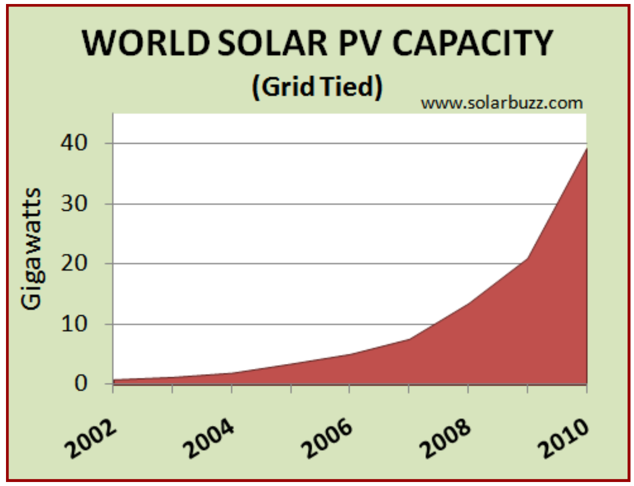
Solar Photovoltaic Technology

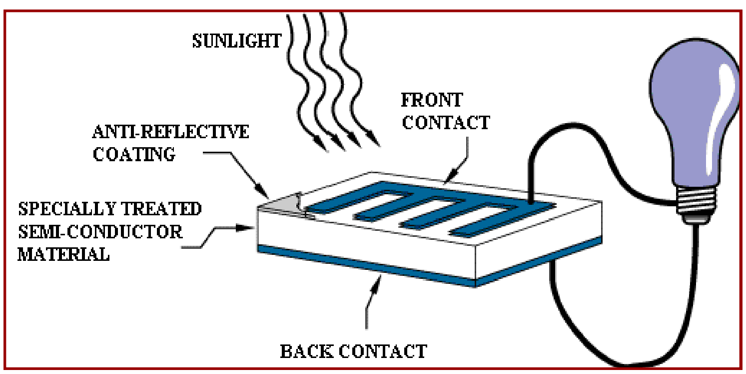
Solar cells, also called photovoltaic (PV) cells by scientists, convert sunlight directly into electricity. PV gets its name from the process of converting light (photons) to electricity (voltage), which is called the *PV effect*. The photovoltaic effect was first noted by a French physicist, Edmund Bequerel, in 1839, who found that certain materials would produce small amounts of electric current when exposed to light. The first photovoltaic module was built by Bell Laboratories in 1954, but it was too expensive for practical applications. During the energy crisis in the 1970s, photovoltaic technology gained recognition as a source of power for non-space applications. Today, solar PV systems are found everywhere from wrist watches to airplanes and thousands of people power their homes and businesses with them. Utility companies are also using PV technology for large power stations.

Solar PV Industry

The PV industry has experienced exponential growth in the last few years driven largely by demand in Europe. Cumulative grid-tied capacity in the US went past the 1gigawatt mark in 2009. Germany, by comparison, installed almost 4 gigawatts in 2009 alone, making it the largest PV market even though its solar resources are inferior to Minnesota and about the same as Alaska.

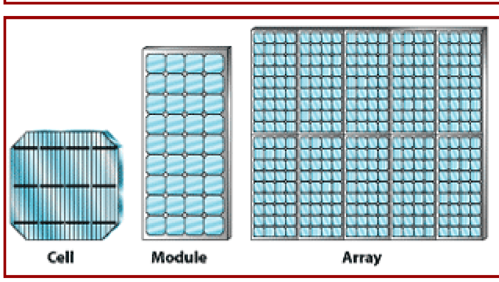


Though solar energy continues to account for less than 1 percent of the U.S. energy supply, its contribution is expected to rise dramatically in the coming years as costs continue to decline. The US Department of Energy is on track with its "Sunshot" initiative to get the installed price of solar PV down to $1 per watt by the year 2020. This will result in the cost of electricity generated by solar panels being directly competitive with electricity generated with fossil fuels.



How it Works

Solar cells are made of the same kinds of semiconductor materials, such as silicon, used in the computer industry. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current -- that is, electricity. This electricity can then be used to power a load, such as a light or a tool.



A photovoltaic (PV) or solar cell is the basic building block of a solar electric system. An individual PV cell is usually quite small, typically producing about 1 or 2 watts of power. To boost the power output, cells are connected together to form larger units called modules. Modules are designed to supply electricity at a certain voltage, such as a common 12 volts system. The current produced is directly dependent on how much light strikes the module. Multiple modules can be wired together to form an array. In general, the larger the area of a module or array, the more electricity that will be produced. Photovoltaic modules and arrays produce direct-current (DC) electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.

