CHAPTER 10
Solar Energy

INTRODUCTION

Solar energy is an inexhaustible resource. The sun produces vast amounts of renewable solar energy that can be collected and converted into heat and electricity.

Texas, due to its large size and abundant sunshine, has the largest solar energy resources among the states. Several other states, however, lead the nation in terms of *using* solar energy, mostly due to state policies and incentives that encourage the installation of solar energy systems.

California is the nation's largest solar energy market by far, and has effective state initiatives promoting the industry. Other states with notable markets for solar energy include New Jersey, Arizona, Colorado and New York.

Even so, in 2006 solar energy accounted for just 0.01 percent of all U.S. electricity, mainly because of its higher costs compared to other power options.[1] Solar energy plays an even smaller role in the Texas electricity market.

Still, Texas has the sunshine, manufacturing base and research institutions needed to become a leader in the development of solar energy.[2] The state is well positioned to compete with other states and countries in a global solar energy market worth $10.6 billion in 2006.[3] One study estimates that Texas could capture about 13 percent of all new jobs and investments related to solar photovoltaic technologies by 2015, primarily in manufacturing.[4]

History

Humans have harnessed the power of the sun for millennia. In the fifth century B.C., the Greeks took advantage of passive solar energy by designing their homes to capture the sun's heat during the winter. Later, the Romans improved on solar architecture by covering south-facing windows with clear materials such as mica or glass, preventing the escape of solar heat captured during the day.[5]

In the 1760s, Horace de Saussure built an insulated rectangular box with a glass cover that became the prototype for solar collectors used to heat water. The first commercial solar water heaters were sold in the U.S. in the late 1890s, and such devices continue to be used for pool and other water heating.[6]

In the late 19th century, inventors and entrepreneurs in Europe and the U.S. developed solar energy technology that would form the basis of modern designs. Among the best known of these inventors are August Mouchet and William Adams. Mouchet constructed the first solar-powered steam engine.[7] William Adams used mirrors and the sun to power a steam engine, a technology now used in solar power towers. He also discovered that the element selenium produces electricity when exposed to light.

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In 1954, three scientists at Bell Labs developed the first commercial photovoltaic (PV) cells, panels of which were capable of converting sunlight into enough energy to power electrical equipment. PV cells powered satellites and space capsules in the 1960s, and continue to be used for space projects.[8]

In the 1970s, advances in solar cell design brought prices down and led to their use in domestic and industrial applications. PV cells began to power lighthouses, railroad crossings and offshore gas and oil rigs.

In 1977, solar energy received another boost when the U.S. Department of Energy created the Solar Energy Research Institute. It was subsequently renamed as the National Renewable Energy Laboratory (NREL), and its scope expanded to include research on other renewable energy sources. NREL continues to research and develop solar energy technology.

In the last 20 years, solar energy has made further inroads and now is used extensively in off-grid and remote power applications such as data monitoring and communications, well pumping and rural power supply, and in small-scale applications such as calculators and wristwatches. But solar energy has not yet achieved its potential to become a major contributor to world electrical grids.

Private and government research and development in solar energy technologies have led to continuing innovation over the last 30 years. The conversion efficiency of PV cells — that is, the percentage of sunlight hitting the surface of the cell that is converted to electricity — continues to improve. Commercially available cells now on the market have efficiencies approaching 20 percent.[9] Cell efficiencies achieved in research laboratories recently surpassed 40 percent.[10]

The worldwide PV market has grown by an average of 30 percent annually for the past 15 years.

The worldwide PV market has grown by an average of 30 percent annually for the past 15 years, an increase that has improved economies of scale for manufacturers.[11] As a result, the cost of electricity generated from PV modules has fallen significantly, from more than 45 cents per kilowatt hour (kWh) in 1990 to about 23 cents per kWh in 2006.[12] In 2006 and 2007, a shortage of silicon (a primary component of crystalline silicon PV systems) temporarily increased PV module costs, but prices are expected to decline once again between 2008 and 2011, when silicon plants currently under construction are completed.

Uses

Solar energy has many uses. It can be used to provide heat, light or to generate electricity. *Passive* solar energy refers to the collection of heat and light; passive solar design, for instance, uses the sun's energy to make homes and buildings more energy-efficient by eliminating the need for daytime lighting and reducing the amount of energy needed for heating and cooling. *Active* solar energy refers to storing and converting this energy for other uses, either as photovoltaic (PV) electricity or thermal energy.

Solar Heating

Solar systems that heat water for homes and businesses, and passive solar design for buildings of all sizes, both have the same effect on the electric grid as conservation. They do not generate electricity per se, but reduce the demand for electricity and natural gas.

From 1998 to 2005, the solar water heating market produced about the thermal equivalent of 124,000 megawatt-hours (MWh) annually.[13] Solar pool heating is the most commonly used solar energy in the U.S.[14] In 2005, it accounted for 95 percent of U.S. solar thermal collector shipments. The second-largest end use for solar thermal collectors was water heating, primarily in residential buildings, accounting for about 4 percent of U.S. shipments in 2005.[15]

Solar Electricity

Solar energy technology is used on both small and large scales to produce electricity.

A unique advantage of small-scale solar energy systems is that, if they include storage devices, they may eliminate the need to connect to the electric grid. PV systems power road maintenance and railroad warning signs, flashing school zone lights, area lighting and other devices without expensive power lines or batteries. Offshore oil rigs, navigational aids, water pumps, telecommunication equipment, remote weather stations and data logging equipment also benefit from PV power.[16]

In 2005, small-scale, off-grid PV-powered devices accounted for about 15 percent of PV capacity installed worldwide.[17] In the same year, most installed PV systems — 59 percent — provided electricity to homes and buildings connected to the electrical grid.[18] The remaining PV systems were installed for use in remote off-grid homes and buildings in industrialized countries and the developing world.

On a larger scale, solar technology can produce commercially significant amounts of electrical power. Utility-scale concentrating solar power (CSP) systems, for instance, typically offer capacities of from 50 to 200 megawatts (MW), and could produce enough electricity to power approximately 7,800 to 31,000 homes in Texas, based on average electric use in 2006, when the sun is shining.[19]

Solar Energy in Texas

In June 2007, the University of Texas at Austin's IC^2 Institute, an interdisciplinary research unit, released a study making a case for supporting the solar industry in Texas.[20] This study notes that Texas has excellent solar resources and should use its high technology infrastructure to build a solar industry that creates high-quality technology and manufacturing jobs. Currently, all of the solar energy generated in Texas accounts for a minute portion of the state's electricity production and comes from distributed PV solar systems on homes and businesses.

