity by 2015 tackles technical and non-technical barriers to market transformation. This initiative is the largest PV commercialization effort to occur in the United States, based on both the (1) scale and complexity of the formal alliances with industry, university, and non-governmental organizations to guide those efforts, and (2) level of accountability by potential partners to perform the necessary work in conjunction with DOE (see section 2.2 for SAI details).

In addition to SAI work, the Solar Program addresses market deployment opportunities in a variety of ways. For example, DOE's Solar Decathlon (www.eere.energy.gov/solar_decathlon/) brings college and university teams from around the world to compete in designing and building houses that demonstrate the benefits of solar technologies. The next Decathlon will occur in Washington, D.C., in October 2007 and promises to be the most exciting event yet, with the inclusion of more international participants. Student teams have been working since the completion of the 2005 Decathlon to prepare for the next event.

According to a report by the Interstate Renewable Energy Council (IREC), U.S. state-supported PV installations grew 36 %, from 63,6 MW in 2005 to more than 101 MW in 2006. In 2006, installations in California, the largest contributor, grew by more than 35 %. The transition to the new California Solar Initiative (CSI)—a 10-year, 3000-MW program to be managed by the California Energy Commission (CEC)—commenced in 2006. One objective of the program is to decrease the subsidy each year, to stimulate lower installed PV systems costs so that PV is "economical" without subsidy in or before 2016. The original bill allotted 2,9 billion USD for solar energy rebates in California over 10 years. The goal is to increase the solar capacity installed on California rooftops by 3 000 MW by 2017. The initial PV incentive levels were set at 2,80 USD / watt effective January 1, 2006, to be reduced by an average of about 10 % annually. The latest bill in support of the CSI added another 150 million USD to the Public Utility Commission's (PUC's) proposed 3,2 billion USD. The increased funding will provide 50 million USD for R&D and 100 million USD in incentives for solar thermal technology. Other critical elements of the initiative involve systems of less than 100 kW, for which the PUC approved a 2,50 USD / watt subsidy for residential and commercial projects and 3,25 USD / watt for systems installed by governments and non-profits. According to the California PUC Web site, the CSI uses performance-based incentives for larger systems and "expected performance-based buy-downs" for smaller systems as the basis for distributing the allocated funds, in lieu of upfront rebates. For more information on the program, visit the California PUC Web site at www.cpuc.ca.gov.

New Jersey's subsidized installations grew 223 % to 17,9 MW from 2005 to 2006. The revised New Jersey renewable portfolio standard (RPS) requires utilities to obtain 22,5 % of delivered power from qualifying renewable energy sources by 2021. The new RPS targets also include a 2,12 % solar set-aside estimated to be about 1 500 MW of PV by 2021. In 2006, the New Jersey Board of Public Utilities determined that the current PV rebate program is not appropriately designed to meet the solar targets established in the bill and is looking at how best to shift from rebates to a performance-based approach. To learn more about the options the Board is considering, visit www.njcleanenergy.com.

It is likely that the adoption of performance-based incentives in California and New Jersey, the two largest PV markets in the United States, is the beginning of a growing trend around the country away from the more common upfront rebates based on the installed PV system capacity. Historically, the "rebate approach" has been used to offset the upfront installation cost of a system. Innovative subsidy programs that do not tie incentives to system size or manner of deployment are making the installation of building-integrated PV and large-scale solar farms more appealing. These incentives are being devised to encourage the design and construction of systems that maximize energy output. Economies of scale are also driving the development of larger PV system installations. In 2006, the United States saw several large systems completed (Maycock, December 2006) in Massachusetts (500 kW in Brockton), California (910 kW in Oakland for the U.S. Postal Service), and Arizona (375 kW at the Luke Air Force Base). In addition, SunEdison announced the development of an 18-MW PV system, the world's largest PV system installation, at a Nevada Army base (Maycock, March 2006). High-profile companies are also "going green" and raising the visibility of solar. In October 2006, the Internet search-engine company, Google, announced plans to build a 1.6-MW system at its corporate headquarters.

As more states implement and expand their PV subsidy programs, and the U.S. 30 % tax credit (started in 2006) is implemented, it is expected that the 35 % sustained growth for the U.S. grid-connected market will continue.

State PV Assistance Programs
The number of states that are implementing subsidy programs for implementing clean energy technologies is growing annually. These funds are commonly used to incentify the purchase of PV systems (rebates), as well as for renewable energy education and outreach, research, and establishing "green-pricing" programs. Ultimately, these assistance programs will grow the solar industry and diversify the energy sources in progressive states.

Highlights of major state-level programs include the following:

California: Prior to the California Solar Initiative, one program initiated by the State of California offered cash rebates of 4,50 USD / W to residential and commercial customers who installed grid-connected PV systems on investor-owned utility grids. These installations amounted to 1,4–1,6 MW in 2001, 8,1 MW in 2002, 12,3 MW in 2003, 18,8 MW in 2004, 20

MW in 2005, and 40 MW in 2006. The cash subsidy was reduced each year and reached 2,50 USD / W in 2006. Cumulative installations of nearly 100 MW have occurred under the direct-subsidy program. In its ongoing effort to diversify energy sources and minimize carbon emissions, California also has a program of renewable power set-asides administered by the California PUC. More than 30 MW were installed by the four key utilities: Pacific Gas and Electric, Southern California Edison, San Diego Gas and Electric, and Southern California Gas Company. Ten cities in California installed 10 MW of PV. In 2006, 71 MW (nearly 50 % of the total U.S. market) was installed in California and contributes to a cumulative 220 MW of PV installed in the state. More than 700 million USD has been invested in grid-connected PV systems in California.

Arizona: More than 12 MW of PV systems have been installed during the last 10 years. Over 9 MW of PV systems were installed in 2002–2006.

New Jersey: New Jersey is implementing one of the most aggressive PV support programs in the United States. More than 100 million USD has been appropriated for the program. About 2 MW of PV was installed in New Jersey in 2004 and increased to 5,5 MW in 2005. In 2006, about 18 MW of PV was installed in the "Garden State." New Jersey is expected to continue its explosive growth in the coming year, and many other progressive states are watching the evolution of New Jersey's RPS as a model for their renewable energy policy.

New York: New York has legislated more than 150 million USD to support solar industry growth, new installations, and studies to accelerate commercialization of PV. New York recently increased the PV subsidy to 5,00 USD / W for grid-connected systems. Estimates from IREC indicate that 2,7 MW were installed in New York in 2006.

Massachusetts, Texas, and Oregon: Each state reported about 0,5 MW of installed PV, and these programs are expected to continue growing. The three states use a combination of renewable portfolio standards and tax credits to incentify system installation. In addition, they all supported the development of state projects for demonstration.

North Carolina: North Carolina provides a 35 % tax credit for PV system installations. After many years of struggle, net metering is now mandated by law in North Carolina. Although in the "other" category, North Carolina joins the states with a state tax credit and net metering. Coupled with the federal 30 % subsidy (limited to 2,000 USD for residential systems), states like North Carolina are expected to experience dramatic growth in the 2006–2007 timeframe.

For details on incentive programs throughout the United States and the federal PV tax credits, visit the Web site at www.dsireusa.org.

2.4 Highlights of R&D

The three areas of Solar Program-sponsored PV research, development, and demonstration are the following: fundamental research, advanced materials and devices, and technology development. Below are brief descriptions of these areas and selected 2006 highlights.

Fundamental Research

Fundamental Research investigates the physical mechanisms of charge-carrier transport, band structure, junction formation, impurity diffusion, defect states, and other physical properties of PV materials and devices, as well as the identification and development of processes for fabricating PV materials and devices. Among the research topics are innovative ideas and technologies with the potential to “leapfrog” current approaches, leading to new, non-conventional concepts that could dramatically improve cost effectiveness in the long term.

> July 7, 2006, marked the ribbon-cutting ceremony for National Renewable Energy Laboratory's new Science & Technology Facility. The 71 000-square-foot, state-of-the-art facility is designed to help accelerate the development and commercialization of promising new energy technologies, particularly in solar, hydrogen, and building-related energy technologies. The facility has space for 75 full-time researchers and features an 11 500-square-foot Process Development and Integration Laboratory (PDIL), which will allow NREL and industry researchers to work together to develop new PV manufacturing processes. This cooperative research will help reduce the time it takes to move new technologies from the laboratory bench to commercial manufacturing.

The following are Fundamental Research topics and sample 2006 accomplishments.

Measurements and Characterization—Provides test, measurement, and analysis support and research for the DOE Solar Program, including national laboratories, external research partners in university and industry laboratories, and PV manufacturers.

> Completed capability to evaluate multiple-junction concentrator cells and modules to 1 000X with the lowest possible uncertainty.

> Investigated local open-circuit voltage and current flow in amorphous and nanocrystalline mixed-phase silicon solar cells.

Electronic Materials and Devices—Carries out research in semiconductor materials, device properties, and fabrication processes to improve the efficiency, stability, and cost of PV.

