Solar Photovoltaic and Solar Thermal Technologies

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Abstract: ***There are two basic categories of technologies that convert sunlight into useful forms of energy, aside from biomass-based systems that do this in a broader sense by using photosynthesis from plants as an intermediate step. First, solar photovoltaic (PV) modules convert sunlight directly into electricity. Second, solar thermal power systems use focused solar radiation to produce steam, which is then used to turn a turbine producing electricity. The following provides a brief overview of these technologies, along with their current commercial status.***

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1.1 SOLAR PHOTOVOLTAIC

Solar PV modules are solid-state semiconductor devices with no moving parts that convert sunlight into direct-current electricity. The basic principle underlying the operation of PV modules dates back more than 150 years, but significant development really began following Bell Labs' invention of the silicon solar cell in 1954. The first major application of PV technology was to power satellites in the late 1950s, and this was an application where simplicity and reliability were paramount and cost was a secondary concern. Since that time, enormous progress has been made in PV performance and cost reduction, driven at first by the U.S. space program's needs and more recently through private/public sector collaborative efforts in the U.S., Europe, and Japan.

At present, annual global PV module production is over 150 MW, which translates into a more than $1 billion/year business. In addition to the ongoing use of PV technologies in space, their present-day cost and performance also make them suitable for many grid-isolated and even grid- connected applications in both developed and developing parts of the world. PV technologies are potentially so useful that as their comparatively high initial cost is brought down another order of magnitude, it is very easy to imagine them becoming nearly ubiquitous late in the 21st century. PV systems would then likely be employed on many scales in vastly differing Environments, from microscopic cells to 100 MW or larger 'central station' generating plants covering square kilometers on the earth's surface and in space. The technical and economic driving forces that favor the use of PV technologies in these widely diverse applications will be equally diverse. However, common among them will be the durability, high efficiency, quiet operation, and lack of moving parts that PV systems offer, and the fact that these attributes combine to provide a power source with minimum maintenance and unmatched reliability.

PV system cost and performance have been steadily improving in recent years. PV manufacturing costs have fallen from about $30 per watt in 1976 to well under $10 per watt by the mid-1990s as can be seen in Figure 5. Installed PV system costs today are about $8.00 to $12.00 per watt, depending on the level of solar insolation at the site and other factors. These installed system costs are expected by some analysts to reach a range of from $3.00 to $6.00 per watt by 2010, and if this is achieved PV systems could achieve a sales level of over 1,600 MW per year by that time.

Figure 1. PV module price trend from 1976 to 1994 along 82 percent progress ratio (Source: U.S. DOE, 1997) PV efficiency has also increased markedly over the past few decades as shown in Figure 6.

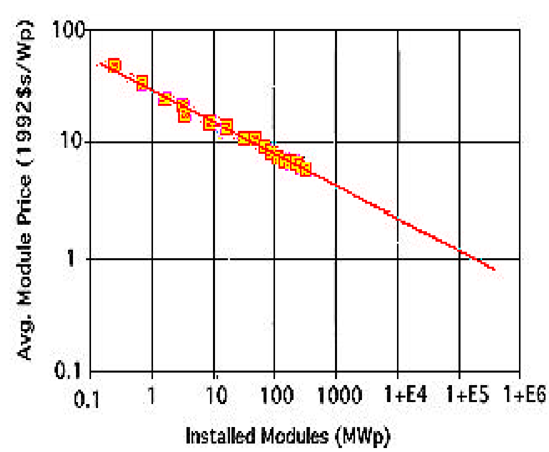
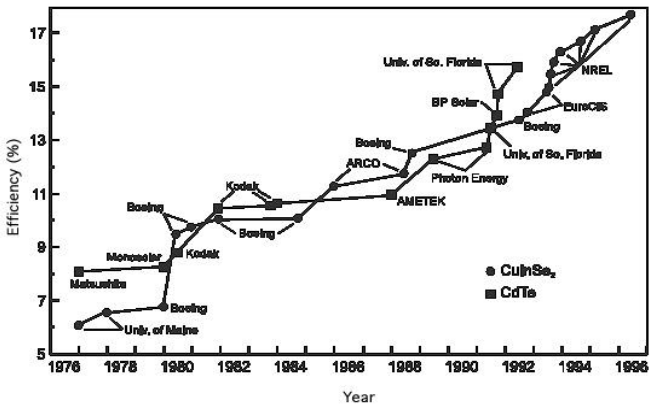


Figure 2. Progress in polycrystalline thin film laboratory

cell efficiencies (Source: U.S. DOE,



The best thin film cells tested in laboratories in 1980 achieved an efficiency level of about 10 percent. This was improved to about 13 percent by 1990 and over 17 percent in recent years, for the best thin film cells made from copper indium diselenide (CuInSe2) or cadmium telluride (CdTe). However, the modules that are currently being manufactured have somewhat lower efficiencies than these recent test cells, with typical values in the range of 9-11 percent for CuInSe2 and CdTe modules, and 8-10 percent for the more common amorphous silicon modules. The efficiency gains made over the last decade or so at the cell level will slowly translate into higher efficiency manufactured products, and this should combine with cell and module manufacturing cost reductions to aid in producing the reductions in per-watt installed system costs discussed above.