Economic Impact

In 2006, global solar industry revenues were $10.6 billion.[21] Texas specific data for solar industry revenues are not available. The IC² Institute expects the solar industry to create more jobs and contribute billions of dollars in investment and income to the U.S. economy over the next decade, if long-term incentives are offered to encourage the solar industry.[22] An IC² study noted that:

> …since high-tech manufacturing employment in Texas has yet to return to pre-recession levels, the PV manufacturing industry creates an opportunity to generate employment for semiconductor and electric component workers statewide whose jobs have been outsourced offshore.[23]

One study that evaluated the state-by-state impact of an expanding U.S. solar PV market found that California and Texas stand to gain a large share of all new solar PV jobs and investment created between 2004 and 2015.[24] The study assumed that the nation's solar PV capacity would grow from 340 MW in 2004 to 9,600 MW total PV capacity in 2015, with an investment value of $34 billion. According to this study, Texas should gain about 13 percent of all new U.S. solar PV jobs and investment, primarily in manufacturing. This translates into approximately 5,567 new jobs — 93 percent in manufacturing and 7 percent in construction/installation — and represents about $4.5 billion of investment in Texas by 2015.[25]

The Solar Energy Industries Association (SEIA) estimates that "every megawatt of solar power currently supports 32 jobs, with 8 of these jobs in system design, distribution, installation and service created where the systems are installed."[26] The Prometheus Institute, a data source on solar energy initiatives, projects that solar energy will create 22,000 American jobs in manufacturing, distribution and various building trades over the next decade.[27]

Austin Energy, a municipal utility, commissioned a study of the economic benefits of solar energy manufacturing and installation in 2006. This study concluded that construction of a 100 MW solar manufacturing plant in the Austin area could create nearly 300 new jobs and add about $1 billion to the regional economy by 2020.[28] In addition, the city of Austin and Travis County would benefit from an increase in sales tax and property tax revenue.

Texas technology companies have demonstrated an interest in the solar industry. In Austin, HelioVolt has developed a low-cost manufacturing process for applying a thin-film PV coating to building materials.[29] On April 15, 2008, Governor Rick Perry announced that HelioVolt would receive $1 million from the state's Texas Enterprise Fund (TEF) for the construction of a development and manufacturing facility. According to the Governor's office, the project is expected to create about 160 jobs and $62 million in capital investment.

In 2006, global solar industry revenues were $10.6 billion.

Entech, located in Keller, Texas, provides advanced solar energy technology including high-efficiency solar cells for NASA spacecraft.[30] The company also has invented a new lighting system to illuminate office buildings, schools and stores. In addition, Applied Materials, which has a semiconductor manufacturing plant in Austin, recently acquired a company called Applied Films in order to enter the PV business. Applied Materials plans to use its chip-industry knowledge to drive down manufacturing costs for solar panels.[31]

The IC² Institute notes that the solar industry could produce substantial savings for Texas energy consumers in the form of "avoided generation capacity capital costs, avoided fuel costs, avoided CO_2 emissions, the value of fossil fuel price hedging and avoided distribution costs."[32] In California, IC² estimated that these savings ranged from eight to 22 cents per kWh in 2005.[33] IC² says that further research is needed to estimate similar savings for Texas consumers.

Solar energy also can reduce price volatility related to fluctuating natural gas prices. As utilities begin to charge higher rates for peak load periods, PV systems that generate the most electricity during the hottest time of the day can produce substantial savings on energy costs. Utility companies would benefit because additional peak load power reduces the strain on their systems and the need for additional power plants.

Production

Sunlight can be converted into heat and electricity in a number of ways. A variety of solar technologies are in production, and many companies and researchers are pursuing efforts to develop devices that convert the sun's energy more efficiently.

Photovoltaic Energy

Photovoltaic cells (PV) are used worldwide to convert sunlight into electricity. The PV cell contains two layers of semiconducting material, one with a positive charge and the other with a negative charge (**Exhibit 10-1**). When sunlight strikes the cell, some photons are absorbed by semiconductor atoms, freeing electrons that travel from the negative layer of the cell back to the positive layer, in the process creating a voltage. The flow of electrons through an external circuit produces electricity.[34]

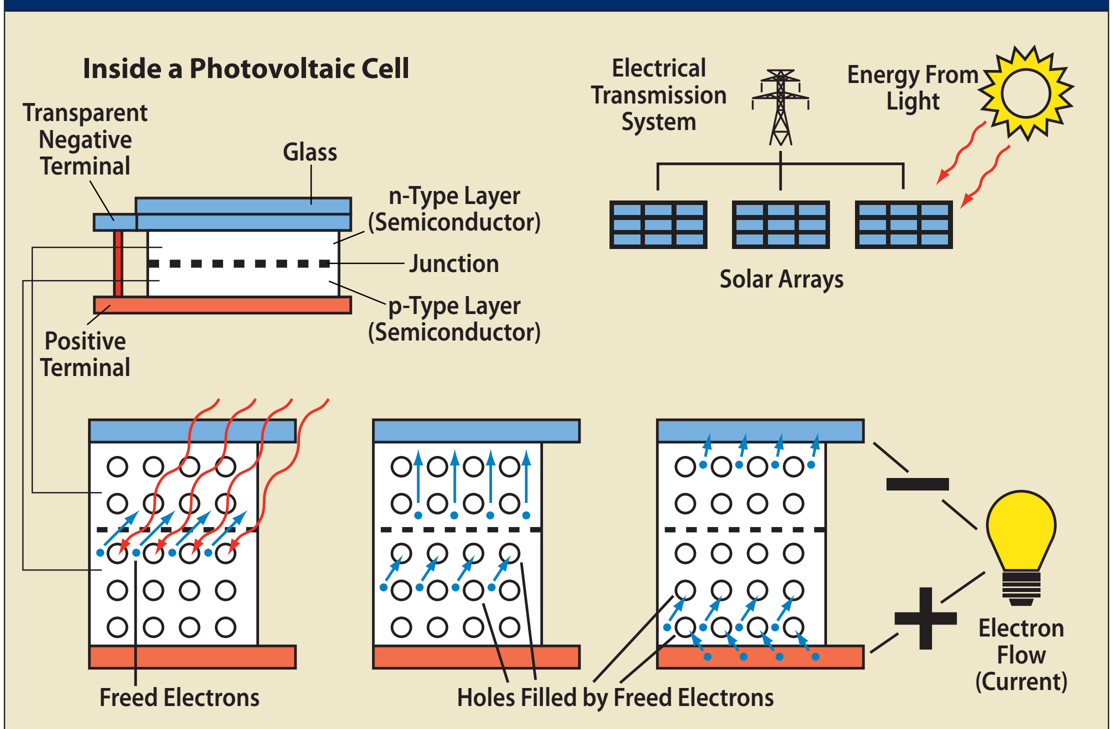
Since individual photovoltaic cells produce little power and voltage — they generate only about one to two watts per cell—they are connected together electrically in series in a weatherproof *module*. To generate even more power and voltage, modules can be connected to one another to form a *solar panel*; solar panels are grouped to form an *array*. The ability to add additional modules as needed is a significant advantage of PV systems.

Several PV technologies are in use or in development. The silicon-based PV cell, made with the same silicon used in the semiconductor industry, has dominated the market and continues to do so. Solar Energy Industries Association (SEIA) reports that 94 percent of PV modules used today are made of crystalline silicon.[35]

Sunlight can be converted into heat and electricity in a number of ways.

EXHIBIT 10-1

The Photovoltaic Cell



Source: U.S. Department of Energy.

The search for cheaper solar energy systems, however, has spurred the development of thin-film PV cells that have semiconductor layers only a few millionths of a meter thick. Thin-film PV technologies are intended to reduce the amount of expensive materials needed to produce solar cells. For example, new methods are being used to produce solar cells that reduce or eliminate the use of high-priced silicon. The U.S. Department of Energy (DOE) estimates that U.S. production of thin-film solar modules will exceed that of crystalline silicon modules by 2010.[36] While thin-film efficiencies are lower than silicon's, the lower cost may tip the balance in thin film's favor.[37]

Research scientists also are working on a new generation of solar cells that include nanomaterials, multijunction cells and various other research efforts that may produce "leapfrog" technologies, offering considerably higher efficiency at a lower cost.[38]

Nanotechnology, for instance, has attributes that, in theory, may triple the amount of energy produced by photons of sunlight. This technology also could result in PV cells that could be painted on homes and buildings.[39] Research on inverted multijunction cells that capture more of the sun's energy also is ongoing, and already has produced a world-record 39.3 percent conversion efficiency.[40] These emerging technologies have the potential to produce higher efficiencies more cost-effectively.