> Made rapid performance improvements in crystalline silicon heterojunction solar cells with amorphous silicon (a-Si:H) layers deposited by hot-wire chemical vapor deposition. The research team achieved an NREL-confirmed conversion efficiency of 17,83 % for a 1-square-centimeter cell with both a front heterojunction emitter and a back heterojunction contact fabricated entirely below 200 °C at NREL. This is the best published cell efficiency on a p-type Si wafer by the a-Si:H / c-Si heterojunction technology.

> Fabricated high-efficiency (19,52 % confirmed) copper indium gallium diselenide (CIGS)-based solar cells using a single-layer, NREL-developed, chemical-bath-deposited CdZnS buffer layer. NREL has been the world leader in fabricating the most-efficient CIGS thin-film solar cells since 2002.

Crystalline Silicon Project—Directs fundamental crystalline silicon R&D involving universities and national laboratories.

> The Georgia Institute of Technology developed and applied its PV module manufacturing cost model in conjunction with the Solar Advisor Model from NREL to show that 18–20 %-efficient low-cost cells with screen-printed contacts using 100- to 200-μm-thick c-Si wafers can reduce the levelised cost of electricity to 0,05–0,10 USD / kWh. Georgia Tech also achieved a cell efficiency of 17,6 % (confirmed by Fraunhofer ISE) on 149 cm^2 float-zone Si by controlling the contact firing process.

> North Carolina State University refined its near-field scanning optical microscopy for the nano-characterization of PV materials. This requires correspondingly higher spatial resolution

instrumentation and techniques to study the role of finer, less active structural defects on device performance. Imaging of the cell performance within the vicinity of these structural defects allows for near-field photocontrast mapping of features smaller than 200 nm.

High-Performance Photovoltaics—Explores the ultimate performance of PV technologies, aiming to approximately double their sunlight-to-electricity conversion efficiencies.

Boeing Spectrolab demonstrated a 40,7 %-efficient GaInP / GaInAs / Ge cell that was verified by NREL at 236 suns. Researchers have been working toward the "40 % barrier" for the past two decades. In the 1980s, multijunction solar cells achieved about 16 % efficiency, and NREL broke the 30 % barrier in 1994. Today, most satellites use these multijunction solar cells, and Spectrolab, a subsidiary of The Boeing Company, recently produced its two millionth solar cell using this multijunction technology. The new Spectrolab cell, developed with DOE funding, could lead to more affordable solar power systems on Earth, costing as little as 3 USD / watt to install and producing electricity at a cost of 0,08 to 0,10 USD / KWh.

Researchers investigated the design of shallower acceptors in ZnO. They proposed new concepts to overcome p-type doping difficulty in wide-gap semiconductors such as ZnO, which is an important transparent conducting oxide for solar cells. The researchers showed that by manipulating the wavefunction character of the defect states, they can design defect complexes that can significantly lower the acceptor transition energy levels, thus providing a new opportunity to make p-type ZnO.

Solar Resource Characterization—Addresses solar resource assessment including access to data and characterization of the solar resource.

The NREL Pyrheliometer Comparison (NPC) was conducted at the Solar Radiation Research Laboratory (SRRL) September 25, 2006, through October 6, 2006. Calibration traceability to the World Radiometric Reference (WRR) is determined by the measurements from seven electrically self-calibrating absolute cavity radiometers maintained by the World Radiation Center in Davos, Switzerland. International Pyrheliometer Comparison in Davos transfers the WRR to regional and national calibration centers. NREL's reference radiometer group is the basis for each NPC and transfers the WRR to participants who bring their radiometers to the SRRL. The 2006 total was 34 participating radiometers operated by the 16 participants, including the National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, Environment Canada, Lockheed Martin, Sandia National Laboratories, and Pacific Northwest National Laboratory.

Environmental Health and Safety (EH&S)—Minimizes potential EH&S impacts associated with current and future PV energy systems and applications.

Brookhaven National Laboratory established a laboratory for studies on recycling of spent PV modules and manufacturing scrap, using hydrometallurgical separation technologies. Also, a patent application was approved related to separating Cd from Te in the CdTe recycling processes.

Advanced Materials and Devices

The Advanced Materials and Devices effort carries out research in semiconductor material properties, device mechanisms, and fabrication processes to improve the efficiency, stability, and cost of PV. The effort focuses on thin films, module manufacturing methods, and module reliability. The following are Advanced Materials and Devices research areas and sample 2006 accomplishments.

Thin Film PV Partnership—Directs subcontracted and collaborative R&D in thin films including CIS and CIGS, CdTe, amorphous silicon, and film silicon.

The Thin Film Center of Excellence (Institute of Energy Conversion, University of Delaware) provided both valuable insights and services. The Center implemented vapor transport deposition of CdTe solar cells and fabricated and analyzed 450 solar cells. A significant effort of their work has been to characterize the role of impurities (in the CdTe absorber and during "contacting") on cell performance.

Two Technology Partners expanded manufacturing facilities in the United States (First Solar, 85 MWp; and Uni-Solar, 60 MWp). A third Technology Partner, Global Solar, announced plans to expand in 2007.

Production of thin films in the United States grew from 12 MWp in 2003 to an estimated more than 70 MWp in 2006.

PV Manufacturing R&D—Assists the U.S. PV industry through cost-shared manufacturing R&D.

Completed the development (achieved manufacturing-line-ready status) of at least three in-line diagnostic processes initiated in FY 2002 awards from the In-Line Diagnostic, Intelligent Processing (IDIP) Solicitation, with at least five of the U.S. PV industry partnerships involved in the IDIP solicitation having reported a minimum of 22 in-line diagnostic processes that have been implemented on U.S. PV production lines.

PV Module Reliability R&D—Develops and applies advanced measurement techniques, diagnostic methods, and instrumentation to help mitigate degradation, reduce module costs, and improve performance. To conduct these activities, NREL and Sandia develop and apply advanced measurement techniques, diagnostic methods, and instrumentation. The intent of this R&D is to optimize the time and funding applied to advancing module technologies from the prototype to the commercial production stage, with respect to meeting acceptable performance, reliability, and cost requirements.

Upgraded and maintained accelerated module testing capabilities (e.g., environmental chamber upgrades, new hail gun) essential to industry partners, and made progress toward becoming an accredited Certified Testing Body Testing Laboratory (quality system development) in a Cooperative Research and Development Agreement with Underwriters Laboratories.

Collaborated with numerous industry partners to develop new encapsulants, provide adhesion and water vapor transmission values, perform water ingress modeling, and infrared imaging for cracked cells and shunt problems.

Inverter and Balance-of-Systems (BOS) Development—Supports engineering advancements through characterization and validation feedback of newly developed power electronics and BOS hardware and establishes suitability for incorporation of new inverters, controllers, and BOS into integrated systems.

Assessed 15 alpha and beta inverter and controller prototypes for conformity to utility interconnection requirements, performance objectives, and manufacturing objectives. The "High-Reliability Inverter Initiative" continued toward higher reliability at no increase in unit cost, namely, via the improvement of meantime between failures to more than 10 years. This advance has a significant positive impact on calculated levelised cost of energy of PV systems. Micro-inverter development unveiled significant design advances to address thermal and environmental failure modes.

Technology Development

The Technology Development activity advances PV performance and systems engineering, improves systems reliability, and develops technology suitable for integration into residential and commercial building structures. The following are Technology Development research areas and sample 2006 accomplishments.

PV Systems Engineering—Characterizes performance and reliability of emerging PV technologies, assists with development and implementation of codes and standards, and provides world-class solar irradiance capabilities, measurements, and standards.

> The 2005 National Electrical Code (NEC) was published with the 42 changes proposed by the SNL "Industry Forum" with new allowances for ungrounded PV arrays and improved but relaxed disconnect requirements. Work on the 2008 NEC progressed to address new technology issues related to safety and installations.
>
> Los Angeles Department of Water and Power revised its solar energy rebate program from one providing a rebate amount based on system size to one based on the estimated energy output predicted by NREL's PVWATTS. (http://rredc.nrel.gov/solar/codes_algs/PVWATTS/) Consequently, rebate amounts will now depend on parameters that determine energy production: size, tilt, azimuth, fixed or tracking, and location of the PV system.

System Evaluation and Optimization—Provides laboratory and field-test information to establish the performance and reliability of current PV systems and identifies opportunities for improved system design and component integration in next-generation systems.

> Operated the PV System Optimization Laboratory, which can perform detailed performance and long-term reliability research on 14 separate nominally 3-kW PV systems with multiple array/inverter combinations. Numerous new module and inverter technologies are being studied. Working with Sandia, both General Electric and Xantrex are currently active in Phase III of the "High-Reliability Inverter Initiative" and have extensive and critically timed commercialization plans for the products developed out of this program. Xantrex expects to use the fundamental high-reliability design as a basis for its next-generation family of products. GE plans to vertically integrate its newly acquired PV module manufacturing capabilities with the new inverter development into its existing new-construction housing market.

Domestic PV Applications—Provides a focal point for DOE activities through developing projects, disseminating information, promoting public awareness, managing subcontracts, and providing technical assistance.

