E3A: Solar Electricity for the Home, Farm, or Ranch

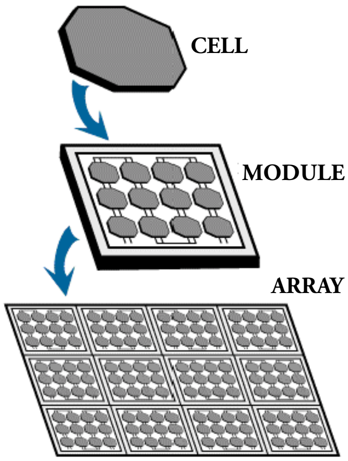
Authors: Bilo, Susan; Sarah Hamlen, Mike Vogel, and Milton Geiger, eds. E3A Program

Steps in the Solar Electricity Series

B-1281 | E3A-SE.0

Introduction

Most of Montana and Wyoming's electricity is generated by coal-fired power plants. An alternative is to use the sun's energy as the fuel to produce electricity. This is accomplished using photovoltaic (PV) technology. The letters PV stand for "Photo" = light and "Voltaics" = electricity. PV technology can potentially be used anywhere the sun shines.



Courtesy of NASA http://science.nasa.gov/science-news/science-at-nasa/2002/solarcells/

Solar electricity is produced through the PV Effect: when sunlight hits a solar cell, electrons are released and flow as electricity through wires to your building or equipment. Solar cells are connected together to form a panel (also called a module). Panels are wired together to form an array.

PV technology is used to power everything from calculators and outdoor lighting fixtures to buildings and satellites. Whatever is powered by electricity (appliances, machinery, etc.) is called the electrical "load." The sun can provide electricity for your home, greenhouse, and barn. It can also electrify fences and pump water.

In addition to the PV panels, a solar electric system (also called a PV system) includes an inverter, meter, and safety equipment. It may include batteries and a charge controller. These systems contain no moving parts, are silent, very durable and reliable, and are low maintenance. Once installed, they only use the sun's energy and their operation produces no emissions. Solar electric systems can produce all or a portion of the electricity needed. PV panels can be added to an existing system over time.

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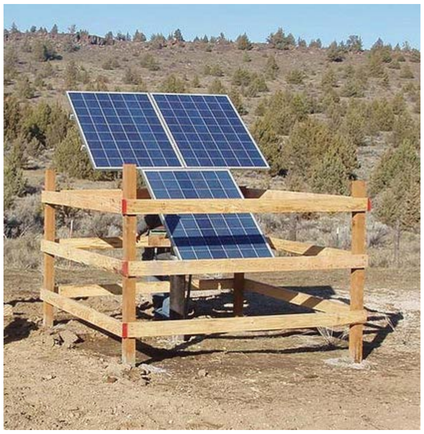

Design of Small Photovoltaic (PV) Solar-Powered Water Pump Systems. Courtesy USDA NRCS. http://blogs.usda.gov/2011/06/01/as-application-deadline-approaches-solar-workshop-energizes-participants/

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Photo by Dennis Schroeder, NREL 22166 http://images.nrel.gov/viewphoto.php?&albumId=207405&imageId=6322760&page=2&imagepos=19&sort=&sortorder=

System costs depend on a variety of factors. As a general rule of thumb, a grid-tied residential system without batteries costs between $3,000 and $5,000 per kilowatt (kW) of electricity produced. This includes installation costs. Utility rebates and government tax incentives can significantly reduce the final system cost.

Dispelling the myth

There is a myth that it takes more energy to make a PV system than it produces over its lifetime. "Energy payback" is the term used to describe the amount of energy it takes to develop/manufacture a system versus the amount of energy it generates. How long does a PV system have to operate to recover the energy that went into making it? The energy payback for rooftop PV systems ranges from 1 to 4 years depending on the type of PV panel. A properly designed, installed, and maintained system can produce energy for and last 30-plus years.

People invest in solar electric systems for a variety of reasons: they want a clean, reliable source of electricity, they want independence from a utility company and price increases, and they want to leave a smaller environmental footprint. Investing in a system also helps support local renewable energy companies and their employees. Montana and Wyoming have and continue to build an infrastructure of qualified and certified companies and independent contractors who install and service solar electric systems.

Montana and Wyoming have an excellent solar resource that makes solar electric systems worth considering. You do not need to be an electrician or PV installer to understand how solar electricity systems work. The factsheets provide basic information that can help you decide if a solar electric system will work for you and help you discuss the topic knowledgeably with an installer. The sheets can be used separately or together for a step-by-step decision-making process.

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1. **Building & Site Assessment:** Building and site conditions to consider.
2. **Conservation & Efficiency:** Conserving and using energy more efficiently can reduce the system size and cost.
3. **System Options:** There are four system options to consider.
4. **System Components:** Provides detailed information about system option components.
5. **System Sizing:** Proper sizing is important for a resource-efficient and cost-effective system. Includes a Panel and System Sizing Worksheet.
6. **Costs:** System costs depend on various factors. Rebates and incentives lower the cost.
7. **Installation:** What to consider when deciding whether to hire a contractor/installer or do-it-yourself.
8. **Operation & Maintenance:** Routine inspections and maintenance keep systems working efficiently and longer.
9. **Electricity Use Worksheet**

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Notes

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STEP 1

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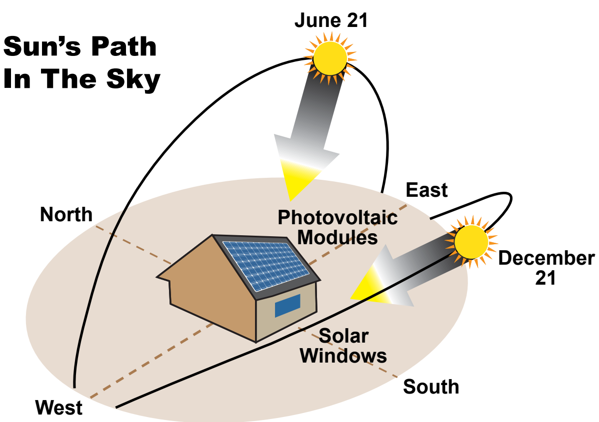
Building and Site Assessment

Answering these questions will help you determine if a solar electric system will work for your building or site.

1. Do you have a south-facing roof?

Because Montana and Wyoming are in the northern hemisphere, PV panels (modules) need to face south for maximum performance. This placement allows panels to take full advantage of the sun's path in the sky. The sun shines longest on a building's south side. Southeast- and southwest-facing panels will perform about 5 percent less efficiently.



☐ Yes! — Move to Question #2

☐ No — Options: PV panels can be used as structure such as a porch cover or window awnings. They can also be ground-mounted or pole-mounted. If you cannot place PV panels to face south, a solar electric system will likely not be an efficient investment.

Panels can be mounted on east- or west-facing roofs to face south, but they stick up, are highly visible, and can be unattractive. Architects and builders can address this by designing "solar ready" buildings and integrating solar technology components into their designs.

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http://farmenergymedia.extension.org

2. Does your roof have enough space for PV panels?

The rule of thumb for PV panels is 100 square feet of space is needed for every kilowatt (kW) of electricity produced. For thin-film PV materials (such as solar shingles), about 175 square feet of space per kW is needed.

☐ Yes! — Move to Question #3

☐ No — Options: If your roof does not have enough space, review the Options section under the previous question.

Photo by Namaste Solar Electric NREL, 15620

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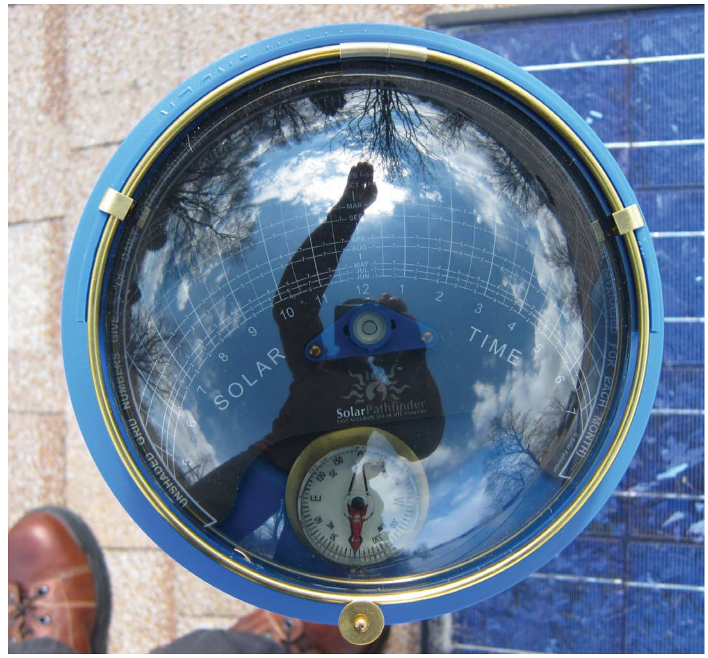
3. Is your roof unshaded?