Some companies are developing faster and more efficient ways to manufacture thin-film solar cells at lower costs. HelioVolt, an Austin-based company, has developed FASST, which it claims is a low-cost manufacturing process for applying copper indium gallium selenide, a thin-film PV coating, to construction materials such as roofing, steel and flexible composites in 80 to 98 percent less time than conventional processes. This would position the company to bring economical building products featuring integrated PV cells to the market. HelioVolt is seeking partners and plans to have some products available by 2008.[41]

The U.S. Army also is interested in lightweight solar panels, since it wants to reduce the need for generators and personal battery packs that soldiers use to power fans, light, radios and laptops.[42] In Texas, the Army's Fort Bliss, in cooperation with the U.S. Naval Postgraduate School and Army Corps of Engineers, is the site for a "Power The Army" project that will conduct large-scale field trials of three new solar energy technologies. The army and others hope that the project will improve solar system efficiencies and lead to lower solar energy costs.[43]

Solar Thermal Energy

Solar thermal energy refers to technologies that use the sun's energy to heat water and other heat-transfer fluids for a variety of residential, industrial and utility applications. Simple and widely used applications of solar thermal energy include solar water heating, swimming pool heating and agricultural drying. In the U.S., solar pool, water and space heating are currently the major applications of thermal energy.

Flat-plate collectors — large, insulated metal boxes with glass or plastic covers and dark heat-absorbing plates — are the most common collectors used for home solar water and space heating (**Exhibit 10-2**).[44] Other common varieties are evacuated-tube collectors and integral collector-storage systems. All three types gather the sun's energy, transform it to heat and then transfer that heat to water, a heat-transfer fluid or air. Flat-plate collectors typically are mounted on the roof. Evacuated-tube collectors are sometimes used to heat water, but also have useful commercial and industrial applications where higher temperatures are required.

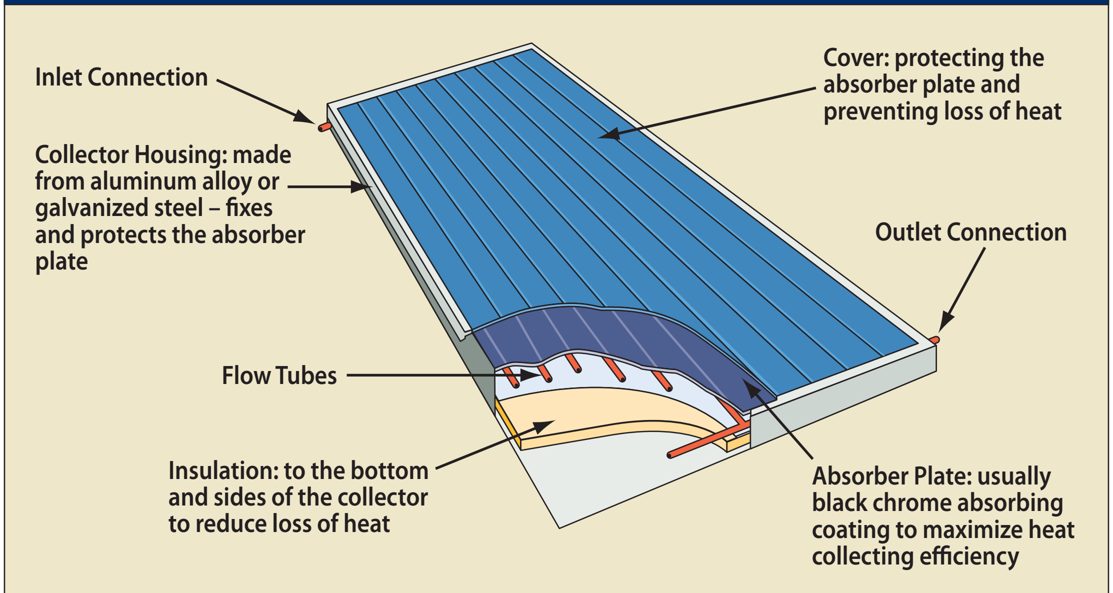
Solar thermal energy refers to technologies that use the sun's energy to heat water and other heat-transfer fluids for a variety of residential, industrial and utility applications.

The most powerful large-scale solar thermal technology, however, is *concentrating solar power* (CSP). While CSP can be PV-based, it generally refers to three solar thermal systems—parabolic troughs, solar dish/engines and power towers—each of which is in use or under development today. These systems use mirrors or reflectors to focus sunlight to heat a fluid and make steam, which then is used to generate electricity.

At present, only *parabolic trough* CSP systems are in commercial use in the U.S., with three installations in three states capable of generating 419 MW of electricity in all.[45] Trough systems consist of a linear, parabolic-shaped reflector that focuses the sun's energy on a receiver pipe, heating a transfer fluid flowing through the pipe; the transfer fluid then generates superheated steam which is

EXHIBIT 10-2

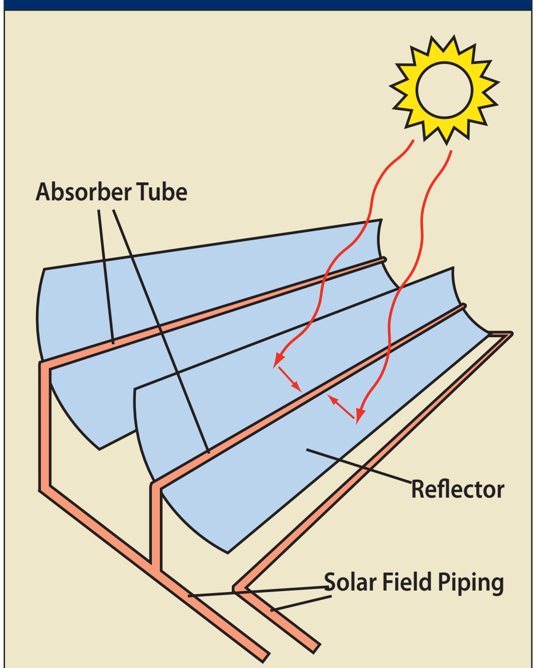
Flat Plate Collector



Source: Green Spec.

EXHIBIT 10-3

A Parabolic Trough System



Source: Hong Kong Engineer Online.