Figure 3, below, shows PV shipments by region and for the entire world, from 1976 to 1998. As shown in the figure, PV sales are growing rapidly. In fact, the sales growth rate throughout the 1990s was approximately 30 percent per year.

Thus, PV systems are declining in cost, improving in efficiency, and increasing rapidly in sales. The cost of electricity produced from PV systems is still higher than from most other competing technologies, at about 30 cents per kWh, but these costs are expected to continue to decline steadily. In fact, the U.S. Department of Energy projects that the cost of generating electricity from utility-scale PV systems could be below 10 UScents/kWh by 2010, while by 2020 this cost could fall to about 6 UScents/kWh. Meanwhile, costs of electricity from residential PV systems could reach about 18 UScents/kWh by 2010, and 10 UScents/kWh by 2020. These potential reductions in cost, combined with the simplicity, versatility, reliability, and low environmental impact of PV systems, should help them to become increasingly important sources of economical premium-quality power over the next 20 to 30 years.

1.2. SOLAR THERMAL SYSTEMS

Solar thermal power systems use various techniques to focus sunlight to heat an intermediary fluid, known as heat transfer fluid that then is used to generate steam. The steam is then used in a conventional steam turbine to generate electricity. At present, there are three solar thermal power systems currently being developed: parabolic troughs, power towers, and dish/engine systems. Because these technologies involve a thermal intermediary, they can be readily hybridized with fossil fuels and in some cases adapted to utilize thermal storage. The primary advantage of hybridization and thermal storage is that the technologies can provide dispatchable power and operate during periods when solar energy is not available. Hybridization and thermal storage can enhance the economic value of the electricity produced, and reduce its average cost.

Parabolic trough solar thermal systems are commercially available. These systems use parabolic trough-shaped mirrors to focus sunlight on thermally efficient receiver tubes that contain a heat transfer fluid. This fluid is heated to about 390° C. (734° F) and pumped through a series of heat exchangers to produce superheated steam that powers a conventional turbine generator to produce electricity. Nine of these parabolic trough systems, built in 1980s, are currently generating 354 MW in Southern California. These systems, sized between 14 and 80 MW, are hybridized with up to 25 percent natural gas in order to provide dispatchable power when solar energy is not available.

Power tower solar thermal systems are in the demonstration and scale-up phase. They use a circular array of heliostats (large individually-tracking mirrors) to focus sunlight onto a central receiver mounted on top of a tower. The first power tower, Solar One, was built in Southern California and operated in the mid-1980s. This initial plant used a water/steam system to generate 10 MW of power. In 1992, a consortium of U.S. utilities joined together to retrofit Solar One to demonstrate a molten-salt receiver and thermal storage system. The addition of this thermal storage capability makes power towers unique among solar technologies by allowing dispatchable power to be provided at load factors of up to 65 percent. In this system, molten-salt is pumped from a "cold" tank at 288° C. (550° F) and then cycled through the receiver where it is heated to 565° C. (1,049° F) and finally returned to a "hot" tank. The hot salt can then be used to generate electricity when needed. Current designs allow storage ranging from 3 to 13 hours.

Dish/engine solar thermal systems, currently in the prototype phase, use an array of parabolic dish-shaped mirrors to focus solar energy onto a receiver located at the focal point of the dish. Fluid in the receiver is heated to 750° C (1,382° F) and used to generate electricity in a small engine attached to the receiver. Engines currently under consideration include Stirling and Brayton-cycle engines. Several prototype dish/engine systems, ranging in size from 7 to 25 kW, have been deployed in various locations in the U.S. and elsewhere. High optical efficiency and low startup losses make dish/engine systems the most efficient of all solar technologies, with electrical conversion efficiencies of up to 29.4 percent. In addition, the modular design of dish/engine systems make them a good match for both remote power needs, in the kilowatt range, as well as grid-connected utility applications in the megawatt range.

System capital costs for these systems are presently about $4-5 per watt for parabolic trough and power tower systems, and about $12-13 per watt for dish/engine systems. However, future cost projections for trough technology are higher than those for power towers and dish/engine systems due in large part to their lower solar concentration and hence lower operating temperature and efficiency. By 2030, the U.S. Department of Energy forecasts costs of $2.70 per watt, $2.50 per watt, and $1.30 per watt, respectively, for parabolic trough, power tower, and dish engine systems.

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