Photovoltaic panels are very sensitive to shading. Any shading will dramatically reduce electricity generation. Installers use a Solar Pathfinder device to determine if there are shading concerns from trees (consider mature height), chimneys, nearby buildings, etc. Keep in mind the sun's path changes throughout the year. For maximum electricity production, make sure panels will be unshaded year-round (especially from 9 or 10 AM until 3 PM).

☐ Yes! — Move to Question #4

☐ No — Options: If the shade is from landscaping, consider removing the plants. Check local and state codes regarding "solar access" rights if a neighbor might produce shade on any solar system you are considering. See the Pre-Installation section of Factsheet 7. If some shade is inevitable, ask the installer about microinverters.



Solar pathffinder. CC BY-NC-SA 2.0 Sam Ley
www.flickr.com/photos/phidauex/4436387544/

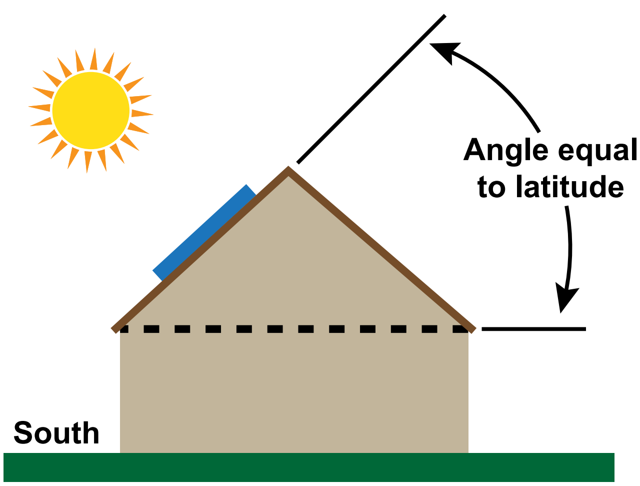
4. What is the angle of your roof?

Installers typically mount panels directly (flush) on an existing south-facing roof for aesthetics. To maximize electricity generated year-round, mount modules at an angle equal to or close to your site's latitude (46 degrees for Helena; 41 degrees for Cheyenne). Installers can tilt at an angle best for your site, system type, and electricity needs.

For more summer electricity production, tilt at latitude minus 10 degrees to 15 degrees; for more winter production, tilt at latitude plus 15 degrees

Flat Roofs: Panels can be angled on flat roofs often found on commercial, industrial, and institutional buildings, but should not be placed flat (horizontal) because of snow build-up that will block the sun.

Solar Collection Orientation



Is your roof in good condition?

Most roofs can safely support PV panels and mounting system weight. The rule of thumb is 2 to 5 pounds per square foot depending on the panel type and installation method. For example, a 230 watt crystalline panel (3.5 feet x 5.5 feet) weighs about 50 pounds. An installer should determine if the roof/structure can handle the added weight. Innovative mounting systems can make panel removal easy, but because panels can last 30+ years, it may be less expensive and labor intensive to make needed roof repairs before installing panels.

☐ Yes! — Move to What's Next?

☐ No — Options: Complete any needed repairs first. If considering a new roof, contact a PV system installer/contractor for roof options/recommendations that might make panel installation easier or less expensive.

What's Next?

If you answered yes to every question or can make adjustments where you answered no, your building or site is a good solar electric system candidate! A system supplier or installer can provide a more detailed assessment. Next, consider how conservation and efficiency measures can result in an efficient and affordable system; then, learn about system options.

Notes

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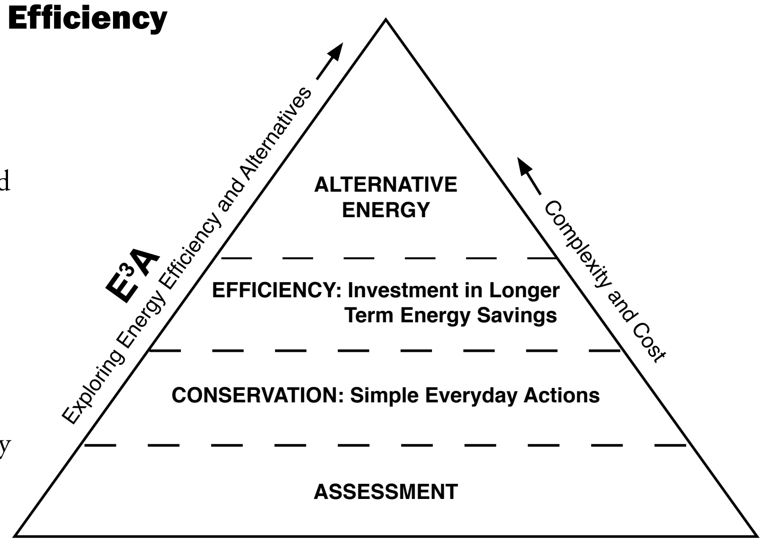
Conservation and Efficiency



Energy conservation and efficiency provide the foundation for a smaller, more efficient and affordable solar electric system.

It is easy to get excited about photovoltaics and other renewable energy technologies, but energy conservation and efficiency measures should be considered first. Why? Because when you or a contractor sizes your system, it is based on the amount of electricity used. The less you use, the smaller, more efficient and affordable the system will be.

It is almost always cheaper to reduce energy use than to buy a larger renewable energy system. Replacing inefficient lights, appliances, equipment, and machinery can significantly reduce the size and cost of your solar electric system. Plus, the electricity savings continue for the life of the replacements.

You or a system installer can review past utility bills to determine your electrical load in order to properly size your system.

EXTRA: If interested, use Step 9: Electricity Use Worksheet to make a list of everything that uses electricity and how much. This exercise will create an awareness of what will be powered by your PV system, how electricity use changes throughout a day, month, or a season, and will help you determine ways to reduce your electrical load. The information can also be used for calculating your system size in Step 5: System Sizing.

As an example, let's consider residential electricity use. According to the Montana Department of Environmental Quality's Energy Saver's Guidebook, the top three residential electricity loads in typical Montana homes are lighting (29 percent), refrigerators (18 percent), and clothes dryers (16 percent). These numbers are for homes that use natural gas for space and water heating.

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Tips to Reduce the Top Three Home-Electricity Loads

Refrigerators

- **Conservation Tips**
  - Keep air filters and grates clean
  - Keep as full as possible
  - Clean door seals to prevent air leakage
  - Keep frequently used items near front for quick access (door not open as long)
- **Efficiency Tips**
  - Buy an energy-efficient Energy Star refrigerator

Clothes Dryers

- **Conservation Tips**
  - Air-dry clothes on a drying rack or on a clothesline outside during warmer months

  For an existing dryer:
  - Use the Moisture Sensor selection if available
  - Use the washer's high spin selection to remove more moisture
  - Frequently clean lint screen
  - Don't overload: air circulation aids quicker drying
  - Keep any external air exhaust connections clean
  - Dry light and heavy clothes separately
  - Use the cool down cycle to use existing heat to dry for remaining time
- **Efficiency Tips**
  - Because clothes dryers use similar amounts of energy to operate, they are not Energy Star rated and will not have EnergyGuide labels. If buying new, select one with a Moisture Sensor that will stop the dryer when clothes are dry. Washing machines are Energy Star rated.

Lighting

- **Conservation Tips**
  - Turn-off when not needed
  - Use natural daylight whenever possible
  - Dim lights if you have dimmer switches
  - Use motion sensors for outdoor lights normally left on all night
  - Remove bulbs not needed/used in recessed can fixtures
  - Use task lighting, e.g., desk lamps or under-counter lights, instead of ceiling lights
- **Efficiency Tips**
  - Install Energy Star compact fluorescent lamps/lights (CFL) or other energy efficient bulbs/tubes
  - Use outdoor solar lights for mood or pathway lighting
  - Install dimmer switches
    - Install skylights and solar tubes for natural daylight

Whether for your home, farm or ranch, upgrading to efficient lighting is one of the easiest ways to save money and reduce electricity use. If using standard incandescent bulbs for lights typically turned on for 15 minutes or longer, consider replacing them with CFL bulbs (Compact Fluorescent Lamps/Lights). CFLs use 75 percent less energy and last 10 times longer than incandescent bulbs. They also produce 75 percent less heat than incandescent bulbs. This makes them safer to operate and they can cut home or building cooling costs.

CFLs cost more at the store, but they cost less to operate (the second price tag) and are cheaper overall. They will save you money when you are paying for utility electricity and may help reduce the size or number of PV panels needed for your solar electric system! Review this comparison of a 23 watt CFL and 100 watt incandescent bulb. Both provide the same level of brightness (lumens).