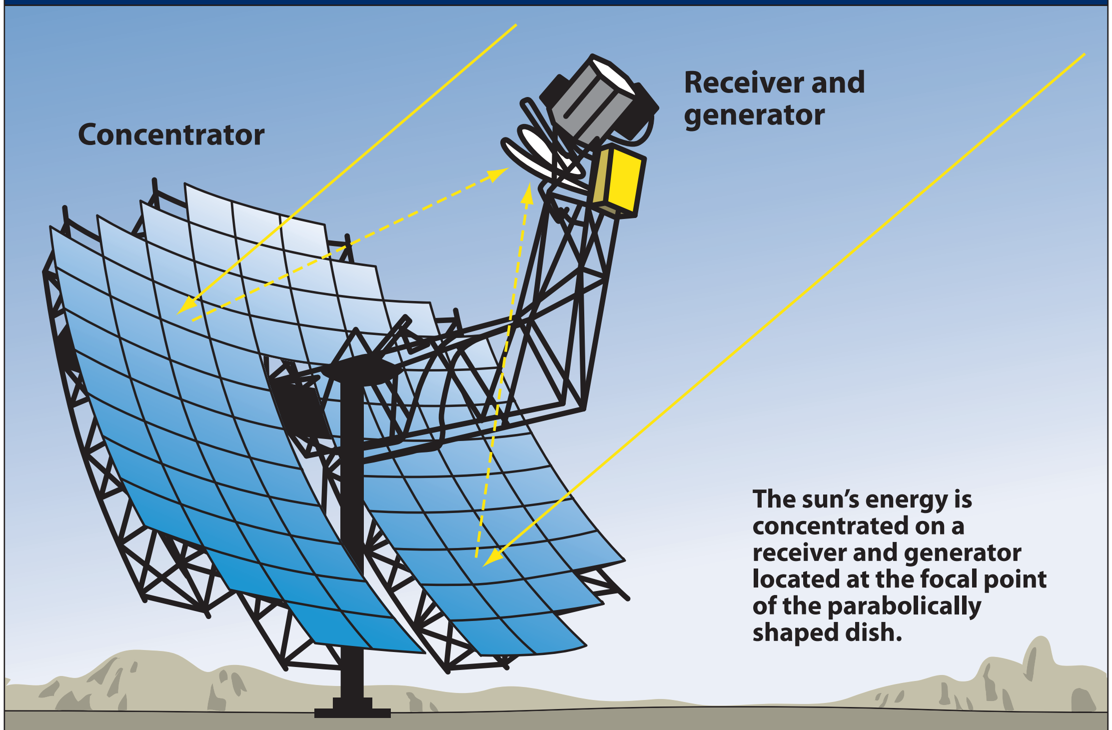
fed to a turbine and electric generator to produce electricity. The troughs track the sun from East to West during the day so that the sun is continuously focused on the receiver pipes (**Exhibit 10-3**).

A *solar dish/engine* system consists of a solar concentrator — glass mirrors in the shape of a dish that reflect sunlight onto a small area — and a power conversion unit that includes a thermal receiver and a generator (**Exhibit 10-4**). The thermal receiver includes tubes for the transfer fluid — usually hydrogen or helium — that transfers heat to a generator to produce electricity. In 2006, Stirling Energy Systems, a Phoenix-based provider of such systems, signed agreements to build two large plants employing the technology in Southern California.[46] This would be the first commercial installation of a solar dish/engine system in the U.S.

Solar *power towers* use a large field of sun-tracking mirrors called heliostats to concentrate sunlight on a receiver located on the top of a tower. The receiver heats a heat transfer fluid such as molten nitrate salt that is then used to generate steam to power a turbine-generator to produce electricity

EXHIBIT 10-4

Solar Dish/Engine System



Sources: Florida A&M University and Florida State University.

Solar energy differs from most energy technologies in that it can be generated on site, reducing or eliminating fuel transportation and electricity transmission and distribution costs.

(**Exhibit 10-5**). The molten salt reaches about 1,050 degrees Fahrenheit in the receiver before being stored in a tank where it can retain its heat for several hours.

In the U.S., two large-scale power tower demonstration plants — Solar One and Solar Two located in the Mojave Desert near Barstow, California — have generated 10 MW of electricity each. Solar One operated off and on from 1982 to 1988 and used water as its heat transfer fluid, while Solar Two used molten nitrate salt for heat transfer, operating periodically from 1996 to 1999.[47]

Europe's first commercial solar power tower went online in Spain in late 2006 and currently generates 11 MW of electricity, enough to power just under 6,000 homes.[48] More fields of mirrors are being added to this plant. Solucar, its developer and operator, plans two more power towers at other locations in Spain.[49]

Transmission

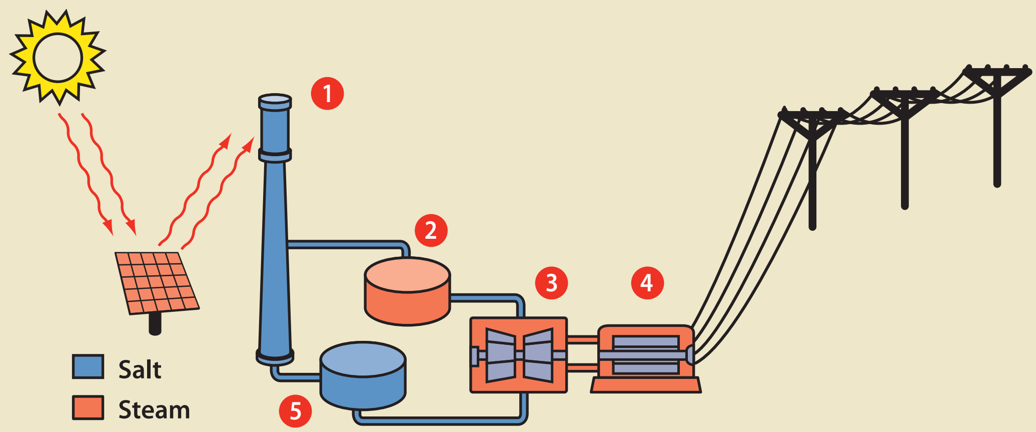
Solar energy differs from most energy technologies in that it can be generated on site, reducing or eliminating fuel transportation and electricity transmission and distribution costs. Solar water heating and space heating devices are "stand-alone" systems that are not connected to the electric grid. A PV system provides electric power directly to a user and can be used either as a "stand-alone" power source or connected to the electricity grid (**Exhibit 10-6**).

Systems offering this flexibility sometimes are called *distributed* power generators. By contrast, utility-scale concentrating solar power plants use *centralized* power plants and transmission lines to distribute electricity to customers.

In 2005, off-grid PV systems accounted for about 18 percent of all PV installed worldwide.[50] Homes in remote areas can use PV systems for lighting, A home or business with a PV system that is connected to the electric grid has the option of supplementing its energy needs with electricity from the local utility company and delivering excess electricity to the grid.

EXHIBIT 10-5

Solar Power Towers



Schematic of electricity generation using molten-salt storage:

1. sun heats salt in receiver;
2. salt stored in hot storage tank;
3. hot salt pumped through steam generator;
4. steam drives turbine/generator to produce electricity;
5. salt returns to cold storage tank

Sources: Florida A&M University and Florida State University.

home appliances and other electrical needs, saving the cost of extending power lines to a remote location. These systems require a storage device to store power generated during the day for nighttime use; typically, this is a lead-acid battery bank. Unlike gasoline-powered generators, PV systems do not require fuel deliveries and are clean and quiet to operate.

Distributed, Grid-Tied PV

At night and even on cloudy days, a PV system is not likely to produce enough energy to power a home's needs, while on sunny days it may produce more electricity than needed. A home or business with a PV system that is connected to the electric grid has the option of supplementing its energy needs with electricity from the local utility company and delivering excess electricity to the grid. Grid-tied PV systems thus can reduce strains on the power grid.

