Photovoltaics (PV)

Solar Electricity

Semiconductors that convert solar energy directly into electricity are called photovoltaic (PV) devices or solar cells. Although there are about 30 different types of PV devices under development, there are three main technologies in commercial production – monocrystalline cells, polycrystalline cells and thin-film cells.

The Technology

Monocrystalline – or single crystal – solar cells are manufactured from a wafer of high-quality silicon and are generally the most efficient of the three technologies at converting solar energy into electricity.

Polycrystalline solar cells are cut from a block of lower-quality multi-crystalline silicon and are less efficient but less expensive to produce.

Thin-film solar cells are manufactured in a very different process that is similar to tinting glass. These solar cells are made of semiconductor material deposited as a thin-film on a substrate such as glass or aluminum. Thin-film solar cells are generally less than half as efficient as the best cells, but much less expensive to produce. They are widely used for powering consumer devices.

Solar cells are encapsulated into *modules*, several of which are combined into an *array*. There is, however, a growing market of "building-integrated" PV devices that are manufactured as part of conventional building materials such as roof tiles or glass paneling.

A PV array is usually part of a *system* that may also include energy storage devices (usually batteries), support frames and electronic controllers; these are collectively referred to as the *balance-of-system* or BOS.

The amount of power from a PV array is directly proportional to the intensity of the light hitting the array. Photovoltaic arrays produce direct-current (DC) electricity but can be configured to produce any required combination of voltage and current – including conventional residential alternating current (AC) voltages.

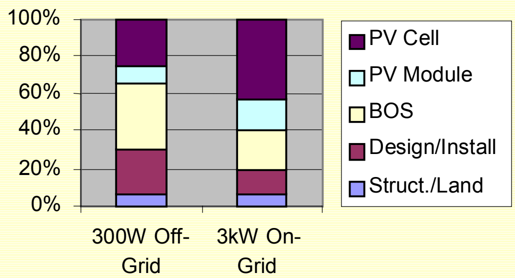
There are currently about 400,000-800,000 photovoltaic systems operating worldwide in applications ranging from individual consumer products and small-scale stand-alone units for rural use (for example, solar home systems) to grid-connected roof-top systems and large

Example of a PV grid-connected system. (Photo courtesy NREL.).

Costs

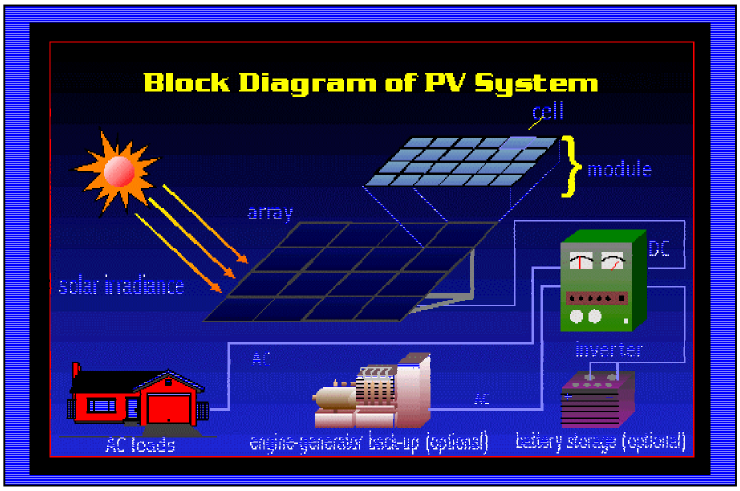
Capital cost PV module:	*$2600 - 5000/kW*
Capital cost PV system (3 kW)	*$4700 - 7000/kW*
Operating Life:	*30 years*

Typical Cost Breakdown



Key Points:

- *PV is most competitive in remote sites, far from the electric grid and when relatively small amounts of power are required, typically less than 10 kW.*
- *PV is a modular technology that can be used in most parts of the world and integrated with diesel, wind, and hydro systems;*
- *PV systems have high capital and low-operating costs.*
- *Few environmental risks are relevant to PV - planning approval and environmental assessment are usually not necessary.*
- *PV technology and systems continue to evolve rapidly.*



central-grid power stations. In the period 1995-2000, more than 20,000 solar pumps were installed globally.