Compact Fluorescent Lamp (CFL) & Incandescent Cost and Energy Use Comparison

	CFL	Incandescent
Equivalent Light Output Wattage	23 watts	100 watts
Bulb Cost	$7.00	$0.25
Bulb Lifespan	10,000 hours	1,000 hours
Bulb Cost for 10,000 Hours	**$7.00**	$0.25 x 10 = **$2.50** (takes 10 bulbs to get 10,000 hours)
Energy Used in kWh	10,000 hours of light at 23 watts = 230,000 watt-hours. 230,000 ÷ 1,000 watts = **230 kilowatt-hours (kWh)**	10,000 hours of light at 100 watts = 1,000,000 watt-hours. 1,000,000 ÷ 1,000 watts = **1,000 kilowatt-hours (kWh)**
Utility Electricity Cost for 10,000 hours of light at $0.08 / kWh	230 kWh x $0.08 = **$18.40**	1,000 kWh x $0.08 = **$80.00**
Store Purchase Cost + Electricity/ Operation Cost = Total Cost	$7.00 + $18.40 = **$25.40**	$2.50 + $80.00 = **$82.50***

Add the "value" of the time it takes to replace burned-out incandescent bulbs 9 times.

CFLs can replace incandescent bulbs for most of a building's lighting needs. They work best and are most efficient when left on for at least 15 minutes (less than that shortens their lifespan). Halogen and light emitting diodes (LEDs) are also more energy efficient than incandescent bulbs. Larger, agricultural-based buildings can be retrofitted to use T-8 fluorescent tube lighting and other efficient lights.

Other efficiency measures for the farm or ranch include modifying irrigation systems by switching from high- and medium- to low-pressure sprinkler systems and using variable speed drives for pumps, fans, and other equipment. A farm can reduce electricity use by as much as 35 percent with variable speed drives alone. If energy and water resources are a concern, planting crops with lower water requirements reduces water use and the electricity needed for pumping. Converting to drip irrigation or a linear/pivot system also saves both energy and water.

Conserve where you can and buy energy efficient fixtures, appliances, and machinery. Look for Energy Star labels and compare the bright yellow EnergyGuide labels.

The Montana Department of Environmental Quality and U.S. Department of Energy have booklets with numerous tips on how to save money and energy.

- *Montana Energy Savers Guidebook: Practical ways to Save Money and Improve Comfort*:
- *Energy Savers Booklet: Tips on Saving Energy & Money at Home*: http://www.energysavers.gov/pdfs/energy_savers.pdf

If you hire a business to conduct an energy and/or water use assessment, select one that has trained and certified employees. BPI (Building Performance Institute) and RESNET (Residential Energy Services Network) are two certification programs for homes that use the HERS (Home Energy Rating System). Your utility company may provide a free or low-cost assessment.

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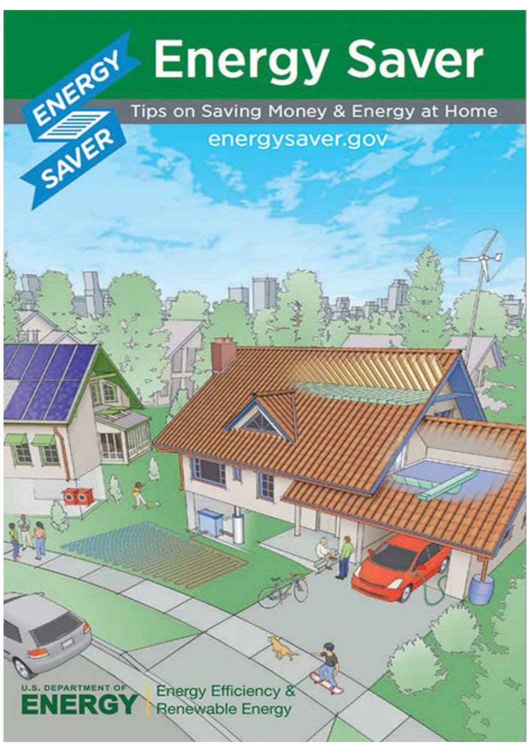

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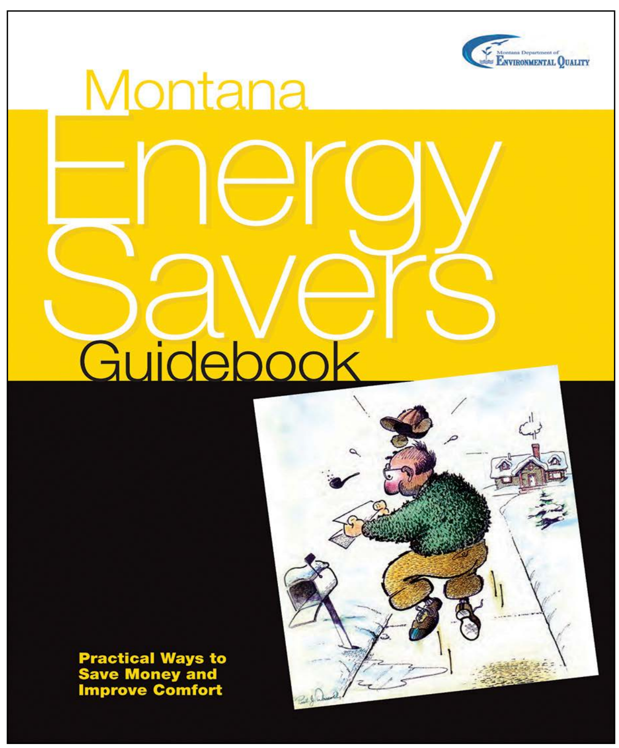

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STEP 3

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System Options

This factsheet provides flow charts for the four most common solar electric system options. Each system is designed based on whether it includes batteries, whether it is connected to the utility grid, and the electrical load. The term "grid" refers to a utility company's system of transmission and distribution lines that carry and deliver power plant-generated electricity to your home or business. Step 4: System Components factsheet provides information about each major component.