Net Metering

Net metering standards allow owners of qualifying solar energy systems to be compensated for the value of electric energy they produce; they have been proven to promote solar energy systems. The IC² Institute report that examined opportunities for the development of the Texas PV industry recommended the adoption of retail net metering in the state.[51] Retail net metering credits customers at the utility's full retail rate for each kWh generated rather than at the utility's avoided-cost rate, which is lower (see Chapter 9 of this report for further discussion of net metering).

The grid-connected PV market continues to grow more rapidly than off-grid PV and accounted for about 59 percent of the world PV market in 2005.[52] Between 1995 and 2005, the grid-connected PV market rose by more than 50 percent annually, compared to 29 percent for all solar applications.[53] In the U.S., cumulative installations of grid-tied PV systems surpassed those of off-grid systems in 2005. The Prometheus Institute expects that grid-tied PV systems for homes and businesses in the U.S. will become even more popular in the coming years.[54]

EXHIBIT 10-6

Types of Photovoltaic Energy Systems

System	Energy Source	Connected to the electricity grid?	Energy storage device in the system?	Examples
Grid-tied* solar system	PV cells	Yes	No	Home system that draws on the electricity grid at night and exports excess power in the day
Stand-alone grid-tied* solar system	PV cells	Yes	Yes (batteries)	Home or business system uninterruptible power (e.g. for computers, servers). Still operates when the grid is down
Stand-alone solar system without energy storage	PV cells	No	No	Water pumping
Stand-alone solar system with energy storage	PV cells	No	Yes (batteries)	Remote homes, lighting, TV, radio, telemetry
Stand-alone off-grid hybrid solar system	PV cells in combination with another energy source (e.g. diesel, wind)	Most often not	No	Remote large-scale communications, industrial uses

* also called "grid-connected."
Source: Solarbuzz.

California accounts for the majority of the U.S. PV market, with a cumulative grid-tied PV capacity of more than 198 MW at the end of 2006 (**Exhibit 10-7**).[55] The second-largest market is New Jersey, with more than 35 MW of grid-tied PV installed capacity.[56] Both California and New Jersey have generous PV incentives that have spurred growth in installations. Texas ranked fifth in grid-tied capacity in 2006, with more than 1.7 MW.[57]

EXHIBIT 10-7

Grid-tied PV Installed Capacity: Leading States*

State	Capacity Megawatts (MW)
California	198.0 ***
New Jersey	35.5 **
Colorado	4.0***
New York	2.3 **
Arizona	1.7**
Texas	1.7**
Massachusetts	0.5 ***
Nevada	0.5 ***
Oregon	0.3 ***
Connecticut	0.3 ***

*Estimates
**Data from mid-year 2007, does not include all installations.
***California data are through end of 2006. Other data are projected from actual mid-year 2006 capacity.
Source: Texas Comptroller of Public Accounts and Prometheus Institute.

Central Power Generation

Utility-scale concentrating solar power plants usually are connected to the electric grid and often require the construction of new transmission lines. This is because they are generally located in remote areas with high rates of solar radiation, far away from urban centers, rather like wind farms. And, like wind farms, CSP systems can produce significant amounts of electricity.

A 2007 DOE study identified seven southwestern states — California, Arizona, New Mexico, Nevada, Utah, Colorado and Texas — as good candidates for CSP. These states have the combined solar capacity needed to generate up to *16 billion* MWh of electricity.[58] Arizona, New Mexico, California and Nevada account for 87 percent of this potential capacity. West Texas has enough potential solar capacity to generate up to 351 million MWh of electricity.

CSP can supply peak power during summer months, when wind and hydro energy can be scarce.[59] Energy costs for CSP plants are fixed and are not subject to fuel price swings. In addition, CSP plants generate electricity without emitting carbon dioxide and other greenhouse gases.

CSP plants occupy large tracts of land in areas that, as noted above, usually are far away from urban areas, entailing increased transmission costs. A CSP plant needs about five to 10 acres of land to produce 1 megawatt of installed capacity.[60] The recently completed Nevada Solar One CSP plant near Las Vegas can generate 64 MW of electricity and has a collector field that covers 400 acres, which translates into about 6.25 acres of land to produce 1 megawatt (**Exhibit 10-8**).

In the U.S., the largest and longest-operating CSP systems are the Solar Energy Generating Systems (SEGS) parabolic trough plants located in California's Mojave Desert. These plants, built between 1985 and 1991 and covering about 1,000 acres, continue to perform well and can generate a combined total of 354 MW.[61] In 2006, the SEGS plants accounted for more than half of all grid-connected solar power generated in the U.S.[62] The plants generate electricity during the daytime and shut down at night.[63] Located about 155 miles northeast of Los Angeles, the SEGS plants generate enough electricity to power over 100,000 homes.[64]

Technological advances have renewed interest in CSP plants in the U.S. and Europe. In 2006, the Arizona Public Service utility completed a 1 MW CSP power plant, the first parabolic power plant built in the U.S. in 20 years.[65] In June

CSP can supply peak power during summer months, when wind and hydro energy can be scarce.

Exhibit 10-8

Nevada Solar One, CSP Plant

Source: HotWatt Solar.

2007, another parabolic trough power plant went online in Boulder City, Nevada, near Las Vegas, with a generation capacity of 64 MW — enough electricity to power about 15,000 homes.[66] This plant will minimize transmission costs because it was built adjacent to an existing gas power plant and transmission lines.[67] Several other U.S. CSP plant construction projects have been announced (**Exhibit 10-9**).

In Texas, Austin Energy has solicited proposals for CSP power from sites in West Texas, but has not made a final decision on how or whether to proceed.[68] CSP plants must be located in areas with high solar radiation readings, and in Texas such places are particularly common in the western part of the state, much of which lacks an extensive transmission infrastructure.

Extending transmission lines to such areas is expensive. The Electric Reliability Council of Texas (ERCOT) estimates that building transmission lines to transport wind generated electricity from West and Northwest Texas to urban areas will cost about $1.5 million per mile; CSP projects in the same areas would require similar expenditures.[69] Some large landowners, furthermore, may object to Texas utility companies acquiring property and easements as needed through the use of eminent domain.

Availability

Solar energy is available everywhere on Earth, in varying amounts. Solar radiation that reaches the earth's surface in an unbroken line is called *direct*, while sunlight scattered by clouds, dust, humidity and pollution is called *diffused*. The sum of the direct and diffuse sunlight is called *global-horizontal insolation*. Concentrating solar technologies, which use mirrors and lenses to concentrate sunlight, rely on direct radiation, while PV cells and other solar technologies can function with diffused radiation.

Insolation is a term referring to the amount of solar radiation that strikes the planet's surface over some period — a minute, hour, day, month or year. NREL has developed insolation estimates for the U.S. based on solar measurements taken at a number of stations throughout the country, as well as computer modeling that uses meteorological data to predict insolation at a large number of sites.

