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Photos, left to right: JAGA North America, SolarWorld, Electron Connection, American Water Heaters, Stephen Hren, Ted Dillard

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On the Cover

Renewable energy can be paired with in-floor radiant heating systems for more sustainable space heating.

Cover photo by Studio Chlorophylle

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What Did You Say?

We love to hear from our readers—what you like (and don't like) about the magazine; what aspects of renewable energy you are most interested in learning about and which ones you could care less about. Although you can reach us through a variety of venues (Facebook, Twitter, HomePower.com, email—and even, gasp!—the postal mail), this August, we reached out with a reader survey to get your unabashed opinions about *Home Power* (and one lucky subscriber won a TED5000 energy monitor for participating in the survey—see "Mailbox" on page 32).

Here are just a few of the things we found out:

- **You're goal-oriented:** More than half of you read the magazine to get information on implementing home energy-efficiency upgrades and renewable energy systems.
- **You are information seekers.** More than 40% read the magazine just to bone up on renewable energy in general—to learn about system types, components, and options.
- **You count on our expert opinions.** Four out of five *Home Power* readers rely on us to guide their purchasing decisions.
- **Some of you are handy, some are not; but you all want to be highly informed consumers and involved in selecting products for your projects.** One-third of you plan to install your own home RE system; 32% will hire a professional installer.

You had a lot to say—we received more than 2,000 individual comments from the 14% of our subscribers who responded.

"So many energy issues relate to other topics (land use, lifestyle, international differences, pollution, and depletion of resources) and it seems like an understanding of a variety of these issues will help inform the populace to make good decisions for themselves and collectively."

"I have enjoyed your magazine for many years. We plan to install an owner-installed grid-tied system this year, especially since panel prices are so low."

"As a newer digital subscriber trying to plan an off-grid system, I've found the comparison and ratings articles very helpful. Some of the advice particularly regarding battery systems has been thoughtful and detailed, and provides a good check and balance to what individual suppliers are telling me."

Wherever you are on your renewable energy path, we will continue to reach out for your guidance, input, and ideas on how to craft *Home Power* to best serve your needs. But there's no need to wait 'til you're asked. Visit HomePower.com/contact or drop a note to mailbox@homepower.com anytime. We love to hear from you.

—Claire Anderson, for the *Home Power* crew

Think About It...

What is needed now is a transformation of the major systems of production more profound than even the sweeping post-World War II changes in production technology. Restoring environmental quality means substituting solar sources of energy for fossil and nuclear fuels; substituting electric motors for the internal-combustion engine; substituting organic farming for chemical agriculture…

—Barry Commoner, American biologist, college professor & politician (1917–2012)

contact us

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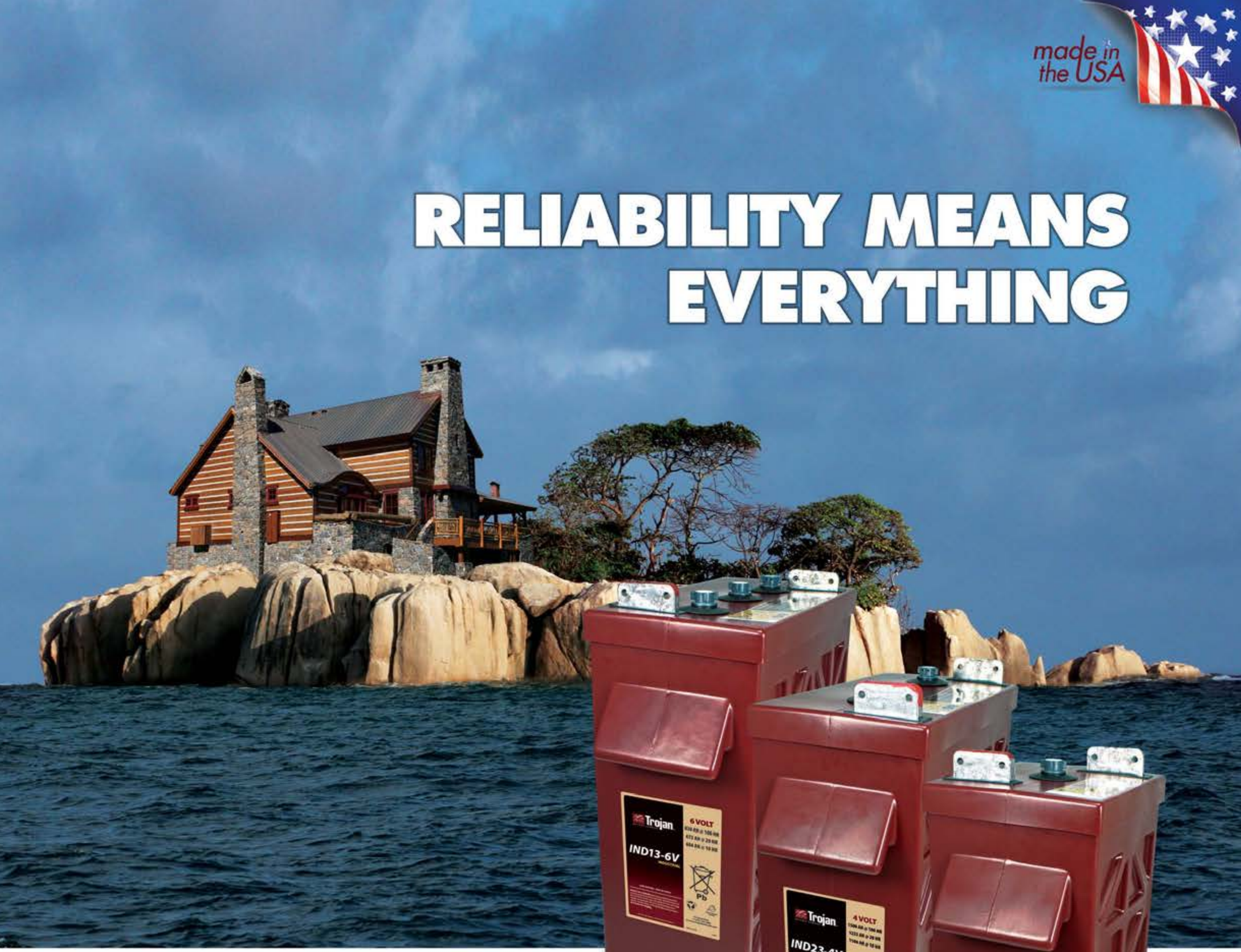

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		CAPACITY Amp-Hours (AH)		
TYPE	VOLTAGE	5-Hr Rate	20-Hr Rate	100-Hr Rate
IND9-6V	6 VOLT	355	445	545
IND13-6V	6 VOLT	533	673	820
IND17-6V	6 VOLT	711	897	1090
IND23-4V	4 VOLT	977	1233	1500
IND29-4V	4 VOLT	1245	1570	1910
IND27-2V	2 VOLT	1183	1457	1780
IND33-2V	2 VOLT	1422	1794	2187

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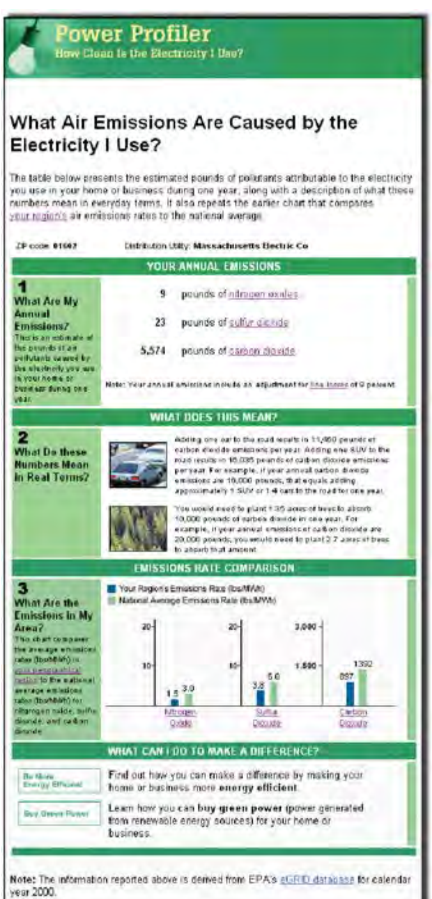
How Clean Is Your Electricity?

On-gridders have plenty of reason to be concerned about where their electricity comes from these days. But exactly how much of it comes from miner-killing and mountaintop-removing coal; aquifer-polluting and fracked "natural" gas; radiation-producing nuclear; war-causing oil; or fish-killing dams? How much comes from carbon-free renewables—and just how "green" are *they*?

U.S. Subregional Grids

This is a representational map: Many of the boundaries shown on this map are based on companies, not strictly on geographical boundaries. USEPA eGRID2010 Version 1.0. December 2010

Twenty-six subgrids provide energy to various regions throughout the United States, though energy is often bought and/or sold between subgrids at different times of the day or year.



Courtesy EPA (2)

The Environmental Protection Agency's Power Profiler (1.usa.gov/EPAPowerProfiler) is an online database that shows the fuel mix of the electricity you buy from the grid. By plugging in your ZIP code and electric utility's name, you can find the fuel mix and pollution emissions of the electricity in your subregional grid (one of 26 generally independently functioning electrical grids in the United States) and compare it to the national average.

The 2009 data comes from the EPA's Emissions & Generation Resource Integrated Database (eGRID, bit.ly/EPAeGrid). The eGRID summary tables are a great way to see how your subregional grid stacks up against the others.

You can also get EPA data on generation sources by state, but since electric energy is consumed on grids—which can be a subset or a superset of states (or parts thereof)—it's most accurate to assess your electricity sources by including the entire subregional grid.

And, when it comes to being green, there are several important, but different, metrics—climate-friendly, earth-friendly, and human-friendly. By any measure, fossil fuel (coal, oil, natural gas, etc.) is not "green."

Best & Worst U.S. Subregional Grids

Pollutant, Problem, or Solution	Greenest U.S. Subregional Grid	Worst U.S. Subregional Grid
Carbon dioxide equivalency (CO_2e): aggregate effect of methane & other greenhouse gas as if other pollutants were effectively CO_2.	NYUP	RMPA
Smog-producing oxides of nitrogen (NO_x)	NYCW	HIMS
Acid rain-producing sulfur dioxide (SO_2)	NYCW	RFCM
Nuclear power as a percentage of sources	AKGD, AKMS, HIMS, HIOA, NYLI, RMPA, SPSO	RFCE
Solar power as a percentage of sources	CAMX	19 subregional grids report none
Wind power as a percentage of sources	MROW	7 subregional grids report none

Source: Environmental Protection Agency Emissions & Generation Resource Integrated Database Summary Tables

Biomass, typically burned to produce electricity, produces emissions and causes air-quality issues. And carbon emissions from biomass-produced electricity is not much of a short-term winner for the climate.

Hydropower is renewable as long as the rain falls, but large dams have large environmental impacts, including decimating or eliminating wild runs of salmon and other fish, and destroy entire canyons and river runs.

Nuclear power generation doesn't emit carbon dioxide into the atmosphere, but uranium mining, plant construction and decommissioning, and the manufacturing of their highly specialized equipment releases a lot of CO_2. Plus there are the matters of catastrophic failures and storing radioactive waste.

Geothermal steam that is tapped to turn turbines to make electricity is fairly climate-friendly, but depending upon the rates of extraction, it may not be sustainable. Depending upon where it is located and the size of the facility, it may or may not have significant environmental impact.

Only a few generation sources come out tops in all categories. **Photovoltaic (solar) electricity** is tops for the climate and for earthlings, but it's even more planet-friendly if distributed over thousands of roofs rather than having tens of thousands of PV modules clustered in one spot. **Wind power**, although also pollution-free, can be bad for birds if poorly sited.

In 2009, the most solar electricity as a percentage of a subregional grid (0.30%) was generated in California, with Hawaii following at 0.046%. (The Paradise State produces more than two-thirds of its electricity from burning oil.) Due to a boom in PV installations, however, the percentage of solar-generated electricity has increased dramatically.

—Andy Kerr

GREENING YOUR OPTIONS

You can take steps to optimize the climate-, earthling-, and earth-friendliness of the electricity you purchase from your grid.

Reduce your energy consumption. Insulate and seal your conditioned spaces to reduce heating and cooling needs. Install energy-efficient lights and appliances. The less electricity—of any kind—you have to buy or make, the better.

Purchase "greener" electricity. Most electric utilities offer their customers "clean" or "green" electricity. In many jurisdictions, regulators separate the costs of generation (the electricity itself), transmission (the bigger power lines), and distribution (the smaller power lines) on your electric bill. You may be able to buy your electricity (generation) from a greener electric company. You would still pay your existing utility for transmission, distribution, and connection costs. Study the options carefully as such electricity can be green-washed. What sources are used to generate the electricity? Do your dollars go to support building new green sources, or is everyone else's energy turning browner?

Mitigate your pollution. Consider buying renewable energy credits (RECs), which, according to the EPA, are "the property rights to the environmental, social, and other nonpower qualities of renewable electricity generation. A REC can be sold separately from the underlying physical electricity associated with a renewable-based generation source." You pay for them in dollars, but they are denominated in megawatt-hours (MWh—1,000 kWh) of the electricity they are associated with. Legitimate RECs are independently certified by organizations such as Green-e, which is the largest independent RECs certifier.

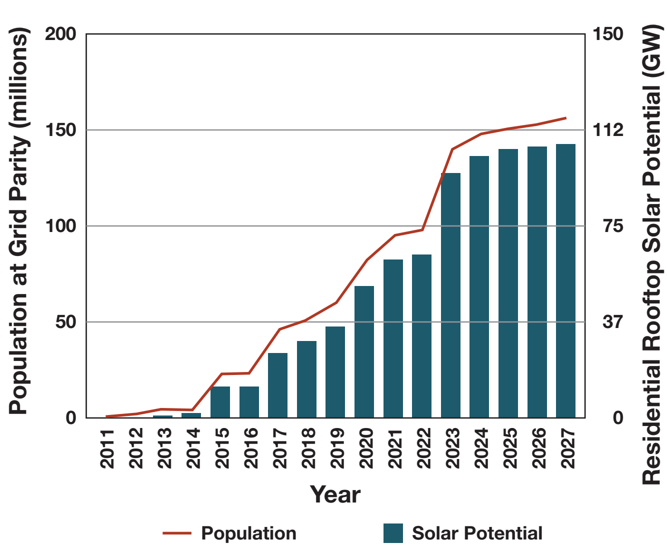
PV & Grid Capacity

In California, Hawaii, New Jersey, and other states, commercial and roof photovoltaic (PV) systems are starting to overload the system—not the grid itself, but the system of companies and regulators that control and manage the electric grid.

As distributed generation (DG) began to take hold in 2011 in California and Hawaii, utilities claimed to be worried that too much DG would compromise the grid's safety and reliability. An extremely crude rule is that the base load (the minimum amount of electricity ever required) is approximately one-third of the peak load (the maximum amount of electricity required). As a safety margin, utilities round down to 30% and then divide by two to determine the maximum amount of distributed generation allowable on any portion of the grid. In the absence of better information and more experience, this rationale, in the name of safety and reliability, was embedded into policies of the Federal Energy Regulatory Commission (FERC).

In Hawaii, the state with the highest electric rates (most of its electricity comes from burning imported oil), PV has boomed to the point that it's coming up against the 15% rule for many main distribution circuits. Most electric bills list a per-kWh fee for generation, transmission, and/or distribution. Generation is the energy itself. Transmission occurs via the huge power lines between central generating stations and major substations. Distribution is in the smaller lines going from the major substations, often through more substations, to customers.

Residential Rooftop Solar Potential & Population at Grid Parity



In February 2012, the Solar Energy Industries Association (SEIA) petitioned FERC to grant a PV-only exception to the 15% rule to allow as much PV-generated electricity on a distribution circuit to match the minimum peak demand between 10 a.m. and 2 p.m. In July, FERC held a day-long technical conference on the proposal. The National Renewable Energy Laboratory also has made recommendations to modify the 15% rule by using screening criteria specific to solar electricity. Rather than using the absolute minimum load for a circuit (usually at night) or a percentage of the peak load (which usually occurs in the daytime during the summer), a more useful metric is a percentage of the minimum daytime load. If the capacity of solar-generated electricity on a distribution circuit is lower than the lowest amount of demand, then the PV-generated electricity does not have the potential to overwhelm the circuit.

In California, a longstanding policy was to limit net-metered PV system connections to 5% of "aggregated customer peak demand"—the combined peak momentary demand for all customers. With the current rate of PV being installed, the state's largest utility, Pacific Gas and Electric (PG&E), was expected to reach this limit in 2013. The California Public Utilities Commission (CPUC) has now redefined that 5% to be the sum of the non-coincident peak demands of all utility customers. The practical effect is that the PV system capacity cap on a circuit is now more than twice what it was.

The CPUC is conducting a study, due by 2015, to consider the costs and benefits of increased PV penetration on the grid. SEIA's western states director, Sara Birmingham, says the CPUC ordered the study because of widespread disagreement on the issue of cost-shifting between solar-generating and nonsolar-generating customers. She believes the study will find any costs as minimal.

Just how much PV power can a grid utilize? In Germany, during a particular sunny Friday, nearly one-third of the nation's electricity came from PV systems. Twenty-four hours later, PV supply approached 50% of the total usage—it was still particularly sunny and demand was lower because of the weekend. While these are just peak events, it shows that the limits are more bureaucratic and political than technical and economic.

—Andy Kerr


Mounting Solar on Tile
Just Got a Whole Lot Easier

The Big Fix

Courtesy The Big Fix (2)

From the filmmakers of the award-winning documentary *Fuel* comes the *The Big Fix*, which details the BP oil spill in the Gulf of Mexico.

On April 20, 2010—ironically, the 40th anniversary of Earth Day—the Deepwater Horizon offshore oil drilling rig exploded and sank, creating the worst oil spill in history. In the documentary *The Big Fix*, Josh and Rebecca Tickell expose the root causes of the oil spill—and what happened after the news cameras left the Gulf states. Though it earned a coveted spot as an official selection of the 2012 Cannes Film Festival, the film struggled to get broad distribution, even with big star power behind it—it was executive produced by Tim Robbins and features Peter Fonda. Here, filmmaker Josh Tickell shares his motivation for making the film.

His inspiration: I have a long history with oil in Louisiana—I grew up in Louisiana and watched family members and other people I knew get sick from the acute pollution that came from the many oil refining complexes there. Conversely, my wife Rebecca (who is also the film's producer/co-director) is from Vermont, where an oil refinery dare not tread. We decided to go to Louisiana to do a think tank with local nongovernmental organizations on immediate solutions to the spill that didn't rely on the government or BP. Jason Mraz, Amy Smart, and Peter Fonda joined us, and while we were in New Orleans, we staged a small, peaceful march to say, "Hey, what about green energy? After all, that's the ultimate solution." The next day, we went down to the beach and found that the oil had literally been covered up with sand. That's how they were convincing media that it had been "made OK."

The physical cover-up was the smoking gun. From that point, we decided it was our responsibility to tell the story as no one in the mainstream media seemed willing to dig beneath the surface, of the sand. For Rebecca, the oil spill became very personal, as she was exposed to the oil-Corexit (a dispersant) mixture and sustained what some doctors have told us is irreversible skin damage.

His hope: The movie is so white-hot controversial because we show how the Obama Administration was complicit in the whole BP oil spill. It's a truth that isn't very popular with our normal audience. So, although it may be a hard pill to swallow, I think it is an important look at what happens when corporate money gets involved and everything goes wrong. My hope is that Obama gets a second term, watches the movie—our last movie, *Fuel,* was screened in the White House—rolls up his sleeves, and gets federal agencies to clean up the mess that still exists in the Gulf of Mexico. As far as we know, oil was still leaking until very recently, and Corexit is still approved for use by the Environmental Protection Agency. These are just a few of the things that public pressure can change. Awareness is key—and *The Big Fix* is the side of the story that the government and BP would rather be swept away with the tide.

His future: We're making another movie about what the world will be like in 2050 and what we can do to make sure that is the world we want for our kids. We're tackling the fuel/oil situation head-on, and we're showing how every car in the world can be run on alternative fuel—right now. It's a hopeful movie. I'm also going back to doing strategy and consulting work now, helping green companies raise money and position themselves for success. There's plenty of work to do, and luckily I believe we still have time to turn everything around.

—with Kelly Davidson

Executive producer Tim Robbins with filmmakers and energy activists Josh and Rebecca Tickell.

See It!

Download *The Big Fix* or purchase the DVD online. For more information, go to thebigfixmovie.com.

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"Need for Speed" Installation Bake-Off. Winning team receives gift cards to local restaurant.

4:30 p.m.
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Courtesy Eltek

Eltek THEIA HE-t String Inverters

Eltek (eltek.com), a Norwegian power electronics company, received the UL1741 listing for its THEIA HE-t string inverter line. Its four UL models (2.0, 2.9, 3.8, and 4.4 kW) utilize NEMA 4X enclosures and include an integrated combiner box and DC disconnect. The inverters use a high-frequency transformer for high efficiency with galvanic isolation—the specification sheets list CEC efficiencies at 96.8% for the two smaller models and 97% for the two larger models. Unlike high-efficiency transformerless inverters, these units do not require the array to be ungrounded—thus disconnects and overcurrent protection are required only on one DC conductor (rather than both); and PV-wire module leads are not required. All models can be configured for 240 or 208 VAC output and can accommodate negative or positive array grounding. Each inverter includes an integrated Web server; installations using multiple inverters can designate a single inverter as a central monitoring hub.

—Justine Sanchez

Power-One Aurora Microinverters

Courtesy Power-One

Power-One (power-one.com) announced U.S. availability of its 250- and 300-watt microinverters. Both have a CEC-rated efficiency of 96% and can be used in residential (240 VAC) or commercial (208 VAC) systems. They can also be used in systems that require positive grounding (SunPower PV modules). They offer module-level maximum power point tracking and monitoring. The data for up to 30 microinverters is collected wirelessly via the Aurora CDD communications hub and system information can be viewed over the Internet through the Aurora Easy View website.

Note: While both Power-One Aurora microinverters and Eltek THEIA HE-t string inverters report CEC values on the specification sheets, these products have just been released and neither inverter line is yet listed on the gosolarcalifornia.com "List of eligible inverters per SB1 Guidelines" as of October 1, 2012.

—Justine Sanchez

Seaward Solar Irradiance Meters

Courtesy Seaward Solar

Seaward Solar (seawardsolar.com) offers the 100/200R Solar Survey meters, which measure solar irradiance, ambient air and module temperature, and array orientation and tilt. Determining that a module or array is performing as it should can be difficult, as a PV module's voltage changes with cell temperature and its current varies with irradiance. These meters provide watts per square meter and temperature readings that can be used in calculations to compare predicted and actual power output. The array orientation and tilt can be useful for estimating and verifying energy output. The irradiance meter also displays Btu/hr.-ft.^{2}, useful for checking the performance of solar heating systems.

The 200R model has data-logging capability, with a USB interface. It can send measurements wirelessly to a PV150—Seaward's Solar Installation Test Kit, which tests open-circuit voltage, short-circuit current, and conductor insulation resistance (used to detect the potential for ground faults). Seaward also manufactures the Solar Power Clamp for measuring inverter efficiency.

—Justine Sanchez

Cool Tools for Learning

A lunchbox? A solar charger? A teaching device? The Solar Schoolhouse has a learning tool that's too cool.

The Solar Schoolhouse's Solar Power Lunchbox packs a little power punch that's helping schoolkids learn about solar electricity. The lunchbox is the brainchild of the folks at the Solar Schoolhouse, a nonprofit program of The Rahus Institute in Sebastopol, California (solarschoolhouse.net). The program has hosted seminars and workshops to help educators teach solar concepts to students of all ages. The lunchbox kit is the latest teaching tool offered for $90 through the Schoolhouse's catalog—which includes DIY solar projects like a PV cell classroom set and a solar fountain kit.

Courtesy Solar Schoolhouse

"There is a growing interest at K-12 schools in learning about solar energy, and we're here to introduce teachers and students to hands-on activities and projects—and put real products in their hands," says Tor Allen, Schoolhouse's executive director and founder of the Rahus Institute.

The program relies on donated solar products to develop teaching kits or demonstration projects at low cost. In 2009, GE Solar donated 25,000 1.25 W monocrystalline solar laminates after the original buyer backed out. Custom-made to power a 12-volt battery for a GPS signal mounted on truck trailers, the cells were ideal for any number of DIY projects. Schoolhouse aimed to create a teaching tool that would appeal to teachers and students alike. Equipped with a USB charger for cell phones and iPods/music players, and a custom LED light for nighttime use, the handy box seems to hit the mark. Adding to the learning experience, an LED fuel gauge shows the battery's state of charge.

"The lunchbox allows teachers and students to play with, and understand, solar electricity in a relatively inexpensive way that has some application to their lives," Allen says. "We created the kit with all the parts but we encourage students to innovate the design. The whole idea is to play, explore, and come out with a new interest in clean energy."

Students do just that, according to Casey Shea, a math teacher at Analy High School in Sebastopol. Some of his students built solar lunchboxes in class last year. One student, who found the lunchbox too cumbersome for his personal use, designed a more compact version.

"When they're using the lunchboxes, you can just tell that they 'get it'—they understand that energy is a commodity, rather than something that is always going to be there," says Shea, who says he regularly uses his lunchbox when traveling.

Through its partnership with Schoolhouse, the Glendale Unified School District in southern California expanded its after-school program to offer hands-on solar projects, including the solar lunchbox. "What's really cool is watching the students build the lunchboxes. They're extremely engaged from start to finish, turning a pile of parts into a working solar charger. They use soldering irons and connect the wires, and, in the end, they're so proud. They have this really cool box that uses the sun to charge their cell phones [and music players], and the best part is that they did it themselves," says Carol Gregory, who supervises the district's after-school program. "These little projects show the students that there are many ways, big and small, to bring solar energy into their lives—and that's probably the biggest benefit of all."

So far, Schoolhouse has sold more than 300 lunchbox kits via its catalog and lunchbox workshops. "Do the math, and

Spreading Out

Though most workshops have been held in California, Schoolhouse is working with several sponsor partners to offer workshops in other states and countries. Those who can't attend the workshops can order teaching aids and project materials online. To learn more, go to **solarschoolhouse.net**.

needless to say, we still have quite a few solar laminates left, but they won't go to waste," Allen says. "The laminates are nice little building blocks for a variety of projects."

Schoolhouse created other kits utilizing the donated laminates—including a steampunk custom solar module, which uses a redwood frame to bundle 10 laminates for solar fountain projects. Prototypes for a solar bike light, a backpack version of the lunchbox, and DIY solar garden lights are in the works as well. The laminates also are available in bulk (50 per box, at a low cost) for larger educational projects.

—Kelly Davidson

Courtesy Solar Schoolhouse

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Zero Net-Energy School Days

Courtesy CMTA Consulting Engineers, Inc.

Until recently, zero net-energy buildings were found only in areas having moderate to high utility rates, like California, or were owned by people concerned about "green" energy, even if it was more expensive. Now, net-zero has come to coal country, where electricity is as cheap as it gets.

Richardsville Elementary School, in Bowling Green, Kentucky, is the first net-zero energy public school in the United States. This 72,000-square-foot public school achieved net-zero energy status and stayed within the budgetary constraints of the Kentucky Department of Education. An energy goal of using no more than 18 kBtu per square foot per year was set at the beginning of the design phase. High-performance features, such as geothermal HVAC, occupancy controls, insulated concrete form walls, and a dedicated ventilation system with demand control, helped drive down energy usage.

A combination of clerestory windows and tubular daylighting devices admit natural light into teaching spaces. Supplemental artificial lighting is controlled by a dimming system. Computer labs and classroom computers were eliminated in favor of mobile laptop carts, which use less power and are easy to shut down when not being used.

One of the energy-reduction strategies was to eliminate the kitchen's Type 1 exhaust hoods, since they are big energy consumers. Instead, steamers and convection ovens, which produce no grease-laden vapors, were selected, thus allowing only Type 2 hoods, which require much less exhaust and make-up air.

Overview

Project name: Richardsville Elementary School

System type: Batteryless grid-tied PV

Installer: Morton Solar & Wind

Date commissioned: January 2011 (rooftop array); January 2012 (parking canopy)

City: Bowling Green, KY

Latitude: 37°N

Average daily peak sun-hours: 4.74

System capacity: 348 kW STC

Average annual production: 410,000 kWh

Average annual utility bill offset: 112%

Equipment Specifications

Number of PV modules: 1,452 thin-film; 720 crystalline

PV manufacturer & model: UniSolar PVL-144 & Sanyo HIT Double 195

Module rating: 144 W; 195 W

Inverters: 2 Satcon Powergate Plus

Inverter rated output: 250 kW; 135 kW

Array installation: Tremco Hook & Loop, applied directly to a flat membrane roof.; Unirac on custom canopy

Array azimuth: 180°

Tilt: Flat; 15°

Once modeling showed that energy consumption was driven as low as economically practical, a 348 kW photovoltaic system was designed to completely offset all electricity usage. A 208 kW thin-film PV system was installed on the rooftop, and a 140 kW parking lot canopy supplements the rooftop system. The system will maintain the building's net-zero energy status over its entire lifetime.

Richardsville Elementary takes advantage of the TVA Generation Partners program, which credits each kWh at $0.24. Between September 2011 and August 2012, the PV system generated $82,000 worth of credit. The PV system has a dedicated generation meter, and all solar electricity generated is reimbursed at $0.24 per kWh—about three times the retail electricity rate. Because this generation is presented as a credit toward the normally purchased electricity of the building, each utility bill has the normal energy charges plus a generation credit.

After two years of full occupancy, the building is operating at 17.3 kBtu per square foot per year—below the projected estimate and less than 25% of the energy used in a typical Kentucky school designed to current energy code, which specifies an energy usage of 72 kBtu per square foot per year or less. If this building had been designed to current energy code, the PV system required to offset all the school's consumption would have cost more than $11 million. Due to its focus on implementing efficiency first, a smaller PV system was needed. The system was put out to bid in 2008 and cost $2.9 million.