Photo courtesy of Warren Gretz, NREL 10927

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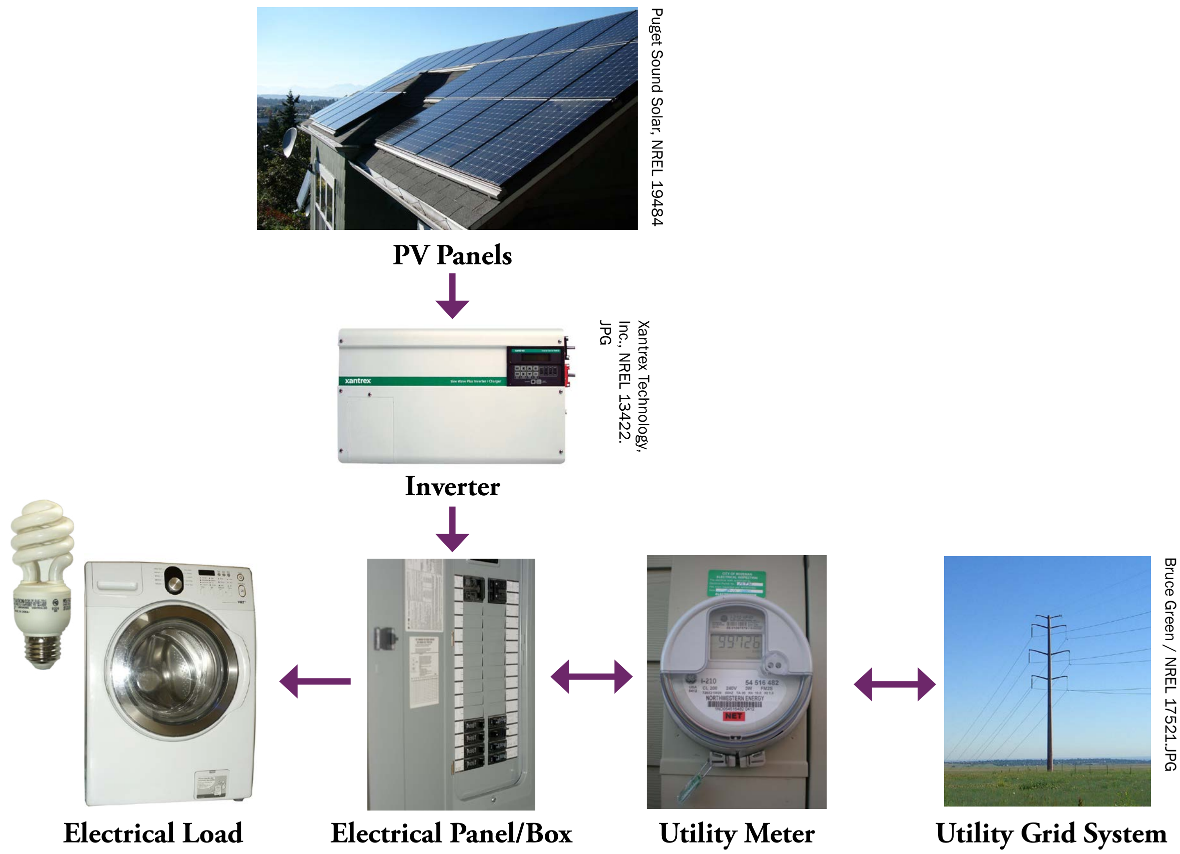
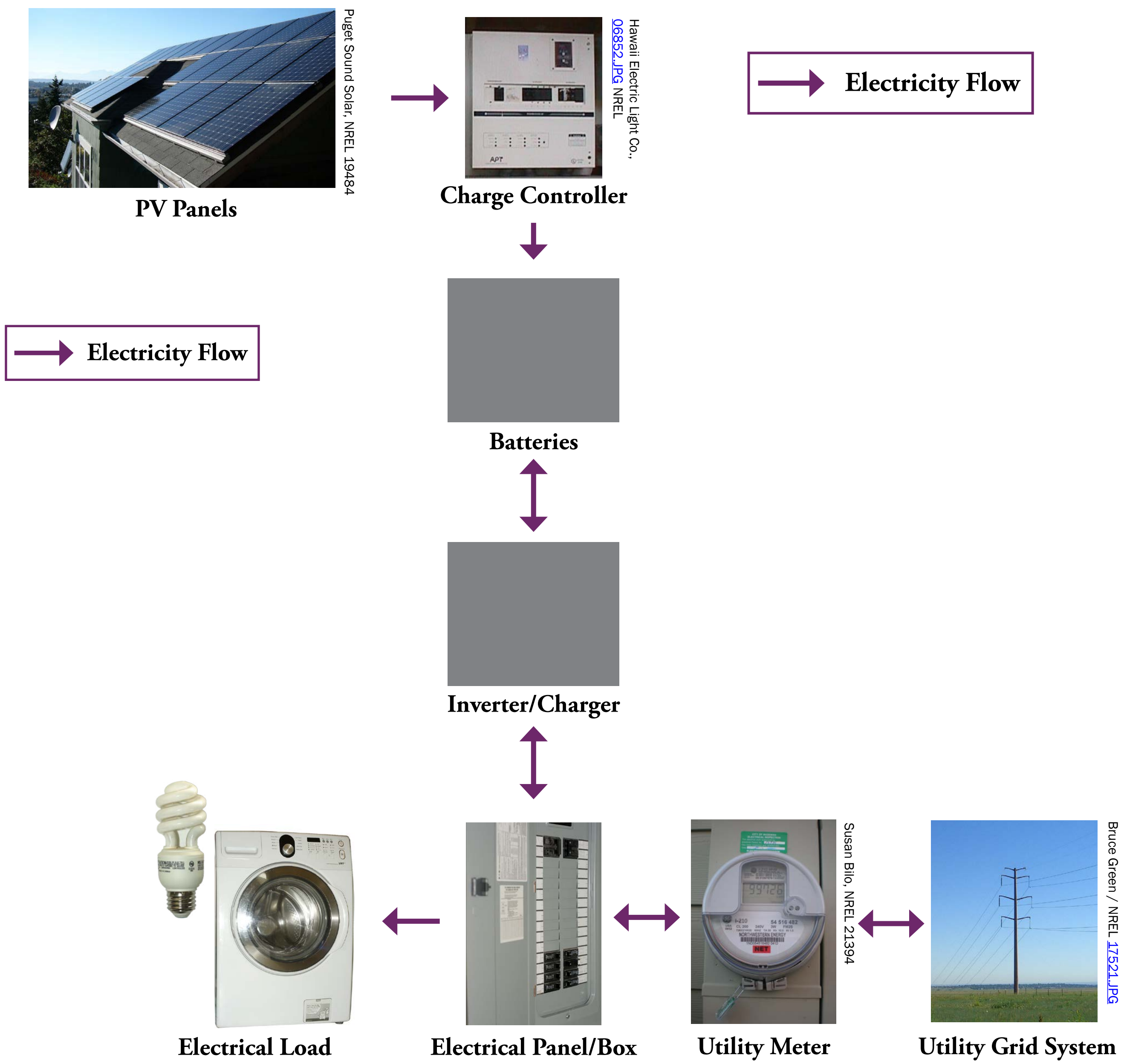
Grid-Connected Systems

Grid-connected systems are connected to the utility power grid. They are also called grid-tied systems. Grid-connected systems without batteries are currently the most common/popular system type. PV panels produce electricity when the sun is shining during the day. At night, electricity comes from the utility grid. If during the day the building or equipment needs more electricity than the PV panels are producing, electricity is provided by the utility grid. If the PV panels are producing more electricity than needed, the extra electricity is fed into the utility grid. If there is a daytime power outage, the PV system automatically shuts down (does not supply electricity) for utility worker safety.



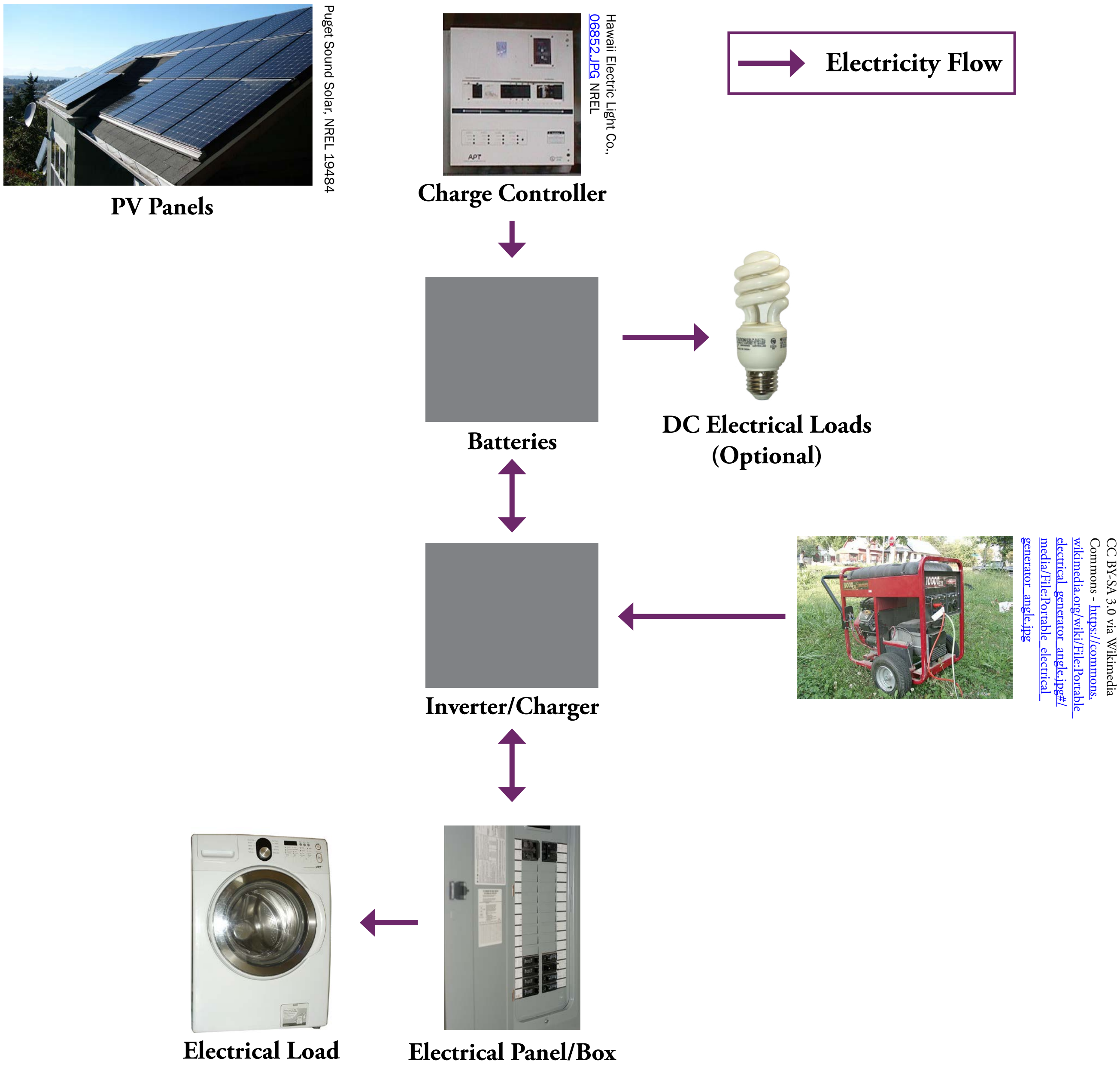
Grid-Connected Systems with Batteries

Grid-connected systems with batteries work exactly the same way as grid-connected systems except electricity is stored in batteries for use during a utility power outage. Homes/buildings can have dedicated “critical” electrical loads powered by the batteries. These loads might include a refrigerator, water- and heat-related pumps, furnace fans, medical equipment, or a computer for a home-based business.