According to NREL's measurements, the nation's most plentiful solar resources are found in the Southwest. California, Nevada, Arizona, New Mexico, Utah, Colorado and Texas, and they possess some of the best insolation values in the world. According to DOE, "enough electric power for the entire country could be generated by covering about nine percent of Nevada — a plot of land 100 miles on a side — with parabolic trough systems."[70]

In all, the U.S. has a relatively abundant supply of solar resources. A 1 kW solar electric system in the U.S. can generate an average of more than 1,600 kWh per year, while the same system in

Exhibit 10-9

U.S. Completed and Planned CSP Plant Construction

Utility/State	Capacity (MW)	Developer Name/ Complete Dates
Arizona Public Service	1	Solargenix-Acciona/2006
Florida Power & Light SEGS, California	24	Solel/2007
Nevada Power & Light	64	Solargenix-Acciona/2007
Southern California Edison	500	SES/2012
Southern California Edison	350	SES/2014
San Diego Gas & Electric	300	SES/2012
San Diego Gas & Electric	600	SES/2014
Pacific Gas & Electric	500	Luz II/unknown
Total 2006 US CSP Contract Potential	2,339	

Source: Prometheus Institute.

southern Germany (which installs eight times as many PV systems as the U.S.) would be able to generate only about 1,200 kWh per year, due to that nation's weaker insolation. A 1 kW system installed in parts of Nevada, Arizona, New Mexico and far West Texas can produce 2,100 kWh per year. [71]

Texas has abundant solar radiation statewide, but again, the highest insolation readings are in West Texas. West Texas has 75 percent more direct solar radiation than East Texas, making it an ideal location for utility-scale CSP technologies.[72] Virtually all of Texas, however, has adequate to very good solar radiation.[73]

A study commissioned by the State Energy Conservation Office (SECO) in the mid-1990s found that Texas has 250 "quads" of solar energy accessible per year. Given that one quad is *one quadrillion* British thermal units (Btus) of energy — enough to meet the annual needs of about 3 million people — Texas' solar energy potential is enormous.[74] The 2007 Texas Legislature directed SECO to update a 1995 assessment of Texas renewable energy resources. This report, which will be released before the start of the 2009 Texas Legislative Session, will include up-to-date data on the availability of various renewable energy resources.

Virtually all of Texas has adequate to very good solar radiation.

While the U.S. possesses some of the world's best solar radiation values, it accounted for only 8 percent of worldwide PV installations in 2006. Germany was the undisputed leader in that year, accounting for 55 percent of the world market (**Exhibit 10-10**). Japan came in second place, with 17 percent of the PV world market. Spain's PV installations rose by more than 200 percent in 2006, while the U.S. market expanded by 33 percent.[75]

The U.S. was once a leader in the PV market, but over the last decade it has lost ground to Japan and Germany. Both governments offer generous subsidies to stimulate their solar energy markets. The U.S. has not offered similar subsidies at the federal level, and has not established a long-term, consistent strategy in its approach to solar energy at either the state or federal levels, creating periodic uncertainty in the market.

Costs and Benefits

Both thermal and PV solar systems can produce electricity at significantly lower costs today than in the 1980s, but costs remain high compared to fossil fuel energy sources.

In the U.S., 2006 retail electricity prices for all sectors averaged more than eight cents per kWh, and for residential electricity, the price averaged about 10 cents per kWh.[76] By contrast, parabolic trough-style CSP systems generated electricity at a cost of 12 cents per kWh in 2006, while PV systems generated electricity for about 18 to 23 cents per kWh.[77]

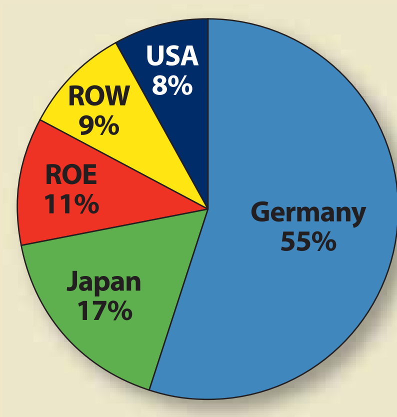
The retail price of electricity during peak hours, however, can rise to between 25 and 40 cents per kWh in some parts of the U.S., making PV systems more competitive during peak periods.[78] PV systems usually generate more electricity during the hottest time of the day, and thus can help to offset the need to add expensive electric generating capacity to satisfy peak demand in warm areas of the country.

PV costs per kWh declined significantly over the last 16 years (from more than 45 cents per kWh in 1990 to about 23 cents per kWh in 2006), due primarily to manufacturing economies of scale as well as improved solar cell efficiency.[79] The Solar

Exhibit 10-10

2006 PV Installations By Market

Total: 1,744 MW



(Note: ROW=rest of world; ROE=rest of Europe)

Source: Solarbuzz 2007.

Energy Industries Association (SEIA) notes that "each doubling in cumulative manufacturing has brought prices down by about 18 percent."[80]

In the past five years alone, the world PV industry has grown by an average of 30 percent or more each year. In 2006, the U.S. PV industry expanded by 33 percent, compared to 19 percent for the world.[81] The expansion of federal income tax credits for commercial and residential solar energy projects, and state and utility incentives, particularly in California, fueled the U.S. industry's impressive growth in 2006. These federal tax credits, however, are set to expire at the end of 2008, and were not extended by Congress in 2007.

A shortage of silicon and growing global demand for solar PV modules led to some cost increases in 2006 and 2007.[82] About 90 percent of PV modules today still are made of crystalline silicon (polysilicon), which has been in short supply globally, constraining production and temporarily increasing the cost of solar cells.[83]

Polysilicon supplies are expected to remain tight and prices high until new plants under construction are completed.[84] Solarbuzz, an international solar energy consulting firm, predicts rapid growth in polysilicon capacity through 2011, and a resumption of faster rates of growth for the PV market.[85] Unprecedented investment in manufacturing capacity is expected to result in lower PV costs over the long term.

The cost of solar modules accounts for 50 to 60 percent of the total installed cost of a PV system, with other system parts, materials, assembly and installation accounting for the remainder.[86] PV module costs have declined by about 80 percent over the last decade, but the installation costs have not dropped appreciably in recent years.[87] Installation costs vary depending on available sunlight, the typical energy usage of the home and the availability of experienced installers in the area. Unlike other energy sources, however, 90 percent of the cost of a PV system is incurred up front.[88] Once the system is installed, there are no fuel costs and the system requires little maintenance.

A PV system designed to supply about 60 percent of the energy needs of a home in California costs about $16,000 to $22,000, minus any tax credit or rebate. In San Diego, California, the federal income tax credit (see below) and a California Solar Initiative (CSI) rebate have reduced the total installed cost of a $17,460 residential PV system by $7,000, for a final cost of $10,460.[89] Solarbuzz notes that government incentive programs can lower solar PV system costs to about 10 to 12 cents per kWh, compared to a range of 22 to 40 cents per kWh without incentives.[90]

The PV industry's overarching goal is to improve solar cell efficiency while reducing their cost. Government research labs and private companies have invested in research and development in the expectation of a breakthrough that will make solar energy competitive with other sources of energy.

Solar cell efficiencies have improved significantly since the 1950s, when they had efficiencies of less than 4 percent.[91] Today, solar cell efficiencies range from 15 to more than 30 percent, but most commercial PV systems are about 15 percent efficient.[92] In December 2006, Boeing-Spectrolab Inc., manufacturer of space solar cells and panels, announced that, with DOE funding, it had developed a solar cell with a conversion efficiency of 40.7 percent.[93] This "multi-junction" solar cell uses a new class of semiconducting materials that allows it to capture energy from more of the solar spectrum. This breakthrough may lead to less expensive, more efficient solar cells.

In the past five years alone, the world PV industry has grown by an average of 30 percent or more each year.