> The National Western Stock Show in Denver, Colorado, is recognized broadly as one of the foremost livestock shows and rodeos in the world. The Stock Show celebrated its 100th anniversary in 2006 and was heavily advertised in the local and regional media, leading to record attendance of more than 700 000. The event marked NREL's 11th year of hosting free workshops on renewable energy for the farmer, rancher, and homeowner. About 600 people attended these workshops. Farmers and ranchers, particularly in the large, remote ranches of the western United States, are pioneers in using PV and other renewables and are hungry to learn of the newest technologies.

Building-Integrated PV—Fosters widespread acceptance of PV-integrated buildings by overcoming technical and commercial barriers and facilitating the integration of PV into the built environment through technology development, applications, and key partnerships.

Published a technical report detailing the 2005 Solar Decathlon university competition. The full report, which gives an overview of the competition, including final results, team strategies, and detailed descriptions of each home, is available on the Solar Decathlon Web site, www.eere.energy.gov/solar_decathlon. Early in 2006, DOE announced the selection of 20 teams for the 2007 Solar Decathlon, a competition to design and build energy-efficient solar homes. DOE will award each team 100 000 USD over the next two years. Sixteen of the teams hail from 13 states—California, Colorado, Georgia, Illinois, Kansas, Maryland, Massachusetts, Michigan, Missouri, New York, Ohio, Pennsylvania, and Texas—and the remaining four are located in Puerto Rico, Canada, Germany, and Spain. This will be the first time that a team from Germany has participated in the competition.

PV System Analysis—Performs systems performance and cost modeling, market / value / policy analysis, and benchmarking projects.

Expanded the number of default markets/systems included in the Solar Advisor Model and expanded partnered activities on commercial and utility-scale systems to further refine determinations of life-cycle cost, system reliability, and system availability. In addition, developed a working version of the Solar Deployment Systems model with an initial set of scenarios and expanded work on PV value analysis to include both identifying best practices and information sharing, aimed at helping to inform state-level policymaking.

Regional Experiment Stations—Provides technical support to the DOE Solar Program, including reducing systems costs, improving systems reliability, improving system performance, and removing barriers to deployment.

Four inverters were placed in service for long-term performance testing at two locations, the Southeast Regional Experiment Station in Cocoa, Florida, and the Southwest Regional Experiment Station in Las Cruces, New Mexico.

Technical assistance and installer workshops to the industry and users have resulted in an evolving design review and approval standard that provides guidance for uniform designs and system documentation. This activity promotes a level of quality recognized and practiced by other industries that develop products in successful markets and advances domestic and international standards and codes.

Outreach and Technology Transfer

The increased attention on clean energy technologies and a national push to reduce U.S. dependence on foreign oil brought many high-level visitors to the national laboratories in 2006. The roster of visitors included: President George Bush, Energy Secretary Samuel Bodman, and U.S. Senator Ken Salazar; dignitaries and industry representatives from China, France, India, Japan, Jordan, and Taiwan; and representatives from a range of U.S.-based organizations, such as building material manufacturers, financial analysts, major trade associations, and national TV networks.

2.5 Public budgets for market stimulation, demonstration / field test programmes and R&D

Table 2 shows the federal and state R&D funding levels at 122 million USD for FY 2006 (calendar year [CY] 2005–2006). The Congress passed a new energy bill that included a 30 % tax credit for PV systems. The program was implemented starting in January 2006. The federal subsidy was in addition to the state incentives. The federal government and U.S. Congress primarily support emphasis on research, development, and engineering activities by the Solar Program and its national laboratories. However, with the implementation Market Transformation portion of the Solar America Initiative in 2007, about 12 million USD in funding awards over a five-year period is proposed for demonstration and deployment activities by strategic partners of the Solar Program.

State tax-credits for PV systems totaled more than 300 million USD and are expected to increase in 2007. Nearly 60 % of the total state support funding occurred in California, making it the largest PV market in the United States, accounting for nearly 80 % of the installed grid-connected PV systems in 2006. The effect of the federal tax credit for 2006 is not included in these calculations.

The estimated total for the federal-level market assistance is 140 million USD based on the following assumptions:

- If federal credits were applied to the 60 MW of commercial systems installed in 2006 (assuming 7,00 USD / W average cost @ a 30 % credit), the federal portion of the cost-share would be valued at more than 120 million USD.

- 40 MW of residential grid-connected systems at an average size of 4 kW / system would be equivalent to 10 000 residences at 2 000 USD tax credit per system would be 20 million USD.

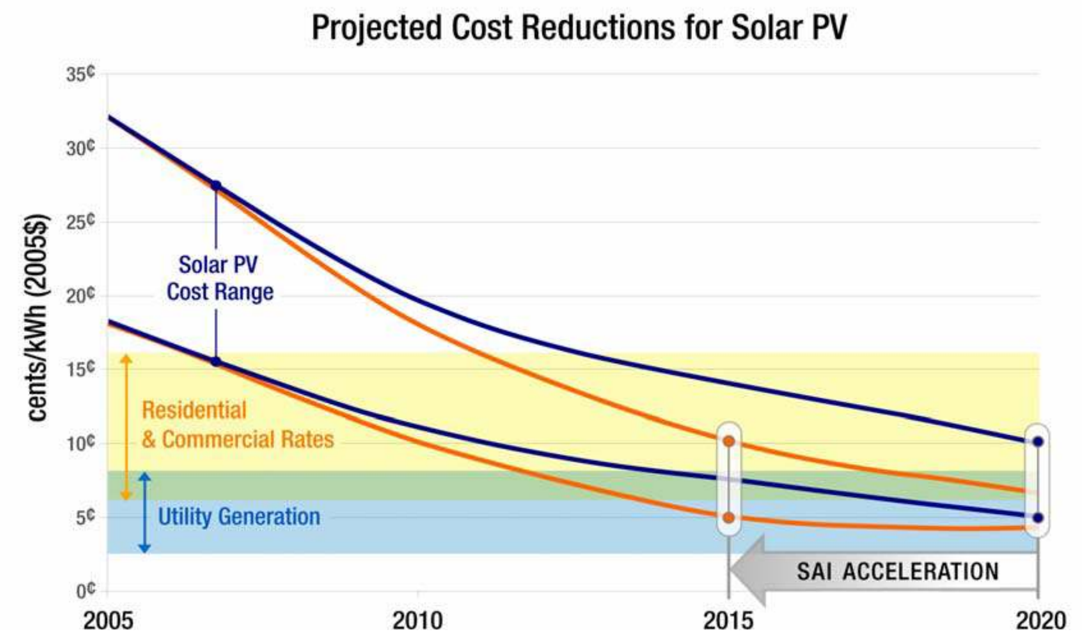
Table 2: Public Budgets for R&D, Demonstration / Field Test Programmes, and Market Incentives (in million USD)

	R&D	Demo / Field Test	Market
National/federal	81,8	--	140,0 (est)
State/regional	40,0	3,0	300,0
Total	121,8	3,0	440,0

An important feature of DOE research in solar technologies is the goal to fund high-risk, high-return research, development, and testing of PV components and systems. These efforts are undertaken in partnership with the PV industry and universities to bring clean, affordable electricity to the marketplace.

In 2006, PV generated excitement in the United States, with advances in state-level policies in favor of solar and other clean technologies. Public support for PV appears to be increasing as well, as evidenced by support of the PV incentives mentioned later in this report. Early in the year, the Solar America Initiative (SAI) was announced in support of the President's Advanced Energy Initiative, laying the groundwork for the SAI to be rolled out in FY 2007. The DOE Solar Program leads the SAI.

The primary mission of the SAI is to reduce the cost of PV technologies to the point that PV-generated electricity is cost competitive with conventional electricity sources by 2015. As Fig. 1 indicates, the 2015 PV goals are 0,08–0,10 USD / kWh in the residential sector, 0,06–0,08 USD / kWh in the commercial sector, and 0,05–0,07 USD / kWh in the utility sector. Achieving these goals will require reducing installed PV system costs by 50–60 % between 2005 and 2015, from 5,50-8,50 / Wp to 2,25–3,50 / Wp in 2005 USD. This initiative accelerates the achievement of these goals by 5 years.



Market Sector	Current U.S. Market Price Range (¢/kWh)	Cost (¢/kWh) Benchmark 2005	Cost (¢/kWh) Target 2010	Cost (¢/kWh) Target 2015
Residential	5.8-16.7	23-32	13-18	8-10
Commercial	5.4-15.0	16-22	9-12	6-8
Utility	4.0-7.6	13-22	10-15	5-7

Figure 1: SAI brings increasingly cost-competitive PV systems to market between now and 2015, with benefits accruing from the early SAI years. (DOE)

The Solar Program made a budget request and obtained 148 million USD in FY 2007 (CY 2006) for the SAI. This is a 65 million USD (78 %) increase over the FY 2006 appropriation, to accelerate the development of PV technologies.

The SAI enhances DOE's business strategy of partnering with U.S. industry to accelerate commercialization of improved PV systems that can meet aggressive cost and installed capacity goals. The Initiative is split into two areas of emphasis:

Research and development emphasizes PV component R&D and system designs, including low-cost approaches for manufacturing.

Market Transformation emphasizes non-R&D activities aimed at reducing market barriers and promoting market expansion and complements the core R&D and engineering activities of the SAI.