Typical system size varies from 50 watt (W) to 1 kilowatt (kW) for stand-alone systems with battery storage and small water pumping systems; from 500 W to 5 kW for roof-top grid connected systems and larger water pumping systems; and from 10 kW to megawatts for grid-connected ground-based systems and larger building-integrated systems.

Photovoltaic devices are solid state devices with no moving parts and a demonstrated record of reliability. PV modules may operate for 30 years and are usually sold with 10-20 year manufacturer warranties. Although PV modules themselves require little maintenance, other BOS components, particularly storage batteries, generally require maintenance.

To accurately assess the value of electricity from a PV system it is necessary to compare the cost of the PV system to the minimum cost of providing the *same energy service* by an equivalent alternative.

This is particularly relevant for stand-alone systems in remote areas where the temptation is to simply compare the capital costs between PV and other energy supply options. A more accurate approach is a life-cycle cost analysis that includes fuel, maintenance, depreciation, interest and other expenses. PV systems generally have a high capital cost, but a low running cost, as the “fuel” is sunlight.

For rural villages in developing countries, PV technology offers an immediate, direct and safe alternative to kerosene lamps and diesel generators. In such countries a solar home system to power lights and small appliances can be purchased for as little as $350 and may be much cheaper than a grid extension or diesel generator.

Project Risks

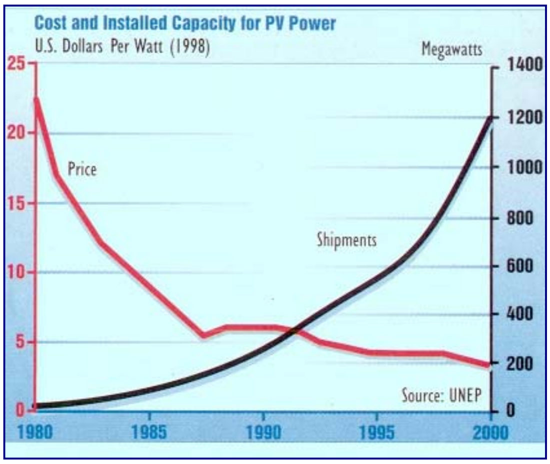
Technology: *Some BOS components, such as power electronics, are relatively new and may be prone to higher failure rates. System design, more than the individual components, is critical to technology risk management.*

Environmental: *Most commercial photovoltaic materials pose no threat to humans or the environment, but components such as batteries do contain hazardous materials. Small PV system projects do not generally require environmental impact assessments as the systems are usually fixed to existing structures. From a government policy perspective, however, recycling or disposal of system components, such as batteries, are important in the design of larger PV programmes.*

Planning: *Off-grid PV systems need minimal planning approvals. Grid-connected systems require grid access permits. These permits are usually standardized with fixed tariffs, and therefore project development risk is usually also low for these systems. PV systems can also be vulnerable to theft and vandalism.*

The Industry and Market Trends

The PV market grew by an average of 15 percent annually from 1990-2000. In 2000, approximately 200 MW of PV modules were sold for a total revenue exceeding US$1.1 billion. The total installed capacity worldwide is now about 1,200 MW, with an average cost of approximately US$4 per watt. Costs have fallen by 20 percent for each doubling of cumulative sales.



At least 30 firms worldwide fabricate PV cells and many more assemble these cells into modules. The top ten cell manufacturers control more than 79% of world shipments. Increasing mass production of PV technology continues to reduce costs in line with the classic “learning curve” for new technologies. Since 1975, PV costs have been reduced by 20 percent for each doubling of cumulative sales.

There is general consensus that thin-film technologies offer the best long-term prospects for very low production cost, but crystalline technology still has large potential for cost reduction through economies-of-scale and technological improvements. Research and development is aimed at improving both the cell and module efficiencies and reducing the cost for BOS components, which currently make up half the cost of the system.