Courtesy CMTA Consulting Engineers, Inc.

To address this expense, the financial model recognized the value of cost-shifting elements of a "typical" school that were not needed in the Richardsville design. For example, eliminating computer labs saved on wiring infrastructure and removed 1,000 square feet of space. Also, the building envelope was designed to reduce exterior surface area compared to the building's volume, resulting in a roughly rectangular shape. This helped reduce energy consumption and saved approximately $1.2 million on construction. The final building cost of Richardsville Elementary—with its PV system—was $206.50 per square foot—*less* than the national median ($216 per square foot) for a school building that would generate none of its own energy.

—Brian Turner

PV Array Sizing for kWh

Courtesy Lumos

While your budget may dictate how big your PV array will be, you likely have a kWh production goal that you'd like to meet. Most folks want to have a grid-tied PV system designed to offset most or all of their annual electricity usage.

The first step in going solar is not sizing the PV system, but reducing your electricity usage through conservation and efficiency measures. Once these measures have been implemented, you're ready to size a PV system to offset the remaining energy usage. To determine the PV array size needed, you'll need to know the average daily peak sun-hours for your location. Once you've determined your annual kWh production goal and the peak sun-hour value, use an overall system efficiency factor to calculate the required PV array size.

Let's say we have a home near Eagle, Colorado. After implementing energy-efficiency strategies, this home consumes an average of 300 kWh per month. However, we would also like to use an electric car, which will use an estimated 250 kWh per month for charging. Now we have a total annual energy consumption estimate of 6,600 kWh per year. Using solar data for Eagle, supplied by the National Renewable Energy Laboratory (bit.ly/SolarData), you'll find the average peak sun-hours per day for a south-facing array, mounted with tilt equal to latitude (in this case, 40°) is 5.5. Let's use an overall average system efficiency factor of 72% (see below).

To calculate the array size needed to meet our predicted annual energy consumption, divide the annual kWh consumption by 365. This gives an average daily consumption in kWh. Divide this amount by average daily peak sun-hours to get the approximate array size in kW. That value is then divided by the system's efficiency factor:

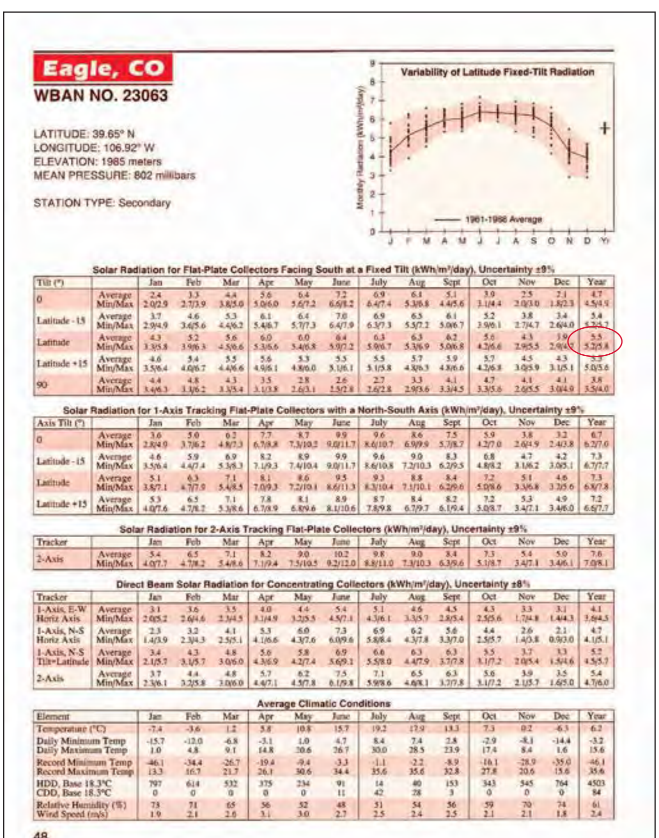
6,600 kWh/yr. ÷ 365 days/yr. = 18.1 kWh/day
18.1 kWh/day ÷ 5.5 sun-hours/day = 3.3 kW
3.3 kW ÷ 0.72 efficiency factor = 4.6 kW array

To offset 100% of the home's (and EV's) electricity consumption over the course of a year, a 4.6 kW system is needed.

The 0.72 efficiency factor is based on the following assumptions: average solar access of 95% (shading derate factor); modules with a positive-only production tolerance; inverter efficiency of 96%; module temperature derate factor of 0.88; DC and AC wiring derate of 0.98 and 0.99; module soiling derate = 0.95; module mismatch derate = 0.98; system availability derate = 0.99:

0.95 × 0.96 × 0.88 × 0.98 × 0.99 × 0.95 × 0.98 × 0.99 = 0.72

—Justine Sanchez



Eagle, CO
WBAN NO. 23063

LATITUDE: 39.65° N
LONGITUDE: 106.92° W
ELEVATION: 1965 meters
MEAN PRESSURE: 802 millibars

STATION TYPE: Secondary

Solar Radiation for Flat-Plate Collectors Facing South at a Fixed Tilt (kWh/m²/day), Uncertainty ±9%

Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	2.4	3.3	4.4	5.6	6.4	7.2	6.9	6.1	5.1	3.9	2.5	2.1	4.7
	Min/Max	2.0/2.9	2.7/3.9	3.8/5.0	5.0/6.0	5.6/7.2	6.6/8.2	6.4/7.4	5.3/6.8	4.4/5.6	3.1/4.4	2.0/3.0	1.8/2.3	4.5/4.9
Latitude - 15	Average	3.7	4.6	5.3	6.1	6.4	7.0	6.9	6.5	6.1	5.2	3.8	3.4	5.4
	Min/Max	2.9/4.9	3.6/5.6	4.4/6.2	5.4/6.7	5.7/7.3	6.4/7.9	6.3/7.3	5.5/7.2	5.0/6.7	3.9/6.1	2.7/4.7	2.6/4.0	[illegible]
Latitude	Average	4.3	5.2	5.6	6.0	6.0	6.4	6.3	6.3	6.2	5.6	4.3	3.9	5.5
	Min/Max	3.3/5.8	3.9/6.3	4.5/6.6	5.3/6.6	5.4/6.8	5.9/7.2	5.9/6.7	5.3/6.9	5.0/6.8	4.2/6.6	2.9/5.5	2.9/4.7	5.2/5.8
Latitude + 15	Average	4.6	5.4	5.5	5.6	5.3	5.5	5.5	5.7	5.9	5.7	4.5	4.3	5.3
	Min/Max	3.5/6.4	4.0/6.7	4.4/6.6	4.9/6.1	4.8/6.0	5.1/6.1	5.1/5.8	4.8/6.3	4.8/6.6	4.2/6.8	3.0/5.9	3.1/5.1	5.0/5.6
90	Average	4.4	4.8	4.3	3.5	2.8	2.6	2.7	3.3	4.1	4.7	4.1	4.1	3.8
	Min/Max	3.4/6.3	3.3/6.2	3.3/5.4	3.1/3.8	2.6/3.1	2.5/2.8	2.6/2.8	2.9/3.6	3.3/4.5	3.3/5.6	2.6/5.5	3.0/4.9	3.5/4.0

Solar Radiation for 1-Axis Tracking Flat-Plate Collectors with a North-South Axis (kWh/m²/day), Uncertainty ±9%

Axis Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	3.6	5.0	6.2	7.7	8.7	9.9	9.6	8.6	7.5	5.9	3.8	3.2	6.7
	Min/Max	2.8/4.0	3.7/6.2	4.8/7.3	6.7/8.8	7.3/10.2	9.0/11.7	8.6/10.7	6.9/9.9	5.7/8.7	4.2/7.0	2.6/4.9	2.4/3.8	6.2/7.0
Latitude - 15	Average	4.6	5.9	6.9	8.2	8.9	9.9	9.6	9.0	8.3	6.8	4.7	4.2	7.3
	Min/Max	3.5/6.4	4.4/7.4	5.3/8.3	7.1/9.3	7.4/10.4	9.0/11.7	8.6/10.8	7.2/10.3	6.2/9.5	4.8/8.2	3.1/6.2	3.0/5.1	6.7/7.7
Latitude	Average	5.1	6.3	7.1	8.1	8.6	9.5	9.3	8.8	8.4	7.2	5.1	4.6	7.3
	Min/Max	3.8/7.1	4.7/7.9	5.4/8.5	7.0/9.3	7.2/10.1	8.6/11.3	8.3/10.4	7.1/10.1	6.2/9.6	5.0/8.6	3.3/6.8	3.2/5.6	6.8/7.8
Latitude + 15	Average	5.3	6.5	7.1	7.8	8.1	8.9	8.7	8.4	8.2	7.2	5.3	4.9	7.2
	Min/Max	4.0/7.6	4.7/8.2	5.3/8.6	6.7/8.9	6.8/9.6	8.1/10.6	7.8/9.8	6.7/9.7	6.1/9.4	5.0/8.7	3.4/7.1	3.4/6.0	6.6/7.7

Solar Radiation for 2-Axis Tracking Flat-Plate Collectors (kWh/m²/day), Uncertainty ±9%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
2-Axis	Average	5.4	6.5	7.1	8.2	9.0	10.2	9.8	9.0	8.4	7.3	5.4	5.0	7.6
	Min/Max	4.0/7.7	4.7/8.2	5.4/8.6	7.1/9.4	7.5/10.5	9.2/12.0	8.8/11.0	7.3/10.3	6.3/9.6	5.1/8.7	3.4/7.1	3.4/6.1	7.0/8.1

Direct Beam Solar Radiation for Concentrating Collectors (kWh/m²/day), Uncertainty ±8%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
1-Axis, E-W Horiz Axis	Average	3.1	3.6	3.5	4.0	4.4	5.4	5.1	4.6	4.5	4.3	3.3	3.1	4.1
	Min/Max	2.0/5.2	2.6/4.6	2.3/4.5	3.1/4.9	3.2/5.5	4.5/7.1	4.3/6.1	3.3/5.7	2.8/5.4	2.5/5.6	1.7/4.8	1.4/4.3	3.6/4.5
1-Axis, N-S Horiz Axis	Average	2.3	3.2	4.1	5.3	6.0	7.3	6.9	6.2	5.6	4.4	2.6	2.1	4.7
	Min/Max	1.4/3.9	2.3/4.3	2.5/5.1	4.1/6.6	4.3/7.6	6.0/9.6	5.8/8.4	4.3/7.8	3.3/7.0	2.5/5.7	1.4/3.8	0.9/3.0	4.1/5.1
1-Axis, N-S Tilt=Latitude	Average	3.4	4.3	4.8	5.6	5.8	6.9	6.6	6.3	6.3	5.5	3.7	3.3	5.2
	Min/Max	2.1/5.7	3.1/5.7	3.0/6.0	4.3/6.9	4.2/7.4	5.6/9.1	5.5/8.0	4.4/7.9	3.7/7.8	3.1/7.2	2.0/5.4	1.5/4.6	4.5/5.7
2-Axis	Average	3.7	4.4	4.8	5.7	6.2	7.5	7.1	6.5	6.3	5.6	3.9	3.5	5.4
	Min/Max	2.3/6.1	3.2/5.8	3.0/6.0	4.4/7.1	4.5/7.8	6.1/9.8	5.9/8.6	4.6/8.1	3.7/7.8	3.1/7.2	2.1/5.7	1.6/5.0	4.7/6.0

Average Climatic Conditions

Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°C)	-7.4	-3.6	1.2	5.8	10.8	15.7	19.2	17.9	13.3	7.3	0.2	-6.3	6.2
Daily Minimum Temp	-15.7	-12.0	-6.8	-3.1	1.0	4.7	8.4	7.4	2.8	-2.9	-8.1	-14.4	-3.2
Daily Maximum Temp	1.0	4.8	9.1	14.8	20.6	26.7	30.0	28.5	23.9	17.4	8.4	1.6	15.6
Record Minimum Temp	-46.1	-34.4	-26.7	-19.4	-9.4	-3.3	-1.1	-2.2	-8.9	-16.1	-28.9	-35.0	-46.1
Record Maximum Temp	13.3	16.7	21.7	26.1	30.6	34.4	35.6	35.6	32.8	27.8	20.6	15.6	35.6
HDD, Base 18.3°C	797	614	532	375	234	91	14	40	153	343	545	764	4503
CDD, Base 18.3°C	0	0	0	0	0	11	42	28	3	0	0	0	84
Relative Humidity (%)	73	71	65	56	52	48	51	54	56	59	70	74	61
Wind Speed (m/s)	1.9	2.1	2.6	3.1	3.0	2.7	2.5	2.4	2.5	2.1	2.1	1.8	2.4

48

Courtesy NREL

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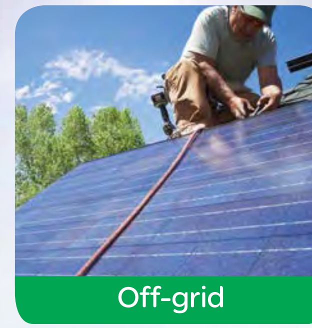

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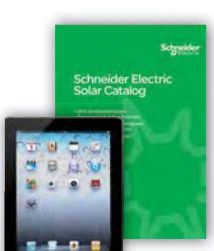

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Schneider Electric

Courtesy TED

Reader Survey Winner!

The *Home Power* crew would like to extend a big *thank you* to all who participated in our 2012 reader survey. We appreciate you taking some time to provide us with valuable and candid feedback on what we're doing well—and what we could be doing better.

Congratulations to *Home Power* reader Eric Lovgren from Pewaukee, Wisconsin, who was chosen at random to win the TED home energy monitor. Eric, let us know the skinny on your household energy use once you've collected some data.

Joe Schwartz •
Home Power executive editor & CEO

Roof Safety

The front cover of *HP151* shows a worker on a roof. He's wearing a hard hat (required, but totally useless) and a safety harness (which is an OSHA requirement if the pitch is 4:12 or greater), but the harness is not connected to anything.

It is almost impossible to work on a roof without violating some OSHA regulation. However, a couple of companies who had working photos in articles in *The Journal of Light Construction* have been fined because the photo is evidence that they were not following OSHA requirements. Workable or not, you ought to show workers with harnesses! (In any photos you publish!)

Jim Newman • via email

The cable that connects the harness to the roof is hard to see, but there. You can see its reflection going across the module and disappearing behind the print on the cover. If you look at the second photo of True South Solar installer Eric Hansen, on the contents page, you will see both it and its reflection.

Field manager and installer Shawn Schreiner of True South Solar gives the details:

"Eric is connected to a retractable cable lanyard. This is a fall arrest system, and connected to his harness via an 18-inch extension. The cable is anchored on the other side of the roof ridge. True South Solar is committed to 100% fall protection—if we are on the roof, we rope up."

Michael Welch • Home Power *senior editor*

Shawn Schreiner (2)

Electric Tiller

I enjoyed Ted Dillard's "DIY Electric Tiller Conversion" article in *HP150.* I wish I had built this *years* ago—thanks for the idea and guidance! I'm tired of playing with gas and oil, changing the oil, cleaning the gas tank, rebuilding the carburetor, replacing the spark plug, etc. I was spending more time on maintenance and repair than actually using the tiller. The last straw was that I lent the tiller to my neighbor, and when I got it back, I couldn't even start it with starting fluid.

So I found a *very* nice "used" motor on eBay—it actually looks new. It's a Dayton 1 hp, 3,450 rpm, single-phase, capacitor-start, and can be wired for 120 VAC or 240 VAC, and will turn in either direction. The only drawback is that this motor doesn't have a thermal cutout. So I'll have to be careful. I added a box with an industrial switch and #10 AWG 3/C SOOW cord. Here is a photo (at right) of the result.

Dale Reed • Cleveland Heights, Ohio

Home Power *absolutely* loves *to hear from readers who try out our projects. Check out the lawn tractor conversion project in this issue by the same author!*

Michael Welch • Home Power *senior editor*

Courtesy Dale Reed

Electrical Energy Equivalency

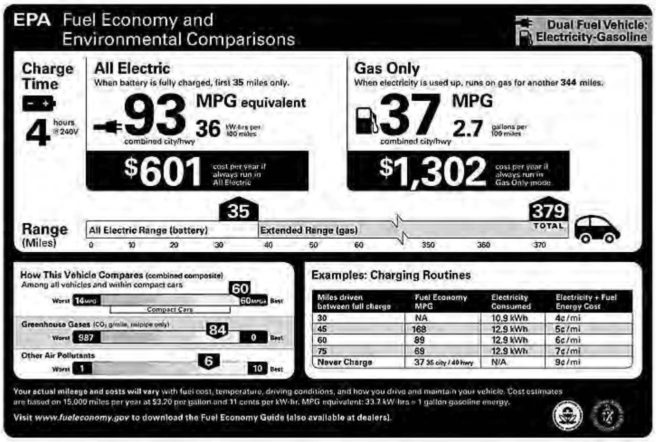
In the article "Plug-In Vehicles" (*HP151*), Andy Kerr points out that 1 gallon of gas has the "energy equivalent of 33.7 kWh" and that an electric vehicle that gets 3 miles per kWh would be equivalent to 100 miles per gallon [of gasoline].

This is a bit misleading because not all the energy in 1 gallon of gas can be turned into electricity. Even with the best engine technology, the second law of thermodynamics puts a limit on the percent of heat energy that can be converted.

Typically, utilities turn about one-third of the heat generated into electricity. The best they can do is close to 50%. This puts the equivalent energy consumption of 3 miles per kWh between 33 miles per gallon and 51 miles per gallon.

Larry Schlussler • Arcata, California

The U.S. EPA developed "miles per gallon-equivalent" (MPG-e) because consumers are used to mpg for their gasoline- (or even diesel-) powered cars and needed a way to compare. The EPA says "Electric vehicles convert about 59% to 62% of the electrical energy from the grid to power at the wheels—conventional gasoline vehicles only convert about 17% to 21% of the energy stored in gasoline to power at the wheels." (See bit.ly/EPA_EV.)



Courtesy Chevrolet

The methodology they developed (described here: bit.ly/MPGequivalent) came up with 1 gallon of gasoline equaling 33.7 kilowatt-hours. In other words (and yes, I would agree it is approximate, if not misleading), a car can travel the same distance on 1 gallon of gas or 33.7 kWh of electricity.

Andy Kerr

[Editor's note: If you scroll to the bottom of the Wiki page that Andy mentions above, it details "well-to-wheel" comparisons, "accounting for the upstream efficiency of electricity generation and transmission, etc. In the example provided by the U.S. DOE in its final rule, an electric car with an energy consumption of 265 Wh per mile in urban driving and 220 Wh per mile in highway driving resulted in a petroleum-equivalent fuel economy of 335.24 miles per gallon."]

EVs, Carbon & Rainwater

I wish to make several points. First, in the plug-in vehicles Q&A in *HP151* ("Plug-In Vehicles"), you quote the CO_2 per year emissions from various EVs. These figures seem to offer little advantage over a typical Japanese four-cylinder ICE car. For example:

- The U.S. national average for EV emissions is 8,035 pounds of CO_2 per year.
- My Honda Accord emits 0.71 pounds of CO_2 per mile.
- Say I drive 12,427 miles per year: That's 8,823.5 pounds of CO_2 per year, about the same emissions as the U.S. national average for an EV.

This result makes me wonder what the U.S. national average is for the distance an EV is driven annually? It seems from these results any lowering of emitted CO_2 would be negligible by switching from a four-cylinder gasoline car to an EV.

Second, while I enjoy reading about all of the new and novel products discussed in your magazine, I also see a very polarized view of the current climate predicament we have placed ourselves in. Due to the requirement we adhere to—a maximum average global surface temperature warming of 2°C—the range of pathways for our future emissions are limited, resulting in a global carbon budget. These emission pathways have been modeled. This can be taken a step further whereby it is recognized that all 7 billion of us on this planet have an equal right to the remaining carbon emissions in our remaining global carbon budget.

Such constraints are explained in *AVOID: Avoiding Dangerous Climate Change* (bit.ly/AVOIDcc) and *Solving the Climate Dilemma: The Budget Approach* (bit.ly/SOLVINGcc). They certainly paint a different picture than that presented by your magazine. I do not think it unreasonable to state that your magazine presents a future where we can have our cake and eat it too—using technology to maintain our current lifestyles. This would have been possible with this technology a decade or two ago, but not now. In light of the remaining emission pathways even in exclusion of equal rights to per capita emissions, any dependence on technology as a solution to climate change is delusional. That is a pity, because I do enjoy your magazine.

And finally, I agree with your New Zealand reader in the letter about rainwater. We've lived off of rainwater collected from our roof for seven years without any first- flush diverter or sterilization rubbish—that gear is all a con. Our rainwater is crystal-clear and is the best-tasting water I've ever had. We've got 70,000 U.S. gallons in storage, just collected from our roof, and nothing more than mesh filters are used on the gutter down-pipes. Lovely.

Shane White • South Australia

While we don't know the average EV miles driven per vehicle per year (there are too few data points), we do know that the national average commute is 40 miles—most EVs can get there and back for such commutes.

It's important to remember that averages are just that. If your grid is full of electrons from very dirty coal, then CO_2 emissions reductions from not burning gasoline may be negligible. If your grid is much cleaner, so will the effective emissions from driving an EV. If you use PV-generated electricity to fuel your EV, your CO_2 emissions, for all practical purposes, are zero.

If an EV is charged at night, when coal plants are nonetheless polluting but producing little electricity because of lower demand, your effective CO_2 emissions from driving are far less because you didn't burn any gasoline on board and you used kilowatt-hours that otherwise wouldn't be used, but pollute just the same.

—Andy Kerr

Courtesy Norm

Cruising with Renewables

I have spent most of my life building and traveling on the Bandersnatch, the boat shown here. Back in the 1960s, I got the itch to have a boat because it was the closest thing I could get to a spaceship. I thought I would have to charter in the Caribbean to make a living with it, but I got older faster than the boat got built, so now it has turned into a retirement boat. I launched it in 1981 and retired from the Merchant Marines in 1996. Shortly thereafter, I met Jan and we have cruised aboard Bandersnatch ever since.

We have 1,300 watts of Kyocera PV modules, two KISS wind generators, and an 8 kW diesel generator aboard. We get most of our electricity from the PV, use the generator for a while on cloudy days, but don't use the wind-spinners much.

We are nicely set up with satellite TV, a couple of laptop computers, several printers (Jan loves photography), and all the usual comforts of home, including three cats. We do have air conditioning, but have to run the generator to use it, so we rarely do. Instead, we adjust to the local climate!

The dinghy, which we call "The White Rabbit" (an *Alice in Wonderland* connection with the "frumious bandersnatch," which is in the poem *Jabberwocky*), is a 10-foot inflatable. We put a PV module on the dinghy outboard to keep the battery topped up. There is no regulator. The loads are: the starter, running lights, bilge pump, and depth-finder.

After some months of use, the module failed. I opened the PV housing and found a postage-stamp-size PC board with a resistor for the indicating LED and a diode for preventing reverse-current. All of them were corroded and a wire was broken. I removed the diode, installed it in the negative line, and discarded the rest. I soldered all the connections, buried it all under clear RTV silicone, and put the housing back together. We'll see how it holds up. The PV module is especially useful when rain causes the bilge pump to operate. And it recharges the battery so I get good engine starts.

Home Power has had a large influence in my life. I was a charter subscriber—if you can call receiving a free magazine being a subscriber! I first learned about many of our renewable energy system components, including our Staber clothes washer, Trojan batteries, Trace inverter, SunDanzer freezer and refrigerator, and lots of other things, in *Home Power*. It has been delightful watching the magazine grow from almost a mimeographed newsletter to a slick publication for sale at national bookstores!

Norm, S/V Bandersnatch •
Lying Julington Creek, Florida

Playing in the Field

HP151—another winner. Thanks! Always appreciate Andy Kerr's take on the numbers of whatever it is, including the analysis in the current issue in "The Subsidy Game" article. On page 78, Andy notes that the playing field is not quite level. For years, I have thought that it wasn't so much about leveling, but about the fact that one end of the playing field is on fire and is radioactive! I believe that a new playing field is called for. Presumably with sustainable/renewable grass and everything else. Keep up the great work.

Mark Cherniack • Mosier, Oregon

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Published letters are edited for content and length. Due to mail volume, we regret that unpublished letters may not receive a reply.

Microhydro Cost

How much does a 4 kW microhydro power plant cost, complete with all of the components?

John Sabor • Memphis, Tennessee

There are so many variables behind your simple question that a simple answer would not be helpful. We need to look at the site and what it has to offer. Equally important is the load you will be running and how best to meet your needs.

My first question is: What does "4 kW" mean? If it means producing 4 kW all the time, this would be a fairly large amount of energy produced for a residential application (96 kWh per day), unless you are planning to *heat* with electricity. If 4 kW is only the peak load, then you might not need a 4 kW turbine; it could be more sensible to choose a smaller turbine that produces the daily energy that you need. You would meet the peak power demand from batteries (via an inverter), or from the grid.

If this is an off-grid situation, adding a battery and an inverter will maximize the usefulness of the energy from your hydro turbine. Producing 4 kW all the time calls for a very good hydro resource—and a big investment. If you cannot store energy, then much of the energy from your 4 kW turbine will arrive when you do not need it. The control system will have to discard this excess as heat, which may have no value in summer. It is unusual to find a site where significant amounts of water can be stored in a dam, so battery/inverter systems (like the ones used for off-grid solar and wind) are a popular option.

Similarly, an on-grid turbine that is sized to meet your peak demand will export a lot of energy. Will this pay off? If you have a very good hydro resource, then you may not care about wasting energy because it is cheap, but most of us don't have that kind of resource. In most cases, you should size your hydro in line with your daily kWh needs, rather than thinking peak power. A smaller turbine that uses less water will also tend to have a better capacity factor or, in other words, it will run for more hours per year.

Courtesy Ian Woofenden (2)

Choose an appropriate turbine to match your microhydro resource.

With adequate head and flow, an on-site creek or stream can be an excellent source of renewable energy for your home.

A small stream that runs steadily and falls steeply can be a very good electricity source. The potential power in watts would be roughly the flow in gallons per minute times the vertical fall in feet, divided by 10. To get 4 kW, you might, for example, use 400 gallons per minute falling 100 feet in height. The water will need to pass through a pipe between the source and the turbine 100 feet below, and the friction of the pipe walls and any angles in the pipe will use up some of the pressure, diminishing the energy available at the bottom. On a steep slope, you might use 500 feet of 5-inch pipe. But if the slope is gentler, you might need 2,500 feet of 8-inch pipe. By the time it is laid, the pipe often costs much more than the turbine itself.

There are many options to consider. Will the turbine adjust its flow automatically to make the best of the water in the stream? Will it be better to buy several off-the-shelf turbines or one big custom-built unit that might not work so well at times of low flow? Should the generator produce AC directly? Should you connect this system directly to the grid, or even with the output of an inverter? Or should it produce DC that charges batteries or feeds a grid-tied inverter like a PV array? Should you invest in a foolproof intake system or will you be happy to hike up there from time to time and clear blockages? Hydro system costs can vary widely depending on the energy needed, the head, the flow, and the distances between intake, turbine, and wherever the energy is being used. It's easy to look at the cost of the turbine—home- to ranch-scale models range from perhaps $1,500 to $10,000. But that is only a fraction of the cost of the whole system, which includes intake, pipeline, turbine, tailrace, controls, perhaps batteries, inverter, etc.

A fully installed hydro system for the average use of a modern household might cost $20,000 to $100,000 (or more). But it's not wise to look at these numbers as anything more than a very general range of possible costs. The cost for your system will depend on the resource available (head and flow), the demand (watts and kWh), the distances involved, and the specific components you choose.

Hydro can often be the most economical renewable electricity resource over the long haul. Investing well up-front will make your system last a long time, which decreases the cost per kWh. Let's hope you have a good hydro site, because it's a wonderful thing to develop. I hope that helps you start the planning process.

Hugh Piggott • Scoraig, Scotland

Low-Cost Wind Electricity

I am looking for a low-cost batteryless grid-tied wind-electric system for my home in southern California. I already spoke with the city building planning department and the utility, and they both support wind-electric systems.

I consume an average of 192 kWh per month (6.4 kWh per day). I would like to generate at least some of my energy, but not at the level or cost of the systems mentioned in your articles and wind buyer's guide. It is often windy here at night and our electrical baseline is very low, so I thought that it would be cool to get net metering and sell a little back to the utility. Any suggestions?

Rainer Boelzle • San Diego, California

Your request is common, though problematic. While it's quite possible to start with a small solar-electric system and add onto it later, wind electricity is generally impractical to approach on a modular basis, and cost effectiveness decreases the smaller you get. The fundamental reason for this is the nature of the wind energy resource.

The power available in the wind increases cubically with increasing wind speed. When comparing a 6 mph wind to a 12 mph wind, the difference in energy is $6^3 = 216$ vs. $12^3 = 1{,}728$. That's eight times as much energy potential with a doubling in wind speed. You can see that it's *very* important to expose the generator to higher wind speeds.

The other pertinent fact is that wind speed increases as you move away from ground level and its hills, trees, buildings, and other obstructions. Wind speed increases more quickly as you rise above rough surface terrain than over water and other smooth surfaces.

The clear conclusion is that effective wind-electric systems need to include tall towers to get well above any ground obstructions. The standard rule in the industry is to make sure the lower blade tip is *at least* 30 feet above anything within 500 feet—and higher is better.

So when you contemplate making "a little" wind electricity, you're often fighting the reality that tall towers are expensive, and that's what's needed to get into the viable wind resource. While it's possible to get lightweight towers (such as anemometer towers) to put very small machines up high, the cost of the tower will be significantly more than the machine. A larger machine with an appropriate tower will get you renewable energy for a lower cost per kWh.