To accelerate attainment of systems goals, SAI will employ public-private partnerships to pursue component and system technologies. The industry-led project teams will demonstrate manufacturing approaches that deliver low-cost, high-reliability commercial products. Ultimately, by 2015, the efforts of the SAI will contribute to making PV electricity cost competitive with traditional energy sources in all U.S. sectors without government support.

By 2015:*

PV electricity will be cost-competitive in all sectors—residential, commercial, and utility—without government support.

PV will provide approximately 5–10 GW of electricity generating capacity in the United States—roughly the current electricity generation capacity of New Mexico—enough to power 1–2 million households.

U.S. industry grows from 1 billion USD / year to 10 billion USD / year, creating 30 000 new jobs for American workers.

Roughly 10 million metric tons per year of CO_2 emissions will be avoided.

By 2030:*

PV will provide approximately 70–100 GW of electricity generating capacity in the United States—roughly the current electricity generation capacity of California and New York combined—enough to power 10–20 million households.

PV systems provide roughly 40 % of all new electric capacity in the United States.

U.S. industry grows from 10 billion USD / year to 30 billion USD / year, creating 80 000 new jobs for American workers.

Roughly 150 million metric tons per year of CO_2 emissions will be avoided.

** Estimates include SAI-PV benefits only. The addition of SAI-concentrating solar power activities at FY 2007 funding levels raises these benefit estimates by roughly 10 % in both 2015 and 2030 (Wilkins, April 2006).*

The Solar Program is in the early stages of a selection process to choose participants in both the Technology Pathway Partnerships and Market Transformation areas of the Initiative. Funding awards are anticipated to be made during the spring and summer of 2007 (www.eere.energy.gov/solar/solar_america/).

3 Industry and growth

3.1 Production of feedstock and wafers

Table 3 shows U.S. production of feedstock: polycrystalline silicon, single-crystal silicon, edge-defined film-fed growth (EFG) wafers, and solar-grade silicon feedstock. At the time of this report, prices were not available for each feedstock producer. However, according to Prometheus Institutes' report, 2006 Polysilicon: Supply, Demand, & Implications for the PV Industry (2006, www.prometheus.org), the average silicon price in 2005 was 45 USD / kg and the estimated average silicon price in 2006 and 2007 was 55 USD / kg and 60 USD / kg, respectively.

Table 3: Production and Production Capacity Information for the Year for Silicon Feedstock, Ingot, and Wafer Producers

Producers	Process & Technology	Total Si Production (MT)	Maximum Production Capacity *(tonnes / year)*	Solar-grade Si (MT unless specified) *Part of total Si production*	Product Destination (Solar-grade Si)	Price (Ave. Estimate*)
Hemlock Semiconductor Corp.	Polysilicon feedstock / Siemens	*6 800*	*10 000*	2 000	500 US 1 500 Export	55*
REC Advanced Silicon Materials	Polysilicon feedstock / Fluid Bed Reactor (FBR)	*2 700*	*3 000*	0	0	55*
REC Solar Grade Silicon	Polysilicon feedstock / Siemens	*2 100*	*2 800*	2 100	800 US 1 300 Export	55*
MEMC	Polysilicon feedstock / Siemens	*1 700*	*3 800*	400	400 US	55*
Mitsubishi Polysilicon America	Polysilicon feedstock / Siemens	*1 200*	*1 250*	100	100 US	55*
Solar-grade scrap (from semiconductor industry)	Polysilicon feedstock			500		55*
Reject wafers from IC industry	Wafers			18 MW	18 MW US	
Solar World America	Wafers			40 MW	15 MW US 25 MW Export	
BP Solar	Wafers			40 MW	15 MW US 25 MW Export	
Evergreen Solar	Ribbon			14 MW	14 MW US	
Solec International (export to Sanyo)	Wafers			30 MW	30 MW Export (Sanyo)	

3.2 Production of photovoltaic cells and modules

Module manufacturing, as defined by the industry, is where—in the process of producing PV modules—the encapsulation is done. A company may also be involved in producing ingots, wafers, or processing cells, in addition to fabricating the modules with frames, junction boxes, and other components. The manufacturing of modules may only be counted to a country if the encapsulation takes place in that country.

Table 4 shows the 2006 U.S. production and peak capacity quantities of PV cell and module manufacturers. Two thin-film manufacturers made significant increases in production. The major increase in production came from First Solar's manufacturing of cadmium telluride thin-film modules for export to Europe. United Solar Ovonics also increased production of its amorphous silicon on stainless-steel substrate.

Table 4: Production and production capacity information for the year for each manufacturer

Cell/Module Manufacturer	Technology (sc-Si, mc-Si, a-Si, CdTe)	Total Production (MW) Cell	Module	Concentrators	**Maximum** Production Capacity (MW / yr) Cell	Module	Concentrators
Crystalline							
Solar World (US)	sc-Si	*35*	*35*		*60*	*50*	
BP Solar (US)	mc-Si	*25,6*	*25*		*30*	*30*	
GE Energy	sc-Si	*22*	*22*		*25*	*25*	
Schott Solar	EFG ribbon	*13*	*13*		*15*	*15*	
Evergreen Solar	String ribbon	*13*	*13*		*15*	*15*	
Thin-Film							
United Solar	a-Si	*28*	*28*		*40*	*40*	
First Solar	CdTe	60	60		75	75	
Global Solar	CIS	2,5	2,5		3	3	
Others		2	2		3	3	
Concentrator							
Others				*0,5*			*1*
TOTALS		**201,1**	**200,5**	**0,5**	**266**	**256**	**1**

Additional Manufacturer Information
The following are select 2006 highlights of some of the previously mentioned companies.

SolarWorld (formerly Shell Solar)

SolarWorld Industries America owns the two U.S. production facilities formerly run by Shell Solar Industries: a silicon crystal-growing production site in Vancouver, Washington, and the integrated production facility of solar silicon wafers, cells, and modules in Camarillo, California. In 2006, SolarWorld completed expansion work in the newly acquired Camarillo, CA, production facilities, purchased from Shell Solar. With the acquisition of the Camarillo facility, the company expected to double U.S. solar cell production over that of the previous year. SolarWorld's PV production is fully integrated, from the production of ingots to encapsulated modules. The company purchases "solar-grade" polysilicon, melts it, and uses the latest 6- to 8-inch-diameter pullers to produce single-crystal silicon ingots. The ingots are then sliced into 200-µm-thick wafers using wire saws. The ingot and wafer production are in the company's Washington plant. The wafers are processed into cells and modules in an automated plant in Camarillo, CA. Modules are certified to all standards including Institute of Electrical and Electronics Engineers (IEEE), ISPRA, and Underwriters Laboratories (UL).

BP Solar (US) is the world's third-largest producer of cast-ingot multicrystalline silicon cells and modules behind Kyocera and Sharp. BP Solar's U.S. plants produced 26,5 MW of cells and 25 MW of modules in 2006. The company purchases solar-grade polysilicon scrap and new silicon to make all of its wafers, cells, and then modules. BP Solar manufactures modules with power outputs of 150–300 W and offers a standard 25-year warranty on all products.

GE Energy

GE Energy produces single-crystal cells and modules from rejected wafers of the semiconductor industry. In 2006, GE produced 22 MW of single-crystal silicon cells and modules. During the summer of 2006, GE Energy's solar division was selected for one of the largest solar power projects in Asia—a 3-MW facility being developed at Yong Gwang, Korea. GE will supply its 200-W solar power modules for the project, along with BOS equipment. KD Solar Co., Ltd., of Seongnam City, Korea, the primary contractor for the project, is responsible for engineering, system design, and installation. The solar installation is being developed by Korea Hydro Nuclear Power Co., which supplies more than 40 % of Korea's power. Electricity generated by the Yong Gwang solar power plant will be transmitted to the national grid.

This represents GE's largest single order for solar equipment globally to date. The GE solar equipment for the Yong Gwang project will be manufactured at the company's facilities in Newark, Delaware and will be shipped to the project site over the next year. The new solar installation is expected to enter commercial service in 2008. The Yong Gwang solar project marks GE's expansion in the renewable energy business in Korea.

SCHOTT Solar (Formerly ASE GmbH)

In 2006, SCHOTT Solar produced and shipped 13 MW of cells and modules in the United States. SCHOTT Solar also produced 24 MW of wafer slices in the United States, which were shipped to SCHOTT Solar GmbH for its cell manufacturing facilities in Germany. SCHOTT Solar's U.S. division gained attention for its role in developing a solar demonstration project. Using SCHOTT Solar-supplied ASE 300 modules manufactured at the company's production facility in Billerica, Massachusetts. Global Solar Inc. designed, built, and now maintains the Brockton Brightfield located in Brockton, MA. These solar panels will generate an estimated 535 MWh of electricity annually—enough energy to power about 70 homes. The project serves as a renewable energy education tool for the community of Brockton.