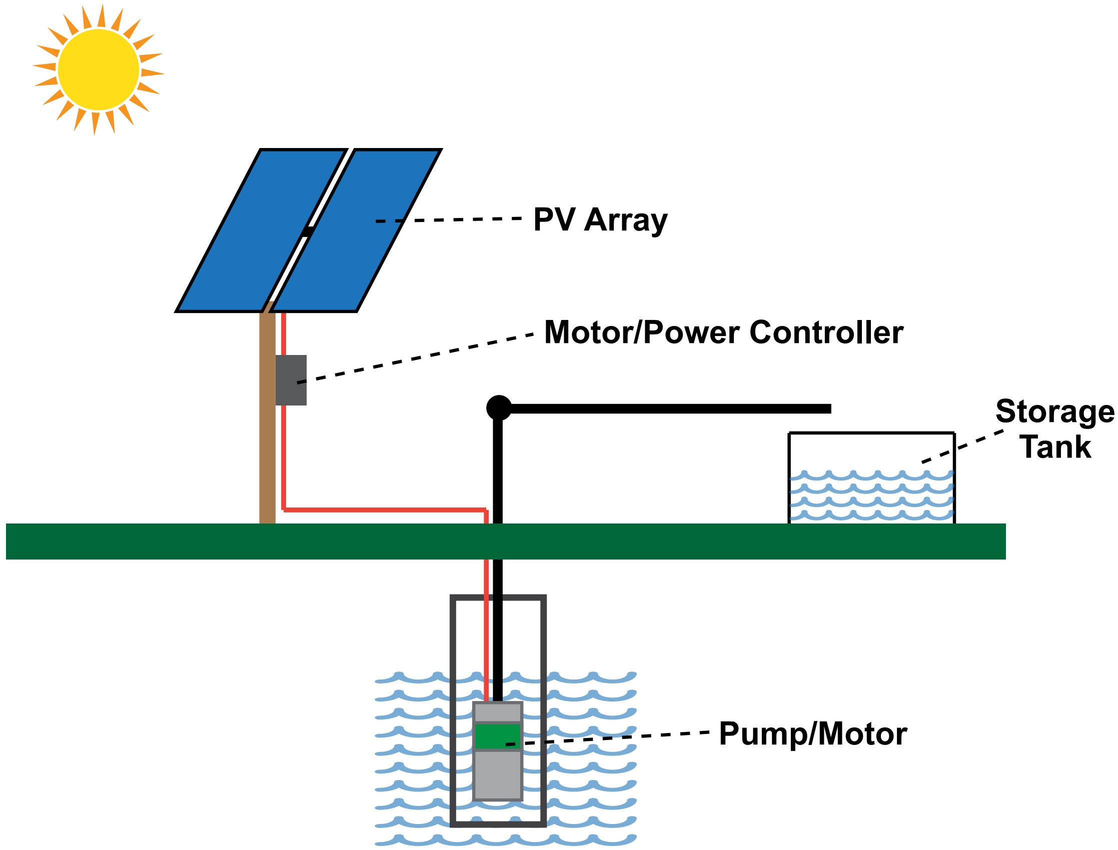
Off-Grid Systems

Off-grid systems are not connected to the utility grid. They are also called stand-alone systems. PV-generated electricity is stored and used from batteries. These systems are typically installed in remote areas where connecting to the utility grid costs more than an off-grid system. Off-grid solar electric systems typically have supplemental and back-up power from a small wind turbine and/or a fossil-fueled generator.



PV-Direct Systems

PV-direct systems do not entail batteries and are not tied to the utility grid. Thus, they only power the load when the sun shines. They can have moving parts such as pumps. These systems have the fewest components and are used with DC-powered appliances or equipment. Applications include water pumping, building ventilation, etc.



PV-powered water-pumping system illustration.

Simple, DC-powered systems can have batteries for applications such as electric fences that need to be powered at night. Whether from the ground or a river, water can be pumped for crops or livestock using photovoltaics.

Solar Livestock Watering System
Photo courtesy of Steve Fletcher, University of Wyoming. CC BY-NC 3.0 http://farmenergymedia.extension.org/

Parmak PV electric fence charger.
Plattville, Colorado; Aristocrat Angus Ranch; Don Currie, Photo courtesy of Warren Gretz / NREL, 04346

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STEP 4

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System Components

Photovoltaic (PV) Materials

Photovoltaic (PV) materials are the electricity producing component of a solar electric system. PV materials are made of solar "cells." When the sun's light energy (not heat energy) hits and is absorbed by the cells, electrons are released and flow as electricity. The greater the amount and intensity of the sunlight, the more electricity generated. PV materials generate direct current (DC) electricity. Commercially available PV materials include crystalline silicon panels and thin-film materials that are both made in various sizes with various wattages of electrical output.

On partly cloudy days, PV materials will produce about 80 percent of their capacity. Extremely overcast days may reduce electricity output to 30 percent of capacity. PV materials are relatively unaffected by severe weather and temperatures, although 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 namebrand panel is tested to withstand one-inch hail at 51 mph). They typically come with a 25-year power output warranty, but most will produce electricity 30-plus years.

Crystalline Silicon

Crystalline silicon flat-plate panels range in size and electrical output. They can be used for a variety of applications. Those typically placed on home rooftops range from about two-to-three feet wide by four-to-five feet long with a three-inch thickness. Electrical output ranges from 175 to 250 watts.

Close up of silicon crystalline solar cell. (Photo by Dennis Schroeder / NREL, 21770)
Four, 250-watt PV panels = 1,000 watts = 1 kilowatt (kW). Together, they produce 1 kWh of electricity per hour in direct (peak) sun. If the panels get 4 hours of direct sun, the system may produce 4 kWh that day.

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 very thin layer (human hair thickness) directly onto base materials. This makes them ideal for building-integrated products such as roof shingles, tiles, building facades, windows, and skylight glazing.

Photo courtesy of Wayne Appleyard, NREL 09690
http://images.nrel.gov/viewphoto.php?imageId=6313910

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

Photovoltaic Material Types	
Crystalline Silicon	**Single-Crystalline Silicon** Also called Monocrystalline • Made from a single, large silicon crystal • Most commonly used • 15-20%+ efficient: currently the most efficient material for converting sunlight into electricity • Costs more per watt than multi-crystalline; less than thin-film
	Multi-Crystalline Silicon Also called Polycrystalline • Made from silicon blocks with many, small crystals • 10-15% 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 • 6-10% efficient • Currently costs more per watt than both crystalline silicon types

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. Like sunflowers, tracking devices follow the sun's skypath. A single-axis tracker follows the sun 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 increase power production by 20 to 30 percent. For the more hands-on homeowner or building manager, adjustable rooftop mounting structures are available for making seasonal sun angle adjustments.

PV Material/Panel Performance

Manufacturers will provide a minimum warranted power rating (in watts) that may be called peak power or peak tolerance rating, etc. Many panels are tested under either Standard Test Conditions (STC) or PVUSA Test Conditions (PTC). The main difference is the testing temperatures. A PTC rating is deemed a more realistic rating. If the panels you are considering have a STC rating, actual performance may be 85-90 percent of stated wattage output. Be sure to also compare efficiency ratings.

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System Performance

If you are sizing your own complete system, you can use the rated wattage output (referred to as nameplate DC rating) to estimate the number of panels you will need to meet your targeted electrical load. Actual output of electricity will depend on factors such as roof orientation, tilt angle, and overall system efficiencies. 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 on-line tool) for an estimate of the amount of electricity that will actually reach your electrical load. For example: a 230 watt DC Nameplate rating x .77 = approximately 177 watts of actual electrical power will reach your electrical load.

Balance-of-System (BOS)

Balance-of-System (BOS) is a term that refers to the remaining components that accompany PV panels. BOS includes an inverter, meter(s), safety equipment (disconnect switches, etc.), batteries, and a charge controller. It also includes conduit, cables, and combiner boxes.

Inverter

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

Inverter/Charger

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

All 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 accompanying equipment changes that would also be required. 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. Warranties are typically for 10 years.

Some installers will connect microinverters to each individual PV panel instead of installing one larger inverter. Microinverters work well where there might be potential panel shading. 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, etc.). When the sun is shining, the PV system generates electricity. If your building or machinery does not use all of the electricity being generated at any one time, it is fed into the utility's grid. When this occurs, you are credited at either a retail or wholesale rate from 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.