If you opt to put up a very short tower, you will find that there isn't much wind energy available, regardless of local anecdotal observation or your gut feeling. When there are windy times at those low levels, it's very turbulent wind, which is hard on wind generators.

Using your 192 kWh per month and a simple formula, we could do some reverse calculations and make some wild guesses about what size of wind generator you might need if you wanted a wind system to provide all of your electricity. Bear in mind that I (and perhaps you, too) have no idea what your resource actually is.

You can multiply the swept area (in square feet) by the average wind speed cubed (in miles per hour), and divide that total by 32,000 to get a rough estimate of average daily kWh production. Dividing by 1,050 instead of 32,000 gives a monthly average. So going the other way, 192 kWh × 1,050 = 201,600. If we stipulate an average wind speed of 10 mph, we see that you'd need a wind generator of about 200 square feet ($201{,}600 \div 10^3$) to generate your total kWh requirements in a 10 mph average wind speed resource. This will be a turbine with about a 16-foot-diameter rotor; the machine alone might cost between $15,000 and $20,000 (the full system cost will be several times that).

Courtesy Ian Woofenden

This turbine is mounted on a tower with a height well above the minimum of 30 feet above anything within 500 feet.

Bear in mind that to actually get the turbine into a 10 mph resource *almost anywhere you might live*, you will need a tall tower. If you choose a 30- to 60-foot tower to economize, surprise: You will actually be spending *more* money per kWh delivered. Looking at our recent wind turbine buyer's guides, you'll see that even a 2 mph drop in wind speed will decrease production of a turbine like this by about half. A 50% cut in production means a doubling of the cost per kWh, unless the purchase cost of the system also is cut in half (which it will not be, since shortening the tower is usually only a small reduction in overall system cost). And if your tower is even shorter—closer to the height of surrounding buildings and trees—your turbine won't even have an 8 mph resource to capture.

The bottom line is that in most cases, trying to go cheaper—by going with a smaller machine or a shorter tower—ends up with more costly electricity. The best way to lower the cost of wind electricity is to choose a large rotor diameter machine and put it on a tall tower. Cutting corners on either swept area (square footage) or wind speed (via shorter towers) will reduce the financial satisfaction. It's tough news to hear, but perhaps this will save you disappointment later.

Ian Woofenden • *Home Power* senior editor

Grounding DC Systems

Do I need to ground the negative poles of the batteries and modules in a 24- or 48-volt off-grid solar-electric system? If so, how? I'm thinking about connecting one wire from the positive battery terminal to the load (with breaker), and two from the negative battery terminal—one to the load and the other to ground. Is this the correct way to do this?

James Tohls • via email

Many things can go wrong with electrical systems to make them unsafe, so the *National Electrical Code (NEC)* has been developed to help mitigate these dangers. One of the most basic guidelines is to connect metal, which can get energized, to earth. This is called "grounding" or "equipment ground." All electrical systems need to be connected to earth in case the exposed metal becomes energized by some sort of equipment failure. Earth-grounding reduces the danger of shock if the exposed metal is subsequently touched. And, if there is a short circuit, it also allows the fuse or circuit breaker to trip. Equipment grounding also helps protect the electrical system and appliances from lightning surges.

All touchable metal parts of an electrical system need to be kept at the same potential (voltage) as earth. So wires (usually bare or green wires) are routed through the system, and attached to all the metal boxes, metal conduit, module frames, metal equipment cases, and other metal. The other end of these "grounding" wires leads down to an earth connection, often a ground rod. In this way, we keep the metal that can be touched from shocking someone standing on the earth. (See "Get Grounded" in *HP118* for a more thorough treatment of this subject.)

In electrical systems in the United States, one of the wires carrying the electricity (typically the "neutral" in AC systems and the negative in DC systems) is connected to the equipment grounding. (This is also what makes an electrical system "grounded.") This is in addition to the requirement that all metal be connected to earth. However, it is unfortunate that the word "ground" is used to describe these very different concepts.

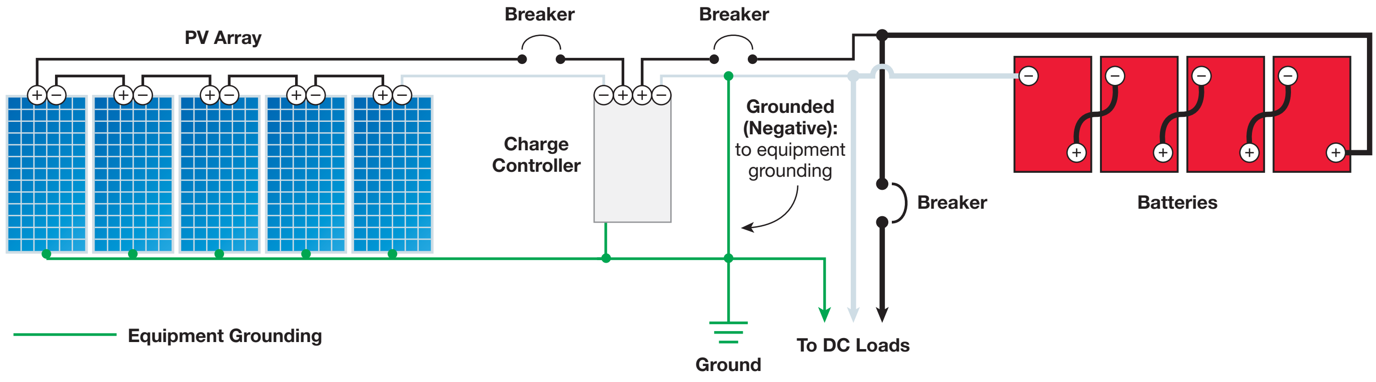
There's more than one option for your situation, which can make figuring out what to do difficult. The *NEC* allows a stand-alone system that has a 24 V (or lower) battery bank to be "ungrounded." This means that you don't have to attach one of the wires carrying the electricity to the equipment grounding. But the requirements for ungrounded systems are rigorous, such as requiring overcurrent protection on both the positive *and* negative wires; it is much easier to configure a grounded system. Here's what I recommend:

- Attach equipment-grounding wires to all the exposed metal of your system—PV module frames, PV racking, metal electrical boxes and conduit, and metal equipment boxes, like load cases and the ones that house the charge controller. Make sure to establish a good electrical "bond" (low electrical resistance) that can last the lifetime of the system. Read the equipment instruction manuals to see what is recommended. Run the equipment grounding wires to a grounding terminal block in a DC circuit breaker box (like MidNite Solar's Big Baby Box, fitted with a grounding terminal block). Attach a single, larger wire (commonly a bare #6 AWG solid copper conductor) to that grounding terminal block with the other end attached to the ground rod.

- There will only be one place in your system where you will attach the negative wire to the equipment grounding. (If you have SunPower PV modules, you'll attach the positive wire to the equipment grounding.) If there is ground fault protection (GFP), this connection is normally made through the GFP (follow the GFP instructions.) If there is no GFP, this connection will normally be made on the battery side of the charge controller at the grounding terminal block. Be sure to make that connection (between negative and equipment grounding) in one place only.

Kelly Larson, renewable energy consultant • SolarKelly.com

Equipment Grounding in DC-Only Systems



Courtesy Silicon Energy

EV charging with renewable energy can be most easily accomplished with a grid-tied system.

Tesla Charging

After numerous Internet searches, I have yet to get an answer to my most burning current question: Which 12-volt DC to 110 AC inverter do I need to buy so I can charge an electric car? I want to use my own stand-alone solar-electric array—five 33-watt, 12-volt Siemens PV modules and two pairs of 6-volt deep-cycle golf cart batteries with extended amp-hour capacity—installed 12 years ago. I am willing to take an extra day or two to charge the car or, as income allows, add more PV modules.

Jon Dieges • via email

Without factoring in typical system losses, the most you can get out of your array in "perfect" conditions is 165 W (5 x 33 W), which is not enough to charge any EV I know of. Even the slowest Tesla Roadster EV charging regimen (30 hours) requires more than 10 times that amount—1,800 W (15 A at 120 VAC). The charge rate probably tapers off over time, but you can check with Tesla owners to find out how many kilowatt-hours it takes to accomplish a full charge.

The bottom line is that you need a much larger array and battery bank to accomplish car charging directly from a stand-alone PV system. However, a grid-tied solar-electric system negates the need for an expensive battery bank and related balance-of-system components required for stand-alone systems and thus can make sense for car-charging. Your array can simply offset your energy consumption when the sun is shining and you can draw on the grid for any supplemental electricity required or tap into your PV-production credits if you need to charge at night. Your EV will get charged, then, no matter when you plug in.

With the grid as backup to the PV array, you are not relegated to the slowest, low-wattage charging means, but can take advantage of the fastest possible charging—regardless of the size array you can afford.

Michael Welch • *Home Power* senior editor

write to:

asktheexperts@homepower.com

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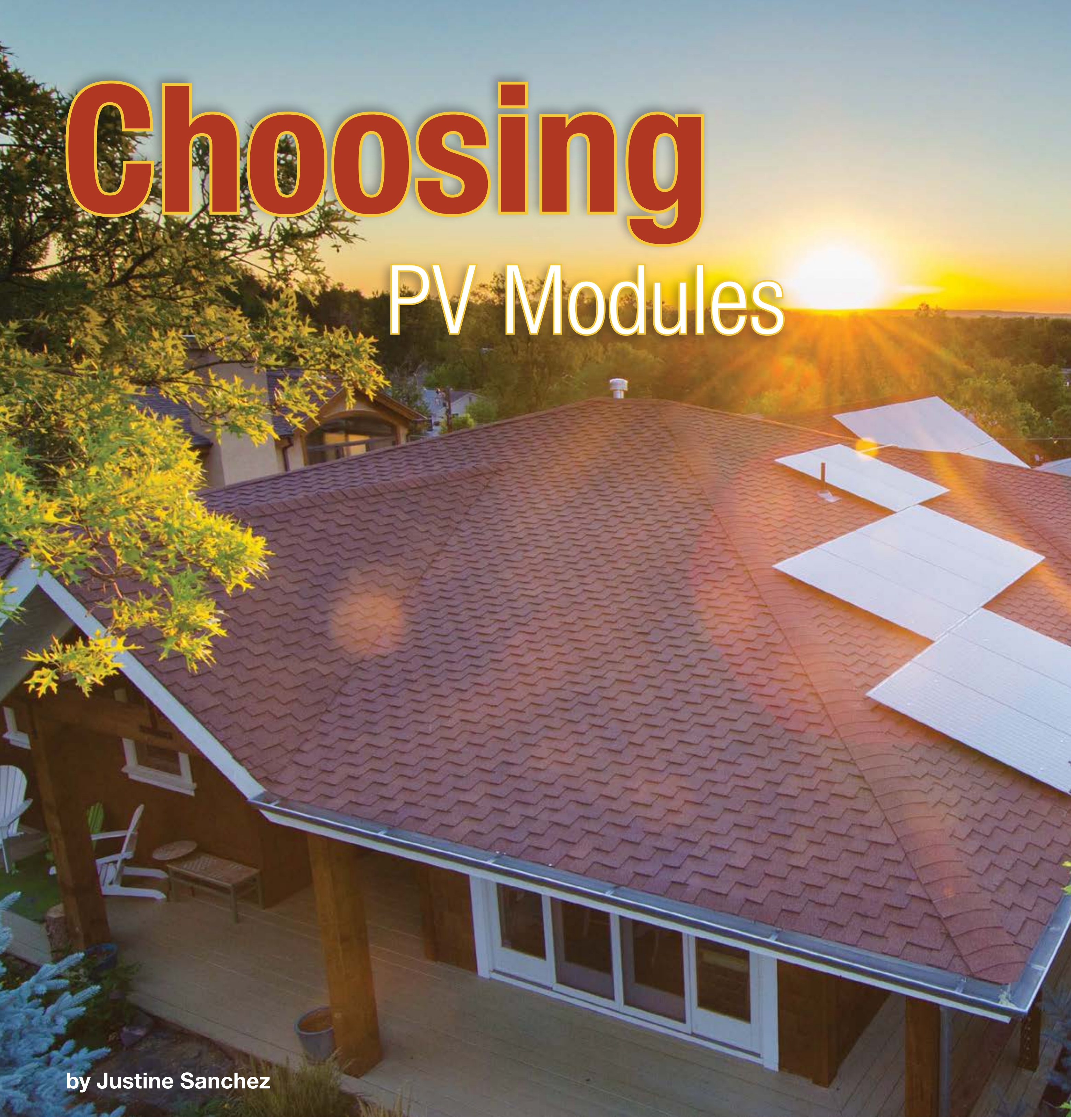
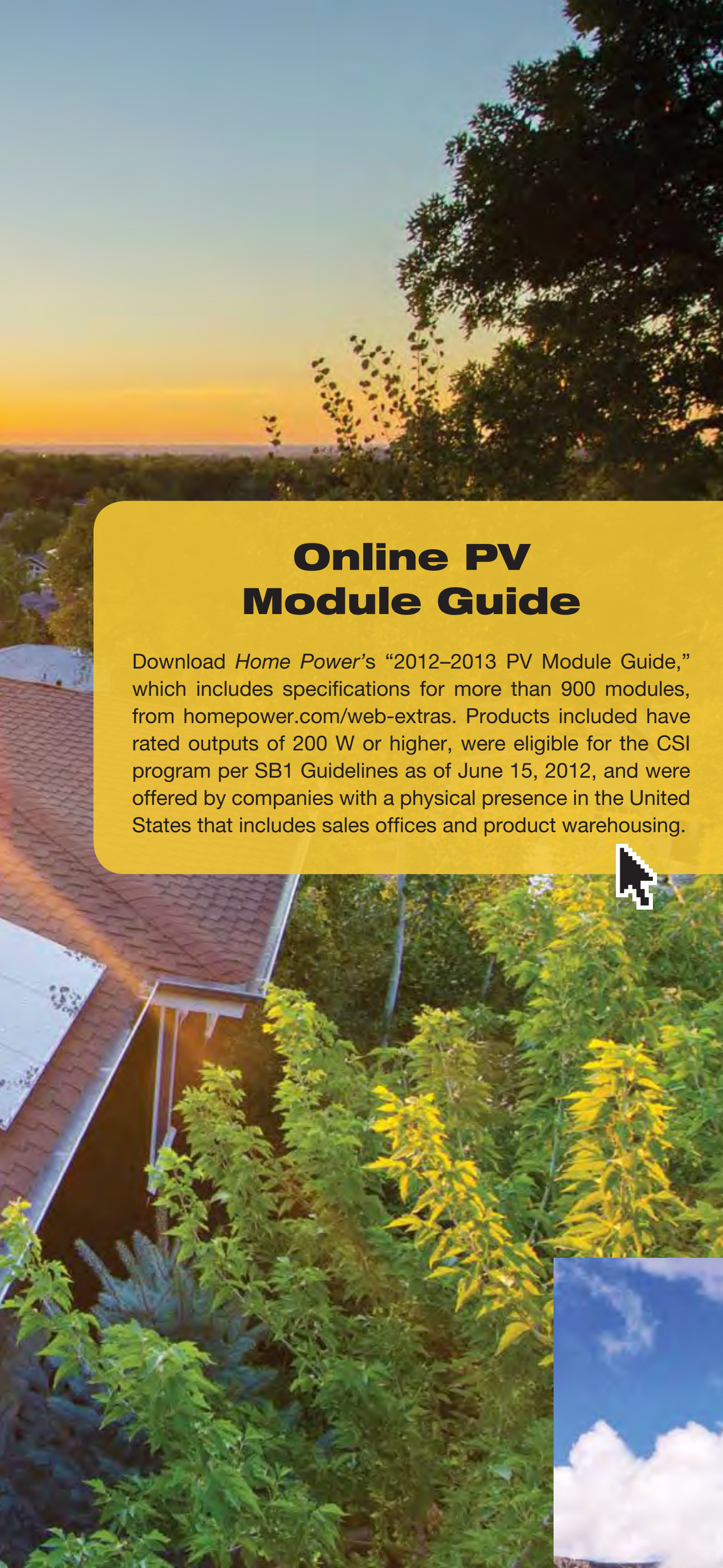
Choosing PV Modules



by Justine Sanchez

Once again, life has shifted for my family of four and we are looking for our next home. While the home's square footage, layout, and yard space are considerations, the feature I tend to get most excited about is where we can mount our next PV array. We are considering a home that has a large garage roof. Its excellent southern solar exposure and the lack of pesky vents and dormers to work around has got me thinking again about PV array design—and module selection. There's ample mounting space, which could accommodate increasing the array size to not only meet 100% of our electricity needs annually, but also support a future electric vehicle.

There are a lot of modules to choose from (see the "Online PV Module Guide" sidebar) but there is also uncertainty about the survival of many PV module manufacturers because of the large supply-versus-demand imbalance that currently exists, along with the challenge for many manufacturers to produce their products at today's cheap module pricing.



Courtesy Lumos Solar

Online PV Module Guide

Download *Home Power*'s "2012–2013 PV Module Guide," which includes specifications for more than 900 modules, from homepower.com/web-extras. Products included have rated outputs of 200 W or higher, were eligible for the CSI program per SB1 Guidelines as of June 15, 2012, and were offered by companies with a physical presence in the United States that includes sales offices and product warehousing.

These factors—combined with the usual considerations, such as module output ratings, power tolerance, efficiency, and pricing, along with new inverter, mounting, and module-level electronics options—make module selection more complex. To help me wind my way through the choices, I've devised a list of top considerations that will be helpful for any array design exercise. Additionally, a module selection example is provided, given our potential roof space and energy generation goals.

Power tolerance is a measurement of how close a module's actual output will be to its rated output under standard test conditions (STC: cell temperature = 77°F and irradiance = 1,000 watts/m^2). For example, if a 200-watt module has a power tolerance of +/-3%, its actual output (under STC conditions) can vary from 194 W to 206 W. Some modules have a positive-only (such as "+5/-0") power tolerance, which means that these modules should be able to produce at least rated power under STC, and possibly more.

PTC ratings (PTC-to-STC ratio) specify module power output for settings that more closely represent real-world conditions, which makes them lower than STC ratings. The STC temperature of 77˚F for a module's cells is often not a very realistic temperature for these dark cells exposed to direct sunlight; their temperature will commonly be much higher. As cell temperature increases, voltage drops, which reduces module power output. PVUSA test conditions (PTC) calculate module output using an ambient air temperature of 68˚F (at 1,000 watt/m^2 irradiance), which typically causes cell temperatures to be about 113°F to 122°F (36°F to 45˚F higher than STC).

However, modules are sold based on their STC-rated power output rather than by PTC ratings, making it more difficult to compare realistic performance between modules.

Courtesy Justine Sanchez

This large, south-facing garage roof has access to a wide-open solar window—the perfect location for a future PV array.

A PTC-to-STC ratio is included in the table for all modules. The closer the PTC rating is to STC, the higher the module output is under more common conditions. For example, if a "200-watt" module has a PTC-to-STC ratio of 0.9 or better, then its PTC rating should be 180 W or higher; if the ratio is 0.85, then its PTC rating will be only 170 W. Although that difference may seem negligible, when you add the power up for an entire array, it can be significant.

Module voltage and string inverter input window need to be considered for any grid-tied PV project that uses a string inverter. Each module has a specific maximum power point and open-circuit voltage, and each site has specific temperature ranges it will experience, which will determine the actual voltage each module will operate at.

Additionally, each inverter has its own input voltage limitations, which will dictate string size for module models being considered. Many string inverter manufacturers have online sizing calculators to help find string configurations that work for each PV module, considering local climate.

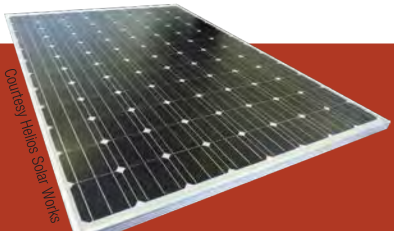
Power density of a module is dependent on module efficiency and is given in watts per square foot. The greater the density, the more power the array can generate per square foot. But higher module efficiency also means more dollars per watt, so before you assume you need a high-efficiency module, check the amount of space you have compared to the total power you want (see the "Selecting Modules for My Garage" sizing example).

Module dimensions need to be considered, especially if you're working with limited mounting space but trying to maximize array capacity. Often, you'll have to compare layouts, including both portrait and landscape configurations, to find the appropriate array layout for a rooftop. When using a string inverter, layout options may need to consider the required number of modules in series (and the number of parallel strings) to make sure the array layout is compatible with the inverter's input and output limitations.

Courtesy REC

This Peak Energy module from REC has a PTC-to-STC ratio of 0.91.

Using high-efficiency modules can reduce the mounting space required. This 12 kW array uses SunPower Signature black solar modules for aesthetics.



Courtesy Helios Solar Works

This 420 W module from Helios Solar Works is manufactured in Milwaukee, Wisconsin, and has a +3/0 power tolerance.

Courtesy SunPower (2)

This SunPower 435 W module is 20.1% efficient. High-efficiency modules allow a higher-capacity array to fit within a limited area.

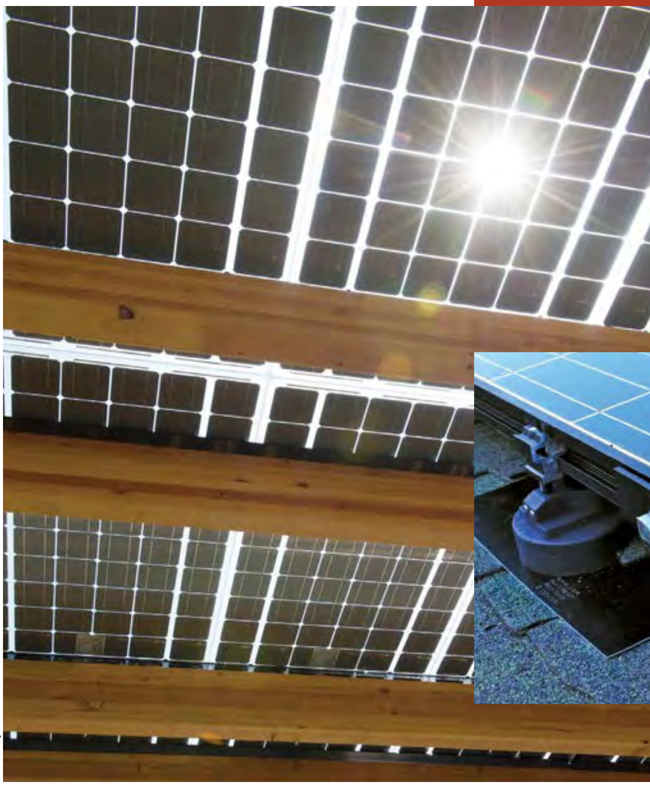
PV Manufacturer Profiles

SolarPro magazine's "2012 Module Guide" (October/November 2012) offers background information for 40 different PV module manufacturers. Information includes manufacturing longevity, location, and recent technological and business developments. Helpful details such as which companies are currently offering warranties backed by third-party insurance companies are also included. Access the article at: bit.ly/SPprofiles.

PV manufacturer location can be an important factor. First, some production-based incentives, such as Washington state's RE System Cost Recovery program, pay a higher per-kWh incentive for systems with locally manufactured equipment. Systems funded by the American Recovery and Reinvestment Act (ARRA) and installed on public buildings must use domestically manufactured modules (or foreign modules that use 100% domestic cells). The less distance a module has to travel to its ultimate destination, the less embodied energy that module has. Finally, many people want to support local manufacturing jobs over foreign jobs and imports. See "PV Manufacturer Profiles" sidebar for information on how to find manufacturers offering ARRA- and Buy American Act-compliant modules.

In some programs, purchasing components made in-state qualifies the system for larger incentives.

Courtesy Blue Horizon Energy



Courtesy Lumos Solar

Courtesy Trina Solar

Courtesy Upsolar

Left: An awning that uses Lumos Solar frameless modules with clear back sheets allows light to filter through. Bottom and right: Zep Solar-compatible modules from Trina Solar and Upsolar have grooved frames to accommodate hardware for rail-less mounting.

Module frames and back-sheets are important to mounting technique and aesthetics. Options include frameless modules, module frames with mounting grooves for rail-less mounting, modules that allow some light to pass through (popular for awning systems), and dark back-sheets (black), which provide a more uniform look within the array.

PV wire leads are required for ungrounded arrays. Transformerless inverters are becoming increasingly popular because of increased inverter efficiency and enhanced safety (see "Ungrounded PV Systems" in *HP150*). However, they do require the array to be ungrounded, and the modules selected must have "PV-wire" cables for these installations. (PV-wire has specific benefits over standard USE-2 conductors including thicker insulation, higher voltage ratings, better UV resistance and flexibility in extreme cold.)

Warranty is important, and while most PV manufacturers offer 25-year power output warranties, material warranties can range from two to 10 years. A warranty is only helpful if the company offering it sticks around to service a future claim. With the PV manufacturing industry undergoing so much change right now, and many companies merging or exiting the market, some manufacturers are offering noncancellable warranties serviced by third-party insurance companies.

Cost is always a factor and budget can dictate the array you ultimately purchase. Module pricing has been on a downward trend over the last few years. A brief online search shows many modules are available for $1.50 per W; some even below $1.

Online module shopping—to try get the cheapest deal—instead of buying from a local module supplier/installer has drawbacks. While the array may cost less up-front, you may be without support should problems arise. In certain areas, installing a grid-tied system without a licensed installer means forfeiting some incentives. While the modules table lists more than 900 modules, no matter whether you buy online or through your local PV installer, available options will be limited to those modules currently offered by that supplier.

Courtesy Jinko Solar

This Jinko Solar 245 W module has 10-year materials and 25-year linear power warranties.

Module-Level Electronics

If you want to monitor individual modules, which is helpful for keeping tabs on your system, you will need either microinverters or DC-to-DC optimizers ("maximizers") on each module, or you'll need to install AC modules. Benefits include maximum power point tracking (MPPT) for each module and the ability mix different modules or orientations in the same PV array. Additionally, partially shaded modules will not impact other modules in an array. Make sure the modules you buy are compatible with these module-level electronics. Microinverter manufacturers provide compatibility lists for each model, and DC-to-DC maximizers need to match module output specs. AC-modules avoid this step in system design because they are preinstalled with a compatible microinverter (offered by various companies including BenQ/AUO Solar, Canadian Solar, Sun Earth Solar Power, SunPower, and Westinghouse). "Smart modules" are becoming available (from companies such as Trina and Upsolar), which have DC-to-DC optimizers already mounted on the modules' backs.

The reliability of these module-level devices is a consideration. The embedded electronics in these units will be subjected to high temperatures, especially in rooftop installations. Accessibility also needs to be considered in the instance that one (or more) devices fail after installation and need to be replaced.

This SolarEdge screen shot shows module-level monitoring for side-by-side comparisons of each module's output.

Courtesy SolarEdge

This Upsolar module comes with a Tigo Energy Maximizer pre-installed.

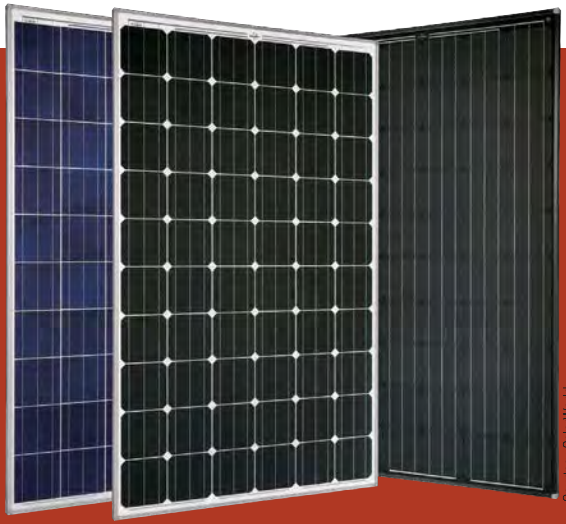
Courtesy Upsolar

Right: An Sun Earth Solar Power AC module with its permanently affixed Exeltech microinverter.

Every residential installation is unique—and selecting PV modules can be both a science and an art, where production, budget, and aesthetic goals are balanced within a given space.

Courtesy SunPower

Selecting Modules for My Garage



SolarWorld offers U.S.-made modules. Its Hillsboro, Oregon, facility performs each step in the manufacturing process, from growing silicon crystals to module assembly.

While the rooftop itself measures 25 by 18 feet, and setbacks are generally not required for detached garages, I would like an approximate 2.5-foot access path on both sides of the array (and about 6 inches of clearance at the top to the ridge and 12 inches at the bottom of the array to the eave). These criteria leave us with an available mounting area measuring 20 by 16.5 feet, providing an approximate 330-square-foot area. After estimating our annual electrical consumption, considering our Colorado solar resource, and figuring in typical system derating, I calculated that a 4.6 kW array would meet our electricity needs (see "PV Array Sizing" in this issue for details on sizing).

Using this number, I calculated the minimum module power density required:

4,600 W ÷ 330 ft.^{2} = 13.9 W per ft.^{2}

Of the more than 900 modules listed, 360 modules have a power density greater than or equal to 13.9 W per square foot.

My next criteria are that modules for this project have positive-only power tolerances and a minimum PTC-to-STC ratio of at least 0.90. That shrinks the possibilities to 147 different modules. If I opt for a minimum materials warranty of 10 years, this shaves off another 13 module options, leaving me 134 modules to consider.

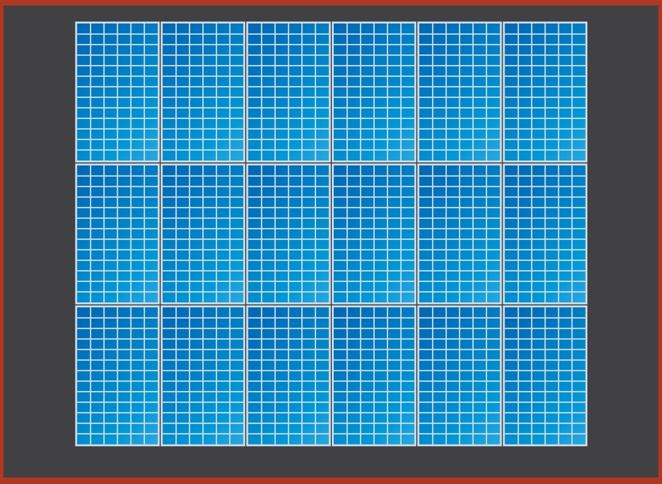
I then looked at some of the many module options, like Canadian Solar's NewEdge module line for rail-less mounting. These modules are backed by a noncancellable product warranty and the company has been manufacturing modules since 2001.