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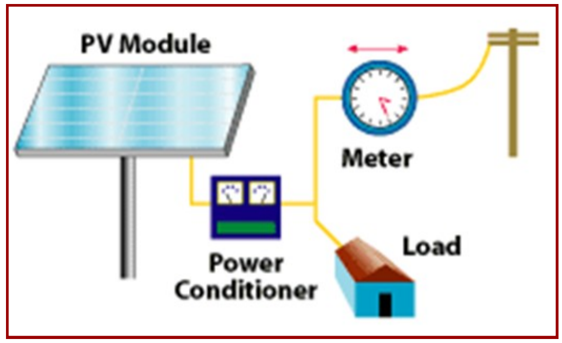
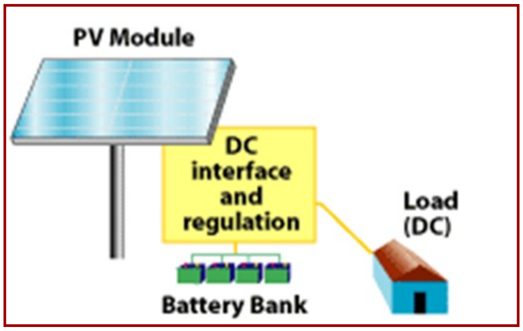
System Architecture

By themselves, modules or arrays do not represent an entire PV system. Structures to orient them toward the sun and components that take the direct-current (DC) electricity produced by modules and convert it to alternating-current (AC) electricity are needed. Batteries to store electricity or conditioning equipment to prepare electricity for the utility grid are also needed. All these items are referred to as the "balance of system" (BOS) components.

Grid Tied Systems

A grid-connected small solar electric or photovoltaic (PV) system receives back-up power from a utility's grid when the PV system is not producing enough power. When the system produces excess power, the utility is required to purchase the power through an arrangement called net metering. A grid connected system requires in inverter and power conditioning equipment to provide electricity that meets utility company standards. Also, safety disconnects are required to allow the utility company to ensure lines are not energized while repairs or maintenance is being done.





Stand Alone Systems

In remote locations, stand-alone systems can be more cost-effective than extending a power line to the electricity grid (the cost of which can range from $15,000 to $50,000 per mile). But these systems are also used by people who live near the grid and wish to obtain independence from the power provider or demonstrate a commitment to non-polluting energy sources. Stand alone systems also require an inverter if AC loads will be used. Batteries are used to store excess electricity and a charge controller is needed to control the charging process and protect the batteries from over charging. Deep cycle lead acid batteries are typically used and have a long life when properly used.

Design Considerations

In a stand alone system, energy efficiency should be assessed first as every dollar spent on efficiency can save from $3 to $5 on PV system costs, and a back-up generator may be needed. All systems start with the determination of the energy needed per day in watt*hours. From this, the battery bank (if used) and the solar array can be sized accounting for losses in the equipment and wiring, dust, temperature losses, etc., which can be 20% to 40%. Solar panels are rated assuming the solar irradiance (intensity) is 1000 W/m^2. So the daily energy output is calculated by multiplying a panel's rated power output by the number of peak sun-hours, which are the equivalent number of hours per day that a particular location will have 1000 W/m^2. The annual average of peak sun-hours for most of Minnesota is 4.5. Finally, the charge controller, inverter, fuses and wiring are sized for worst case conditions. PVWatts is a free model that can predict monthly power output and electric bill savings for any location and is available at www.nrel.gov/rredc/pvwatts/version2.html.

PVWatts Model of USFW 21.6 kW System

Month	Irradiation (kWh/m2/day)	Electricity (kWh)	Savings
JAN	3.16	1782	$136.22
FEB	4.06	1996	$152.57
MAR	4.19	2217	$169.47
APR	5.28	2547	$194.69
MAY	5.45	2608	$199.36
JUN	5.57	2489	$190.26
JUL	5.73	2638	$201.65
AUG	5.48	2544	$194.46
SEP	4.80	2225	$170.08
OCT	4.09	2054	$157.01
NOV	2.91	1468	$112.21
DEC	2.71	1464	$111.91
YEAR	**4.45**	**26031**	**$ 1,989.81**

Morris US Fish and Wildlife Office PV System

The system went online in 2010 and is expected to generate a zero net energy bill for the office and visitor's center.

System Facts

- Rated total power is 21.6 kW , 96 modules at 225 W each (4 arrays)
- Modules provided by Solon Corp., model Blue 220/01, eff. = 13.7%
- 240 V, 21 Amp true sine wave inverter with peak power tracking
- Inverter provided by SMA America Inc., model Sunny Boy 5000US

Solar PV systems are still a relatively expensive method of generating electricity due to high module manufacturing costs and the inherent inefficiency of solar cells (about 6% to 17%). A lot of research is currently being conducted to address these issues.

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