How is grid-tied system electricity tracked? Typically, a special Net Meter is provided and installed by the utility company once a grid-tied system installation is completed. This meter spins forward (clockwise) when you are using electricity from the grid and spins backward (counterclockwise) when you are generating excess PV-generated electricity that is fed 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. Safety equipment includes AC and DC disconnect switches, grounding equipment, and surge protection. This equipment is very important for protecting people and system components from power surges, lightning strikes, ground faults, and equipment malfunctions. Automatic and manual disconnect switches are recommended. Disconnect switches shut down the system so it can be worked on safely whether for routine maintenance or repairs. Switches also prevent the system from sending power to the grid and endangering utility workers while they conduct repairs.

Charge Controller

A charge controller regulates battery charging. When batteries are part of a solar electric system, a charge controller, also called a regulator, is required. It is connected between the PV panels and the batteries. 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 for proper function. 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. Off-grid buildings require batteries as part of the solar electric system. 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 back-up typically have a small battery bank used to store electricity for use during utility power outages. Batteries can lower the overall efficiency of a solar electric system because they only release a percentage (80-95 percent) of the electricity that is fed into them. Batteries need periodic maintenance, and have safety considerations. They may last from seven to ten-plus 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:

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Notes

STEP 5

E3A: Solar Electricity for the Home, Farm, or Ranch

Authors: Bilo, Susan; Sarah Hamlen, Mike Vogel, and Milton Geiger, eds. E3A Program

Steps in the Solar Electricity Series

System Sizing

The size of your solar electric system depends on:

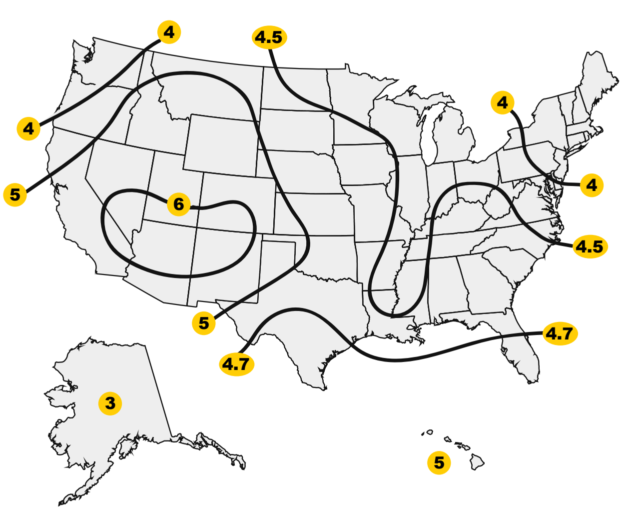
- How much electricity is used and the percentage of solar electricity to be generated.
- Type of PV material used (crystalline silicon or thin-film).
- Roof or other PV material mounting surface orientation, tilt, area, and condition.
- Local solar resource (solar radiation) and peak (direct) hours of sunlight.
- Budget.

You or a system installer can review your utility bills to determine how much electricity you use–typically shown in kilowatt-hours (kWh). If the information is not on your bill, contact your electricity provider and ask for your average monthly use in kWh.

One method for approximating system size is using **Daily Peak Sun Hours**:

1. Determine your average monthly electricity use in kWh.
2. Divide by 30 for average use per day.
3. Find the Peak Sun Hours for your location on the map. Peak sun hours are the hours of direct sunlight that fall on a PV panel (not total hours of daylight).
4. Divide the answer calculated in #2 by your Peak Sun Hours.

Annual Average Daily Peak Sun Hours



#4's answer is a rough estimate of the solar electric system size you will need (in kW) for 100% of your electricity.

Example:

1. A Helena home's monthly average electricity use is 856 kWh/month.
2. 856 kWh ÷ 30 = **28.5 kWh** average per day
3. Helena is near the diagram's "5" line = 5 annual average peak sun hours per day.
4. 28.5 ÷ 5 = **5.7 kW** PV system would be needed to produce 100 percent of this home's electricity.

B-1281 | E3A-SE.5

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NOTE: This method provides a rough estimate and should not be used to size a system. The actual system will most likely be larger due to many system-related factors.

For more accurate sizing, use the worksheet below. It takes conservation and efficiency measures and system component inefficiencies into account.

Solar Electric PV Panel/System Worksheet *Based on a South-Facing PV Module at a Fixed Tilt (Latitude Angle)*		
Steps	Example: Home in Helena, Montana	Your Home/Building
1. Average monthly electricity used in kilowatt-hours (kWh).	856 kWh/month	
2. Multiply by 1,000 to convert to watt-hours used per month.	856 X 1,000 = 856,000 watt-hours/month	
3. Divide by 30 for total average watt-hours used per day.	856,000 ÷ 30 = 28,533 watt-hours/day	
4. Subtract daily watt-hours eliminated through energy conservation and efficiency.	28,533 – 8,953 = 19,580 watt-hours/day	
5. Multiply by the percent of electricity you want provided by the sun.	For 50%: 19,580 X .50 = 9,790 watt-hours/day	
6. Divide by the average monthly solar radiation for your city or the city nearest you. Find in **Table A**. (on next page)	9,790 ÷ **4.7 kWh/m²/day** = 2,083 watts	
7. Multiply by 1.2 to account for system inefficiencies (wire losses, etc.)	2,083 X 1.2 = 2,500 watts	
8. Divide by 1,000 for the size of the overall system in kilowatts (kW). Will be used to approximate system cost.	2,500 ÷ 1,000 = **2.5 kW** PV array/ “system” size	
9. Divide #7’s answer by the Peak/Max Power (in watts) of the PV panel you will install. (230 watts is a typical average)	2,500 watts ÷ 230 watts = 10.8 (11) panels	
10. Round up to a whole number. This is the number of PV panels needed to provide electricity based on the selected criteria.	**11**, 230-watt PV panels (11 x 230=2,530 watts) or **10**, 250-watt panels (10 x 250=2,500 watts)	

Worksheet Notes:

1. Montana homes used an average of 856 kWh/month of electricity in 2009.
2. 1 kilowatt-hour (kWh) = 1,000 watt-hours
3. 365 days/year divided by 12 months = 30 average days in one month.
4. Energy conservation and efficiency measures can reduce the size of your system.
5. PV panels can be added to a system over time.
6. The solar radiation value used to rate panels is 1 kW/m² and thus the results are in watts.
7. The amount of PV-produced electricity decreases as it flows through wires, the inverter, and other system components. NREL’s PV Watts on-line tool addresses this using a de-rate factor.
8. Converts watts back to kilowatts (the units used to describe a system’s “size”).
9. If you know what PV panel you will use, divide Box 7’s watts by the Peak Power (in watts) of the panel to determine the # of panels needed. Do you have enough space on your roof?

After the number of panels is determined, the remaining balance of system components (inverter, etc,) can be sized accordingly. While the kW output calculated in Step 8 above is specific to the PV panels/array, the kW number is also referred to/used as the “system size.”

Find your city or city nearest your site for your average daily Solar Radiation (Solar Resource):

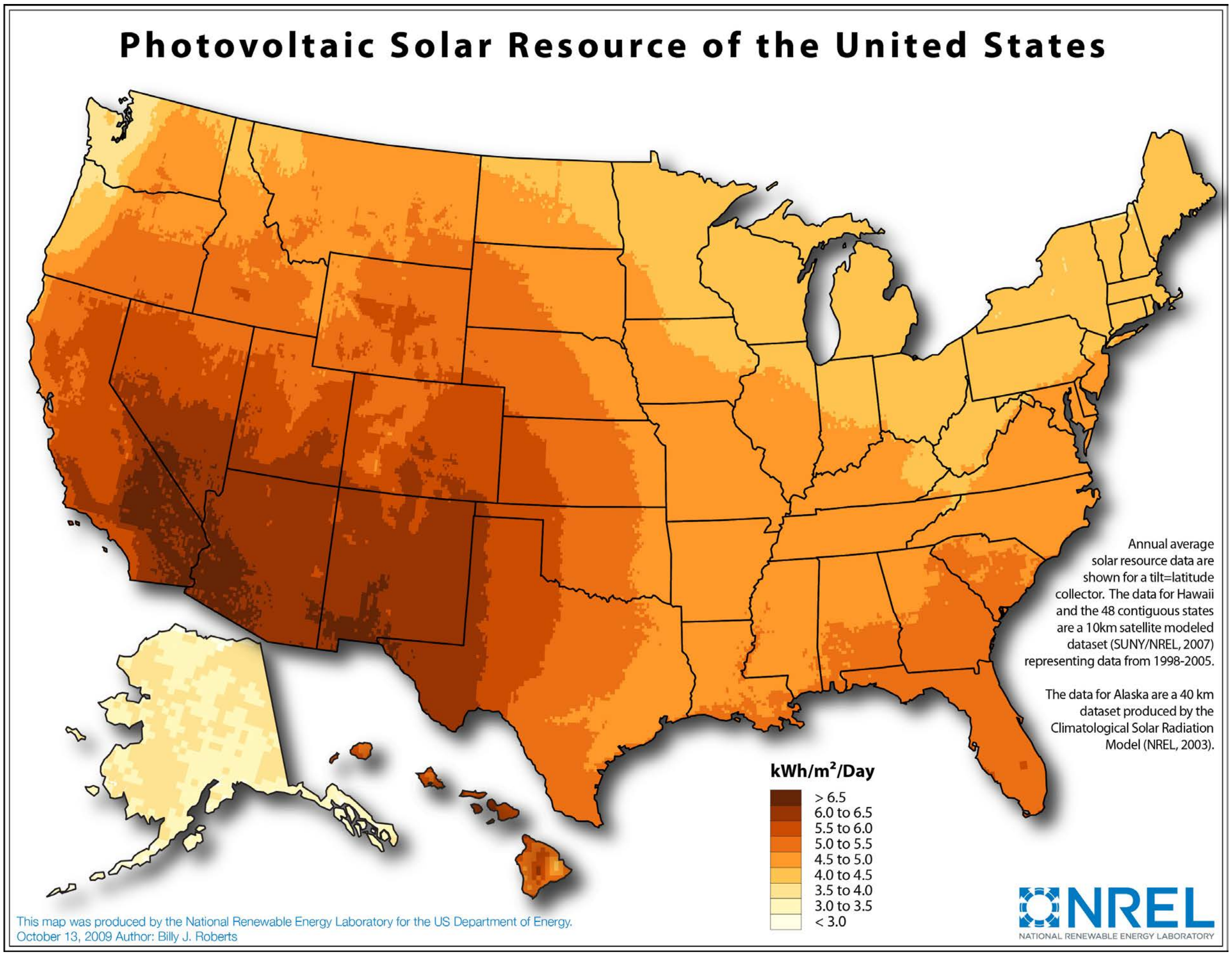
Table A: Solar Radiation Data for Flat-Plate Collectors/Panels (south-facing, fixed tilt at latitude angle)