I wanted to see how they might fit on the roof. Two models matched up: the 245- and the 250-watt versions; both 64.5 by 38.7 inches. The mounting hardware requires 1/2-inch spacing between modules. I have room for 18 modules on the roof (three rows of six modules in a portrait orientation). Using the 250 W modules would give me a 4.5 kW array—very close to my 4.6 kW goal.

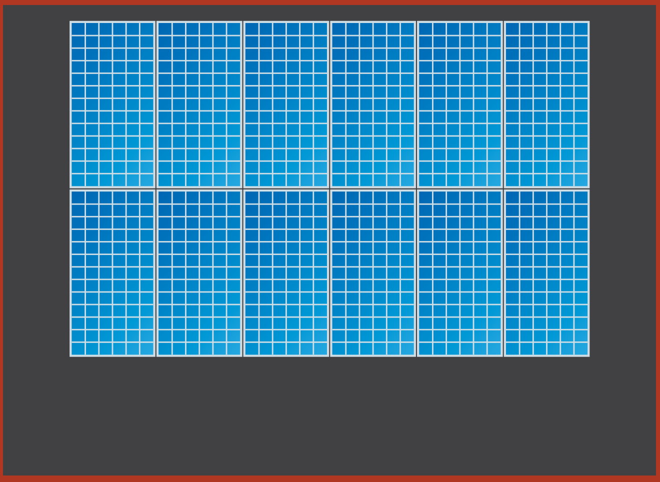
Another option is MPE MS08 Schüco modules, which have 245 to 260 W models—all of which measure 65 by 39.1 inches. I could also fit 18 of these modules on the roof. Using the 260 W models would yield a 4.7 kW array. However, a noncancellable warranty isn't available for Schüco modules—a consideration. The same exercise could be completed from numerous manufacturers such as Jinko, Samsung, Trina, and Yingli.

A U.S.-made option would be to use 18 SolarWorld SW250 modules, which would yield 4.5 kW. While they are without a positive-only power

Careful consideration of module dimensions is important. Using the 250 to 260 W modules discussed above results in an array capacity of 4.5 to 4.7 kW on this roof.



Conversely, using 295 W modules, which measure 77.5 by 39.4 inches, would only yield a 12-module, 3.5 kW array.



Courtesy Michael Pendy

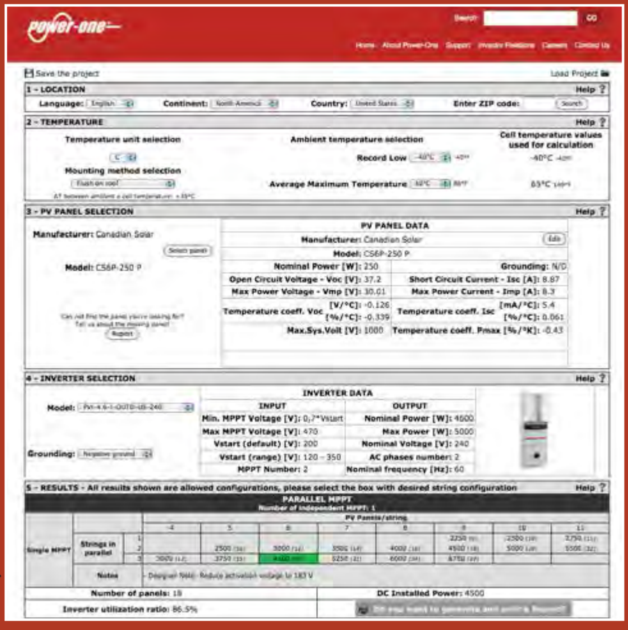
The author with her PV-ready garage.

tolerance (+/- 3%), SolarWorld's U.S. manufacturing history dates back to 1977. They offer an all-black version (frames and backsheet), which makes an attractive, uniform-looking array.

While I hope to utilize module-level monitoring via either microinverters or DC-to-DC power optimizers, I did check that array configurations of three strings of six modules would also work with several string inverters. If, for some reason, the module-level electronics don't stand the test of time, I could easily run these three six-module strings to a conventional string inverter.

And finally, it is important to realize our module table only lists 200-watt and larger module options, so in reality there are many more modules I could consider in this exercise if I bypassed this limitation.

Several string inverters are suitable for our example 4.5 kW array. This Power-One string-sizing program shows that its 4.6 kW inverter can accommodate three strings of six 250 W Canadian Solar modules.



Courtesy Power-One

Who Will Survive?

Included in the August 2012 issue of *PVNews* was "Consolidation Dynamics in PV Manufacturing," which detailed the fate the authors expect for many PV manufacturers: success (a handful of mostly Chinese companies); acquisition (a few); or failure (many). Several companies' fates are classified as undetermined, and will depend on local market forces and the actions they take now.

In this fluctuating market, then, how can you best choose which modules to purchase? Considering the possibility that a manufacturer may not be around to service a future warranty claim, module quality becomes an even more important factor. Manufacturer longevity, although no guarantee, is correlated with module quality—companies that have been manufacturing modules longer are more likely to have worked out manufacturing bugs.

Compromises Are Inevitable

Weighing all of these factors can be a time-consuming process that inevitably ends up in compromise. And each system designer or homeowner will have to establish their own priorities.

This will be the third PV array our family has installed, and cost, while important, is no longer at the top of the list. With our two previous homes, low module cost was the highest priority, and I simply jumped on "deals." The first array used Astropower modules, which are no longer under warranty since the manufacturer is long gone. The second array contained a few underperforming modules (see "Potential PV Problems" in *HP143*). While both arrays are still pumping out energy, I have learned to consider more than just cost. Unfortunately, there is no long-term module quality specification, so it is difficult to know if a module is and will continue to be a top performer—manufacturers are not required to publish module failure test data.

As the PV industry matures and module-level monitoring becomes more common, we'll likely have more data on how specific modules perform over the long term. Pressure from within the industry (such as larger system integrators and project developers) also may help remedy this situation. It is an unfortunate reality, but not a reason to keep me from investing in my next array. Will my next array perform as expected five or 10 years from now? I don't know. Will the manufacturer I buy from be around to honor a warranty claim? That's an uncertainty, too.

What I do know is that my last two arrays are still working—in spite of a defunct module manufacturer and a few underperforming modules. And with that confidence in basic PV technology, I will optimistically move forward with my next solar adventure.

Access

Justine Sanchez (justine.sanchez@homepower.com) is a *Home Power* technical editor and an instructor for Solar Energy International. She is certified by ISPQ as a PV Affiliated Master Trainer. Justine is hoping to close on her new family home soon, so she can start ordering the equipment to make her next dream PV system a reality.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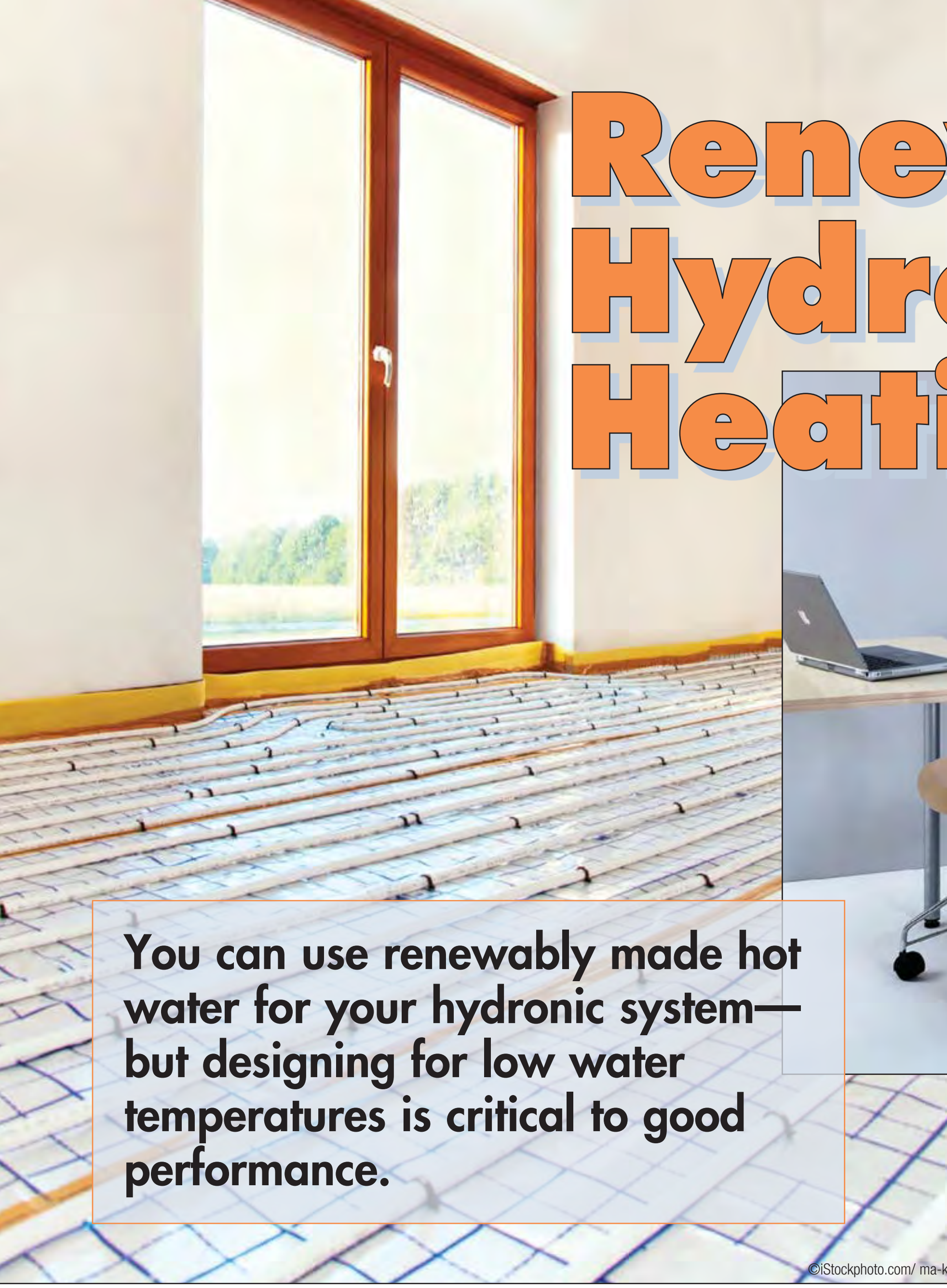
Renewable Hydronic Heating

by John Siegenthaler



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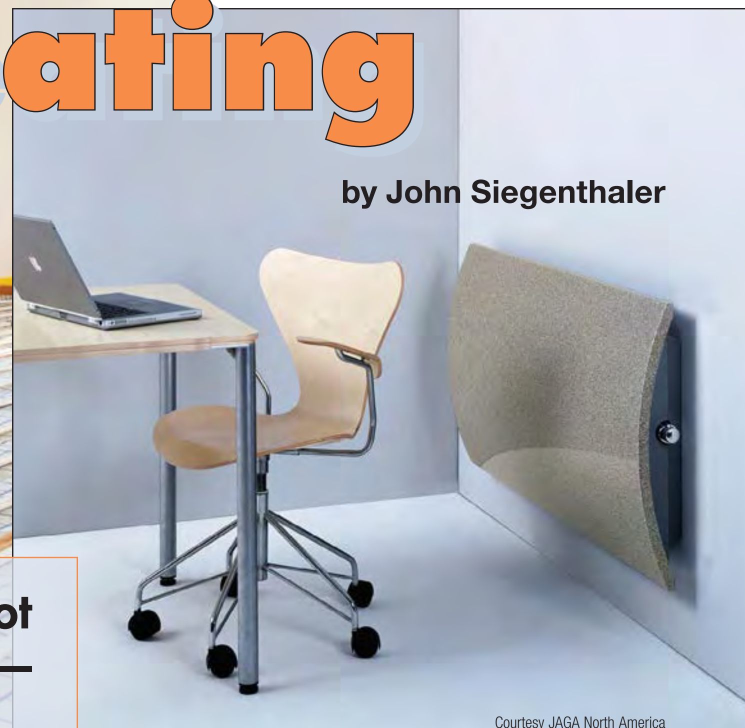


Courtesy JAGA North America

You can use renewably made hot water for your hydronic system—but designing for low water temperatures is critical to good performance.

Whether hidden in the floor slab (left) or hung on a wall (above), hydronic heating systems can provide comfort for your home.

Hydronic heating is the technology of moving heat using water. It has been used for decades in millions of North American homes, most of which have a gas-fired or oil-fired boiler as their hydronic heat source. Good hydronic design is also the "glue" that holds together renewable energy thermal systems that provide space heating and domestic hot water. In other words, pick a renewable heat source, do a good job with the underlying hydronics, and you'll likely be pleased with the results. Treat the hydronics as "whatever," and you're likely to be disappointed.

In the past, solar hydronic heating meant using solar collectors as sunny-day substitutes for conventional boilers or water heaters. Designers focused on the collectors, storage, and control aspects of the solar subsystem, but devoted little thought to a compatible means of distributing solar-derived heat within the building.

Most hydronic distribution was designed around high-temperature supply water. Residential systems commonly used fin-tube baseboard heaters with water temperatures sometimes exceeding 200°F.

But those high water temperatures were beyond what solar collectors could produce consistently. Sure, there was an occasional "perfect solar day" in winter when the storage tank got hot enough to heat a home during the following night. However, performance over a typical northern heating season was often disappointing. As a result, after investing thousands of dollars in collectors, storage tanks, and controls, many early systems spent much of their time distributing heat generated by conventional fuels rather than by the sun.

The North American heating industry has a tendency to focus on heat sources rather than overall heating systems. This mindset continues to limit the performance of not only solar thermal, but also heating systems supplied by sources such as geothermal heat pumps and wood-fired boilers.

Low Temperatures = High Efficiency

All renewable heat sources yield better performance when combined with low-temperature distribution systems. To see why, take a look at the thermal performance characteristics of a solar collector and a geothermal water-to-water heat pump. The "Solar Collector" graph below shows how the thermal efficiency of a flat-plate solar collector is affected by the temperature of the fluid entering its absorber plate. On this typical sunny, midwinter day in the northern United States, the thermal efficiency of the collector drops rapidly with increasing inlet fluid temperature.

For example: If the fluid entering the collector is 90°F, the outdoor air temperature is 30°F, and the sun is bright (solar intensity is 250 Btu/hr./ft.^{2}), the graph indicates that the fluid gathers about 56% of the solar energy striking the collector. However, if the entering fluid temperature is 160°F, while the other conditions remain unchanged, the collector's efficiency falls to 33%—a significant "penalty" when the collector operates at the higher inlet temperature. It's the result of greater heat loss from a collector to outside air, much like the increased heat loss associated with keeping your house at 75°F rather than 68°F.

The relationship between efficiency and the entering water's temperature also holds true for hydronic heat pumps. The "Heat Pump" graph shows a similar effect for a modern water-to-water geothermal heat pump operating with a constant earth-loop inlet temperature (at the condenser side of the heat pump) of 45°F.

The coefficient of performance (COP) is the heat pump equivalent of efficiency: the ratio of the heat output divided by the electrical input. A COP of 4.0 means that the heat output is four times greater than the electrical energy required to operate it. The higher a heat pump's COP, the lower its operating cost.

The graph shows the heat pump's COP dropping rapidly as the hydronic heating system's water temperature increases. Thus, for the highest possible COP, the water temperature supplied to the hydronic heat emitters should be kept as low as possible.

Temperature Trends

The trend toward low-temperature hydronics is relatively new in North America, but it's been happening in other places for several decades. Europeans accept low water temperature distribution systems as the norm, while some American hydronic systems are still being designed around water temperatures exceeding 180°F because the heat distribution hardware is cheaper.

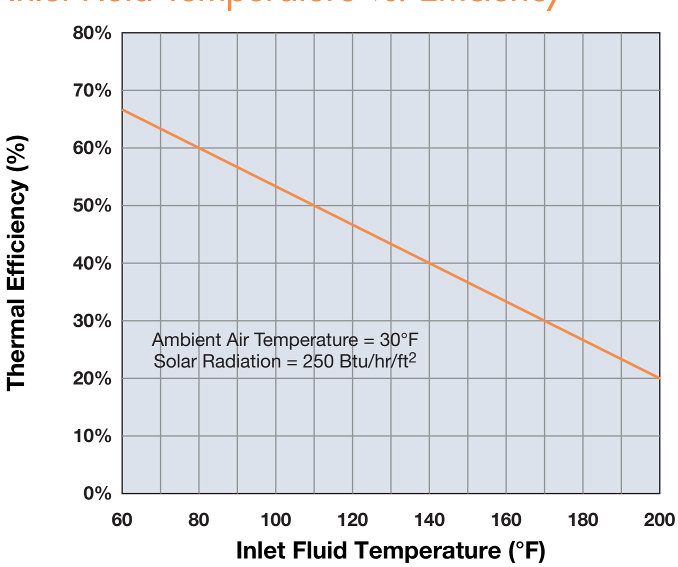
Standard fin-tube baseboard heaters are a good example. Originally designed to replace cast-iron radiators, most haven't changed much over the last several decades. When fin-tube baseboard heaters first entered the market, fuel was cheap so nearly all boilers operated at 180°F or higher. Some manufacturers' literature still lists water temperature as high as 240°F. The economics are simple—the higher the water temperature, the greater the heat output. The greater the heat output, the shorter the required fin-tube length. The shorter the length, the lower the equipment cost. But, unfortunately, the higher the temperature, the higher the energy and fuel costs.

Wood-fired boilers can produce higher water temperatures, even up to 200°F, but that doesn't negate the benefits of matching a wood-fired boiler to a low-temperature distribution system. These heat sources are best used with a thermal storage tank. They add heat to the storage tank, and the heating distribution system draws heat out. The lower the tank temperature can go and still supply sufficient heat to the building, the less often the boiler has to be stoked.

For the best efficiency, design hydronic heating systems supplied by either solar collectors or hydronic heat pumps so that the supply water temperature to the load (under maximum load conditions) doesn't exceed 120°F. This temperature is a reasonable compromise between maintaining good heat source performance, while not overly increasing the cost and space requirements of the heat emitter.

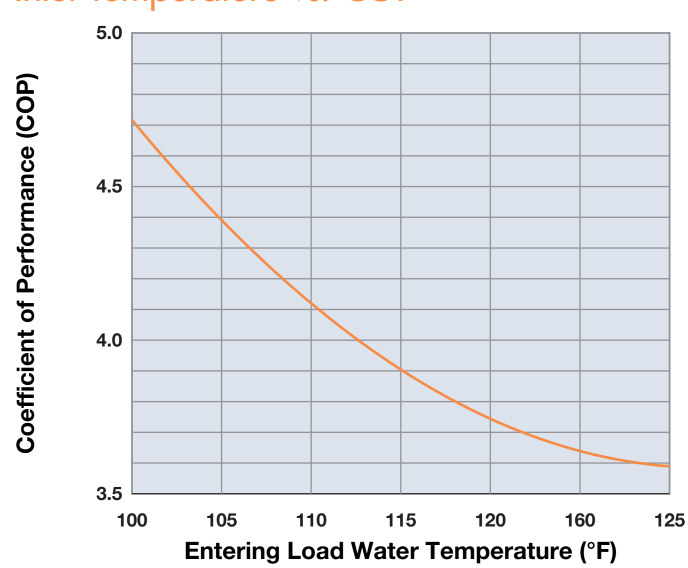
Solar Collector

Inlet Fluid Temperature vs. Efficiency



Heat Pump

Inlet Temperature vs. COP



Making It Happen

It's critical to understand what determines the supply water temperature (the temperature being supplied to the load via heat emitters) in a hydronic heating system. Some designers think that it is determined by the heat source—because many boilers come with a dial or digital control that "sets" the temperature produced. Unfortunately, that's not how it works. That setting is only a high-temperature *limit* on the heat source output. It does not guarantee that the set water temperature will ever be reached. The water temperature in any operating hydronic heating system climbs only high enough for thermal equilibrium—where the rate of heat release from the heat emitter balances the rate of heat input from the source. Once thermal equilibrium is reached, there is no thermodynamic incentive for the water temperature to climb higher, and it won't!

It's the hydronic distribution system's design, rather than the high-limit setting, that determines the system's operating water temperature. Almost everyone who designs heating systems wants to maximize thermal efficiency. For hydronic systems, this means moving away from high water temperatures by using heat emitters with larger active surfaces, or other details, such as internal microfans, that increase both convective and radiant heat transfer. This allows thermal equilibrium to occur at relatively low water temperatures during both maximum and partial load conditions.

Emitter Evolution

There are several ways to design modern hydronic distribution systems around RE's lower water temperatures, starting with the heat emitters—any device that removes heat from water flowing through it, and releases it into the room.

Many homeowners are used to the look of fin-tube baseboard heaters. From the outside, modern baseboard heaters look similar to older ones—but what's inside is very different. Fins can be about three times larger than traditional baseboard heaters, with multiple copper tubes running through those fins. Tubes can be piped for either parallel or series flow. In the latter case, the hottest water flows in the upper tube, makes a U-turn at the end of the heater, and flows back in the lower tube.

Assuming an average water temperature of 110°F, this baseboard releases about 290 Btu/hr./ft.^{2} at 1 gpm when the tubes are configured for parallel flow. With 4 gpm, the output increases to about 345 Btu/hr./ft.^{2} If the two tubes are configured for series flow, the output drops about 10%.

Consider a 12- by 16-foot room in a well-insulated home, with a maximum heating load of 2,880 Btu per hour (e.g., 15 Btu/hr./ft.^{2}). This load could be met using a 10-foot length of Heating Edge baseboard operating at an average water temperature of 110°F at 1 gpm. A 10-foot length of conventional residential baseboard heater would require an average water temperature of about 150°F. This temperature is well above what a typical geothermal heat pump can produce, and would significantly lower the efficiency of solar thermal collectors. An additional 14 feet of conventional baseboard would be required (24 feet total) to deliver the same output at an average water temperature of 110°F.

Radiant Solutions

The key to low temperature operation is large emitter surface area. The greater the heated surface area, the lower the required water temperature for a given rate of heat output. By embedding tubing in floors, walls, and ceilings, it's possible to create very large heated surfaces within a room, called hydronic radiant panels. Radiant floor heating is the best-known form, and can be installed in several ways that allow it to operate at relatively low water temperatures.

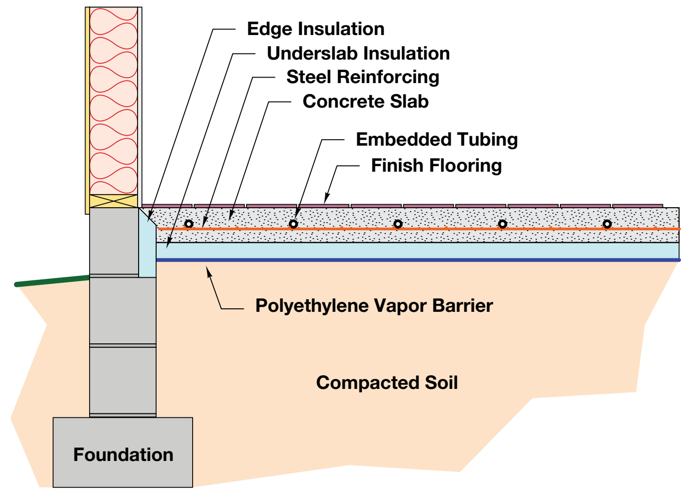
Courtesy Smith's Environmental Products (2)

The Heating Edge is a recent development in low-temperature fin-tube baseboard heating.

Courtesy John Siegenthaler (2)

Tubing embedded in a concrete floor slab is the most common form of radiant floor heating.

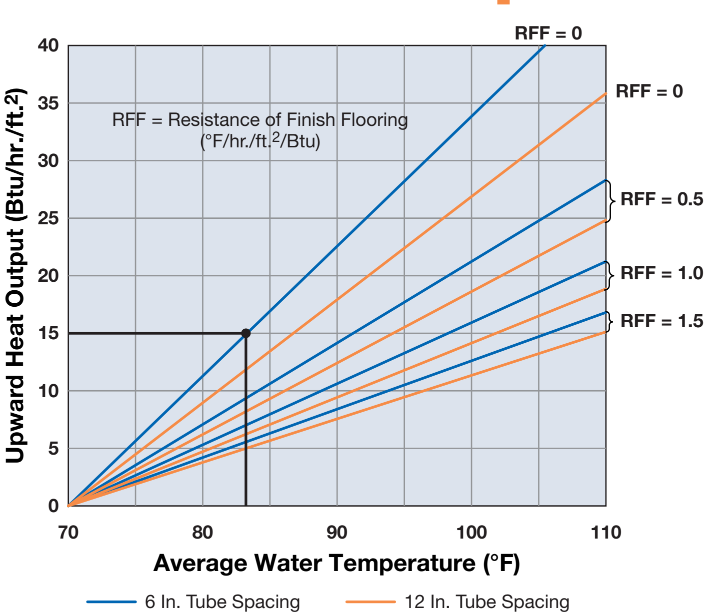
Hydronic In-Slab System



For a heated slab-on-grade floor, the tubing should be placed about mid-depth within the slab, and the underside and edge of the slab should be well-insulated. These details are crucial for low-temperature performance. It's also important to use low-resistance (or even no-resistance) floor coverings. A painted, stained, or stamped concrete slab surface is ideal. If that doesn't suit your tastes, consider ceramic tile or vinyl flooring. If you must have carpet, it's best to use only 1/4-inch-thick commercial-grade loop carpet, and glue it directly to the slab. Covering a radiant slab with a pad and carpet will insulate your living space from the slab's heat.

The "Radiant Heat Output" graph can help guide tube spacing and floor covering selections. Assuming you're satisfied with a 70°F indoor air temperature, this graph gives you the required average water temperature in the floor tubing based on tube spacing, the R-value of the floor covering (if any), and the rate at which heat must leave the floor under maximum heating conditions (in Btu/hr./ft.^{2}).

Radiant Heat Output



For example, assume the room's maximum heating load (which is calculated manually or by using one of several available software packages) divided by the heated floor area is 15 Btu/hr./ft.^{2}. You've decided to space the tubing at 6 inches, and finish the concrete slab with a sealed stain (RFF = 0). The required average water temperature in the embedded tubing is only 83°F. It's common to design floor circuits with overall temperature drops of 16°F to 20°F. Thus, the supply water temperature is half this overall temperature drop (8°F to 10°F) above the average water temperature. The temperature drop along the circuit is due to the heat being released from the water flowing through the circuit. Under these assumptions, the slab needs to be supplied with 93°F water to cover the maximum heating load. The supply water temperature can be lower under partial load conditions.

Such temperatures give excellent performance from a renewable energy heat source. Although the floor surface temperature will likely only be in the low- to mid-70s, that's as hot as the floor needs to be to release all the heat the room needs. I always stress this point so that occupants understand that a "toasty warm" floor implied by some advertisements simply doesn't occur in low heating load conditions, and in systems optimized for low water temperature operation.

The graph only reflects a maximum finish flooring resistance of 1.5 and a maximum average water temperature of 110°F (with the assumption of a maximum supply water temperature of 120°F). If you're serious about building a good performing system, don't exceed these limits. Here are some more suggestions for a heated slab floor with a renewable energy heat source:

- Tube spacing within the slab should never exceed 12 inches.
- The slab should have a minimum of R-10 for both underside and edge insulation.
- Tubing should be placed at approximately half the slab depth. Doing so decreases the required water temperature for a given rate of heat output. For a 4-inch concrete slab, the average water temperature would need to be about 7°F higher if the tubing is at the bottom of the slab. Placing the tubing closer to the top of the slab risks putting it in the path of sawn control joints.

Floor Covering R-values

Material	R-Value Per Inch	Typical Thickness (In.)	Typical R-Value
Concrete (bare, no covering)	0.00	0	0.00
Terrazzo	0.08	3/8	0.03
Concrete (120 lbs./ft.^{3} and k=8)	0.13	4	0.50
Cement board	0.14	1/4	0.04
Concrete (40 lbs./ft.^{3} and k=1.3)	0.78	1 1/2	1.16
Thinset mortar	0.80	1/8	0.10
Oak	0.85	3/4	0.64
Marble	0.90	1/2	0.45
Engineered bamboo	0.96	3/4	0.72
Ash	1.00	3/4	0.75
Ceramic tile	1.00	1/4	0.25
Engineered wood	1.00	1/4	0.25
Engineered wood	1.00	3/4	0.75
Maple	1.00	3/4	0.75
MDF/Plastic laminate	1.00	1/2	0.50
Plywood/wood panels	1.08	3/4	0.81
Softwood	1.10	3/4	0.83
Fir	1.20	3/4	0.90
Carpet pad/slab rubber, 33 lbs.	1.28	1/4	0.32
Carpet pad/slab rubber, 33 lbs.	1.28	1/2	0.64
Dense rubber flooring	1.30	21/64	0.43
Pine	1.30	3/4	0.98
OSB	1.40	3/4	1.05
Plywood (Douglas fir)	1.58	1/2	0.79
Plywood (Douglas fir)	1.58	5/8	0.99
Engineered wood flooring pad	1.60	1/8	0.20
Sheet vinyl	1.60	1/8	0.20
Vinyl composition tile (VCT)	1.60	1/8	0.20
Synthetic fiber pad, 20 oz.	1.80	15/64	0.42
Laminate floor pad	1.92	5/32	0.30
Synthetic fiber pad, 27 oz.	1.98	18/64	0.55
Linoleum	2.04	1/4	0.51
Linoleum	2.04	1/8	0.26
Synthetic fiber pad, 32 oz.	2.10	19/64	0.63
Recycled rubber flooring	2.20	1/2	1.10
Synthetic fiber pad, 40 oz.	2.20	11/32	0.77
Brick	2.25	1/2	1.13
Cork/MDF/laminate	2.35	1/2	1.18
Carpet pad: Waffle rubber, 25 lbs.	2.48	1/4	0.62
Carpet pad: Waffle rubber, 25 lbs.	2.48	1/2	1.24
Carpet	2.80	1/4	0.70
Carpet	2.80	3/8	1.05
Carpet	2.80	1/2	1.40
Carpet	2.80	5/8	1.75
Carpet	2.80	3/4	2.10
Cork	3.00	3/8	1.13
Carpet pad: Frothed polyurethane, 10 lbs.	3.22	1/2	1.61
Carpet pad: Frothed polyurethane, 12 lbs.	3.48	1/4	0.87
Hair jute	3.88	1/2	1.94
Bonded urethane	4.20	1/2	2.10
Wool carpet	4.20	3/8	1.58
Wool carpet	4.20	1/2	2.10
Prime urethane	4.30	1/2	2.15

Data courtesy healthyheating.com

Heated Thin-Slabs

Another common method of hydronic floor heating uses a 1.5-inch "thin slab" poured over a wooden deck. The slab can be either concrete or poured gypsum, but should never be lightweight concrete, which uses vermiculite or polystyrene beads instead of stone aggregate, and has significantly higher thermal resistance.

