E^{3}A: Solar Electricity for the Home, Farm or Ranch

Steps in the Solar Electricity Series

System components

Photovoltaic materials

Photovoltaic materials are the electricity-producing component of a solar electric system. PV materials are made of solar cells, which absorb sunlight to release electrons that flow as electricity. The greater the amount and intensity of the sunlight, the more electricity generated. PV materials generate direct-current (DC) electricity. PV materials are commonly built using crystalline silicon panels and thin-film materials in various sizes and levels of electrical output.

On partly cloudy days, PV materials will work at about 80 percent capacity. Extremely overcast days might reduce electricity output to 30 percent capacity. PV materials are relatively unaffected by severe weather and temperatures, though like most electronic devices they operate more efficiently at cooler temperatures. Because they are typically a dark color and face the sun at an angle, snow slides off or melts quickly. PV materials are designed to resist hail damage; one name brand panel has been tested to withstand 1-inch hail at 51 mph. They typically come with a 25-year power output warranty, but most will produce electricity for more than 30 years.

Crystalline silicon

Crystalline silicon flat-plate panels vary in size and electrical output, and they can be used for a variety of applications. Those typically placed on home rooftops range from about 2 to 3 feet wide by 4 to 5 feet long with a 3-inch thickness. Electrical output ranges from 175 to 250 watts.

Photo credit: DOE NREL

Multicrystalline silicon PV panels.

Thin-film PV

Thin-film PV materials are flexible and versatile for a variety of applications. They are made by spreading silicon and other materials in a thin layer — about the thickness of a human hair — directly onto a base material. This makes thin-film PV ideal for building-integrated products such as roof shingles, tiles, building facades, windows and skylight glazing.

Thin-film solar shingles.

A third generation of solar materials includes lightweight foil-based panels, solar inks and dyes and conductive plastics. Researchers are investigating how to make PV materials more efficient at converting sunlight into electricity.

If your building does not have a south-facing roof or surface — or you cannot use PV materials as structure — panels can be ground-mounted or pole-mounted in a yard or field. Pole-mounted panels can be in a fixed south-facing position or placed on tracking devices, which follow the sun's path in the sky. A single-axis tracker follows the sun

Table 1. Photovoltaic material types

Crystalline silicon	**Single-crystalline silicon** Also called monocrystalline • Made from a single, large silicon crystal • Most commonly used • 15 to 20 percent efficient: currently the most efficient material for converting sunlight into electricity • Costs more per watt than multi-crystalline; less than thin-film
Crystalline silicon	**Multicrystalline silicon** Also called polycrystalline • Made from silicon blocks with many, small crystals • 10 to 15 percent efficient • Costs less per watt than single-crystalline and thin-film
Thin-film	**Thin-film types** Amorphous silicon and non-silicon materials such as copper indium gallium selenide (CIGS), and cadmium telluride • 6 to 10 percent efficient • Currently costs more per watt than both crystalline silicon types

from east to west. A dual-axis tracker follows the sun from east to west and adjusts for seasonal sun angles. Trackers increase system cost but can also increase power production by 20 to 30 percent. For hands-on homeowners or building managers, manually adjustable rooftop mounting structures allow for seasonal sun angle adjustments.

PV material performance

Manufacturers will provide a minimum warranted power rating in watts, which might also be called peak power or peak tolerance rating. Many panels are tested under Standard Test Conditions (STC) or PVUSA Test Conditions (PTC), the main difference being testing temperatures. A PTC rating is deemed a more realistic rating. Panels with an STC rating might have an actual performance of 85 to 90 percent of stated wattage output, so be sure to compare efficiency ratings.

System performance

If you are sizing your own complete system, you can use the rated wattage output, or referred to as nameplate DC rating, to estimate the number of panels needed to meet your targeted electrical load. Actual electricity output will depend on factors such as roof orientation, tilt angle and system efficiency. Because there are inefficiencies in the remaining components, multiply the PV panel nameplate DC rating by 77 percent — a conservative de-rate factor used in NREL's PV Watts online tool — for an estimate of the actual amount of electricity received. For example: a 230-watt Nameplate DC rating × 0.77 = approximately 177 watts of actual electrical power will reach your electrical load.