Montana Cities	kWh/m²/day	Wyoming Cities	kWh/m²/day
Billings	5.0	Casper	5.3
Cut Bank	4.8	Cheyenne	5.3
Glasgow	4.7	Lander	5.6
Great Falls	4.8	Rock Springs	5.5
Helena	4.7	Sheridan	5.0
Kalispell	4.1		
Lewistown	4.7		
Miles City	5.0		
Missoula	4.3		

Source: U.S. DOE/National Renewable Energy Laboratory (NREL): http://rredc.nrel.gov/solar/pubs/redbook/

These Montana and Wyoming cities have National Solar Radiation Data Base collection stations. The NREL web link provides adjusted panel angles and tracking system data.

If your city is not listed in the table or is not near the listed cities, find your solar resource/radiation number from the map below. If printed/copied in black and white, access the map at http://www.nrel.gov/gis/solar.html



Courtesy of NREL, http://www.nrel.gov/gis/solar.html / www.nrel.gov/gis/images/solar/national_photovoltaic_2009-01.jpg

Computer/On-Line Sizing Tools allow you to consider a combination of PV system options for specific locations using your address or zip code. Know how much electricity you use in one year (in kWh) and the approximate PV system size you are considering before you access the free programs described below.

- **PV Watts** is an on-line calculator that provides energy production and cost savings estimates for grid-tied systems: http://archive.is/mapserve3.nrel.gov

NOTE: After you type-in your zip code and select "Send to PVWatts," a screen will appear that allows you to make selections. Under PV System Specifications, "DC Rating," change the default (set at 4.0) to 1.0. After you select "Calculate," two tables appear. Under the "Results" table, look for the "Year" result (in kWh) under the "AC Energy" column. Divide your yearly electricity use (in kWh) by the "Year" number from the "AC Energy" column to determine the PV system size needed to provide 100% of your electricity from the sun. The "Energy Value" column shows electricity cost savings.

- **IMBY = In My Backyard** estimates solar electric or wind turbine system electricity production: http://www.nrel.gov/eis/imby/
- **My Solar Estimator** estimates solar electric as well as wind and solar hot water system sizes: www.solar-estimate.org

Whether you use pencil and paper or a computer, these exercises provide a sense of what system size will work for you. A consultant or installer can provide a more detailed analysis and can advise on what will work best for your particular needs. Are you interested in solar electricity because you want to reduce your **environmental footprint**? To determine the amount of greenhouse gases you are not emitting into the atmosphere by installing a solar electric system, use Option 1 (insert the kWh provided by the solar electric system) with the **U.S. EPA's Greenhouse Calculator**: www.epa.gov/cleanenergy/energy-resources/calculator.html

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Notes

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Steps in the Solar Electricity Series

Costs

As a general rule of thumb, an installed, grid-tied residential solar electric system without batteries costs approximately $5,000 to $7,000 per kilowatt (kW). Using watt units, $5 to $7 per watt. Larger systems typically cost less per installed kilowatt. An "installed kW" price includes the purchase and installation costs. Using the Helena home system sizing worksheet example, a 2.5 kW system that provides 50 percent of the home's electricity would cost about $15,000. (2.5 kW x $6,000 = $15,000)

Note: Be prepared to pay or finance the full purchase price because some incentives that lower the final cost are received after the system is installed.

Incentives That Lower Costs

There are a variety of federal, state, and local government and utility incentives for energy efficiency and renewable energy. These incentives vary by state and in the length of time they are available. The Department of Energy's Database of State Incentives for Renewables and Efficiency (DSIRE) — http://dsireusa.org — keeps track of tax credits, rebates and other incentives available to reduce your system's final cost.

Estimating Cost Savings and Simple Payback for a Net-Metered System

First, calculate the yearly cost savings of your PV system using the formula:

(PV system size) x (Energy Production Factor) x (Electricity Rate) = $/year saved

For the Helena example:

- PV system size: 2.5 kW
- Energy Production Factor: 4.7 kWh/m2/Day (find in Factsheet 5's Table A: Helena's (Year) average or the NREL map on Page 3) x 365 days/year = 1,716 kWh/kW-year
- Electricity (utility) Rate: $0.09 per kWh

2.5 kW x 1,716 kWh/kW-year x $0.09/kWh = $ 386 saved per year

Simple Payback is calculated by dividing the system price by the amount saved per year. Examples below use the Helena home numbers.

Without Incentives

- System Cost: $15,000 ÷ $386 saved per year = 39-year simple payback

With Current Incentives

- First, apply any utility rebates. Northwestern Energy customers that meet the utility's system qualification requirements are eligible for a $3 per watt rebate ($6,000 limit): For the example: 2.5 kW = 2,500 watts. 2,500 x $3 = $7,500. Thus, the full $6,000 rebate can be used:

$15,000–$6,000 = $9,000

- Federal Income Tax Credit (expires Dec. 31, 2016) is 30 percent of system cost (after utility/local rebates). $9,000 x 30 percent = $2,700 tax credit.

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- Montana State Income Tax Credit (currently no expiration date) is $500 for one taxpayer; $1,000 for a household: $1,000 tax credit.

$9,000–$2,700–$1,000 = $5,300

System Final (Net) Cost: $5,300 ÷ $386 saved per year = 14-year simple payback.

NOTE: Payback times decrease when electricity costs increase. Some conservation and efficiency measures (that can reduce PV system size) also qualify for a tax credit. Visit the DSIRE website for complete and up-to-date information: http://dsireusa.org/

Montana currently provides property tax exemptions for renewable energy systems, but some have expiration dates. Contact the Montana State Department of Revenue for current and applicable information.

PV System Financing

There are a variety of financing options for solar electric systems:

- Montana Department of Environmental Quality Alternative Energy Low-Interest Loan
  Visit: www.energizemontana.com. Under the Renewable Energy heading, select Alternative Energy Loan for details.
- Bank Loan
- Home refinance — roll into a mortgage payment
- Construction loan
- Home equity loan
- Some PV system companies provide financing

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Notes

STEP 7

E3A: Solar Electricity for the Home, Farm, or Ranch

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Installation

Pre-Installation Considerations

Before installing a solar electric system, check local building codes, subdivision covenants, and zoning ordinances or regulations. Contact your local electrical or building inspector to determine requirements. The National Electric Code (NEC) Article 690 provides requirements for designing and installing a safe, reliable and code-compliant solar electric system. Using NEC criteria will ensure local code official approval. Check whether a building permit is required if installing a system on an existing building.

Review the covenants and contact the HOA Board or the management company if you live in an area with a homeowner's association (HOA). You may need to educate local building code officials and local representatives if you are the first in your area to install a renewable energy system. Contact your utility company to ask if it requires a specific Underwriter's Laboratories (UL)-certified inverter. The UL has developed a series of inverter safety requirements (UL 1741).