Because the slab is thinner, it has somewhat poorer heat dispersion characteristics, needing a slightly higher water temperature for a given rate of heat output—but this difference is slight: A 1.5-inch concrete thin-slab with 12-inch tube spacing and covered with a finish flooring resistance of 0.5°F/hr./ft.^{2}/Btu yields about 8% less heat output than a 4-inch-thick slab with the same tube spacing and finish flooring. To get the same efficiency, 9-inch, rather than 12-inch, tube spacing can be used.

The following guidelines are suggested for thin slabs supplied by renewable heat sources:

- Tube spacing for a thin-slab application should not exceed 9 inches.
- Floors under thin-slabs should have minimum of R-19 underside insulation.
- Floor finishes should have a total R-value of 1.5 or less (lower is always better).

A thin-slab radiant panel installation awaits the concrete pour. The 1/2-inch PEX-AL-PEX tubing has been carefully fastened using a special stapler. A layer of 6-mil polyethylene film provides a bond break between the slab and the plywood subfloor underneath.

Courtesy of Harvey Youker

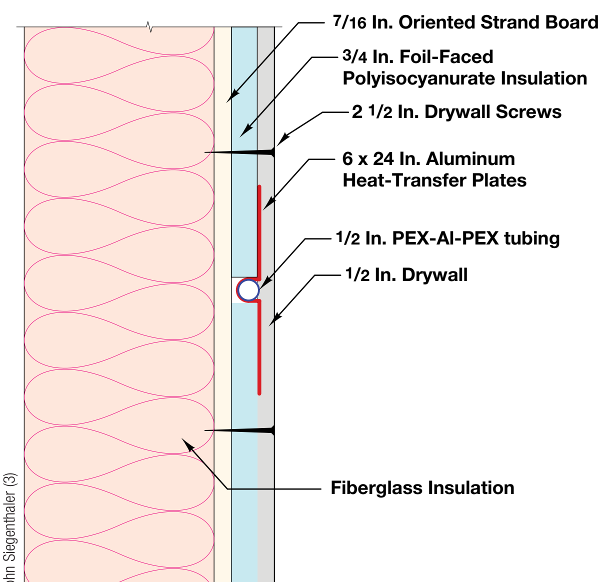
Heated Walls & Ceilings

Walls and ceilings can also be turned into low-temperature hydronic radiant panels. These radiant walls are indistinguishable from a standard interior wall. Its low thermal mass lets it respond quickly to changing room load conditions or zone setback schedules. This fast response is especially important in homes with low heat loss or significant internal heat gain because such spaces can quickly overheat.

The panel's rate of heat emission is approximately 0.8 Btu/hr./ft.^{2} for each 1°F the average water temperature in the tubing exceeds room air temperature. For example, if the average water temperature in the tubing is 110°F in a room with 70°F air temperature, each square foot of wall releases about 32 Btu per hour [0.8 × (110°F - 70°F)]. This average water temperature is well within the range of what most renewable energy heat sources can supply.

If you plan to install this system on the inside of an exterior wall, make sure the R-value of that wall is 50% higher than that of unheated exterior walls. That keeps the rate of heat loss to the outside about the same as for an unheated wall. If you're installing this on an inside partition wall, use 3.5-inch fiberglass batt in the stud cavities behind the heated wall. Finally, radiant wall panels work best constructed no higher than 3 to 4 feet above floor level. These heights bias the radiant heat output into the occupied zone of rooms, and thus improve comfort.

Radiant Wall System



John Siegenthaler (3)

A radiant ceiling system is installed in much the same way as a radiant wall system.

Radiant ceilings use the same construction as a radiant wall. The only difference is that the materials are fastened to the ceiling framing rather than the studs. The infrared thermograph shows such a ceiling as it warms up. The red areas on the left side indicate that the aluminum heat transfer plates are dissipating heat away from the tubing and across the adjacent ceiling surfaces.

Like the radiant wall, a radiant ceiling has low thermal mass and can respond quickly to interior temperature changes. Heated ceilings also have the advantage of not being covered by rugs or furniture, and thus are likely to retain good performance over the building's life, but can be a bit more expensive relative to a heated slab-on-grade floor.

The rate of heat emission from a ceiling panel constructed as shown is about 0.71 Btu/hr./ft.^{2} for each 1°F the average water temperature exceeds room air temperature. Thus, if the ceiling tubing operated with an average water temperature of 110°F in a room with 70°F air temperature, each square foot of ceiling would release about 28.4 Btu/hr./ft.^{2} [0.71 × (110°F - 70°F)]. Although not as high as the radiant wall due to lower convection, this performance is still very acceptable for use with most renewable heat sources.

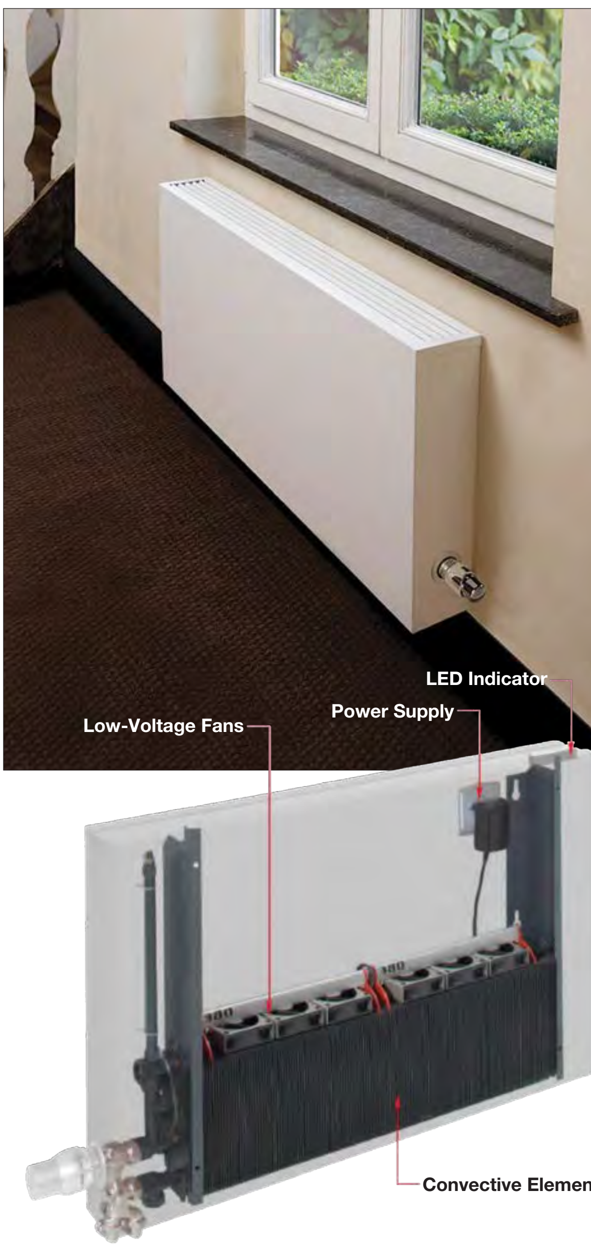
An infrared thermograph of a hydronic radiant ceiling as it is warming up. The water flow is from left to right, as shown by the red and orange areas.

Panel Pleasantries

Generously sized panel radiators can also provide good low-temperature performance. The suggested guideline for sizing panels to deliver the maximum heat output is to use a supply water temperature no higher than 120°F.

Manufacturers provide output ratings for their panel radiators in tables or graphs. Most list heat output for high water temperatures such as 180°F. Correction factors are provided to determine heat output at lower water temperatures. As an approximation, a panel radiator operating with an average water temperature of 110°F in a room maintained at 68°F provides about 27% of the heat output it would yield at 180°F. Larger panels increase surface area to compensate for lower operating temperatures.

JAGA North America's Low H2O panels provide the latest in contemporary looks and thermal performance. Small fans move air past the radiator fins, increasing low-temperature output up to 250%.



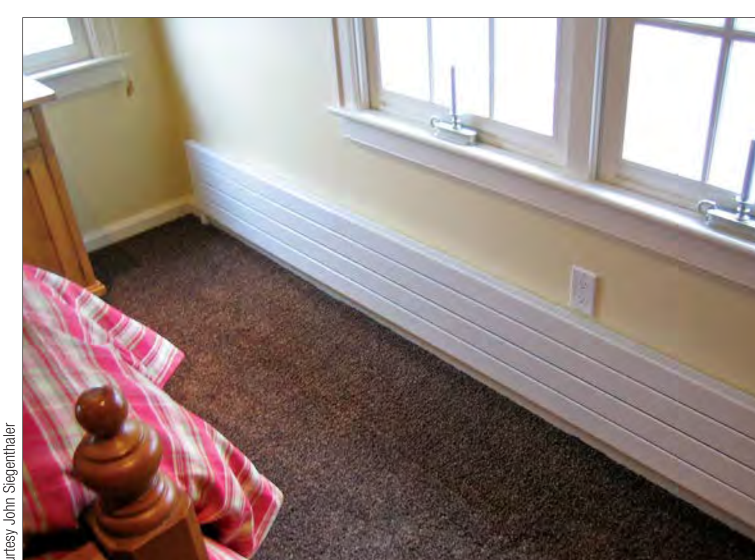
Courtesy JAGA North America (2)

Contemporary radiant panel designs, like this one from Vasco Heating Concepts, can look like a work of art in themselves.

Be sure to verify low-temperature performance when choosing any radiant wall panel.

Courtesy Vasco Heating Concepts

This radiator from Runtal is part baseboard, part wall panel. Radiant panels come in many shapes and sizes to fit almost any application.



Courtesy John Siegenthaler

From Here to There

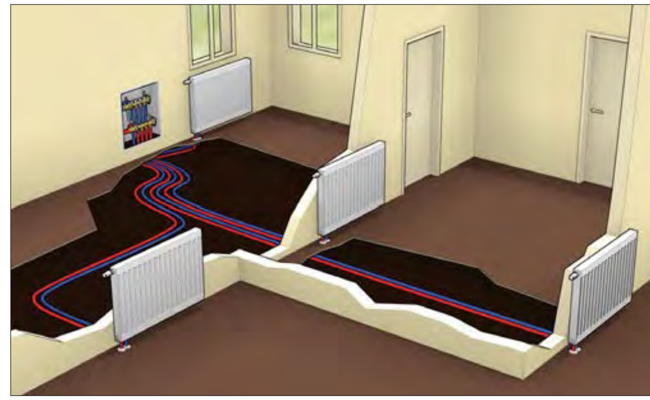
None of these hydronic heat systems will deliver as expected without a well-planned distribution system. Although there are several piping layouts that may serve your purpose, the simplest, easiest to install, and most flexible approach is a "home run" distribution system, which starts with a manifold station—the same kind as used for radiant panel heating.

Two lengths of 1/2-inch PEX or PEX-AL-PEX tubing provide the supply and return from the manifold station to each heat emitter. The flexible tubing allows routing through framing cavities much like an electrical cable. This is particularly helpful in a retrofit situation, where the use of rigid tubing would be difficult.

A variable-speed, pressure-regulated circulator pump provides flow through the home run distribution system. Available from Grundfos, Taco, Wilo, and Bell & Gossett, these circulators can operate over a wide range of speeds, and in different control modes, depending on the application. For a home run distribution system, the circulator is set to "constant differential pressure" mode. Its responsibility is to maintain a constant (installer-set) pressure differential between its inlet and outlet ports. It does this by varying speed in response to changes in the distribution system's hydraulic resistance.

At full speed, the motors in these "intelligent" circulators operate on approximately 50% of the electric power required by standard hydronic circulators of equal capacity. This characteristic, in combination with speed control, delivers annual electrical energy savings of 60% to 80% relative to standard hydronic circulators.

A thermostatic radiator valve (TRV) is used on each panel radiator. Each TRV constantly monitors the room's air temperature. As that temperature drops slightly below the TRV's setting, the valve slowly increases water flow through that panel. This causes a very slight drop in the distribution system's hydraulic resistance, a change that's quickly detected by the pressure-regulated circulator which responds by increasing pump speed to restore the set differential pressure. This yields a slight flow increase through the panel that needs it, and virtually no flow changes in the other panels—a "cruise control" for system flow.



Courtesy Caleffi North America

This home run distribution system is simple and effective, with a manifold accessible through a wall panel.

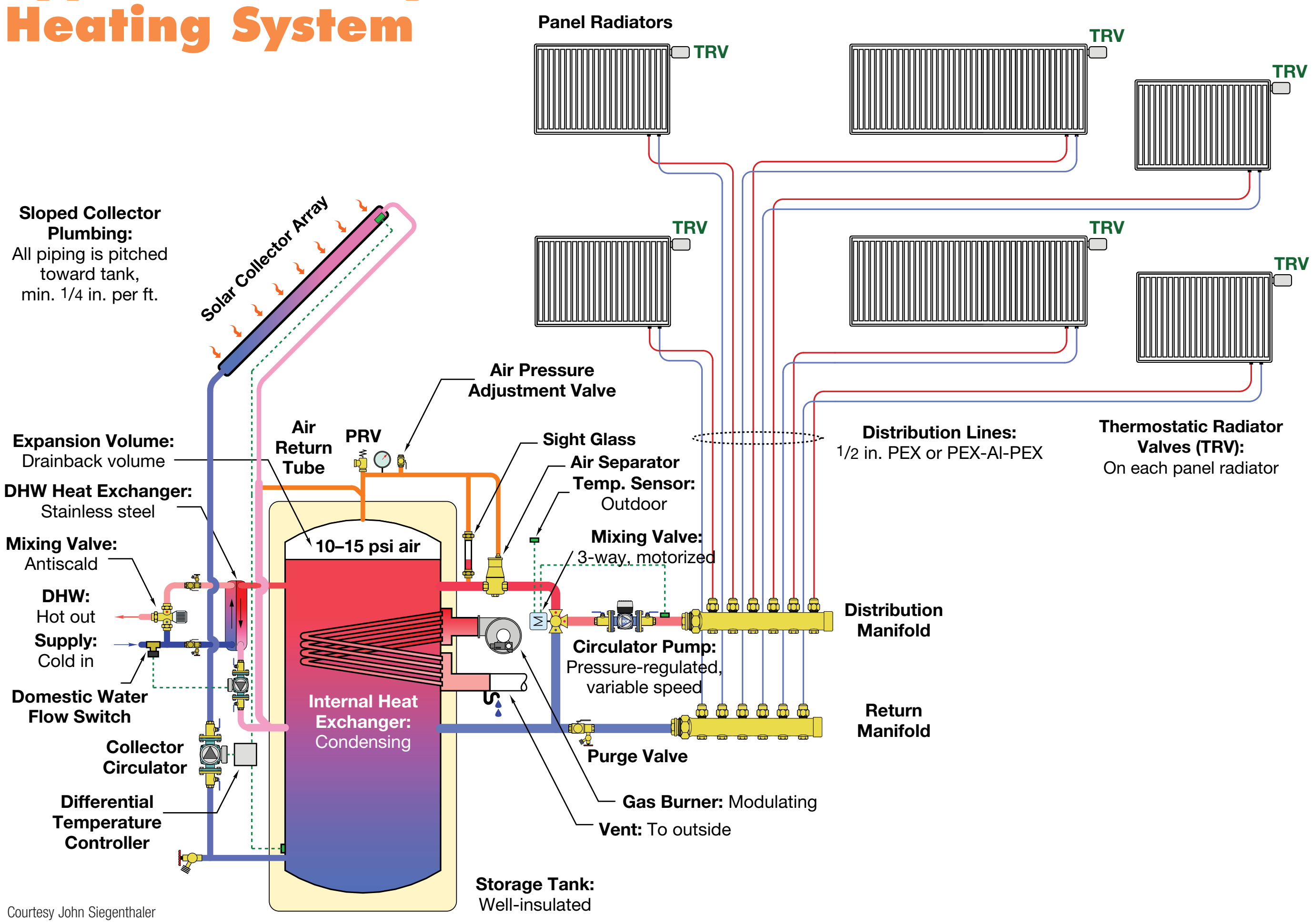
Courtesy John Siegenthaler (2)

A panel radiator with an integrated thermostatic radiator valve.

John Siegenthaler (3)

Pressure-regulated, variable-speed circulation pumps (from left): Grundfos, Wilo, and Bell & Gossett.

Typical Solar Hydronic Heating System



Courtesy John Siegenthaler

The Big Picture

The main component in the schematic (above) is a well-insulated drainback/storage tank equipped with an electrical element or integrated gas burner for backup, with an internal heat exchanger. The element/burner keeps the water at the top of the tank warm enough to provide domestic hot water (typically 120°F to 130°F).

A drainback-protected solar collector feeds the hydronic heat distribution system. The collector circulator runs when the collectors are a few degrees warmer than the water near the bottom of the storage tank. No antifreeze is required in this system, and no heat exchanger is needed between the collectors and the storage tank. These features reduce cost and increase collector efficiency. The same water that flows through the collectors also flows through the heating distribution system. The system is completely "closed" from the atmosphere.

The captive air at the top of the tank is under slight positive pressure. This airspace provides a drainback reservoir, and acts as an expansion tank. The water in the tank provides thermal storage for the solar collectors, and it provides thermal mass to buffer the zoned space-heating distribution system. The latter function protects the burner against short operating cycles, which would otherwise decrease efficiency and increase maintenance. Short cycle protection is very important in a hydronic system with extensive zoning.

A flow switch detects whenever domestic hot water is being drawn at a flow rate of 0.5 gpm or higher, activating a small circulator that moves hot water from the top of the thermal storage tank through a plate heat exchanger. Cold domestic water is heated as it passes through the other side of this heat exchanger, and sent to the taps.

An antiscald thermostatic mixing valve protects against high domestic water temperature when the tank is very hot, like at the end of a sunny, warm day. For the fastest possible response, the piping between the thermal storage tank and heat exchanger should be short and insulated. Combination isolation/flushing valves should be installed on the domestic water inlet and outlet of this heat exchanger. They allow the heat exchanger to be isolated and flushed if necessary to remove scale.

A single variable-speed pressure-regulated circulator feeds the home run distribution system for space heating. One circulator can supply the entire distribution system in a typical 2,500-square-foot house using no more than 40 watts under maximum heating load.

Each panel radiator has an adjustable thermostatic valve that monitors room temperature, and adjusts the flow rate to maintain that temperature. No thermostats, batteries, transformers, or programming—just simple, effective, and reliable room-by-room temperature control.

The mixing valve upstream of the manifold station protects the distribution system from what could be a very hot storage tank following a sunny spring or fall day. It also adjusts the water temperature supplied to the panels based on outdoor temperature, known as "outdoor reset," and stabilizes room temperature for optimum comfort.

Access

John Siegenthaler (john@hydronicpros.com) is a mechanical engineering graduate of Rensselaer Polytechnic Institute, a licensed professional engineer, and professor emeritus of Engineering Technology at Mohawk Valley Community College. "Siggy" has more than 32 years of experience designing hydronic heating systems. The third edition of his textbook, *Modern Hydronic Heating,* will be released in January 2013.

Hydronic Heating System Products:

Caleffi • caleffi.com • Solar collectors, storage tanks, controls, thermostatic valves

Grundfos • grundfos.com • Hydronic circulators

Heatlines • heatlines.com • Panel radiators

HTP • htproducts.com • Hydronic heat sources, including solar integration

Jaga • jaga-usa.com • Low-temperature hydronic heat emitters

Smith's Environmental Products • smithsenvironmental.com • Low-temperature baseboard

Wilo • wilo.com • Hydronic circulators

Xylem/Bell & Gossett • completewatersystems.com • Hydronic circulators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CONSIDERATIONS for Off-Grid PV Systems

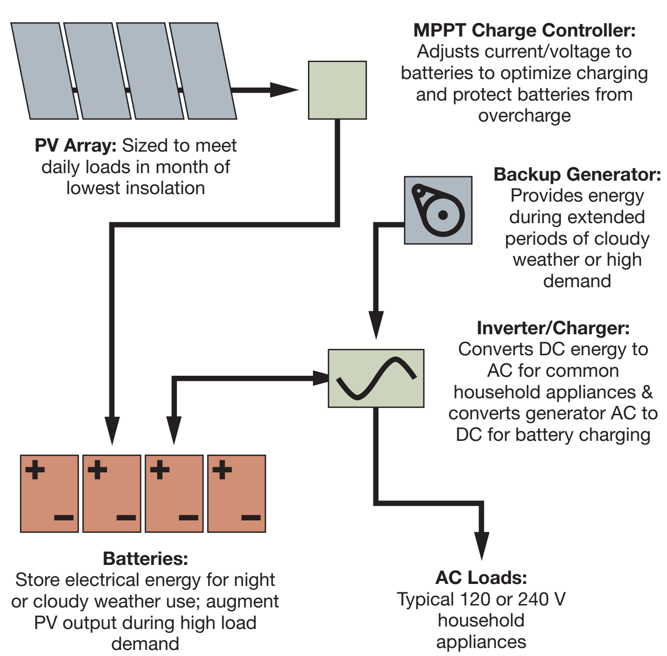
by Carol Weis

Courtesy Electron Connection

There are many reasons for choosing an off-grid PV system to power a remote home or cabin. Some people want to avoid the high cost of extending a utility line, while others like the independence of homemade energy production, as well as having a silent, emission-free energy source with a 25-year warranty.

Off-grid (or "stand-alone") PV systems are very different than batteryless grid-tied systems. Without the utility as a supplemental electricity source, a PV system's sizing is critical. Off-grid systems require their owners' participation—this means living within the original design's energy budget, planning for future growth, and having a backup energy source for times of high energy usage or low solar production. All maintenance and equipment servicing is also done on-site, at the homeowner's expense, and by the homeowner or installer—instead of by a power company.

Off-Grid System Basics



Should You Disconnect from the Utility Grid?

For most homes in the United States, grid outages are infrequent and short-lived, and a batteryless grid-tied system is the most efficient and economical choice. The utility essentially serves as a giant battery bank, accepting excess PV production during the day and providing electricity at night or during cloudy weather. In utility-serviced areas where outages are common or lengthy, having some on-site battery backup can make sense. However, carefully considering the maintenance, cost, and potential hazards of a battery bank is important. Selecting only what loads are critical to maintain during grid outages will keep the number of batteries needed—and battery cost—down. Off-grid design is the most appropriate when there is no access to the grid and is not typically considered for homes that are already connected to the utility. Often, remote properties can be powered from an off-grid PV system for less than the cost of the utility line extension, making it the most economical option.

System Types Compared

	Off-Grid	Grid-Tied, with Batteries	Grid-Tied, Batteryless
Grid independence	Yes	Limited during utility outages	No
Live beyond the utility lines	Yes	No	No
Utility payments	None	Yes; may also earn credit or payments from utility	Yes; may also earn credit or payments from utility
Combine with other RE sources (like wind or hydro)	Yes	Yes	Yes
Incentives available	Some	Yes	Yes
Design must consider worst-case scenario	Yes	Only for backup loads	No
Maintenance	High	Medium	Low
Requires batteries	Yes, for all loads	Yes, for critical loads	No
Number of components	Most	Most	Least
System size	Must be large enough to power all loads	Must be large enough to power backed-up loads	Any size; the grid can power the additional loads
Efficiency	Lowest; more components & large battery cause higher losses	Moderate; some energy used to keep batteries fully charged for an emergency	Highest; fewest components & no battery losses
Surplus energy	Wasted, unless diversion-load used	Banked for future—net billing	Banked for future—net billing
Utility outages	Irrelevant; system works all the time	Battery backup provides power for selected loads	System will not work
Grid requirements	None	Must be reliable most of the time	Must be reliable
Complexity	High	Highest; requires specialized inverter	Least
Cost	Highest, because of large battery	Moderate; smaller battery bank required	Lowest; no batteries & fewer components

Loads

Carefully considering the appliances—or loads—in a home is crucial in off-grid system design. The first step is to list the power requirements of every desired appliance and determine the average daily hours each will be used. A *load analysis* calculates the energy consumed by each appliance, with the ultimate goal of determining the total average daily energy consumed by *all* loads in the home. This daily consumption value is then used to design a battery bank large enough to store that energy each day and a PV array large enough to produce the energy.

Other considerations include whether the appliances will use alternating current (AC) or direct current (DC). All off-the-shelf appliances that can be plugged into a standard wall outlet are AC. For off-grid homes with full-time occupancy, the benefits of AC appliances typically outweigh the benefits of DC appliances. Conventional appliances are readily available, and they run at higher voltages, so you can

"Load shifting" means shifting tasks to other energy sources besides electricity, literally taking a load off your PV system.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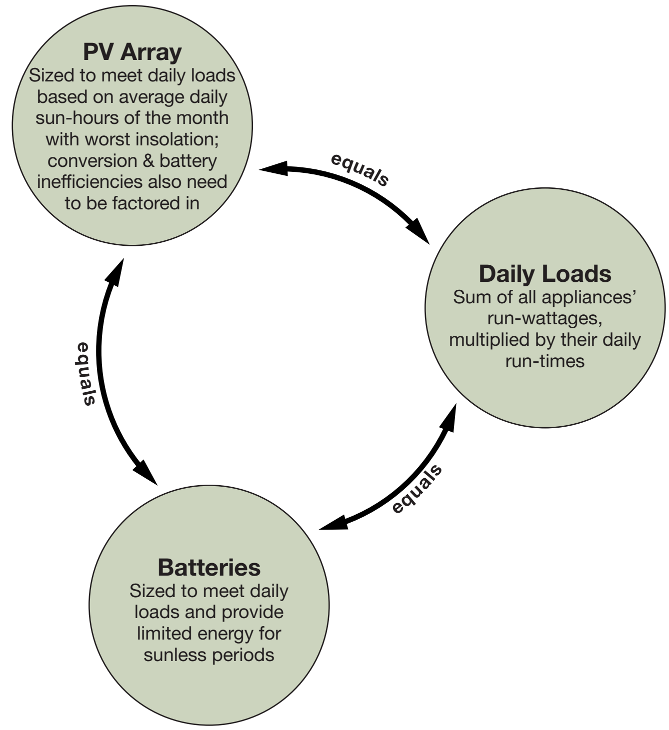
In an off-grid scenario, every kWh is important. Energy efficiency is the key to keeping system costs down.

Off-Grid System Design Balance



use smaller, standard AC wiring in your household. In certain applications, such as a system for a small cabin, an RV, or a boat, the greater efficiency created by eliminating the inverter can justify more expensive, harder-to-source DC appliances. For example, a PV system for a boat may run 12 VDC lights, a radio, a TV, and a refrigerator directly from the battery to avoid the need for an inverter.

Certain loads need special consideration because of their high energy use, including space heaters and coolers, water pumps, refrigerators, water heaters, and cook stoves. For these applications, it is best to first determine if there are non-electric methods of accomplishing the same task, such as drying clothes on a line instead of using an electric clothes dryer. If an electrical appliance is still going to be used, consider ways to reduce the demand for the load, and then buy the most efficient appliance that will serve that need. As an example, correct window placement and properly sized overhangs can help reduce cooling loads, as will high-performance windows and well-insulated walls. After exhausting all non-electrical means of cooling, using evaporative coolers (in arid regions) or low-energy ceiling fans are good options instead of using a compressor-type air conditioner. If an air conditioner is used, consider cooling only a portion of the home.

Off-grid consumers need to be aware of their energy allowance and shop carefully for efficient appliances. Many appliances, having large power draws and standby features, can be large energy users. The U.S. Department of Energy's Energy Star website (energystar.gov) is a good place to research the most efficient appliances—however, even within Energy Star-rated appliance categories there still are wide variances in energy consumption. For instance, a sample LG Energy Star 42-inch plasma TV energy consumption is estimated at 140 kWh per year, compared to an equivalently sized LCD model which ranges from 83 to 152 kWh per year. Similarly, comparing refrigerators from Whirlpool demonstrates that a side-by-side model uses about 30% more energy than a refrigerator with the freezer on the top.