United Solar Ovonics (Uni-Solar)

In January 2006, Uni-Solar announced plans to expand solar module manufacturing capacity to 300 MW by 2010. The first phase of the expansion plan included the construction of a third manufacturing facility with an annual capacity of 50 MW, expected to be operational in late 2007. Considered the world's largest thin-film plant, Uni-Solar manufactures solar modules at a 25–30 MW production facility in Auburn Hills, Michigan, and completed construction of a second 25–30 MW production facility (also in Auburn Hills) in 2006. The company garnered national attention when President Bush toured the plant to promote the Advanced Energy Initiative in 2006. United Solar produced 28 MW of building-integrated PV (BIPV) products in its Michigan facilities in 2006.

Evergreen Solar

In 2006, Evergreen Solar, Inc., a manufacturer of solar power products with its proprietary, low-cost string-ribbon wafer technology, produced 14 MW of string-ribbon cells and modules in the United States. According to a Businesswire article, the company took steps to accelerate the goal of bringing the cost of solar to grid parity with other forms of electricity by forming a polysilicon supply agreement that will allow its EverQ partnership to increase solar module production capacity from about 30 MW in 2006 to about 300 MW by 2010 (and possibly as early as the second half of 2009). In conjunction with the execution of the supply agreement, Evergreen Solar, Q-Cells AG of Germany, and Renewable Energy Corporation (REC) of Norway become equal partners in EverQ. In accordance with the terms of the agreement, REC agreed to supply EverQ with a total of 7 400 metric tons of granular polysilicon over seven years beginning in 2008. Shipments of about 400 metric tonnes are expected to begin in the second half of 2008 and increase to 1 200 metric tonnes annually by 2010, continuing through 2014. These shipments are in addition to the 190 metric tonnes that REC is currently supplying EverQ annually under an existing arrangement. Evergreen Solar plans to continue marketing and selling all modules manufactured by EverQ under the Evergreen Solar brand, as well as managing customer relationships and contracts.

Observers believe the intrinsic 7–9 grams / watt capability of the Evergreen string-ribbon process, coupled with Q-Cells' wafer processes, will lead to a major (50 %) reduction in the silicon required to make a PV cell.

First Solar, LLC

First Solar produces CdTe modules using a continuous close-spaced sublimation process to deposit the CdTe on glass coated with a transparent conducting oxide. Modules measuring 24 in. x 48 in. have been produced with efficiencies over 9 %. The company transitioned to an aggressive growth phase in 2005 with the production of more than 20 MW per year. First Solar is in the final stages of completing its 100-MW CdTe coating line and a 25-MW cell and module production line. The coating line and the first stage of the cell and module line (about 10 MW) were to be completed in late 2000. After more than a year of "fine-tuning," production from the new plant was delayed until 2003. In 2006, the expanded plant produced 60 MW of CdTe modules. Expansion plans to 100 MW in the United States, 100 MW in Europe, and 100 MW in Malaysia have been announced. The company also implemented the industry's first comprehensive environmental product life-cycle program, which includes pre-funded end-of-life product reclamation and recycling. In addition to the R&D and expansion activities, First Solar completed an initial public offering in late 2006.

Amonix

Amonix has advanced the "point-contact" cell into a production-model, 24 %-efficient concentrator cell at 250–350 times concentration. During 2002, Amonix produced about 500 kW of its 20-kW system using its design for all components. The systems operated with installed efficiency above 18 %, which was a record for PV. Amonix increased production capacity to 1 MW / year in the last half of 2002 and shipped 500 kW in 2006.

Table 5 illustrates average PV module prices in the United States. Factory PV module prices increased slightly, from 3,60 USD / W_p in 2005 to 3,75 USD / W_p in 2006. These prices are for customers that are on a "scheduled-release" contract.

Table 5: Average PV Module Prices (USD / W_p)

Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Price*	4,00	3,75	4,00	4,15	4,00	3,50	3,75	3,50	3,25	3,00	3,50	3,60	3,75

*Estimated by PV Energy Systems, Inc.

3.3 Manufacturers and suppliers of other components

The cost for BOS components for a PV system is as much, if not more, than the PV modules. Nearly one half of the installed PV systems involve stand-alone systems that have storage (usually deep-cycle lead-acid batteries) and charge controllers that control charging of the battery to extend the service life by optimum charging and by preventing the load from exceeding the design discharge levels. Most stand-alone systems have direct current (dc) loads and use 12- and 24-volt battery banks. When alternating current (ac) loads are used, the stand-alone system has an inverter. Some stand-alone systems are designed as hybrids with diesel or gasoline generators as an integral part of the system.

More than 100 MW of grid-connected systems were installed in the United States in 2006. The systems use all types of PV modules and are usually connected to an inverter that permits the PV system to first serve the building's load and then to send excess power to the utility grid. When grid power is not available, the inverter may be designed to switch to "standby" and power the local load from energy stored in a battery bank. The U.S. utility-interactive market now surpasses all other markets for new installations.

PV Inverters

More than 15 inverter manufacturers serve the U.S. market, and some inverters are branded to be sold under several different names. A large percentage of the inverters used in the United States are now imported, with manufacturing of inverters primarily an international activity. The SMA inverter market share for 2006 was reported to be greater than 60 % for total numbers of grid-interactive inverters. The dramatic increase in the market for grid-connected residential PV systems greatly increased the numbers of models and sales of small inverters. Sharp, which installed more than 100 000 inverters in Japan, entered the U.S. market in 2003. All utility-interactive inverters installed in the United States must be listed for safety under the UL1741 standard by one of three major nationally recognized testing laboratories. The California Energy Commission list of eligible inverters for its Emerging Renewables program now exceeds 150 models. Sandia National Laboratories continued to work with Xantrex (Trace) and GE Energy on their high-reliability inverter designs.

Battery Charge Controllers

Battery charge controllers are essential for PV systems that store energy in batteries. The charge controller charges the battery and controls the discharge of the battery to the load. It is designed to optimize the charge and discharge of the battery to obtain maximum battery life and provide the highest charge and discharge efficiency. The United States has several producers of charge controllers. In 2006, at least 22 brands were available for the U.S. market. Major manufacturers include Morningstar, Xantrex, Specialty Concepts, Sun Selector, and Outback Power. Total production is estimated at 130 000–150 000 units per year. Most U.S. charge controllers (more than 60 %) are exported.

Systems Designers and Installers

About 30 companies in the United States are dedicated primarily to the design, sale, and installation of PV systems. When the market was primarily off-grid, stand-alone systems (prior to 1996), large distributors had a systems designer-installer who served most of the larger commercial systems, e.g., telecommunications, water pumping, power supplies for remote-sensing devices and remote military applications. These include Atlantic Solar, Solar Depot, Hutton Communications, and SunWize. When state tax-credits for grid-connected systems (residential and commercial) were established, several of the distributors became full-service systems installers. Many new or expanded companies were formed to deal exclusively with grid-connected systems. The most notable of these companies is PowerLight, which installs more than 20 % of U.S. grid-connected systems. PowerLight combines PV with foam insulation to form building-integrated flat roofs. Several 2006 PowerLight systems were larger than 5 MW, and were located primarily in Europe.

3.4 System prices

Costs and Prices
Table 6 illustrates average ranges of turnkey prices (excluding sales tax) per watt for the various categories of installation. Prices shown do not include maintenance charges after installation such as battery replacement or operation and maintenance. Additional costs incurred due to the remoteness of the site or special installation requirements are not included.

Table 6: Turnkey Prices of Typical Applications

Category / Size	Typical applications	USD* per W

OFF-GRID Up to 1 kW	Telecom, signals, lighting, highway signs, navigation aids, irrigation, cottages (small applications where connecting to the grid is not practical)	10–20 (depending on storage, remoteness)
OFF-GRID >1 kW	Telecom, homes, farms, irrigation, signals, government sites, parks	10–20
GRID-CONNECTED Specific case	2–5 kW roof-mounted system	7–9
GRID-CONNECTED Up to 10 kW	Homes, business, schools, parking, irrigation,	7–8
GRID-CONNECTED >10 kW	Government buildings, warehouses, RPS (renewable power set asides-utilities)	6,5–7,5

*Prices do not reflect add-on costs for warrantees, service contracts and training. Additional energy storage for uninterruptible power will also increase costs.

The increased volume for grid-connected PV systems has caused intense competition, more effective use of installation labor, packaged systems, and purchasing power. The installed cost of grid-connected PV systems remained nearly constant as the cash subsidies, especially in California, decreased from 4,50 USD / W_{ac} installed in 2000 to 2,50 USD / W_{ac} in 2006. The installed prices remained relatively constant at 7,00–8,00 USD / W_{ac} despite increased module prices. Some high-volume customers, primarily builders, were sold PV systems at low prices of 6,50 USD / W_{ac}. Reductions in installed costs to compensate for higher module costs were made possible by volume discounts, reduced labor costs owing to increased volume of installations, module efficiency increases, and reduced profits. Table 7 shows average price ranges of grid-connected residential systems since 1994 and Table 8 illustrates typical single- and multicrystalline silicon module prices since 1992.