Other installation issues might include: historic district guidelines/restrictions, and future shading. Will any trees on your property or nearby property grow and shade the system panels? Be sure to communicate with neighbors about your plans and determine if they might plant trees or add a second story to a home that may shade your panels. Some government jurisdictions have solar access zoning regulations that prevent the blocking of the sun required for operation of any solar energy system. Montana law

home with solar photovoltaic system in Olympia, WA
Photo courtesy of Sam Garst / NREL 15616

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(70-17-301) allows the creation of easements to protect solar and wind energy rights. This requires negotiation with neighboring property owners. Some Wyoming cities and counties have solar access-related codes.

Who Will Install Your System?

Proper installation of your solar electric system will ensure maximum electrical output. Hiring a qualified company or contractor is recommended because proper installation entails numerous considerations and requires attention to safety (roof work, electrical hook-ups, etc.). Some manufacturers will extend a system's warranty if installed by one of their trained contractors. Some utility rebates will only be given if a system is installed by a trained and certified professional. Protect yourself and feel confident you are hiring a qualified professional by asking questions about experience, licensing, certifications, and customer service.

Experience

Does the company or individual contractor have experience installing and providing maintenance for the type of system you want installed? Do they warrant their installation work? Do they provide system commissioning? Ask for the contact information of other customers, and if possible, take time to see those systems and ask the owners about their experience with the system and the level of customer service received.

Licenses

Some states require a contractor to be licensed. The States of Montana and Wyoming currently do not require licensing for the installation of any renewable energy systems. It is suggested you hire a contractor with either an A, B, C-10, or C-46 license. Note: A licensed electrician is required to connect grid-tied systems to the utility's grid.

Insurance

Be sure to ask about and see confirmation of liability and workman's compensation insurance. Have they taken safety training?

Certifications

Many installers take specialized training and exams to receive certifications. The North American Board of Certified Energy Practitioners (NABCEP) is one group that tests and certifies solar electric and other renewable energy system professionals. Their website lists NABCEP-certified professionals in each state (www.nabcep.org).

Trade organizations

Ask the company or installer if he/she is a member of a trade organization such as the Solar Energy Industries Association (SEIA). Are they a member of the Better Business Bureau (BBB)?

In an area prone to power outages, one homeowner in Strafford, Vermont, installed a set of batteries and attached a PV panel to the side of his barn to keep them charged. Photo courtesy of Alan Ford / NREL:09499

System Monitoring

Many companies now offer a system monitoring service that allows them/you to monitor the system through a web-based computer program.

Where Can You Find an Installer?

The Solar Energy Industries Association and its state chapters often provide lists of solar energy system companies by state or city. The Montana Renewable Energy Association (MREA) website (www.montanarenewables.org) provides information on Montana companies and individual contractors that install renewable energy systems and lists their certifications. Wyoming Cooperative Extension Service maintains a similar list on their extension energy website: www.wyomingrenewables.org. You can also search the local phone book yellow pages.

Comparing Bids

Get bids from more than one company and compare. Have bids specify the system type, size, electricity output, and maintenance requirements in addition to cost.

- Ask the installer if he/she installs packaged systems and whether the system or the individual components are UL certified.
- Because different PV panels generate different amounts of electricity, ask for the maximum generating capacity (measured in DC watts or kilowatts) under a Standard set of Test Conditions (STC) or under PVUSA Test Conditions (PTC). Or, ask the electricity output of the system at the inverter.
- Ask for an estimate of the amount of electricity the system will produce on an annual basis in units of kilowatt-hours (kWh) that will actually reach your electrical load.
- Ask how the panels will be attached to the roof/what type of mounting system will be used.
- Ask about whole system or individual component warranties. Some solar rebates require a minimum system warranty. Installers may offer longer warranties.
- Ask that the bid include the following costs: installation, initial set-up and commissioning, all hardware, required National Electric Code (NEC) signage, permits, sales tax, and warranties.
- Some companies will also research and complete the paperwork for available federal, state, local and utility incentives. Be sure to ask if they are including incentive deductions in their cost estimates, and be aware some incentives arrive after the system is installed and that you will typically need to pay the full, initial cost up-front.

Are You a "Handyman" or "Handywoman"?

If you decide to install your own system, be sure to educate yourself and take time to attend classes, workshops, or trainings where you can learn from qualified instructors.

Whether you hire a contractor or install the system yourself, make sure it is done correctly and safely.

References

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Notes

STEP 8

E3A: Solar Electricity for the Home, Farm, or Ranch

Authors: Bilo, Susan; Sarah Hamlen, Mike Vogel, and Milton Geiger, eds. E3A Program

Steps in the Solar Electricity Series

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Operation and Maintenance

Solar electric systems are low maintenance with no moving parts, but like any electronic equipment, they do require routine, periodic attention for maximizing performance. System performance can now be monitored in a variety of ways.

Maintenance

The Installation factsheet suggests sources for finding qualified companies and contractors. These professionals may also conduct system inspections and perform maintenance tasks. Ask your system installer what is required or recommended and be sure to read the owner's manual. Companies may provide a yearly maintenance checklist specific to your system. It is recommended you hire a licensed and/or certified contractor, but if you plan on doing the work yourself, here is a list of what maintenance may include:

Panels/Array

- Panel shading: Visually check for shading during the day (mid-morning, noon, and mid-afternoon) on an annual basis. Any shading can greatly reduce electricity generation. Check for leaves or other debris. Regular rain and snow will clean panels adequately.
- Glass and seals: UL-approved panels are sturdy and weatherproof-tested to handle hailstorms. After hailstorms or high-wind storms with airborne debris, be sure to check panels. If the tempered glass cracks or seals are not in good condition, moisture can enter and cause corrosion and panel failure.
- Support/mounting structures: Check all nuts and bolts attaching panels to any support structures for tightness.
- Wiring connections: All wiring connections should be tight and free from rust/corrosion. Wires should be secured/zip-tied (fastened) to prevent blowing in the wind (a ground fault hazard).

Roof Penetrations

Flashing and sealant around roof penetrations should be in good condition.

Batteries

Require the most maintenance of any solar electric system component.

- Flooded (unsealed, watered) batteries require periodic electrolyte level checks to see if distilled water needs to be added. Battery charges must also be equalized.
- Connections and terminal posts need to be checked and cleaned if corroded.
- Keeping batteries stored at the manufacturer's suggested temperature prolongs their life.

If components of your system are not working or get damaged, see if repair or replacement is covered under warranty by the manufacturer or your installer. If not, a

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standard homeowner's insurance policy may cover damage from hail, etc.

System Monitoring

It is important to know your system is operating efficiently and producing the amount of electricity intended. Monitoring devices allow system owners to view production at any time and to view historical production for comparison over time. For example, inverters are equipped with a display that shows current and lifetime power production.

Web-based monitoring/data-logging systems allow you to access information from your own computer or anywhere internet access is available. The information can include equipment performance, how much electricity was sent to the utility grid, how much money was saved, and the amount of greenhouse gases not emitted.

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Electricity Use Worksheet

Address: ____________ Calculated by: ____________ Date: ____________

Electrical Device	* Wattage (Volts x Amps = Watts)	X	# of Hours Used Per Day (when used)	X	# of Days Used Per Year	=	Watt-hours Used Per Year	Divide by 1,000 = kWh	Kilowatt-hours (kWh) Used Per Year
Example: Flat Screen TV	120 watts	X	2	X	269	=	64,560	64,560 / 1,000	64.56 kWh
Example: Dishwasher (not using the drying feature)	1200 watts	X	1	X	104	=	124,800	124,800 / 1,000	124.8 kWh
		X		X		=		____ / 1,000	
		X		X		=		____ / 1,000	
		X		X		=		____ / 1,000	
		X		X		=		____ / 1,000	
		X		X		=		____ / 1,000	
		X		X		=		____ / 1,000	

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Electrical Device	Wattage	X	Hours Used/Day	X	Days Used/Year	=	Watt-hours	÷1,000 =	KWh Used/Year
		X		X		=		1,000	
		X		X		=		1,000	
		X		X		=		1,000	
		X		X		=		1,000	
		X		X		=		1,000	
		X		X		=		1,000	
		X		X		=		1,000	
		X		X		=		1,000	
		X		X		=		1,000	
Total kilowatt-hours (kWh) Used Per Year									
Divide by 12 for Average KWh Used Per Month Use this number for the Solar System Sizing Exercises in Factsheet 5.									

* An electrical device has a metal plate/sticker showing **wattage** on or near the back or side. If not shown, use the amperes (amps) number times the voltage to get wattage.
Most U.S. appliances use 120 volts. Larger appliances (electric clothes dryers and cooktops) use 240 volts.

- **Refrigerators**: Because they cycle on and off to maintain a set temperature, divide the total time the refrigerator is plugged in by 3.
- **Phantom loads** are electrical loads used by devices even when they are turned "off." These loads can increase a device's consumption by up to 15 watts. Avoid this unnecessary "stand-by" consumption by unplugging electronics and appliances when not in use or by plugging them into a power strip (or surge protector) and using its on/off switch.