Courtesy SunDanzer

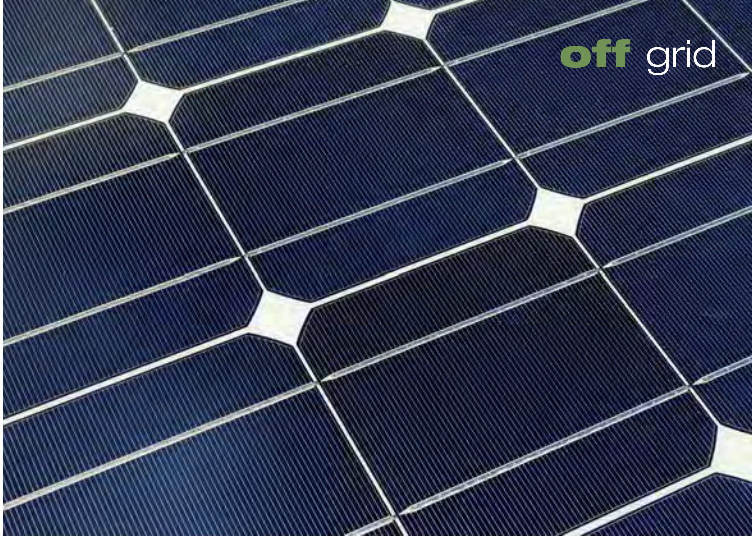
Courtesy Sun Frost

Left: Refrigeration can be the largest load in an off-grid home. Though modern, mainstream refrigerators are more efficient than ever, some off-gridders choose the super-efficiency of units designed specifically for RE systems. Their higher cost is offset by reducing dependence on PV or generator energy.

PV Modules

When choosing PV modules for your off-grid system, it is important to look at the price, the technology, how they attach to the roof or rack, the voltage and current specifications, the UL listing, and the warranty. The most typical type of module (240 W, aluminum-framed, with quick-connect positive and negative wires) has an output voltage that integrates easily with arrays configured for grid-tied inverters. The off-grid market can also take advantage of these common modules by using a maximum power point tracking (MPPT) charge controller that can step down array voltage to the lower voltage of a battery bank. There are still some modules on the market that are a nominal 12 V (or 24 V), made to directly charge a 12, 24, or 48 V battery bank through a non step-down charge controller, but they are becoming harder to find and are typically more expensive.

Proper array sizing is crucial in off-grid design. It ensures that the loads you need to run will have energy and that the battery can be fully recharged after a period of no sun. To size an array, you'll need to know the modules' STC watts, the average daily peak sun-hours in the worst month, and the amount of energy the loads consume. An array needs to produce as much as the average daily loads consume (plus efficiency losses) and be able to recharge the batteries and "catch up" after cloudy periods. Whenever possible, oversize the array to account for inclement weather (see "More PV, Fewer Batteries" sidebar). Most designers also specify a generator to accommodate for long stretches of low (or no) sun, which then removes the need to oversize the array further.



Courtesy Joe Villacci

These days, most photovoltaic modules are not made with nominal voltages to match battery voltage. Rather, modern MPPT charge controllers are able to accept a wide PV voltage range and step it down to a lower battery voltage.

PV Mounts

Because off-grid home sites often have more room than city lots, there are usually more locations for array placement beyond a home or garage roof. Ground mounts, pole mounts, shed or barn roofs, and solar trackers are options. A pole- or ground-mount system allows the array to be adjusted seasonally, and this additional energy production can reduce a backup generator's run time (reducing fuel use and maintenance) during winter. For example, adjusting a 3,000 W array in Pueblo, Colorado, from a fixed latitude tilt to a steeper tilt will gain 0.5 daily peak sun-hours during the winter. That additional energy calculates to be about 1,500 Wh per day (3,000 W x 0.5 hours/day).

Nunatak Alternative Energy Solutions

Ground and pole mounts allow seasonal tilt adjustment, optimizing system output for when it's needed most.

Courtesy Electron Connection

Ground and pole mounts allow PV arrays to be located in the sunniest location, even if far from the inverter and/or batteries.

For the greatest energy harvest from an array, a solar tracking mount can be used, so long as a clear solar "window" is present (dawn-to-dusk solar access is ideal). With decreasing module prices, however, the additional cost of the tracker plus the introduction of moving parts to an otherwise non-mechanical system makes this option harder to justify. Often, it's a better investment to increase the array size to increase the system's year-round output.

Charge Controllers

A charge controller's primary function is to prevent the batteries from overcharging. Charge controllers monitor the battery voltage—when the batteries are fully charged, they disconnect the charging source (in this case, the PV array) from the battery until it is next needed. Some smaller controllers also have an additional feature that prevents overdischarging from DC loads.

When choosing a residential-sized charge controller, first evaluate whether MPPT, which helps maximize the energy harvest from the array, is needed. MPPT controllers continually track array output—during shifting temperatures and irradiance levels—to optimize the amount of energy sent to the battery. The additional cost is justifiable in nearly all larger systems, since it yields between 10% and 25% more energy. MPPT charge controllers also have a "voltage step-down," so they can convert high array voltages (up to 600 VDC) to lower battery voltages (typically 24 or 48 VDC). This allows more modules to be wired in series and the use of smaller-gauge (and less expensive) wire from the modules to the controller. Having a large difference in voltage between the array and the battery decreases a charge controller's efficiency, but the benefits of being able to place the array farther away from the battery bank, reducing the wire size, and having smaller overcurrent protection devices, can be worth it. Non-MPPT controllers still hold a large market share, but generally make sense only in smaller system applications, such as for boats, lighting, RVs, and small cabins. Additional information needs to be considered in choosing a controller, including monitoring requirements, temperature compensation, voltage and current specifications, and the size of the array-to-battery voltage step-down window.

Courtesy MidNite Solar

Modern MPPT controllers maximize PV output and allow a variety of PV configuration voltages independent of battery system voltage.

Inverters

Using AC appliances in an off-grid home requires an inverter to convert the PV array and battery bank's DC electricity to the AC electricity needed. When choosing an inverter, one should consider options such as metering, programming flexibility, type of waveform, idle power draw, generator backup, surge capability, and overall power needed by the loads.

Sizing an inverter requires adding up all the power needs of the appliances that will be on simultaneously. Some loads with motors, like a refrigerator's compressor, also require a boost of power to start, called a surge, which is typically two to seven times larger than the appliance's normal operating power needs—continuous power and surge power need to be considered. Choosing an inverter with a higher power rating may be important if loads increase or there may be future system expansion. Inverters also use some energy in standby mode (waiting for any load to run), so choosing an inverter with a low "idle power draw" is important.

AC appliances require a sine wave that alternates between positive and negative voltages 60 times a second. Inverters take DC current and create this AC sine wave with varying degrees of accuracy. Modified square-wave inverters create a rudimentary waveform that can run most appliances but has trouble with more sophisticated electronics, such as dimmers and computers. A true sine wave will run most equipment, especially motor-based, more efficiently—which translates to more useful energy from the system. Thus, many off-grid homeowners choose true sine-wave inverters, which can run all electronic appliances without a problem.

Most home appliances require 120 V to operate. Other loads, like well pumps or some shop tools, require 240 V. In this case, you'll need to choose a single inverter that provides 120/240 V, or use two inverters that each produce 120 V but can be connected (or "stacked") to provide 240 V. Alternatively, a transformer can be used between a 120 V inverter and a 240 V load to step up the voltage when needed.

Off-grid PV systems commonly use a generator for backup. If you'll be using a generator, you'll need an inverter with a large battery charger to change the generator's AC electricity to DC for the batteries, and run any AC loads. Most higher-end inverters offer programming options for interfacing with generators, such as automatic start and stop, pre-set quiet hours, and maximum charge amps. Additionally, metering allows users to see how much charge is going from the generator to the batteries, how much energy is leaving the battery to the loads, and the battery's state of charge.

Most off-grid inverters can be "stacked" for increased power and higher voltage. Here, four inverters are stacked to provide 120/240 VAC and higher power output.

Courtesy Gardner Engineering AES

Batteries

Battery considerations include the technology type, cost, preferred system voltage, ambient temperature, maintenance requirements, and battery location. Nearly all home battery banks are deep-cycle lead-acid, which can handle being regularly and deeply discharged (up to 80%, but 20% to 50% depth of discharge will significantly increase longevity). For lead-acid, the first decision is whether to use a flooded battery that requires regularly adding distilled water, or a sealed valve-regulated lead-acid (VRLA) battery that does not require watering. Sealed batteries are more expensive and have a shorter life than equally sized flooded batteries, but this trade-off can be worth it in cases where the battery maintenance cannot or will not be done.

Modern off-grid battery banks are typically 24 or 48 V, which allows the use of smaller-gauge wire than 12 V systems, which have higher current for the same power level. Choosing a higher-voltage battery also means wiring more batteries in series to increase the voltage, thereby reducing the number of parallel battery strings required for the same energy available. This, in turn, helps reduce imbalances across the battery bank. If there are 12 V loads that need to be powered, a DC-to-DC converter can be used to supply the right voltage.

It is important to keep flooded batteries out of living spaces and all batteries should be protected from unauthorized access—as they contain caustic chemicals and pose shock and burn risk if not handled properly. Choosing a location with moderate temperatures (77˚F is ideal) is critical for battery longevity. For every 18°F increase in temperature the battery experiences, the number of available cycles drops by half.

Courtesy Gardner Engineering AES

Batteries are both an essential element and weakest link of off-grid systems, adding cost, complexity, and maintenance, while having the shortest lifespan of any component.

For example, if a battery is rated at 3,600 cycles at 77˚F (or approximately 10 years, at 1 cycle per day), it would then be expected to last 1,800 cycles, or about five years, if installed in a climate of 95˚F. At lower temperatures, a battery will gain lifespan, but its available capacity will decrease.

Maintenance requirements for all batteries include keeping the terminals and tops of batteries free from corrosion, dirt, and debris. This helps keep electricity flowing equally through the entire battery bank. The battery should be charged to 100% on a weekly basis (and daily is better)— keeping batteries in a discharged state can decrease their life. The electrolyte level must never expose the lead plates to air. Flooded batteries also need to be equalized—a controlled overcharging that is commonly done every few months. Equalization helps to rebalance cell voltage and improves the health of the battery by mixing up the electrolyte, which can stratify over time. Properly venting explosive hydrogen gases (produced by charging lead-acid batteries) from a battery box to the outdoors is extremely important. Passive venting can be accomplished by intake air vents installed at the bottom of a battery box combined with higher outlet vents at the top. This allows the lighter hydrogen gases to rise up and out. Active venting by a DC fan can also be used.

Sizing a battery bank starts with load analysis. The battery needs to store the amount of energy needed for the daily loads. If the loads need to work on some days where there is no sun available (but before the generator kicks in), then the battery bank needs to be larger—known as days of autonomy. Beyond that, batteries will yield more cycles when less is drawn out of them on a daily basis. For example, a battery that's discharged 20% may provide 3,300 cycles; if discharged 80%, it may only provide 675 cycles.

More PV, Fewer Batteries

The perpetual issue in battery-based system design is how to charge the battery bank to 100% full, preferably daily, but at least once a week. Problems arise when there isn't enough sun to meet the daily load, and after a few days, the battery has less opportunity to get completely full.

Whenever budget allows, it can be beneficial to oversize the PV system. During sunny weather, the modules will stop charging the battery earlier in the day—but during periods of cloudy weather, there will be more PV production to boost the batteries and less reason to turn the generator on.

With a larger array, specifying a smaller battery bank becomes possible, since it is also more likely to get fully charged on a regular basis. If the loads can be coordinated to operate during the daytime while the PV array is producing, then a smaller battery capacity can be used successfully.

With module prices significantly declining over the last few years, and battery prices climbing, increasing PV array size is viable for more system owners. Additionally, diversion loads (such as hot water elements) can be utilized to take advantage of excess PV system output on sunny days.

Hybrid Systems

There are other sources of backup power besides an engine generator. Both wind and microhydro turbines can be good renewable sources, if the property has consistent winds or a creek. Sometimes multiple sources of energy are available that work well together throughout the seasons. For instance, in the wet Northwest, there are seasonal creeks that can run microhydro turbines in the rainy season, and then in the dry season solar can kick in to make up for a lack of flowing water. Sites in the Midwest often have winter winds, with the PV system augmenting production on sunny, windless, summer days.

Backup Generators

Backup power sources are usually included in off-grid PV systems for when it's not sunny. Engine generators, which may run on gasoline, propane, or diesel-compatible fuel, are the most common backup source because they provide power on demand. Generators are used more during the shorter days of the winter and for periods of cloudy weather. They can be set up to auto-start if a compatible inverter/charger is used, though many off-gridders do not recommend it—generators should be checked for fluid and fuel before starting. Generators are also important for equalization charging, as it is difficult to get enough power and energy from a PV array to perform this function.

Generator options include fuel type, size (kW), and fuel storage. Noise, exhaust fumes, and access for maintenance influence generator location. Regular maintenance—checking the oil, changing filters, and tuning—is needed so the generator can be available when needed. A generator typically needs to be sized to both handle charging batteries and run the loads simultaneously. Inefficiencies due to high elevations and temperature, and the limitations of the charging capacity available in the inverter/charger, will also influence sizing.

Courtesy Gardner Engineering AES

Whether gasoline, diesel, or propane, a backup generator is instrumental in almost all off-grid power systems. But good system design can minimize run time. This generator has a small solar module to keep the starter battery charged and ready.

Meters & Data Monitoring

Meters and data monitoring for an off-grid system are even more critical than for a grid-tied system, since you'll need to make sure the batteries are reaching 100% full on a regular basis; track the trends of loads versus charging over time; and monitor the battery's state of charge. Meters and monitoring also help you gain insight on future system needs—for example, if more modules are needed to keep up with household usage and to determine when the batteries need replacing.

Data monitoring can show trends about battery charging and load profiles and to help spot potential problems. Some inverters and controllers can log the daily energy consumption and production data, and the minimum and maximum battery state of charge.

System metering is important for monitoring system status, general condition, and troubleshooting.

Courtesy Outback Power Systems

User-Interactivity

Living off-grid requires much more interaction with the energy system than does living with a grid-tied system. In a grid-connected system, if there is no sun or if more energy gets used on one day than another, the grid is a (mostly) reliable backup source. In an off-grid system, the user has to strategize to ensure adequate energy to meet the loads—every day. Users with stand-alone systems have to monitor and adjust their energy consumption, watch weather patterns and time usage accordingly, and make sure there's fuel for the backup generator. Additionally, troubleshooting is more difficult in this complex system—and the stakes are higher when the utility is not there as a backup.

Access

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Domestic Hot Water

Reduce Demand and Improve Efficiency

Before you buy a new water heater, implement these hot-water saving strategies.

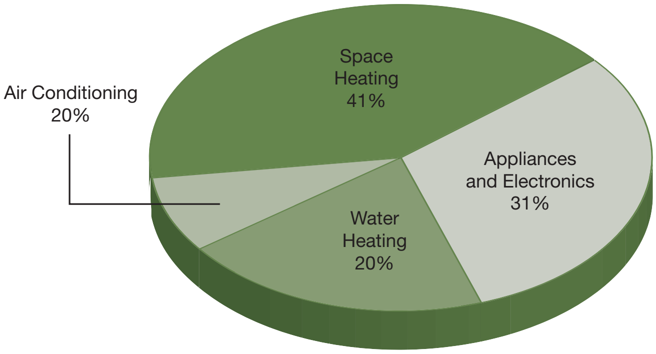
Courtesy David Emrich

by Alex Wilson

In the past, heating water was typically the second- or third-largest energy user in homes—after space heating and, sometimes, air conditioning. As we're doing a better job insulating our homes, though, the proportion of home energy used for water heating has steadily risen. In 1978, according to the U.S. Department of Energy (DOE), water heating accounted for 14% of the energy use in homes, compared with 66% for space heating. By 2005, those percentages had shifted to 20% and 41% respectively.

In today's ultra-energy-efficient "passive houses," which accomplish their space-heating needs primarily through passive solar gain and use high levels of insulation to minimize heat transfer through the envelope, it's not unusual for water heating to be the largest energy consumer in a home—and it can be as much as twice that of space heating. A standard residential electric water heater is responsible for nearly half the carbon dioxide emissions of an average passenger car.

Residential Energy Consumption



Source: U.S. Energy Information Administration, 2005 Residential Energy Consumption

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Faucet aerators increase the effectiveness of a flow of water by spreading a stream into tiny droplets.

Courtesy Delta Fauce

The H20kinetic low-flow showerhead from Delta Faucet uses 1.5 gallons per minute.

Courtesy Alex Wilson

Front-loading washers, like this Whirlpool Duet (bottom), use less water than conventional top-loaders, which can also translate into water-heating energy savings.

This article takes a broad look at the things you can do before you select a water heater, including reducing demand for hot water and distributing it more efficiently.

Start by Reducing Hot Water Demand

In seeking to reduce a water heater's energy consumption, it makes sense to start by reducing demand. Strategies include installing low-flow showerheads and faucet aerators, and replacing older clothes washers and dishwashers with more efficient models. Fortunately, there have been dramatic advances in water-conserving products and appliances in recent years. Product directories, such as BuildingGreen's GreenSpec Directory, can lead you to state-of-the-art products to help reduce hot-water demand (see Access).

Address System Efficiency

After reducing the demand for hot water, then seek to eliminate water heating system inefficiencies, which include how the water is heated (combustion efficiency, standby losses, etc.) and distributed. A lot of attention is focused on how to heat water efficiently (see "Efficient Water Heaters" in this issue). Unfortunately, very little attention is paid to distribution losses.

"DOE views water heating as the province of an appliance—the water heater," says researcher Dan Cautley of the Energy Center of Wisconsin. But distribution losses, due primarily to heat loss from pipes, are far from insignificant.

Gary Klein, a leading researcher on hot water distribution, estimates that distribution losses range from 10% to 30% in typical American homes. In homes with continuous-circulation hot water systems, no pipe insulation, and relatively little hot water use, he has seen distribution losses as high as 90%.

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Pre-formed pipe insulation makes installation easy.

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While many water heaters have significant insulation, wrapping one with an insulating water heater blanket can save even more energy.

Courtesy David Emrich

"Even a modest drip from a hot-water faucet can waste thousands of gallons of hot water per year."

That's why it's important to insulate all hot-water pipe runs. Pipe insulation won't eliminate heat loss from hot water pipes, but it will slow that loss considerably. And it will increase the likelihood that a homeowner won't have to wait for hot water after a relatively short period of non-use.

During new construction, it's easy to insulate pipes. Buy foam pipe insulation that's designed for the diameter pipe you're insulating, slip it on, miter-cut corners, and use quality tape to seal it. Retrofitting pipe insulation is a lot harder, and it usually doesn't make sense to pull apart walls to do it—unless you needed to get into those walls anyway.

Then there's the issue of wasting water as you're waiting for hot water—in a typical U.S. home, that can add up to as much as 10,000 gallons of water per year. The amount of water wasted depends on the pipe diameter and the distance between the water heater and the tap. There can be a five-fold difference in the wait time between 3/8-inch-diameter and 1-inch-diameter pipe. The smaller the pipe, the more quickly hot water reaches the tap and the less the water and energy waste. Larger-diameter pipe wastes additional energy, because more hot water remains in the pipe after the tap is turned off, and there is more pipe surface area for heat transfer to occur.

In new construction, different pipe diameters can be used for different fixtures and appliances (see "Home-

Improve System Efficiency

- **Fix plumbing leaks.** Even a modest drip from a hot-water faucet can waste thousands of gallons of hot water per year. Fix leaks right away.
- **Insulate the storage water heater.** Insulating a hot water tank can significantly reduce its standby heat loss. Insulating an electric water heater is easier than insulating a gas water heater, because venting of the electric model is not required. Separate tanks used for indirect water heating (in which a zone off a boiler used for space heating circulates through a heat exchanger in a separate tank) should also be well-insulated.
- **Insulate hot water pipes.** Water sitting in insulated hot water pipes between uses will not cool as quickly, so hot water use will be reduced some of the time.
- **Install heat traps.** Heat traps are one-way valves or piping loops that reduce the thermosiphoning of hot water within hot water delivery pipes. Some water heaters may incorporate heat traps; if not, the heat traps can be added at the time a water heater is installed.

An on-demand recirculation system (with small pump and control housed in a bathroom or kitchen sink cabinet) saves water, but not energy for water heating.

Run Plumbing Systems"), but in existing houses, there is usually no easy way to match pipe diameter to water flow requirements.

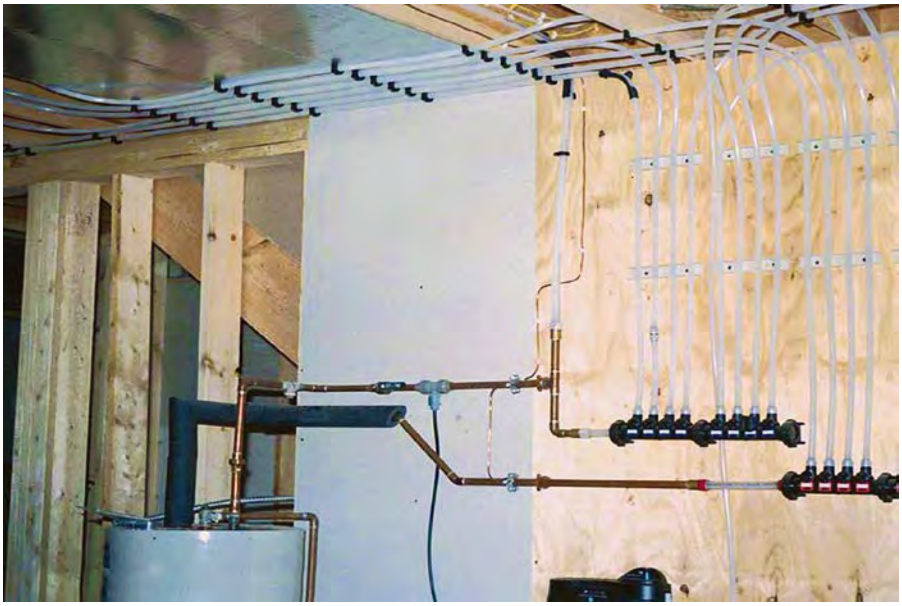
To eliminate the delay in hot water at a source, recirculation ("recirc") systems are sometimes installed. Hot-water piping is installed in a loop, and a small pump circulates hot water through these pipes so that hot water will be available almost instantly—even at fixtures farthest from the water heater. Even with pipe insulation, recirc systems use a lot of energy, both electricity to operate the pumps and heat lost from the pumps. Continuous-circulation systems should not be installed.

Instead, on-demand, button-controlled systems (see Access) that deliver hot water only when needed can be used. A small pump delivers hot water to the tap and cycles the cooled-off water standing in the hot water pipes back to the water heater. The homeowner gets hot water in the bathroom or kitchen very quickly via the small pump, and water is no longer wasted waiting for hot water to reach the user. This practice saves water, and can save energy depending on usage patterns (if homeowners forget that they've turned on the shower to wait for the hot water, for example).

Home-Run Plumbing Systems & PEX Tubing

Small-diameter, cross-linked polyethylene (PEX) tubing has gained popularity for water supply plumbing (cold and hot) in the past two decades and can provide significant water and energy savings. PEX tubing is most commonly used in "home-run" plumbing configurations, in which continuous lengths of tubing extend from a central manifold by the water heater to distributed fixtures and appliances—instead of using branching copper pipe systems with soldered joints. By having each PEX

This "home-run" plumbing system routes individual lines to their own fixture or appliance, reducing friction losses from elbows and fittings.



Reduce Demand

- **Install low-flow showerheads.** The Energy Policy Act of 1992 limits showerheads to 2.5 gpm at 80 psi water pressure. In areas with municipal water and reasonable water pressure, a quality 1.5 gpm showerhead will probably be adequate. In rural areas with well water and variable water pressure, some suggest that 2.0 gpm is required for a satisfactory shower, though I've used a 1.5 gpm model for years with great satisfaction.
- **Install water-efficient faucet aerators.** In residential bathrooms, install faucet aerators that deliver 0.5 to 1.0 gpm. For kitchens, a higher-flow faucet or retrofit aerator may be needed for filling pots. The legal limit is 2.5 gpm. "Laminar-flow" faucets, which produce a hollow "cylinder" of water, create the look and feel of a much fuller flow.
- **Install foot or knee controls for faucets.** This can save significant quantities of water (including hot water), along with adding convenience.
- **Install water-efficient clothes washers.** The best horizontal-axis washers use less than half as much water per cubic foot of capacity as standard vertical-axis washers. A few vertical-axis washers do nearly as well.
- **Install water-efficient dishwashers.** Water- and energy-efficient dishwashers use as little as 4.5 gallons of water per load. The Energy Factor (EF) of dishwashers is a fairly good indicator of water efficiency, since approximately 90% of the energy use of a dishwasher is for water heating.

line run to its own fixture or appliance, fittings and elbows are eliminated, thus reducing friction losses, and the tubing diameter is matched to the fixture or appliance. For example, 3/8-inch-diameter tubing may be used to bring hot water to a bathroom faucet, while 3/4-inch-diameter is used for a bathtub.

Drainline heat exchangers, such as this PowerPipe, capture heat from water going down the drain.

Courtesy RenewAbility Energy

Lowering the thermostat setting on your water heater can also provide some energy savings.

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By using smaller-diameter PEX tubing instead of copper, hot water is delivered more quickly, less water is wasted waiting for the hot water to reach the tap, and less energy is wasted as the hot water in the tubing cools. With a long history of use in radiant-floor heating systems, PEX tubing has proven itself to hold up very well.

Capturing Wastewater Heat

A huge amount of energy is wasted in hot water going down the drain. Even if hot water generation and distribution were 100% efficient, more than 90% of the energy in that water is still lost when it drains *out* of our showers, sinks, bathtubs, and clothes washers. "Drain water may be one of our largest untapped resources," says Cautley.

Fortunately, some of this energy can be recovered. There are several manufacturers of heat exchangers that have copper piping tightly coiled around a section of copper drainpipe. Water on its way to the water heater flows through the coiled pipe and is preheated when hot water flows through the drainpipe (beneath a shower, for example). These are sometimes called gravity film exchange (GFX) systems, reflecting the fact that hot water going down a drainpipe will form a film on the inner wall of the pipe, allowing heat to be transferred across the pipe wall. These heat-recovery units are made by at least four companies (see Access).

A properly installed GFX system capturing waste heat from showers should reduce overall water heating energy use by 12% to 15%, according to *Environmental Building News*. When installed during new construction, the cost typically runs between $500 and $800. These systems are most cost-effective where hot water consumption is very high—for example, laundromats, commercial kitchens, and health clubs.

Access

Alex Wilson is the founder of BuildingGreen in Brattleboro, Vermont, and executive editor of *Environmental Building News.* He recently founded the Resilient Design Institute (resilientdesign.org).

On-Demand Recirc Systems:
ACT D'mand • gothotwater.com
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General Electric's Geospring heat-pump water heater.

Efficient Water Heating Options

by Alex Wilson

In the world of ultra-low-energy homes, water heating is often the largest energy user. It's time to pay attention to this significant energy load.

Selecting a water heater involves decisions about the type of fuel used, how and where the water is heated (especially the issue of storage versus tankless water heaters), and whether water heating can be combined with space heating. Here's a review of the most efficient products on the market to suit your particular water-heating needs.

Storage Water Heaters

The vast majority of water heaters in North America are storage-type—an insulated tank with either an integrated gas burner, or one or two electric-resistance elements. The advantage of storage water heaters is that the water can be heated with a relatively small burner or heating element, while still providing ample hot water. Even when much of the hot water is used up, the tank remains stratified, with remaining hot water staying at the top where it is drawn off.

Recovery time depends on the capacity of the gas burner or electric elements. Hot water recovery is an important property of a storage water heater; it is generally presented as the "first-hour rating" in gallons. This is the amount of hot water that can be delivered by a water heater during one hour. With storage water heaters, this assumes the tank starts fully charged with hot water, so the first-hour rating is the volume of the tank, plus the volume of water that can be heated in an hour (assuming standard assumptions for temperature rise).

To calculate hot water demand for a family, you should figure out the peak usage period, then use rules for hot water use for those needs. The U.S. Department of Energy (DOE) assumes 10 gallons of hot water for a shower, 2 gallons for shaving, 4 gallons for hand dish-washing and food prep, 6 gallons for a dishwasher, and 7 gallons for a clothes washer. So for the morning period, one-hour water use might total three showers, one shave, and one hand dish-washing, for a total of 36 gallons. The first-hour rating would have to meet that.

Disadvantages of storage-type water heaters include the potential to run out of hot water and the standby heat loss from the large temperature difference between the outside and inside (often 60°F or more). Inexpensive storage water heaters may have just an inch of polyurethane insulation, providing as little as R-6. The best have R-12 to R-15 in foam insulation. With gas storage water heaters that have pilot lights, the pilot itself throws out a lot of heat (typically about 300 Btu/hour), which can contribute some heat to the tank, though most of the pilot light heat actually escapes up the central flue. Depending on water heater location in a building, the climate, and the time of year, standby losses may either reduce a building's heating load or increase its cooling load, though the impact of this is fairly modest.

There can also be losses from storage water heaters via the supply and discharge pipes. Storage water heaters should be installed with "heat traps" that prevent the thermosiphoning (natural circulation from hot water rising) that can occur if the water heater is located below a home's plumbing. Adequate pipe insulation should also be a part of water heater installation (see "Reduce Demand—Improve Efficiency" article in this issue).

Electric Storage Water Heaters

Electric resistance. Most electric water heaters rely on electric-resistance heating elements. The conversion of electric current into usable heat is extremely efficient—100%—though the true efficiency drops by about two-thirds when one considers energy generation and transmission by the utility. Water heater efficiencies are generally listed as the energy factor (EF). This is the ratio of the useful energy output of the water heater to the total amount of energy delivered to the water heater and it accounts for heat loss from the tank. The higher the EF, the more efficient the water heater. U.S. law requires a minimum EF of 0.90 for new electric storage-type water heaters. The minimum EF for electric storage water heaters today is volume-dependent, and ranges from about 0.86 for an 80-gallon model to about 0.92 for a 40-gallon model. The highest EFs today are about 0.94.

Electric-resistance water heaters become more economically attractive when off-peak electric rates are offered or if special utility smart meters can turn them off when the utility is operating at or near peak generation capacity—allowing a utility to operate fewer power plants. Because no vent is required for electric water heaters, they can be insulated extremely well, reducing standby heat loss to well below that of the best gas-fired water heaters.