Table 7: National Trends in System Prices (Current) for Grid-Connected Residential PV System Installations

Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Price	12	11–12	10–12	10–12	10–11	9–11	8–10	7–9	6,50–9	6,50–8	6,50–8	6,50–8	6,50–9

Table 8: Typical Single- and Multicrystalline Silicon Module Prices (USD / W_{ac})

Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Price *	4,25	4,50	4,00	3,75	4,00	4,15	4,00	3,50	3,75	3,50	3,25	3,00	3,50	3,60	3,75

*Estimated by PV Energy Systems

3.5 Labour places

The labour places accounts for R&D, manufacturing, design and installation, product distribution, and utility and government sectors of the PV industry. The total labor places in the U.S. PV industry are about 8 000 persons. The labour places can be estimated as follows:

Description	Estimated Labour Places
R&D (not including companies)	350
Manufacturing of products throughout the PV value chain from feedstock to systems, including company R&D	5 200
All other, including within electricity companies, installation companies	2 800

3.6 Business value

The value of PV product and services in the United States can be estimated by adding the total value of the products installed, product exported, and R&D costs in the government laboratories and universities. Table 9 lists the key elements of this analysis. The total value of the installation of U.S. PV systems, export of modules (minus the modules imported), and export of silicon is about 1.8 billion USD.

Table 9: Value of the U.S. PV Industry 2006

Sub-market	Capacity installed *in 2006* ((in kW, unless otherwise specified))	Price per W (USD / W_{ac} Installed, unless otherwise specified)	Value (in million USD)	Totals (in million USD)
Off-grid domestic	14 000	15	*210*	
Off-grid non-domestic	23 000	15	*345*	
Grid-connected distributed	Res =55 000	8	*440*	
	Com = 45 000	7,50	*338*	
Grid-connected centralised	5 000	7	*35*	
				1 368
Export of PV products *(118 000 kW x 3 USD / W x 1000)*				*354*
Change in stocks held				*Not available*
Import of PV products *(65 000 kW x 3,75 USD / W x 1000)*				*(244)*
Export of silicon *(5 000 MT x 60 000 USD / MT)*				*300*
Value of PV business				***1 778***

*Exports included 55 MW of CdTe at 2,50 USD / W resulting in 3,00 USD average price.

4 Framework for deployment (non-technical factors)

4.1 New initiatives

The success of well-known PV programs such as those in California and New Jersey are using effective policies over time to increase solar energy production and reduce system costs. In the United States, policy activity at federal and state levels to promote PV is increasing. In 2006, the Energy Policy Act of 2005 took effect and offered consumers and businesses federal incentives for many renewable energy and energy efficiency technologies. The Act established a 30 % tax credit for qualified PV system expenditures, to a maximum of 2 000 USD for equipment placed in service during 2006–2007. The U.S. PV industry was able to promote the extension of this incentive for one more year to 2008 and efforts are under way to promote extending and expanding the credit to 2016.

An understanding of the regulatory environment in the United States is critical to understanding the market potential for PV. Despite the federal tax credit that is currently available, the United States does not have a coordinated national program to develop PV markets. *Net-metering standards* dictate the value of PV and allow system owners to sell back electricity to the local utility (economic benefit). *Interconnection standards* provide uniformity across utility service territories and render the entire process transparent for installers and consumers (infrastructure benefit). A lack of consistent net-metering (economics) and interconnection (infrastructure) standards from state to state creates barriers to growth of the U.S. PV market. Despite these barriers, 21 states have renewable portfolio standards, requiring that a certain proportion of a utility's generating capacity or energy sales be derived from renewable resources. In addition, three U.S. states—Illinois, Minnesota, and Missouri—have voluntary standards for renewable energy production.

The following is a summary of the more visible state programs:

Arizona
In Arizona, the state approved a requirement mandating that utilities acquire 15 % of the total energy delivered to their customers from renewable energy by 2025. Arizona's Governor, Janet Napolitano, is a strong proponent of renewable energy for the reasons of job creation, energy security, environmental benefits, and the ubiquitous solar resource that exists in the Southwest region of the United States (www.cc.state.az.us/).

California
California has moved to the forefront of the renewable energy development and greenhouse gas emission control with the creation of new initiatives. The most notable state PV incentive program is the California Solar Initiative (CSI). Enacted in 2005, the CSI is the biggest PV program in U.S. history in the largest PV market in the nation. In August 2006, Governor Arnold Schwarzenegger signed into law SB1, a critical piece of legislation to advance CSI. The original bill allotted 2,9 billion USD for solar energy rebates in California over 10 years. The goal is to increase the solar capacity installed on California rooftops by 3 000 MW by 2017. The initial PV incentive levels were set at 2,80 USD / watt effective January 1, 2006, to be reduced by an average of about 10 % annually. The latest bill in support of CSI added another 150 million USD to the PUC's proposed 3,2 billion USD. The increased funding will provide 50 million USD for R&D and 100 million USD in incentives for solar thermal technology. Other critical elements of the initiative involve systems of less

than 100 kW, for which the PUC approved a 2,50 USD / watt subsidy for residential and commercial projects and 3,25 USD / watt for systems installed by governments and non-profits. According to the California PUC Web site, the CSI uses performance-based incentives for larger systems and "expected performance-based buydowns" for smaller systems as the basis for distributing the allocated funds, in lieu of upfront rebates. For more information on the program, visit the California PUC Web site at www.cpuc.ca.gov.

New Jersey

The revised New Jersey renewable portfolio standard requires utilities to obtain 22,5 % of delivered power from qualifying renewable energy sources by 2021. The new RPS targets also include a 2,12 % solar set-aside estimated to be about 1 500 MW of PV by 2021. In 2006, 10 MW of grid-connected PV power was installed under the program. Recently, the New Jersey Board of Public Utilities determined that the current PV rebate program is not appropriately designed to meet the solar targets established in the bill and is looking at how best to shift from rebates to a performance-based approach. To learn more about the options the Board is considering, visit www.njcleanenergy.com.

Washington State

In 2006, Washington State passed an initiative mandating energy efficiency and renewable portfolio standards. The initiative calls for utilities to pursue all cost-effective conservation measures and to acquire 15 % of the energy delivered to customers from renewable energy by 2020 (www.secstate.wa.gov). For more information on state incentive programs, see the Database of State Incentives for Renewable Energy at www.dsireusa.org.

It is likely that the adoption of performance-based incentives in California and New Jersey, the two largest PV markets in the United States, are the beginning of a growing trend around the country away from the more common upfront rebates based on the installed PV system capacity. Historically, the "rebate approach" has been used to offset the upfront installation cost of a system. Innovative subsidy programs that do not tie incentives to system size or manner of deployment are making the installation of BIPV and large-scale solar farms more appealing. These incentives are being devised to encourage the design and construction of systems that maximize energy output. Economies of scale are also driving the development of larger PV system installations.

Noteworthy Projects in the United States

In 2006, the United States saw several large systems completed (Maycock, December 2006) in Massachusetts (500 kW in Brockton), California (910 kW in Oakland for the U.S. Postal Service), and Arizona (375 kW at the Luke Air Force Base). In addition, SunEdison announced the development of the world's largest PV system installation for 18 MW at a Nevada Army base (Maycock, March 2006). High-profile companies are also "going green" and raising the visibility of solar. In October 2006, the Internet search-engine company, Google, announced plans to build a 1,6-MW system at its corporate headquarters.

Table 10 summarizes many of the PV support measures in place in the United States during 2006.

Table 10: PV Support Measures

Description	National / Regional (State) / Local
Enhanced feed-in tariffs	State-by-state: As an example, California @ 0,39 USD / kWh (See www.dsireusa.org for more information on a state-by-state basis.)
Direct capital subsidies	State: California Solar Initiative provides for this in the form of 2,50 USD / watt subsidy for residential and commercial projects and 3,25 USD / watt for systems installed by governments and non-profits.
Green electricity schemes	State and regional: 600+ utilities in multiple states* (equivalent to 20% of all utilities nationally)
PV-specific green electricity schemes	State and regional: 0,2 % of 740 MW renewable energy sales*
Renewable portfolio standards (RPS)	State: 23 states
PV requirement in RPS	State: 23 states plus 3 states with voluntary schemes
Investment funds for PV	National: Blended in several socially responsible investment funds and equated to 5,3 billion USD in 2005
Tax credits	State and National: Federal investment tax credit—30% for commercial PV
Net metering	State: 1) Only 36 states have state-wide net-metering programs and programs vary significantly. No national net-metering standards exist that could simplify and stimulate markets. 2) Only 39 states allow connection to the grid. Current state-by-state situation limits manufacturers and integrators the ability to sell "standard systems." See www.dsireusa.org for state-by-state net-metering standards.
Net billing (net billing quantifies net metering on a billing cycle basis)	State: Net billing exists in the states where net metering is allowed. However, the credit will vary in each state and is not necessarily equivalent to 100% of kWh.
Commercial bank activities	National: 2–3 pilot programs
Electricity utility activities	These activities are split between retail (green-power programs) and power-generation activities, e.g., large-scale projects by utilities such as Xcel Energy, SMUD, PG&E, and Austin Electric projects. Renewable portfolio standards play a role in the implementation of many of these activities.
Sustainable building requirements	Local and State: No federal codes; some states and local jurisdictions

*Source: Lori Bird and Elizabeth Brown. "Trends in Utility Green Pricing Programs (2005)." http://www.nrel.gov/docs/fy07osti/40777.pdf. NREL. 2006

4.2 Indirect policy issues

The United States has completed virtually no indirect policy initiatives that affect the deployment of PV. The international policies that affect the use of PV power systems are few. Under the general aegis of "free trade," the North America Free Trade Agreement NAFTA) with Mexico and Canada permits the sale of PV systems to these markets without duty or trade restrictions, whereas there are duties for modules imported into Mexico from other countries. The U.S. trade with all of the Americas leads to more open markets for the U.S. PV industry.