Photo credits: DOE NREL

Balance-of-system

Balance-of-system (BOS) refers to the remaining components that accompany PV panels. BOS includes an inverter, meters, safety equipment such as a disconnect switch, batteries and a charge controller. It also includes conduit, cable and combiner boxes.

Inverter

An inverter converts and conditions electricity. PV materials produce DC electricity, which can be used for DC-powered appliances, such as equipment for camping and boating. Most appliances, electronics and machinery require alternating-current (AC) electricity, and an inverter converts PV-generated DC into AC electricity. Inverters also condition PV-generated electricity to match the qualities of the utility grid-produced electricity to properly power the electrical load. Contact your utility company to ask if it requires a specific Underwriter's Laboratories-certified inverter.

Inverter/charger

A combined inverter/charger is used in systems with batteries. It converts PV-generated DC stored in the batteries to AC, and it allows batteries to be charged by the utility grid or an off-grid system's backup generator. It converts AC electricity to DC from the utility or generator for battery storage.

Solar electric system components must be matched to work together as a system. If you plan on adding more PV panels at a later date, size your inverter for the future system. It will be less expensive than upgrading to a larger inverter and the necessary accompanying equipment changes. Inverters should be accessible, weather-protected and kept out of direct sun. Inverters can be up to 98 percent efficient and last up to 20 years, though warranties are typically for 10 years.

Some installers will connect micro-inverters with each individual PV panel instead of installing one larger inverter. Micro-inverters work well where there might be panel shading, and they can make system expansion easier and less expensive.

Meters

Meters track the amount and direction of electrical flow in grid-tied systems. Off-grid systems often have meters to track battery charge levels. If your building or machinery does not use all of the electricity generated, it is fed into the utility's grid. When this occurs, you are credited at either a retail or wholesale rate by the utility. The retail rate is the rate you pay for electricity from the utility. The wholesale rate is a lower rate the utility pays for electricity it buys on the market.

To track grid-tied system electricity, the utility typically provides and installs a special net meter once a grid-tied system installation is completed. This meter spins forward (clockwise) when you are using electricity from the grid and backward (counterclockwise) when the system feeds excess electricity into the grid. If at the end of a year's billing period you used more electricity than your PV system generated, you pay the utility company. If your PV system generated more than you used, you receive a utility credit. Contact your utility company to determine if it allows connection to the grid. If it does, ask for current interconnection and net-metering requirements.

Safety equipment

Safety equipment protects owners, utility workers and system equipment. This equipment is important for protecting people and system components from power surges, lightning strikes, ground faults and equipment malfunctions. Safety equipment includes grounding equipment, surge protectors and AC and DC disconnect switches, for which both automatic and manual switches are recommended. Disconnect switches shut down the system, so it can be safely worked on for routine maintenance and repairs. Switches also prevent the system from sending electricity to the grid and endangering utility workers while they conduct repairs.

Charge controller

A charge controller regulates battery charging. A charge controller, also called a regulator, is necessary when batteries are part of a solar electric system. A charge controller regulates and optimizes electrical flow from the panels to the batteries, keeps batteries fully charged and prevents battery overcharging. It also prevents batteries from being excessively discharged, which can damage or ruin them. Charge controllers must be properly matched to the overall solar electric system to function properly. Charge controllers can be up to 98 percent efficient and are typically warrantied for up to five years. Inverters and charge controllers can be combined into one piece of equipment.

Batteries

Batteries store electricity and are necessary for off-grid solar electric systems. Electricity is stored and used from the battery bank, which is sized to provide electricity for the full electrical load for two or three days. Grid-tied buildings with battery backup typically have a small battery bank to store electricity for use during utility power outages. Batteries can lower the overall efficiency of a solar electric system because they only release 80 to 95 percent of the electricity fed into them. Batteries need periodic maintenance and have safety considerations. They might last seven to more than 10 years before requiring replacement. Lifespan depends on factors such as number of discharges and the temperature where they are stored.

Whether installing a solar electric system to power a building or pump water, make sure to purchase quality, certified components.

Component and system certifications

- PV panels: Underwriter's Laboratory (UL) 1703 safety standard
- Inverters and Charge Controllers: UL 1741

Organizations that test and certify system components:

- The Florida Solar Energy Center (FSEC): *www.fsec.ucf.edu*
- Go Solar California: *www.gosolarcalifornia.org* (Equipment Section)

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