Courtesy Kurt Koegel

Rheem's Marathon electric tank-type water heater has an EF of up to 0.94.

Courtesy Nyle Systems

A Geyser add-on heat pump for a tank-type water heater.

Heat pumps. To exceed an EF of 1.0 (100% efficient), heat-pump technology is required. Heat-pump water heaters are gaining popularity, and will get a boost from federal water heater standards that become effective on April 16, 2015. As of then, any electric water heater larger than 55 gallons has to be a heat-pump water heater. The federal standard for these larger water heaters is based on a formula that accounts for storage capacity, but an EF close to 2.0 will be required. For smaller water heaters, the EF requirement will increase somewhat, but will remain below 1.0—so can be achieved with electric-resistance models.

With heat pumps and heat-pump water heaters, the performance is often reported as the coefficient of performance (COP), which is similar to the EF, but not based on the same test standard. A COP of 2.4 means that for every kWh of electricity input, an average of 2.4 kWh of heat output in the hot water is attained—which is like being 240% efficient.

A heat pump uses electricity not to *produce* heat directly but rather to *move* heat from one place to another (using the same principle as a refrigerator). It extracts heat from the air and delivers that heat into the water tank—even though the water tank is at a higher temperature than the surrounding air. It does this by alternately condensing and evaporating a refrigerant; the electricity powers only the pumps and fans—though some models offer an option for more rapid recovery, in which case one or two electric-resistance elements may be included. The most efficient heat-pump water heaters have EF ratings as high as 2.5, and all exceed 2.0.

Because heat-pump water heaters cool the surrounding air as they extract heat from it, they can increase space-heating loads during the heating season. A recent utility-funded study of heat-pump water heaters in Massachusetts and Rhode Island found that a heat-pump water heater that delivers a COP of 2.35 with a room temperature of 68°F will drop to a COP of 1.8 at a 50°F room temperature. If the water heater is installed in an unheated or semi-conditioned space, such as a basement, garage, or attic, the impact on heating costs will be lower, but the heat pump performance may drop. Just as heat-pump water heaters rob heat from the house in winter, they provide free cooling and dehumidification in the summer.

These considerations can be very important. If you use baseboard electric heat during the heating season and the heat-pump water heater is in your heated space, you're "robbing from Peter to pay Paul," and your overall energy use (heat plus hot water) may be noticably affected. If the heat pump is in the basement and there's a lot of waste heat from an inefficient furnace, the impact on your heating costs may be insignificant. If you're in a southern climate and use air conditioning much of the year, the heat-pump water heater can remove a significant amount of ambient heat, reducing your cooling energy use.

Both stand-alone and add-on heat-pump water heaters are available. The former look much like conventional storage-type water heaters (though are usually taller, with the heat-pump on top), while the latter are boxes that sit next to or on top of conventional water heaters, with insulated pipe connections between the two and a pump to circulate water.

Unfortunately, heat-pump water heaters are expensive, and most products on the market are relatively new, without a long track record of performance. Early heat-pump water heaters, 10 or 20 years ago, often had reliability problems. Because they use fans to draw in air from the room, they can be noisy—typically louder than a refrigerator. Ask about noise when selecting a heat-pump water heater (noise ratings range from about 55 to 65 dB), and think about an out-of-the-way spot to install it.

Gas-Fired Storage Water Heaters

Natural gas and propane water heaters are very similar, varying only in the burner orifices, gas valves, and pilot lights. Both offer the potential for very high burner efficiencies. EFs are dependent on standby losses, which are higher compared to electric water heaters because of the uninsulated flue extending up the center of the tank. Most gas-fired water heaters have pilot lights, which reduce the EF somewhat; the highest-efficiency models have electronic burner ignition. Compared with electric water heaters, the EF ratings of gas-fired water heaters are lower: As with electric storage water heaters, the minimum EF is based on tank volume: about 0.52 for an 80-gallon model and about 0.59 for a 40-gallon model. However, natural gas prices are a lot lower than electricity prices (per unit of energy), so gas-fired water heaters usually cost less to operate than electric models. (Propane prices are typically a lot higher and vary significantly from place to place.)

The highest-efficiency gas water heaters use condensing technology. The heat exchangers in condensing water heaters extract so much heat that the water vapor in the flue gas cools and condenses. This condensation has an energy benefit (capturing that latent heat of vaporization of the water vapor), but it also means that condensing water heaters should not be vented into a masonry or metal chimney due to corrosion concerns. They are typically vented through a sidewall, with a drain for the condensate. Gas-fired condensing, storage-type water heaters have EFs as high as 0.86.

Oil-fired stand-alone water heaters are far less common than gas-fired, have lower efficiency, and tend to be more expensive. With so many better options available, these units do not make much economic sense.

American Water Heaters' high-efficiency, tank-type gas water heater.

Courtesy American Water Heaters

Tankless Water Heaters

The alternative to a storage water heater is to heat the water as it is used. That's the principle of a tankless water heater (aka instantaneous or demand). They can be located at the point of use (a bathroom or kitchen) or centrally, with distribution handled as with storage water heaters. Tankless water heaters can be gas or electric, though central tankless water heaters are usually gas-fired. Because hot water is not stored, the heating capacity must be great enough to meet all of the hot water demand.

Gas Tankless

The amount of hot water that a relatively small (115,000 to 125,000 Btu per hour) gas-fired tankless water heater can provide depends on the temperature rise, which can range from about 35°F to more than 90°F, depending on the incoming water temperature and the water heater setting. At a typical temperature rise, such a model may provide about 2.5 gallons per minute (gpm). That's usually enough hot water for a small house with water-efficient fixtures and appliances—*if* the homeowners are willing to avoid operating multiple hot-water-consuming devices at the same time. To serve multiple devices simultaneously or to fill a bathtub quickly, a larger tankless water heater (for example, 180,000 Btu per hour) is required.

Even a fairly small gas-fired tankless water heater takes a lot of combustion air. A 125,000 Btu per hour model operated

Courtesy Rinnai

A Rinnai tankless gas water heater.

at full capacity consumes about 2 cubic feet per minute (cfm) of natural gas and 30 cfm of air. An 180,000 Btu per hour tankless water heater requires up to 45 cfm of air. Such large airflow requirements can limit the options for placement—and produce significant noise from the fan. To simplify air supply, some tankless water heaters are designed for outdoor installation and include built-in freeze protection.

Older gas-fired tankless water heaters all had pilot lights. While the heat from a pilot light in a storage water heater may help to replace standby heat loss from the tank, that can't occur in a tankless water heater. The pilot light energy is simply lost, dropping the EF by 0.10 to 0.12 points. Fortunately, most manufacturers offer tankless water heaters with electronic ignition. These products have EFs between 0.78 and 0.85; a few condensing models have EFs as high as 0.98.

Along with considering the maximum hot water flow from a tankless water heater, also pay attention to the minimum flow rate. Many models won't start if the flow is less than 0.5 to 0.6 gpm—which a low-flow bathroom faucet (and even some dishwashers) may not reach. Varying flow rates can also sometimes produce "cold water sandwich" problems, in which a hot shower is suddenly interrupted with a spurt of cold water.

Another consideration with tankless water heaters is whether the output temperature is thermostatically controlled. Some models are designed to raise the water temperature by a set amount. These "delta-T" models generally work fine with municipal or well water (though some seasonal adjustment in the temperature increase may be required). Such models are not appropriate as backup heat for solar water heaters, however, because the solar-preheated water temperature may vary considerably. More sophisticated tankless water heaters provide output at a set temperature, no matter the input temperature—but they also cost more.

Electric Tankless

With electric tankless water heaters, the power required to provide even a modest hot water flow is significant. One 28 kW model, for example, provides a maximum flow rate of 3.0 gpm at temperature rise of 63°F—and draws 116 amps at 240 volts to do so! (Most homes have 200-amp service; some only have 100 A.) Providing that much power requires very large (and expensive) breakers and large-diameter wire or space in the service panel for several smaller circuit breakers (for example, four 30 A two-pole breakers). Utility companies are rightly concerned about these units, since hot water draws coincide with peak electric demand, in the morning and early evening. In this respect, a tank water heater is better, because it can heat water off-peak for use during on-peak times.

Another significant downside to tankless water heaters in some locations is scale buildup. If your water is mineral-rich, manufacturers recommend periodically flushing the heat exchanger coils with vinegar or another descaling fluid. This can increase installation cost if a special drain has to be plumbed in. If this maintenance isn't carried out, the scaling can significantly shorten the water heater's life.

Always follow manufacturer recommendations on water testing, installation, and maintenance to ensure a long life for your tankless heater. The bottom line is that electric-tankless water heaters do not make sense in most whole-house applications. However, in applications where small models can be installed at a point of use, doing so may be a reasonable option.

Stiebel Eltron's Tempra whole-house electric tankless water heater, with three heaters.

Courtesy Stiebel Eltron

"Hybrid" Water Heaters

A relatively new type of water heater includes features of both storage and tankless models. These gas-fired models have small buffer tanks that eliminate the cold-water sandwich problem and deliver hot water even at very low flow. (Note that "hybrid" is also often used to describe heat-pump water heaters, which are quite different.) There are at least three manufacturers of hybrid water heaters: Grand Hall, which produces the Eternal Hybrid water heater; A.O. Smith, which produces the NEXT Hybrid water heater; and Navien, with its CR-240A. Hybrids use condensing technology to achieve very high efficiencies (greater than 90%) and high flow rates that should satisfy almost any residential situation.

Drawbacks include high cost and standby heat loss—which is the most common reason to choose a tankless model in the first place. These units have small tanks with little or no insulation. In a recent study of tankless water heaters in Minnesota, the Navien hybrid model performed abysmally, which was attributed to the uninsulated buffer tank.

Indirect Water Heaters

Indirect water heaters generally operate as one zone of a boiler system that is used for space heating. They have an insulated tank and a heat exchanger to transfer heat from the boiler into the stored water. Because combustion does not occur at the storage tank, the tank can be better insulated than a conventional gas- or oil-fired storage water heater.

An indirect water heater is usually preferable to a tankless coil (a common feature in gas- and oil-fired boilers) because heat from the boiler is not called for every time hot water is drawn. A tankless coil installed in a boiler functions much as a tankless water heater, with the boiler having to fire every time hot water is needed. The difference is that the boiler has a lot more mass than a tankless water heater, so there is significantly more energy used to heat it up and it takes longer to cool down. Tankless coils in boilers can make sense during the winter in cold climates, when the boiler is hot much of the time, but they are not usually recommended for year-round use.

Coupled with a high-efficiency boiler, indirect water heating is often one of the most cost-effective water heating options. There are some inherent efficiency losses from the heat exchanger, and electricity is required for pumping, but this can still be a very efficient system. It can also be adapted to SHW preheating.

Courtesy A.O. Smith

A. O. Smith's hybrid water heater.

The SuperStor Contender Indirect Water Heater draws energy from a boiler. Hot boiler water flows through an internal heat exchanger in the tank, heating the domestic water.

Courtesy Heat Transfer Products

Combination Space & Water Heating

A step beyond indirect water heaters are integrated space- and water-heating appliances. Several approaches can be taken with these "combo" systems. There are a number of high-efficiency boilers with integrated storage tanks—quite different from the tankless coil systems that can be added to standard boilers, but some such products have disappeared.

While there is a lot of appeal to a space-saving system that serves multiple functions, combined systems are more complex. If one component fails, you may lose both heat and hot water until it is fixed.

A less expensive approach for compact, energy-efficient homes is to use a water heater both for water heating and for space heating through a fan coil—a hydronic coil installed in the air handler that distributes conditioned air throughout the house. Different types of water heaters can be used for this application, but it will take some careful engineering—or experience—by the heating contractor to be sure that hot enough water is produced and that the hot water for domestic uses is tempered so that it isn't dangerously hot (see "Renewable Hydronic Heating" in this issue).

Courtesy American Water Heaters

American Water Heaters' Polaris combination water heater.

Solar & Wood-Fueled Water Heaters

Solar can be a fuel-free water-heating option. A properly sized solar hot water (SHW) system can provide most or all hot water requirements for a family during the summer months and a reasonable portion during the winter. There are several types of solar water heaters, including pumped flat-plate and evacuated-tube collector systems, thermosiphoning flat-plate collector systems, and integrated-collector-storage or "batch" systems.

Because there is a lot more sunlight during the summer months than the winter months, solar water heating can be a good companion to an indirect or tankless-coil water heater that works with a boiler used for space heating (see below).

In more rural areas, solar heating can also be a good companion to a wood stove or wood furnace with an integrated heat exchanger for water heating. In southern Vermont, for example, some houses use solar-thermal and wood-heat water heating very effectively (see photos below); there's plenty of sun for 100% of their hot water needs during the summer, and the wood heaters are used enough in the winter to keep the hot water tank fully charged—with thermosiphoning of hot water into the tank located above the wood stove.

Courtesy Alex Wilson (2)

Purchase Considerations

Water heating is lot like space heating, cooling, or even electrical energy production—it makes sense to focus first on reducing demand. With water heating, we can do this by installing water-conserving plumbing fixtures and appliances. Next, we should look at how hot water is distributed and try to improve efficiency there (see "Reduce Demand—Improve Efficiency" in this issue). Then we can optimize the system's efficiency by choosing the most appropriate heating source.

With natural gas prices as low as they are, it's hard to compete with the economics of simple gas-fired water heaters today. The most environmentally attractive options are solar thermal or electric water heating, powered by a PV system. Beyond that, the options can become quite complex and dependent on other factors, such as climate, the type of space heating system, and usage patterns. If you are in a cold climate and have hydronic heat with a high-efficiency boiler, an indirect water heater may be the best bet. If off-peak electric rates are available, a simple, inexpensive electric-resistance water heater can be an attractive option, especially since the tank can be well-insulated.

In other situations, a high-efficiency tankless water heater with electronic ignition, an integrated space-and-water-heating system with a condensing boiler, a heat-pump water heater, or a gas water heater with electronic ignition and condensing technology may be the best choice. All of these options are more expensive than a basic storage water heater, so the life-cycle costs should be considered.

With whatever type of water heater is selected, make sure it is installed properly. Hire an experienced installer, and ask for references if you are not familiar with the company. Proper installation involves safely venting flue gases with gas-fired water heaters, making sure there's plenty of insulation on a storage-type water heater (adding more than came with the water heater may make sense), installing "heat traps" on the supply and discharge piping where it leaves the water heater to prevent thermosiphoning, and insulating all hot water pipes.

Access

Alex Wilson (alex@buildinggreen.com) is the founder of BuildingGreen, in Brattleboro, Vermont, and executive editor of *Environmental Building News*. He also recently founded the Resilient Design Institute (resilientdesign.org).

Photovoltaic Hot Water

A renewable water-heating option that is becoming more common is to heat water using electricity from a grid-tied photovoltaic (PV) system. As the cost of PV modules has dropped in recent years and heat-pump water heaters have improved in performance, this strategy has become more economical and efficient. Some people even use PV electricity with well-insulated electric-resistance storage-type water heaters.

PV water heating eliminates pumps, pipes vulnerable to freezing, and the risk of collector stagnation. PV systems have no moving parts, so there is little to break down or require maintenance, and the same PV system can satisfy a wide range of other needs. Plus, under a net-metering agreement with a grid-tied PV system, any surplus electricity is credited to your bill. With a standard solar water-heating system, once the water in the storage tank is up to temperature, the system shuts down and any "excess" heat has to have a means of being dissipated.

PASSIVHAUS in Chapel Hill

by Stephen Hren

Stephen Hren

The traditional bungalow architecture of this home in Chapel Hill, North Carolina, belies its incredible energy efficiency and adherence to the strict principles of Passivhaus design.

Homebuilder Chris Senior wants to leave a legacy by creating homes of beauty and super-efficiency that will last for centuries. He's steering his company, Anchorage Building, toward specializing in homes that meet Passivhaus energy-efficiency requirements and use about one-tenth of the heating and cooling energy of conventionally built U.S. homes.

Passivhaus is a construction standard that focuses on minimizing heat loss with an incredibly tight building envelope and insulation levels several times greater than conventional construction. While its German name translates to "passive house," Passivhaus-designed homes go far beyond passive solar, with the result that conventional heating and cooling equipment is unnecessary in most circumstances—even in frigid climates.

A tight building envelope has two additional advantages over previous passive solar designs. It allows useful heat gain from smaller, "passive" sources of energy like human bodies (equivalent to about a 100-watt incandescent bulb) and cooking, and also helps keep buildings cool in summer with minimal effort.

Like a conventional passive solar home, many of the windows in a Passivhaus are still south-facing, but they are fewer in number than previous passive solar incarnations, and are of highly insulating (R-7 or greater) triple-pane construction. Many Passivhaus homes, especially in Europe, are also multi-unit; reducing the number of exterior walls further reduces heat loss.

The Details Make the Difference

In 2011, Chris and Leigh Ann Senior built the second Passivhaus home in North Carolina. Designed by architect Jay Fulkerson and located on a picturesque lake in Chapel Hill, it is the couple's primary residence and was built after completing the first one for a client just a few miles away.

The walls of Chris and Leigh Ann's 2,155-square-foot home are built of 2-inch-thick concrete, which helps regulate interior temperatures. Five-inch-thick concrete vertical ribs provide additional structural support. This high-psi concrete is waterproof and has a lifespan of hundreds, if not thousands, of years, which helps justify its high embodied energy. Eight and a half inches of rigid foam insulation provide an insulation value of R-32. The inside of the wall has conventional 2-by-4 wood framing with 1/2 inch of air space between it and the concrete structural wall. The interior stud walls are attached to the floor and ceiling with metal plates but otherwise float free of the concrete structural wall.

The home's open floor plan allows for easy distribution of heating and cooling without ductwork.

The 15-inch-thick walls have an insulation value of R-42.

Stephen Hren (2)

Plumbing and electrical were run through these interior walls, which were then filled with dense-pack, blown-in cellulose insulation for an additional R-10. This gives the walls a total of R-42—the Passivhaus standard for this climate. The resultant 15-inch-thick walls give the home a fortlike feel and buffer sound transmission from outside.

The majority of the windows (100 square feet of glazing) are clustered on the home's south side to optimize solar heat gain. Chris and Leigh Ann chose Thermo-Tech triple-pane, argon-filled windows with a solar heat gain coefficient of at least 0.5 and a U-factor of about 0.15.

While insulating the walls and floor was fairly straightforward, super-insulating the roof proved to be challenging. Although somewhat distrustful of the long-term stability of oriented-strand board (OSB), using wooden I-joists (made, in part, of OSB) gave the 14-inch depth necessary for insulating to Passivhaus standards. Since wood is a fairly good conductor (relative to insulation), reducing the width of the roof rafters to 1/2 inch from a conventional framing lumber dimension of 1 1/2 inches greatly reduces thermal bridging.

Courtesy Anchorage Building

The floating framed walls inside the concrete shell help minimize thermal bridging and heat transfer, and provide wall space for running plumbing and electrical.

Three-quarter-inch CDX plywood was used to sheath the roof, and a self-adhering membrane applied over the sheathing provides a water- and air-tight seal around every nail or screw used to attach the roofing material to the sheathing. A layer of 2-inch-thick open-cell icynene insulation applied to the underside of the roof sheathing helps complete the air seal. Two-by-fours span the underside of the I-joists, to which drywall was attached, and the remaining $13^1/2$-inch space was filled with blown-in cellulose for an R-value of 62.

Pairing Comfort & Efficiency

The home's passive solar design, plus superior insulation and airtightness, reduce the reliance on mechanical heating systems. Heat from passive solar gain and a Fujitsu ductless heat pump is distributed via airflow through a heat recovery ventilator (HRV). The HRV passes stale indoor air through a heat exchanger, which transfers about 75% of the heat to fresh, incoming air. Although an airtight home is highly energy efficient, an HRV is necessary to ensure good indoor air quality. The 200-cubic-foot-per-minute HRV eliminates the need for bathroom vents, since the HRV also eliminates excess moisture from the home with the rest of the indoor air.

Passivhaus— Past & Present

German physicist Wolfgang Feist is credited as the originator of the Passivhaus concept, having completed his first Passivhaus prototype in 1991. Later in the decade, he received a grant for the completion of a comprehensive five-year survey of existing super-insulated buildings across Europe. This survey became the inspiration for creating a set of achievable standards for building insulation, with the potential for vastly reduced energy use.

During the last two decades, tight, super-insulated windows—pioneered mostly by German manufacturers—with greatly reduced radiant heat loss have made possible building envelope tightness that fits the strict Passivhaus standards. Triple-pane sashes, reductions in thermal bridging through the frames, and low-e coatings have resulted in windows that offer insulation values up to R-10.

Passivhaus came to North America when, in 2003, architect Katrin Klingenberg designed and built a private residence in Urbana, Illinois, to Passivhaus criteria. Klingenberg later founded the Passive House Institute U.S. (PHIUS) to promote the concept in North America. Ironically, she never had her first few projects formally certified to Passivhaus standards. The honor of the first certified Passivhaus building built in the United States belongs to the Waldsee Biohaus, a German language school in Bemidji, Minnesota.

In little more than a decade, Passivhaus has blossomed into a full-grown movement in Europe, with more than 20,000 residences completed (mostly in Germany and Austria) and many more in the works. In the United States, there are an estimated 75 completed structures (not all yet certified), with about 100 more in various stages of planning and building. Unlike the more intimidating LEED standards, builders find Passivhaus' clear and simple guidelines easy to follow—and with integration with the existing HERS rating system, straightforward to certify.

One criticism of Passivhaus has been that most of the insulations used to achieve a high-performance envelope are fossil-fuel-based. Advocates counter that it is better to use fossil fuels once (in a product's manufacture) to create extremely low-energy buildings rather than use them every day in inefficient housing. Innovative builders are using recycled cellulose insulation, along with foam-based ones, to create a tight, superinsulated home while minimizing the use of fossil-fuel-based products.

Stained and polished 4-inch-thick concrete floors provide thermal mass to moderate temperature swings and store heat from the sun.

The Seniors enjoy the sunny deck on the south side of the house.

Stephen Hren (2)

To maximize the home's efficiency and minimize its energy use, energy-efficient appliances—like an Electrolux electric induction range, a Bosch Axxis front-loading clothes washer, and LED track lighting—are used. Chris and Leigh Ann also prewired their home for a future PV system.

Meeting the Standard

There have been a plethora of green building standards over the past two decades, and rightfully so—buildings are a major energy user and contributor to global climate change. In the United States, 76% of all electricity is used for heating, cooling, appliances, and lighting. Among standards set by the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) certification, Living Building Challenge, and the 2,000-Watt Society, Passivhaus standards stand apart in their simplicity and adaptability to individual climates to achieve the same energy-use goals regardless of location. This adaptability is similar to how today's building codes function—and Passivhaus standards are probably the easiest of the green standards to transfer to our existing code-enforcement mechanism. Unlike LEED certification (and other holistic strategies, like the Living Building Challenge), Passivhaus focuses only on energy use. Renewable energy or sustainable material use is not brought into the equation, as it is for LEED and other certification programs. This single-minded purpose generally results in a 90% reduction in typical heating and cooling use and a 70% reduction in overall energy use compared to homes built according to today's conventional standards. Even compared to the standard LEED-certified building, the overall reduction is still about 30%.

It's hard to say that we should have just one green building standard or another, because of so many new and innovative building materials, the acceptance of grid-tied PV systems, and a broader understanding of how a building functions as part of the living landscape. Fortunately, the PHIUS understands that trying to become established in opposition to the existing green building standards is counterproductive—they are trying to make it simpler to integrate Passivhaus certification with the existing Home Energy Rating System (HERS) Index.

Triple-pane, argon-filled windows take up about 100 square feet of the south-facing wall.

Stephen Hren (3)

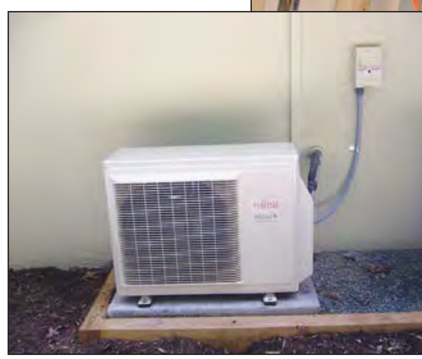
Insulating roofs to Passivhaus standards can be challenging because of the high R-values required and the amount of space this takes. In this home, a 10-inch strip of 1.5-inch-thick foam board, which has been carefully incorporated into the trim pattern, beefs up R-values under the eaves.

HERS rates a home or building's energy efficiency—a typical resale home scores 130 on the index; a conventional new home usually scores 100. A negative score implies that a home produces more energy than it consumes—a concept that may be met with some skepticism by green building professionals, since this number does not account for a home's embodied energy—energy used to extract materials, produce products, and transport them to the building site. While the Seniors' home does not have a HERS Index score, its blower door test resulted in 0.51 ACH at 50 pascals of pressure, or about one air exchange every two hours. For comparison, an Energy Star home based on the EPA guidelines will have a typical value of 3.5 ACH at 50 pascals—that's one-seventh as air-tight as the Seniors' home. Since HERS raters are now common in most parts of the country, this may help make the Passivhaus certification accessible to all potential builders.

To qualify as a Passivhaus, buildings must have a tight building shell that allows no more than 0.6 air exchanges per hour at 50 pascals of air pressure. The heating load must be less than 4.75 kBtu per square foot per year (1.4 kWh/ft.^{2}/yr.), and primary energy must be less than 38.1 kBtu per square foot per year (11.1 kWh/ft.^{2}/yr.). Primary energy refers to *all* energy used for space and water heating, appliances, lighting, fans, pumps, etc. Different sources of energy have a different multiplier for their primary energy score. For example, purchased electricity has a high multiplier of 2.7 (each kWh of electricity consumed is multiplied by 2.7) to include generation and transmission losses; natural gas has a multiplier of 1.1; and grid-tied PV systems have a multiplier of 0.7. The last two requirements are verified by reviewing heating, gas, and other utility bills.

While the Seniors' home is still in the process of becoming certified (a process that takes at least a year, since an entire cycle of heating and cooling, as well as overall energy use, must be analyzed), the house already has met the rigorous building standards. A backlog of applications appears to be slowing the process as PHIUS accommodates growing interest and incorporates the HERS rating system into its standards. These growing pains can only be a good thing as super-efficient building becomes a bona fide movement here in the United States.

Courtesy Anchorage Building



Stephen Hren

Above: An air-to-air heat exchanger exhausts stale air and brings in fresh air, but keeps about 75% of the heat while doing so.

Left: The air-source heat pump delivers heat to the living room.

Access

Stephen Hren (stephenhren@gmail.com) is a builder and writer living in Durham, North Carolina. He is the author of *Tales from the Sustainable Underground: A Wild Journey with People Who Care More About the Planet Than the Law* (see www.earthonaut.net).

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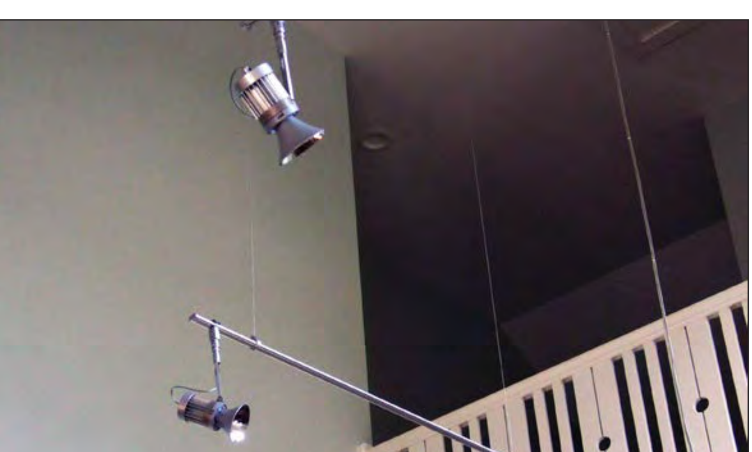
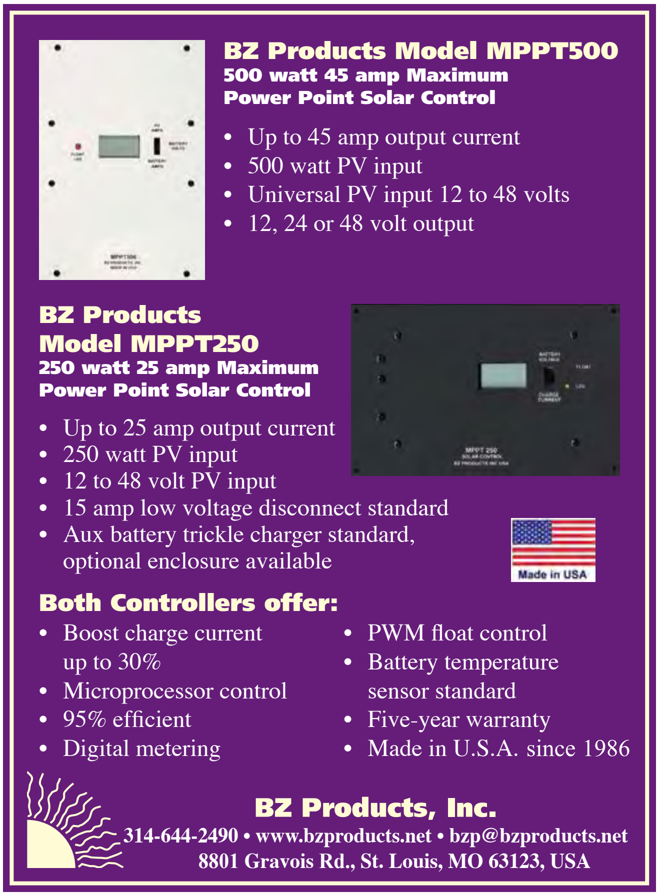


Stephen Hren (2)

Left: The high-efficiency LED track lighting system provides significant energy savings compared to conventional incandescent bulbs.