The United States has not introduced environmental regulations that have affected the deployment of PV. Neither the global warming treaty (Kyoto Accord) nor any part of the treaty has been approved by the U.S. Congress. Some analysts have reported that PV credits would be less than $0.01 / kWh if there were serious efforts to credit PV for mitigation of CO_2 (the carbon tax). The externalities and hidden costs of conventional energy generation were compared to renewable energy in an analysis covering the 1990–1995 timeframe.

Deregulation of the Electric Utility Industry

The U.S. PV industry is benefiting from the federal government's deregulation of the electric utility industry. Utilities have been regulated monopolies in each of the 50 states; but the federal government has now required the states to deregulate utilities and permit the free trade of electricity generation, distribution, and service across the country.

The deregulation process has resulted in several programs being proposed and legislated that affect PV. These include, but are not limited to "green pricing," set-asides for PV, net metering, and interconnection requirements. Because regulation of the production and distribution of electricity has been relegated to the states, the initiatives related to promotion of PV are individually created and adopted by each of the 50 states. The state programs are so diverse that it is virtually impossible to provide a summary.

To provide a detailed overview, DOE has funded the DSIRE (Database of State Renewable Energy) project, managed by the North Carolina Solar Energy Center. The DSIRE project has issued a report, "National Summary Report on State Programs & Regulatory Policies for Renewable Energy," which summarizes more than 120 regulatory incentives in 45 states. The report and the latest updates can be found at the Web site at www.dsireusa.org. Because the 50 states are responsible for implementing the federal utility restructuring mandate, this report has been invaluable for state advocacy groups and energy planners and regulators.

Because there are more than 3 000 private and public electrical utilities in the United States—and all are regulated in detail by the 50 states in which they reside under a federal policy umbrella—a coherent picture is difficult to construct. The two main federal rules affecting PV are the Public Utilities Regulatory Policy Act (PURPA,1978) and the Utility Restructuring Law (1996). The Utility PV Group (UPVG) program, which is now complete, was also an important development process for the utilities to identify and gain experience with early applications for PV.

PURPA established the independent power industry in the United States by requiring that the utilities permit on-line third-party generation of electricity and that the utility allows on-line interface with grid back-up of the system. Not only was the utility required to permit interconnection, it had to pay for excess electricity at “avoided” cost. This law, approved by the U.S. Supreme Court, established a large and growing independent power industry.

All generation options were allowed. Wind energy and PV benefited from the law. However, PV, with its high installed costs, was too expensive (despite a 10 % investment tax credit and some state tax-credits) to compete with natural-gas-powered turbines. With the Million Solar Roofs Initiative, state and federal tax credits, utility leadership, and reduced prices, coupled with restructuring initiatives, the PURPA regulations are vital to the deployment of PV and other renewable energy sources.

Restructuring

Since the federal government passed a law designed to deregulate the utility industry, some of the state monopolies have been replaced with competition, and the market is being broken up into generation, transmission, and distribution; power sales; and service. This means that new companies offering lower rates, improved quality, and better service may contact the customer directly. This has opened the door for the sale of “green energy,” on-site energy generation, and other services that favor the intrinsically distributable PV option. The renewable energy industry has worked with the states that are leading the deregulation process to ensure that options—such as net metering, green pricing, and set-asides for environmentally friendly renewable energy—were included in the restructuring regulations.

At the end on 2003, 12 states had enacted restructuring legislation. Seven of the states have provisions for renewable energy through the legislation of system-benefits charges and/or renewable portfolio standards. Efforts directed at restructuring that include renewable energy are still in the early stages. Additionally, the electricity supply and price problems in California did not add momentum to the deregulation progress. The California experience has caused delays in other state deregulation processes, but will undoubtedly provide insight for other states as they address these issues.

4.3 Standards and codes

The electrical and personnel safety codes and standards undergo continuous updates and thorough examinations by designers, installers, inspectors, and users in the United States. The vital safety and interconnection issues associated with codes and standards are important activities in the national laboratories and PV industry, and the DOE Solar Program supports critical portions of this work. The support and leadership has provided a consensus of utility and industry input into the *National Electrical Code® (NEC®)*, new and revised listing standards for safety, utility interconnect standards, standards input into the international arena, and hardware certification.

An industry forum headed by Sandia National Laboratories recently submitted 42 proposed changes in Article 690—Solar Photovoltaic Systems—for the 2008 edition of the NEC. A comparable number of proposals came from other sources through the public input process. This increase in public proposals shows increased interest in applications of PV technology as a source of interconnected power.

The IEEE has many coordinating committees. IEEE Standards Coordinating Committee (SCC21) was responsible for the IEEE Std 929-2000 utility-interconnect guideline for PV systems and continued progress on a new IEEE Std 1547 interconnect standard to address interconnection of all distributed generation. This activity has tremendous representation by the utilities and is supported by the national laboratories. Personnel from Sandia produced a draft test protocol for performance certification of inverters for PV applications. The California Energy Commission adopted most of the protocol to provide inverter certification for its Emerging Renewables program in 2005. The United States actively participated in the International Electrotechnical Commission activities for PV-related standards. Underwriters Laboratories continued to revise the UL1741, "Standard for Static Inverters and Charge Controllers for Use In Photovoltaic Power Systems," to include inverters and charge controllers for all distributed generation and to match the requirements of the IEEE 1547 standard. The first UL1741 was published in May 1999 and was last amended in 2001. Coordination with both the NEC and IEEE interconnect guidelines will remain a valuable activity for finalizing the new UL1741 standard.

PowerMark Corporation continued as a non-profit certification body for the U.S. PV industry. PowerMark recognized the Arizona State University Photovoltaic Testing Laboratory (PTL) and approved it for performing module certification tests based on the accreditation certificate they received from the American Association of Laboratory Accreditation. The PTL regularly performs tests on all types of PV modules according to IEEE 1262, IEC 1215, IEEE 1262, IEC 61215 (crystalline silicon module qualification tests), 61646 (thin-film qualification), and PV-3 for silicon and amorphous silicon modules. Some testing also includes UL 1703 requirements. Most of the PV modules qualified meet reciprocity requirements with European standards. The PTL tests are accepted throughout the world for international purchases.

4.4 Certification of installers and hardware

Hardware and practitioner certification programs are being developed in the United States. A certification program for PV inverters has been initiated by Sandia National Laboratories to better characterize the operation of inverters and to certify the performance relative to power throughput. Sandia, with strategic partners from BEW Corporation and an active Web-based reviewing process, completed a draft of its "Performance Test Protocol for Evaluating Inverters Used in Grid-Connected Photovoltaic Systems." A large portion of that document was adopted by the California Energy Commission to certify inverters used in its Emerging Renewables program. The program maintains a list of eligible inverters on its Web site, as well as selected testing information. More than 125 inverters are listed, along with the weighted California efficiencies and characteristics.

The framework for a single national voluntary certification program for PV installers continued to be applied with some new developments and evolution consistent with new NEC requirements. This "Voluntary Practitioner Certification Program" began in 2003 and continued through 2005.

The national voluntary practitioner certification program was spearheaded by the North American Board of Certified Energy Practitioners (NABCEP). NABCEP board members are volunteers representing PV and solar thermal manufacturers and installers, federal, state, and local governments, policymakers, labor, contractors and training organizations. Much of the technical input to develop the task analysis, applicant study guide, tests, and general requirements evolved from component and system monitoring and evaluation tasks within the DOE Solar Program. Sandia National Laboratories is joined by its strategic team members and partners—including the National Renewable Energy Laboratory, Solar Energy

Industries Association, Florida Solar Energy Center, Southwest Technology Development Institute, Institute for Sustainable Power, and Interstate Renewable Energy Council. This group spurred practitioner certification efforts by focusing on the initial goal: establish a voluntary practitioner certification program that could be adopted by all states for installers of PV systems. There are now nearly 250 certified PV installers in the United States.

5 Highlights and prospects

The years 2006 and 2007 represent a ramp-up of political discussions in preparation for the 2008 U.S. Presidential election. Energy security and climate change are bipartisan issues that have already been elevated to the top of the national political agenda. Diversification of energy sources and conservation are already emerging as common themes in security and climate discussions. As pro-solar policies are implemented at state and local government levels, PV is poised to become a bigger player in the energy mix. Government standards will have the potential to drive innovation and efficiency.

As a result of the concerted efforts of the U.S. PV industry and the U.S. DOE Solar Energy Technologies Program, it is anticipated that U.S. PV production will continue to expand at least 35 % per year, both in applications and total production.