DOE expects significant PV and CSP cost reductions in the next five to 10 years, making these solar technologies more competitive with conventional fuel sources (**Exhibit 10-11**). Improved PV technologies that use cheaper materials, higher-efficiency devices, new nanomaterials applications and advanced manufacturing techniques should reduce the cost of PV-generated electricity to as little as 11 cents per kWh by 2010.[94] DOE also expects CSP-generated electricity prices to decline to 8.5 cents per kWh by 2010. Texas' average residential retail price for electricity was more than 12 cents per kWh in 2006 and 2007.[95]

In addition to cost, however, solar electricity faces other barriers to widespread market deployment. As a new entrant to the power supply market, PV developers face uncertain and inconsistent treatment, both in Texas and nationally, at the hands of regulators and electric utility companies.

EXHIBIT 10-11

Price Trends for Solar Power Through 2015 Photovoltaics and Concentrating Solar Power (CSP)

2006 Status in the United States:

PV	CSP
18 to 23 cents per kWh	12 cents per kWh

Potential for PV and CSP Pricing:

PV	CSP
11 to 18 cents per kWh by 2010	8.5 cents per kWh by 2010
5 to 10 cents per kWh by 2015	6 cents per kWh by 2015

Source: U.S. Department of Energy.

Processes and rules for interconnection and net metering are not consistent throughout Texas, so development of a statewide marketplace for these technologies has proven difficult. Solar industry professionals want clear, consistent market rules to encourage the development of a single market and the jobs and economic benefits that arise from it.[96]

A federally funded study at the University of Massachusetts-Amherst found that experts in solar technology agree that subsidies alone are not enough to support a healthy solar industry; more investment is needed from the manufacturing sector.[97] Recently, the number of private equity firms and venture capitalists investing in the solar energy sector has grown rapidly, as has the number of companies working on various solar technologies.[98]

Recently, the number of private equity firms and venture capitalists investing in the solar energy sector has grown rapidly.

A 2007 report by the IC² Institute indicated that California leads the nation in U.S. federal research awards, patents, scientific publications and business establishments related to PV solar energy (**Exhibit 10-12**).[99] Texas ranked fourth among states in its number of federal research awards related to PV — 18 to California's 62 — with half going to industry and half to educational institutions. Texas accounted for 3 percent of the U.S. scientific literature on photovoltaics, behind California, Colorado, Ohio, New York and Massachusetts. In its number of PV-related patents, Texas ranked fourth, again behind California. And Texas ranked fifth in the number of PV businesses located in the state.[100]

The IC² study concluded that:

> Texas does have some significant PV technologies and intellectual capital, but the current university, research organization, business and state resources are not sufficient to develop a comprehensive, cohesive and synergistic strategy to achieve sustained success in the global marketplace.[101]

Environmental Impact

Solar energy technologies generate electricity without producing air or water pollution. Solar thermal energy technologies may require cooling water, but most of this water can be recycled. Only small amounts of hazardous materials are produced in the manufacture of photovoltaic cells and CSP equipment and essentially none in other solar thermal applications.

Most PV systems are installed on existing structures such as homes and commercial buildings and require no additional land. CSP plants require large tracts of land, depending on the technology used and the size of the project. For example, a 100 MW CSP plant requires between 500 to 1,000 acres depending on whether thermal energy storage is included. NREL estimates that a CSP plant typically needs about five to 10 acres of land to produce 1 megawatt of installed capacity.[102]

In the US, the largest CSP project covers roughly 1,000 acres in the Mojave Desert and can generate 354 MW, while the recently completed Nevada Solar One CSP plant near Las Vegas covers 400 acres and can generate 64 MW of electricity. California's 354 MW solar plants generate enough electricity to power about 100,000 homes and the Las Vegas 64 MW solar plant produces enough power for about 15,000 homes annually.[103]

According to the U.S. Environmental Protection Agency (EPA), CSP plants do not damage the land, but merely take it out of use for other applications such as agriculture. Wildlife habitat may be displaced from land used for such systems, however.[104]

Solar electricity can reduce carbon emissions by offsetting the need for carbon-producing fuels. For example, Applied Materials has installed solar panels at its manufacturing plant in Austin that will generate about 33.7 MWh annually and

Exhibit 10-12
Productivity in Photovoltaics

State	Number of Federal Research Awards*	Percent of U.S. Total	Number of Scientific Publications**	Percent of U.S. Total	Number of Photovoltaic Patents**	Number of PV Businesses
California	62	15%	261	20%	289	310
Colorado	44	11%	255	19%	63	85
Massachusetts	35	8%	101	8%	73	34
Texas	18	4%	44	3%	68	65
Florida	17	4%	52	4%	30	94
Ohio	15	4%	125	10%	55	14
New York	14	3%	113	9%	83	76
Michigan	13	3%	40	3%	59	29
New Mexico	13	3%	53	4%	27	31
Pennsylvania	13	3%	53	4%	55	22
Virginia	13	3%	41	3%	13	19
Percent of U.S. Total		62%		87%		

*1993-2005
**1991-2005
Source: IC² Institute, The University of Texas at Austin.

eliminate about 54,000 pounds of carbon emissions each year.[105]

EPA reports that PV systems do not generate solid waste in creating electricity. Their manufacture generates small amounts of hazardous materials such as arsenic and cadmium, which must be disposed of properly to avoid harm to the environment and humans. Similarly, CSP plants do not produce solid waste when generating electricity, but the construction and production of plant equipment does produce small amounts of hazardous waste.[106]

State and Federal Oversight

The federal and state regulations that apply to the solar industry are those that apply to other manufacturing facilities as well, such as health and safety and environmental regulations. Solar PV systems also must meet existing electric regulations.

Subsidies and Taxes

The solar energy industry, and in particular the photovoltaics industry, has grown in direct response to federal, state and local tax policies and subsidies.

At the federal level, an important subsidy is a 30 percent federal income tax credit for solar energy equipment offered during 2006 and 2007; this was the first residential tax credit for solar energy established in 20 years. (A tax credit is a dollar-for-dollar reduction of an individual's or business' tax liability.) The tax credit applies to business investments in equipment that uses solar energy to generate electricity, or in solar heating or cooling systems. Homeowners qualify for a residential tax credit up to a maximum of $2,000.

The 30 percent credit originally was set to expire at the end of 2007, but Congress subsequently extended it for another year, through December 31, 2008. The tax credit reverts to 10 percent after that date. Industry analysts say that the federal income tax credit for solar energy has expanded markets for solar products, but note that the limited time period for the credit creates uncertainty in solar industry markets.[107]

State and local initiatives — tax policies, rebate programs, standardized interconnection and net metering rules and renewable portfolio standards — also have encouraged the solar industry's growth in some locations. In Texas, the state provides businesses with both a franchise tax deduction and a franchise tax exemption for solar energy devices. In addition, Texas has a property tax exemption for the appraised value of a solar or wind-powered energy device for on-site energy production and distribution. Thus far, however, these state policies have not resulted in significant growth in Texas' solar market.

Texas provides businesses with both a franchise tax deduction and a franchise tax exemption for solar energy devices.