Plant Expansion: Most plant expansion will be dedicated to the following: (1) Production at the ECD / Uni-Solar 100-MW amorphous silicon plant, in addition to the 50 MW installed; (2) The First Solar 100-MW CdTe plant; and (3) Completion of the new plants announced by Nanosolar, Solar World, and BP Solar.

The Market: The U.S. PV market will experience major sales increases primarily due to state and federal subsidies in California, New Jersey, Illinois, Arizona, New Mexico, and New York. Major changes in the U.S. market growth—greater than 40 % per year—are expected once profitable factory prices of $2.00 / W or less for PV modules and installed costs of $4.00 / W_{ac} are offered.

Technology: The production of thin films (CIS and CdTe) from new facilities in the United States will provide a market test for new module options with lower manufacturing cost. Experience with thin-film performance, stability and reduced costs will compete with the dominant sliced, single- and polycrystalline silicon product. And the creation of new markets for flexible, lightweight thin-film products will ensure further market growth and penetration.

Continued progress in the cast-ingot polysilicon technology with increased cell efficiency (in production), volume production (with its reduced material costs), and automation (with its reduced labor costs) will maintain a robust market for the workhorse of the market and build a base for future expansion. U.S. production should accelerate in 2007; however, most of the new product will come from thin-film technologies that are not affected by the polysilicon feedstock shortage.

The efforts of the Solar America Initiative pay tribute to the potential of solar energy in the United States. The U.S. DOE Solar Energy Technologies Program, through concerted R&D efforts via public/private partnerships, is working to reduce the cost of solar energy systems and to maximize solar energy's promise over the next 10 to 25 years. The aggressive goals of the Solar America Initiative will require the involvement of new participants and unprecedented innovation. Solar energy represents an opportunity to diversify the U.S. energy portfolio using a clean energy source while creating jobs in high-tech manufacturing, installation, and operation of solar power equipment. Ultimately, the hard work and innovation of the PV industry and its collaborators will contribute to the growth of the U.S. economy and the clean energy industry in the 21st century.

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Annex A Method and accuracy of data

The data in this report are primarily the result of the annual survey of PV industry shipments performed by PV Energy Systems, Inc., and published in *PV News.* All U.S. PV manufacturers formally responded to the survey. The U.S. results are crosschecked with DOE Energy Information Administration (EIA) reports. The 2006 data could not be crosschecked because the EIA report has not yet been issued. There is some uncertainty in the base data because details on inventories are not tracked. These data are believed to be accurate to ±10%. The installation data for the United States are the result of an extensive phone survey by one of the authors (PDM) with key manufacturers, distributors, and systems integrators. The accuracy of the U.S. installation data is estimated to be in the ±10% range. The currency used in this report is U.S. dollars ($).

Annex B Country information

This information gives the reader some background about the national environment in which PV is being deployed. It is not guaranteed to be 100 % accurate, nor intended for analysis; readers should do their own research if they require more detailed data.

Description	Value	Source
Retail electricity prices - household, commercial, public institution	Household: 0,058–0,167 USD / kWh Commercial: 0,054–0,15 USD / kWh Public Institution: 0,04–0,076 USD / kWh	U.S. Department of Energy Energy Information Administration
Typical household electricity consumption (kWh)	Median Annual Electricity Consumption: 8 370 kWh / household Mean Annual Electricity Consumption: 10 219 kWh / household	U.S. Department of Energy Energy Information Administration http://www.eia.doe.gov/emeu/consumptionbriefs/recs/percentiles/el_total_tables.html
Typical metering arrangements and tariff structures for electricity customers (e.g., interval metering? Time-of-use tariff?)	These rules vary from state to state. See www.dsireusa.org and www.irecusa.org for more information.	
Median household income (Assumes married household)	52 000 USD	U.S. Housing and Urban Development. http://www.huduser.org/periodicals/ushmc/winter2001/summary-2.html#table3
Typical mortgage interest rate	30-year fixed: 6,21 % 15-year fixed: 5,92 %	Freddie Mac. http://www.freddiemac.com/dlink/html/PMMS/display/PMMSOutputWk.jsp?week=20&ending=20070517
Voltage (household, typical electricity distribution network)	Approximately 110 volts AC	
Electricity industry structure and ownership (e.g., vertically integrated or separate generation, transmission, distribution?; retailers and network businesses – integrated or separate?; state-owned or municipal or private?; electricity industry regulator?)	Diversified and deregulated—separate generation, transmission, and distribution Utility ownership varies: Investor-owned utilities and consumer-owned utilities throughout the United States	
Price of diesel fuel	2,70 USD / gallon	U.S. Department of Energy Energy Information Administration http://www.eia.doe.gov/bookshelf/brochures/diesel/index.html
Typical values of kWh / kW for PV systems (national average range)	Household: 0,23 – 0,32 USD / kWh Commercial: 0,16 – 0,22 USD / kWh Public Institution: 0,13–0,22 USD / kWh	U.S. Department of Energy Energy Information Administration

Annex C Definitions, symbols, and abbreviations

For the purposes of the National Survey Reports, the following definitions apply:

PV power system market: The market for all nationally installed (terrestrial) PV applications with a PV power capacity of 40 W or more.

Installed PV power: Power delivered by a PV module or a PV array under standard test conditions (STC)—irradiance of 1 000 W / m^2, cell junction temperature of 25 ^oC, AM 1,5 solar spectrum—(also see "Rated power").

Rated power: Amount of power produced by a PV module or array under STC, written as W.

PV system: Set of interconnected elements such as PV modules, inverters that convert d.c. current of the modules into a.c. current, storage batteries, and all installation and control components with a PV power capacity of 40 W or more.

Module manufacturer: An organisation carrying out the encapsulation in the process of the production of PV modules.

Off-grid domestic PV power system: System installed to provide power mainly to a household or village not connected to the (main) utility grid(s). Often a means to store electricity is used (most commonly, lead-acid batteries). Also referred to as "stand-alone PV power system." Can also provide power to domestic and community users (plus some other applications) via a "mini-grid," often as a hybrid with another source of power.

Off-grid non-domestic PV power system: System used for a variety of industrial and agricultural applications such as water pumping, remote communications, telecommunication relays, safety and protection devices, that are not connected to the utility grid. Usually a means to store electricity is used. Also referred to as "stand-alone PV power system."

Grid-connected distributed PV power system: System installed to provide power to a grid-connected customer or directly to the electricity grid (specifically where that part of the electricity grid is configured to supply power to a number of customers, rather than to provide a bulk transport function). Such systems may be on or integrated into the customer's premises, often on the demand side of the electricity meter; on public and commercial buildings; or simply in the built environment, as on motorway sound barriers. They may be specifically designed for support of the utility distribution grid. Size is not a determining feature: while a 1-MW PV system on a rooftop may be large by PV standards, this is not the case for other forms of distributed generation.

Grid-connected centralised PV power system: Power production system performing the function of a centralised power station. The power supplied by such a system is not associated with a particular electricity customer, and the system is not located to specifically perform functions on the electricity grid other than the supply of bulk power. Typically ground mounted and functioning independently of any nearby development.

Turnkey price: Price of an installed PV system excluding VAT / TVA / sales taxes, operation and maintenance costs, but including installation costs. For an off-grid PV system, the prices associated with storage battery maintenance / replacement are excluded. If additional costs are incurred for reasons not directly related to the PV system, these should be excluded. (For example, if extra costs are incurred fitting PV modules to a factory roof because special precautions are required to avoid disrupting production, these extra costs should not be included. Similarly, the additional transport costs of installing a telecommunication systems in a remote area are excluded.)

Field Test Programme: A programme to test the performance of PV systems / components in real conditions.

Demonstration Programme: A programme to demonstrate the operation of PV systems and their application to potential users/owners.

Market deployment initiative: Initiatives to encourage the market deployment of PV through the use of market instruments such as green pricing or rate-based incentives. These may be implemented by the government, finance industry, utilities, or others.

Final annual yield: Total PV energy delivered to the load during the year per kW of power installed.

Performance ratio: Ratio of the final annual (monthly, daily) yield to the reference annual (monthly, daily) yield, where the reference annual (monthly, daily) yield is the theoretical annual (monthly, daily) available energy per kW of installed PV power.

Sources:

Lori Bird and Elizabeth Brown. "Trends in Utility Green Pricing Programs (2005)." http://www.nrel.gov/docs/fy07osti/40777.pdf. NREL. 2006.

Cliff Chen, Ryan Wiser, and Mark Bolinger. "Weighing the Costs and Benefits of State Renewable Portfolio Standards: A Comparative Analysis of State-Level Policy Impact Projections." March 2007. http://eetd.lbl.gov/ea/ems/reports/61580.pdf .

Database of State Incentives for Renewable Energy. http://www.dsireusa.org/. Accessed May 30, 2007.

"German Regulatory Authorities Approve EverQ Partnership Agreements." BusinessWire. October 2006. http://www.allbusiness.com/services/business-services/3993340-1.html. Accessed May 25, 2007.

"Evergreen Solar and Energy Conversion Devices Rated Outperformers in Piper Jaffray Solar Report." Bill Baue, February 23, 2006. http://www.socialfunds.com/news/article.cgi/1936.html. Accessed May 30, 2007.