Texas' Renewable Portfolio Standard, or RPS (see Chapter 9) has promoted the growth of renewable energy in Texas, but while it has created a market for wind, it has not proven to be an effective driver for the solar market, where higher costs (relative to wind and biomass) outweigh the higher revenues afforded by the ability to create and sell renewable energy credits (RECs).[108] No solar projects have yet been developed in Texas with the primary intent of creating and selling energy and RECs into the Texas energy and RPS compliance markets.[109]

Interconnection policies and practices are also inconsistent throughout the state. Texas has standardized interconnection policies and procedures developed by the Texas Public Utility Commission that apply to investor-owned utilities, but not to electric cooperatives or municipal utilities.[110] These procedures, moreover, are silent on some issues critical to distributed generators, such as definitions of what types of equipment (such as solar panels, wind turbines and inverters, which convert solar-generated electricity into household current) are eligible for interconnection.[111] Texas' net metering policies and practices are similarly inconsistent and depend upon the type of utility to which the distributed generator is interconnected.

Throughout the U.S. and within Texas, state- or utility-sponsored solar rebate or incentive programs have been the primary driver stimulating demand for solar energy.[112]

Austin Energy currently offers solar rebates ranging up to $4.50 per watt. The cost of installing a 1 kW (1,000 watt) solar system in Austin, for instance, ranges from $6,000 to $10,000, and the Austin Energy rebate pays up to $4,500 toward its purchase and installation.[113] San Antonio's CPS Energy, a municipal utility, offers rebates of $3 per watt for PV panels and installation, capped at $10,000 for residential customers and $50,000 for commercial and industrial customers.[114]

The IC² Institute study of the PV industry, however, concluded that "additional incentives are needed to spur non-wind renewables" in the state.[115]

Other States and Countries

California was the third-largest world market for PV systems in 2006.[116] On August 21, 2006, California gave a huge boost to its solar energy industry when Governor Schwarzenegger signed the "Million Solar Roofs" bill, S.B. 1, directing the California Public Utilities Commission and California Energy Commission to implement the California Solar Initiative (CSI), which offers rebates starting at $2.50 per watt for PV systems up to one MW in size.[117] S.B. 1 took effect on January 1, 2007.

The Million Solar Roofs legislation authorized the state to invest $3.3 billion over 10 years toward the goal of creating 3,000 MW of solar-generated electricity in the state by 2017. It also required that homebuilders begin offering solar panels as a standard option; increased the cap on net metering; and required municipal utilities to create their own rebate programs. California state rebates are estimated to cover about a third of installation costs. In the City of Los Angeles, combined state, local federal and utility rebates can reduce the price of a $35,000 solar system to about $17,500, a 50 percent reduction.[118]

New Jersey, which ranked second in PV installations in 2006, has implemented several initiatives to promote solar energy, including specific targets for solar renewable energy in the state's RPS.
To meet the RPS goals for solar, New Jersey has offered rebates for solar equipment ranging from $2.00 to $3.80 per watt, depending on the size of the PV system, as well as an exemption from the state sales tax for solar energy equipment.[119]

Due to the high number of applications for its solar system rebates, however, the New Jersey

Board of Public Utilities exceeded its budget and had to create a waiting list soon after the program was initiated. In 2007, the state made $47 million available for small (10 kW) residential and commercial installations, but these funds still are not enough to cover current demand.[120] New Jersey is moving its solar strategy away from rebates and toward performance-based incentives, limiting rebates only to small systems based on their estimated performance, and relying more on Solar Renewable Energy Certificates (SRECs) as the primary financial driver for large solar projects.

In New Jersey, an SREC is issued every time a solar electric system generates 1 MWh of electricity. Businesses and individuals can sell or trade them on New Jersey's on-line market for trading SRECs. Electricity suppliers/providers serving New Jersey's retail customers must use the SREC program to meet their solar RPS requirements. Recently, the price for an SREC has averaged about $200 per MWh generated.[121]

Arizona, Colorado and New York also offer substantial incentives for PV system installations.

Germany is currently the largest PV market in the world, with more than 960 MW of installed capacity.[122] By contrast, the U.S. had 526 MW of installed PV capacity in 2006.[123] In Germany, a "feed-in" tariff for solar electricity is the main driver for the PV market. This tariff requires utilities to buy every solar kWh offered by a utility customer at a fixed price for 20 years; utilities, moreover, must connect PV systems to the grid as they are acquired.[124]

Between 1999 and 2003, Germany's 100,000 Roofs Program, which provided low-interest loans for about 340 MW of installed capacity, also contributed to the dramatic growth of the PV industry. Annual installations of PV capacity in Germany rose from 12 MW in 1999 to 960 MW in 2006.

Japan, the second-largest world market for PV installations, accounted for 17 percent of the market in 2006.[125] Japan's 1995 Seventy Thousand Roofs Program provided a 50 percent subsidy for grid-tied PV systems, reducing the net electricity cost to a level competitive with conventional electric options.[126] In the process, this program expanded the PV market and improved the supply chain of manufacturers and installers. In 2006, Japan manufactured about 39 percent of all solar cells.[127]

The Japanese residential PV program expired in 2005, but the PV market is expected to continue growing because the cost of solar energy has become more competitive with retail electricity prices (Japan has some of the highest retail electricity prices in the world). For example, the cost of a typical PV system in Japan has declined from $16,000 per kilowatt in 1994 to about $6,000 per kilowatt in 2005.[128]

The Japanese are the current world leaders in PV manufacturing, creating 824.3 MW in 2005 and accounting for 45 percent of world market share. Europe is in second place, having manufactured 515.3 MW of PV cells in 2005, with 28 percent of the world market share. The U.S. is a distant third, having produced 154.8 MW in 2005 (a 9 percent world market share), barely ahead of China's 150.7 MW (8 percent market share).[129]

Germany is currently the largest PV market in the world.

Outlook for Texas

Government subsidies and incentives have played a vital role in promoting the solar energy industry in the U.S. and throughout the world, and will continue to do so for the foreseeable future. Countries with the most favorable programs and research and development support have experienced the most innovation and most rapid growth in their solar energy industries.

In the U.S., the extension of the federal income tax credit spurred rapid growth in the solar energy market. Since the development of PV and CSP plants requires three to six years, industry advocates support the extension of the tax credit for a longer term.

While Texas has implemented some incentives to spur solar energy development — RPS, franchise tax incentives and some net metering guidelines — several other states have implemented far more generous programs. A recent Texas study also recommended the implementation of additional state-level incentives to spur non-wind renewables.[130]

In November 2006, the President's Council of Advisors on Science and Technology (PCAST) reported that, while the council:

> ...do[es] not believe that solar power will provide the bulk of the Nation's electrical energy requirements in the next few decades, the level of entrepreneurial activity suggests that solar power, particularly for distributed applications, will continue to grow at a rapid rate — perhaps over 50 percent per year — in the near term. Thus, predicting its ultimate place in the electricity generation hierarchy is difficult.[131]

PCAST also noted that some startup companies believe that solar PV will be able to supply power at 10 cents per kWh within five years, allowing solar to compete directly with conventional energy sources.[132]

The IC[2] Institute concluded that Texas has the solar resources and the research institutions needed to achieve significant market share in the global solar energy market.

The IC[2] Institute concluded that Texas has the solar resources and the research institutions needed to achieve significant market share in the global solar energy market, but lacks a cohesive strategy to achieve success.[133] Its report noted that there are many competitors in the global PV industry, and that:

> ...for Texas to acquire and maintain a competitive advantage, it must create opportunities to align research, development, commercialization, and alliance-building strategies necessary to gain a substantial and sustainable foothold in the global marketplace.[134]

The solar energy industry is developing rapidly. Whether Texas becomes a major player in solar energy will depend on decisions made by both public and private entities.

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