Right: Super-efficient appliances save money, energy, and water.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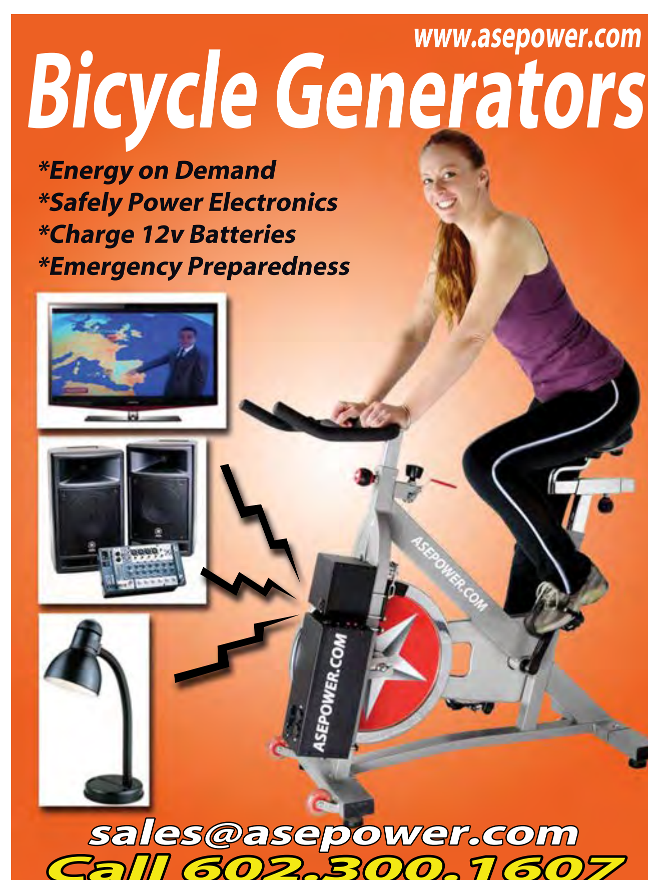
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DIY Electric Tractor

The newly converted tractor earns its keep by hauling a load of firewood.

Story & photos by Ted Dillard

This project uses lead-acid batteries harvested from other equipment; basic safety systems; and a permanent-magnet DC motor specifically designed for light EVs. Inexpensive "donor" lawn tractors are easy to find in the classifieds or at local junkyards. The technology for this project is proven and readily accessible, since it comes from the golf-cart, mobility scooter, and forklift industries. It can be a "just-for-fun" project for riding around the backyard, or a powerful addition to your garden tool stable. And, down the road, the skills and tools you've acquired in this project can be useful in converting other small vehicles.

Roadside Specials

About 1.7 million lawn tractors are sold in the United States every year. With a typical lifespan of seven years, that means about 10,000,000 are in service today, with 1.7 million going to the scrap pile every year—figures supported in studies by the Outdoor Power Equipment Institute. You can find a used (running) tractor for less than $100 and tractors with dead engines may be free for the hauling. New electric lawn tractors can be expensive—reclaiming dead or dying equipment can give you a more inexpensive tool that you can't find in the retail market.

The Basic System

The fundamental parts of any EV are the batteries, motor, and controls. Secondary parts include an on/off switch, speed control, safety systems, and the mechanical attachments and brackets. Finally, you will need a charging system for the batteries.

This project initially used four 12-volt sealed lead-acid (SLA) mobility-scooter/wheelchair batteries that were left over from another project. At 22 Ah and 48 V, they make a pretty small battery pack, but they're handy and will give us real-world testing ability so we can figure out the battery capacity we really need. Used 12 V flooded lead-acid batteries are also an option—they're inexpensive and readily available.

The "beta" motor, which we'll use as a test motor, is a Briggs & Stratton 48 V, 10 kW ETEK. It's small, lightweight, and fairly powerful. Another motor, the Motenergy ME1004, is designed specifically for an electric lawn-tractor conversion. It has a heavy-duty brush design and a 1-inch output shaft to accommodate the stacked pulley that drives both the tractor and the mower deck. It's also rated at 48 V, but can provide more power and torque. If we can demonstrate that the tractor is worth the investment with our beta motor, the ME1004 will be a worthy replacement.

Since most mowers of this type are run at full-throttle most of the time, and the tractor already has a transmission, clutch, and brakes, you can skip spending a few hundred dollars on a DC motor speed controller or a throttle. We're simply going to turn the motor fully on and off, and manage the rpm with battery pack voltage. Forty-eight volts should provide about 3,000 rpm on either motor, which is pretty close to what a gas engine will produce at full throttle.

Some safety mechanisms for the on/off switching are necessary. Almost every EV has a contactor or large electromagnetic relay that uses a small amount of current to control the full power of the battery pack. A fuse is required that can accommodate the motor's 100 to 200 A draw. These parts are available from golf-cart/forklift parts companies or EV conversion suppliers.

The original donor tractor.

TRACTOR PROJECT COSTS

Item	Cost
Electric motor, Motenergy ME1004, 48 V	$550
Batteries, used	140
Donor lawn tractor	100
Contactor	85
Misc. electrical	70
Charger, 48 V	35
Misc. hardware	20
Stacked pulley, used	20
Sale of gas engine (for parts)	-50
Total	$970

Simple gauges, found through golf-cart part suppliers, will indicate battery state-of-charge (SOC). Since the tractor spends most of its life sitting idle, a large, fast, and expensive charging system isn't needed. Although you can charge the batteries individually with an automotive 12 V charger, a low-current charger that matches the voltage of your pack is a smart purchase. Thirty-six and 48 V systems are very common, and a simple 2 A charger costs less than $50. It may take as many as six hours to fully charge the batteries (depending on the battery capacity), but that can be done overnight. You might also use a small PV array and charge controller to recharge the batteries on the tractor's days off.

Clockwise from top: Power switch, SOC meter, main contactor, and 2-amp charger.

STEP BY STEP

1. REMOVE THE GASOLINE ENGINE

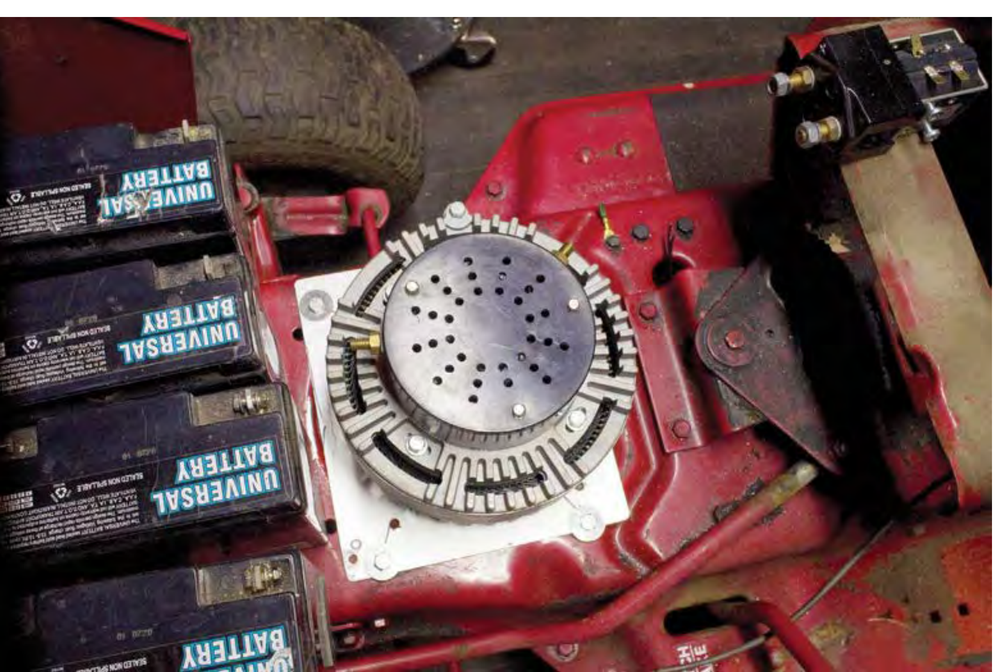
Remove all gasoline-related parts—the motor, control cables, wiring, and fuel tank. Keep what you can in serviceable condition—you may be able to sell the parts. Save the drive mechanism—whatever is attached to the output shaft of the motor (including the pulley).

Before (near right) and after (top right) the engine removal and cleanup. Note the new holes drilled for the motor adapter plate.

2. CLEAN THE TRACTOR

Your EV will operate without making a greasy mess, so take the opportunity to clean everything now. It's up to you if you want to spend time repainting or finishing the old tractor, but getting it clean makes working on it more pleasant.

Before installing the final motor and batteries, test the possible configurations to see which ones work best for your tractor.



3. LAY OUT THE PARTS

Check out the space that's available and try laying out your parts in the chassis. The belt drive requires mounting the motor in the same spot as the gas engine. Finding the best placement for your batteries and controls can take some experimentation.

4. MOUNT THE MOTOR & BATTERIES

Mounting the motor requires drilling a 1/4-inch-thick aluminum plate with a center hole for the output shaft, four holes for the motor, and four holes that line up with the existing holes in the chassis. This doesn't have to be precise or pretty—you can use scrap plate if you have it. Use bolts with washers and lock washers to secure the motor.

A new V-belt drive pulley, similar to the original, will be used. Be sure to match it to the shaft diameter of the electric motor. Since we're running a motor that will develop roughly the same rpm as the gas engine, using the same diameter pulley will keep speeds about the same as original.

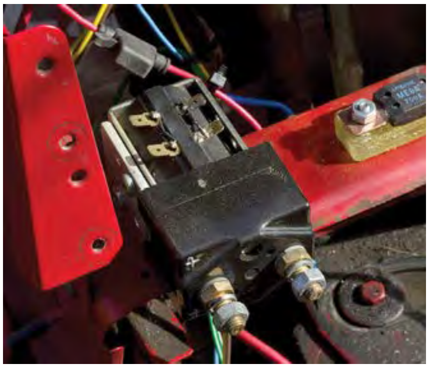
The four sealed lead-acid batteries fit inside a plastic battery tray that was purchased at an auto parts store, and it happened to slide right into a space at the front of the chassis. If you're not so lucky, it may take some effort to figure out the battery placement, especially if the batteries are larger or more numerous. Regardless of where they are placed:

- Mount the batteries securely. It's vital that they do not shift and tip, especially if they're flooded batteries. Many DIYers will build robust battery boxes or racks made from angle iron or aluminum sheet.
- Isolate the battery compartment, if possible. Plastic battery boxes are ideal, both as electrical insulators and to contain electrolyte spills.
- When making electrical connections or just placing the batteries in the chassis, keep in mind that you're dealing with potentially lethal current. Use insulated tools (or insulate yours by wrapping them with electrical tape), and double-check every effort. If you have any doubts about making a connection, check it with a voltmeter first to verify that you're about to do what you think you're about to do. We call unintentional arcing "plasma events," and they're dangerous.

The motor and batteries are placed and preliminary connections made.

The voltmeter, power switch, and charger input receptacle—all conveniently mounted on the dashboard.

The fuse and contactor are mounted behind the dashboard on a cross-brace.



5. MOUNT THE CONTROLS

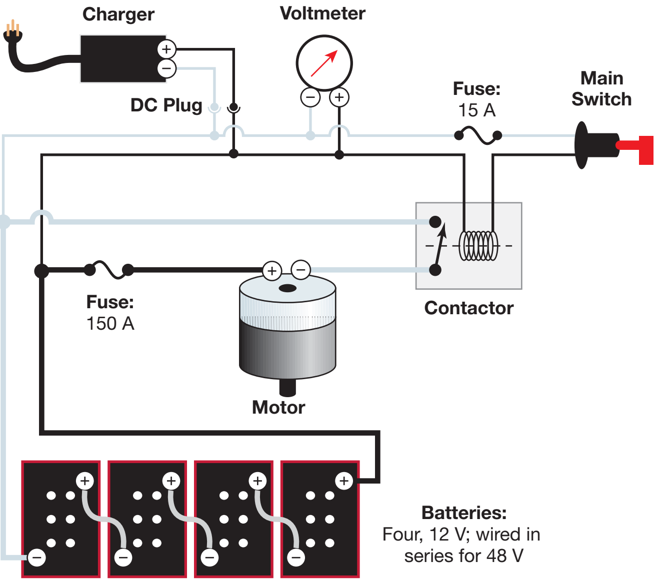
We opted for simple, yet safe and serviceable, controls. Don't put the controls together in a haphazard way, since they are handling large amounts of current. Mount them safely and securely, and tape or put heat-shrink tubing on exposed conductors. You can take care of the cosmetic details like faceplates and labels later.

6. MAKE THE ELECTRICAL CONNECTIONS

Once again, lay out your parts and wiring before making the connections. Keep your basic wiring diagram at hand to avoid mistakes from lapses of attention or simple circuit errors.

It's helpful if the diagram's components are roughly in the same relative location as on the tractor. This makes it a lot easier to visually plan and check your configuration, and avoid errors (and plasma events). Again, test connections with a voltmeter if you have any doubts.

We used 4 AWG welding cable with crimped lugs, which are available from most welding suppliers, and insulated the lugs with heat-shrink tubing. Though there's some debate over the advantages of soldered, crimped, or solder-and-crimp connections, any of the three methods will work well when done correctly. Pre-made cables are available from renewable energy retailers and some auto supply sources.



7. THE FRANKENSTEIN RUN

The "Frankenstein run" refers to the point at which everything is safely wired and ready to run, but a lot of the details are not complete. Besides being a thrill to see your creation take life, it's also helpful for sorting out problems. It saves a lot of time if you can test before worrying about all the extraneous details. Before flipping the "on" switch, make sure that the vehicle is safe for a short test run—that batteries are secure, connections are insulated, and there are no loose wires or bolts.

The converted tractor with the upgraded motor and mower deck, operated by the author's son, Tyler Dillard.

8. FINAL CLEANUP & LAYOUT

Once you can see how the tractor's working, go through each part of the system and double-check everything—mounting hardware, connections, insulation, tie-downs, and the rest. It's possible to have moved through the main steps, leaving the details for later and then to have forgotten about them. Give all your connections one last check. A loose connection will arc, heat, and ultimately burn once you give it a load.

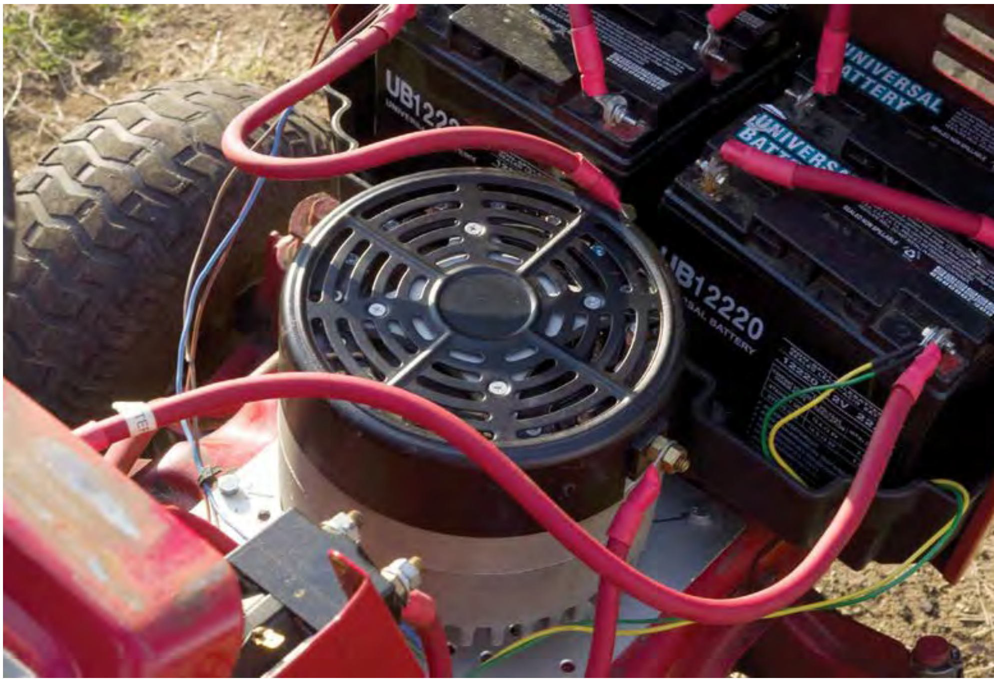
9. GOING TO WORK

Next, see what your EV tractor can do. We had a quarter-cord of oak sitting on the wrong side of the property, so we charged the batteries, mounted a ball to the trailer hitch, and hooked up the trailer. With the tractor's transmission in low gear, we pulled the trailer from the low, back section of the property around to the front, up a slight grade, and around

GASOLINE VS. ELECTRIC MOTOR POWER

This tractor's permanent-magnet DC motor is rated for continuous use—that is, working indefinitely without overheating. The ME1004 is rated at 8 kW, which converts to about 11 hp, which is also the original 400 cc gasoline engine's rating. Add that the gas engine delivers its power over a narrow rpm band, compared to the broader rpm power delivery of the electric motor, and there will be adequate horsepower for the task.

Above: The new Motenergy ME1004 with the stacked pulley in place.



Right: The updated tractor, with the Motenergy motor and mower deck, awaiting its new batteries.

to the wood pile with nary a hiccup. Often a motor will heat up under strain like that, but even our "beta" motor was cool to the touch. The batteries had plenty of juice and the test was a resounding success. Later, we took the tractor to the neighbors'—about a quarter-mile away—in fourth gear with nothing in tow, and got back with just enough energy to pull up to the charger.

The Continuing Project

From the testing, it was clear the tractor will be a productive tool around the grounds. We decided an investment in the purpose-built Motenergy would be worthwhile. The 48 V, permanent-magnet DC motor with a 1-inch shaft will have enough power for the stacked pulley that also drives the mower deck. However, the bigger motor will work well within its load range and will heat up less, and will be more efficient.

Switching the two motors was a matter of unbolting the first one and using the same mounting plate for the new motor. Both motors have a standard NEMA C bolt pattern, so the holes matched up perfectly—and the cable attachment was also a match. Then all we needed to do was remount the mower deck.

This is a great example of building a balanced system. When the tractor had the small motor, small batteries, and a relatively light load, it provided good power and range. Once we increased the motor size, we could add more load, like the mower deck. However, the batteries were not up to the task. Monitoring how much "mowing range" the original batteries provided gave us an understanding for how we'd need to upgrade. The smaller batteries let us mow just barely a quarter-acre, if they had a full charge and we were careful not to waste energy. Increasing the battery capacity to four quality small, flooded lead-acid automotive batteries in the 40 to 60 Ah range was necessary to get an acceptable mowing range of our quarter-acre lawn, with a little extra for insurance. A nearby salvage yard sells used batteries for $35 each. Even better would be to use 12 V deep-cycle batteries, similar to those intended for golf carts.

What will come after that? Adding function is simply a matter of adding another motor, so there are many options: a power take-off, hydraulics, etc. For now, though, it looks like the resident teenager has a lawn to mow!

Access

Ted Dillard (ted@evmc2.com) has been an avid gardener since childhood and is an evangelist for all things electric. He writes *The Electric Chronicles* (devoted to two-wheeled electric vehicles), and is the author of *...from Fossils to Flux*, a basic guide to building an electric motorcycle. When he's not in his garden or in his shop working on his next electric project, he can be found at evmc2.com.

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17. I certify that the statements made by me above are true and complete. Scott M. Russell, Operations Director, 9/27/12.

Grounding & Bonding PV Systems

by Ryan Mayfield

Courtesy Kris Sutton

Traditionally, individual modules were grounded with a continuous copper wire.

The equipment grounding section of the *NEC*'s Article 690 begins with references to Article 250 and the general requirements set there. Part VI of Article 250, Equipment Grounding and Equipment Grounding Conductors, outlines the general requirements, which are discussed here as well as the specific requirements in 690.43.

Starting in Section 250.110, the *Code* says about equipment-grounding requirements: "exposed normally non-current-carrying metal parts of fixed equipment supplied by or enclosing conductors or components likely to become energized shall be connected to an equipment-grounding conductor (EGC)…" when that equipment is exposed to any one of the conditions listed. PV arrays meet multiple conditions described in 250.110, which include being located in a wet environment and operating with any terminal with a potential to ground above 150 V, and so require connection to an EGC.

Section 250.110 helps establish the need for an EGC, but what is an EGC? Section 250.118 lists 14 different types of recognized EGC methods including using a conductor, certain conduit and tubing types, specific cable assemblies, and other metallic surfaces. This gives PV installers many choices in establishing and connecting equipment grounds. In PV installations, the most common EGC is either a stranded or solid copper conductor. Historically, installers have used lugs attached to all modules; conductors are then bonded to the lugs, thereby bonding all of the modules together. As I will discuss, recent changes to the equipment grounding section of 690 has opened the possibility of using other methods to create the required equipment ground connection.

Section 250.134, which is referenced in 690.43(A), provides two allowances for connecting to an EGC: 1) connecting to one of the EGCs permitted in 250.118; or 2) connecting to an EGC running with the circuit conductors. PV installations use the first option by connecting to a EGC as defined in 250.118. An exception in 250.134(B), which discusses DC circuits, allows the EGC to be run separately from the circuit conductors. However, Article 690 does not allow this method in PV circuits.

PV-Specific Equipment Grounding

Although the rules for properly grounding and bonding PV systems are covered in Part V of Article 690, this article contains numerous references to Article 250. Section 690.43, Equipment Grounding, covers the general requirements, listing six different sets of conditions the EGCs must comply with. The 2011 *NEC* breaks this section into multiple subsections. The first two subsections, 690.43(A) and (B), establish that equipment grounding is a fundamental requirement. These state that, regardless of system voltage, exposed noncurrent-carrying metal parts of PV modules and associated equipment must be grounded in accordance with 250.134 or 250.136(A), and are required in accordance with 250.110.

The language in 690.43(C) was new in 2008 and received a lot of updates in 2011. Interestingly enough, "or" appears multiple times, and has a big impact on the proper interpretation of the rules. This section identifies that a structure supporting a PV

Courtesy Wiley

This grounding lug is commonly used to bond a grounding conductor to a mounting system.

Courtesy Wiley

A bonding jumper connects two mounting rails to provide continuous grounding capability.

array can be used to establish the bond to the EGC. The first sentence of this section helps support the concept of using grounding washers to bond PV modules to the mounting structures, as long as the washers are listed and identified for that use. In the second sentence in 690.43(C), you really need to pay attention to the "or" since it has two allowances: the requirement that metallic mounting structures shall be identified as EGCs or the second that, in lieu of the mounting structure being identified as an EGC, that identified bonding jumpers can be used between the mounting sections and the mounting structure must be bonded to the grounding system. This is the method most installers use, due to the lack of mounting systems identified as EGCs.

This WEEB grounding washer can be sandwiched between a module and its mounting rail. The protrusions bite into both, creating an approved ground path between them.

Courtesy Wiley

Many would say this section causes more controversy than closure, but it does offer several options for a module-to-rack bond. One popular method is grounding washers. When installed properly, the barbed washers penetrate the module frames and the racking structure, establishing an electrical bond. However, some question if their listings are appropriate for this use. Their use satisfies most inspectors and thus they are widely used, but have very specific installation requirements to establish the proper bond.

A new listing standard for bonding and grounding—UL2703—is one effort to eliminate this controversy and address Section 690.43(D) in the *2011 Code*. The UL listing allows using mounting systems to provide the required grounding for module frames. Although the standard has not been finalized, multiple racking manufacturers are testing their systems to the draft standard and are offering products that have passed the draft. These products will save installation time and effort, since they eliminate the separate EGC connections.

The last two subsections of 690.43 help clarify the installation requirements. Subsection (E) allows listed devices to be used to bond modules mounted adjacent to each other. Subsection (F) requires that the EGCs for PV circuits run with the circuit conductors as they all leave the vicinity of the array. Although this contradicts the exception noted in 250.134(B), because they are PV circuits, the specific rule laid out in 690 takes precedence.

Access

Ryan Mayfield (ryan@renewableassociates.com) is the principal at Renewable Energy Associates, a design, consulting, and educational firm with a focus on PV systems. His latest personal PV project afforded him the opportunity to evaluate many nuances of grounding and bonding.


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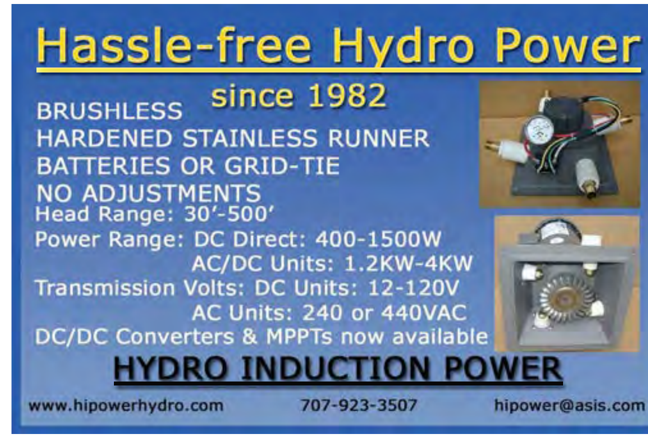
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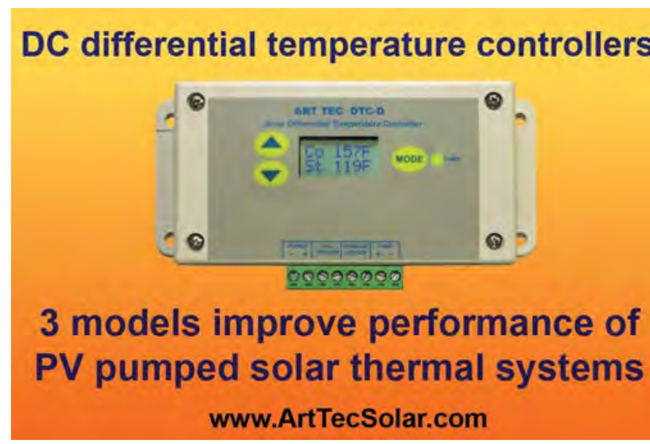
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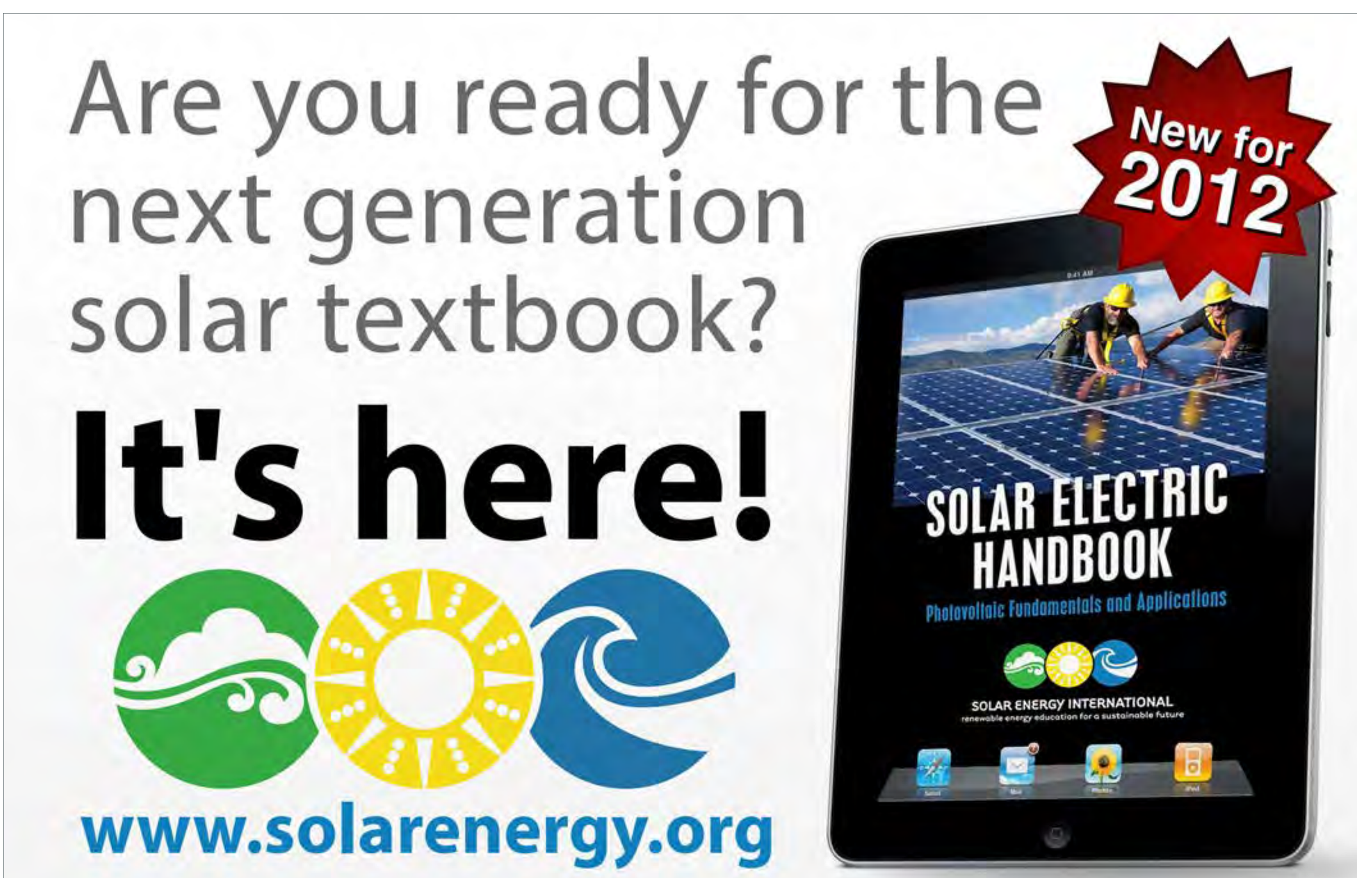
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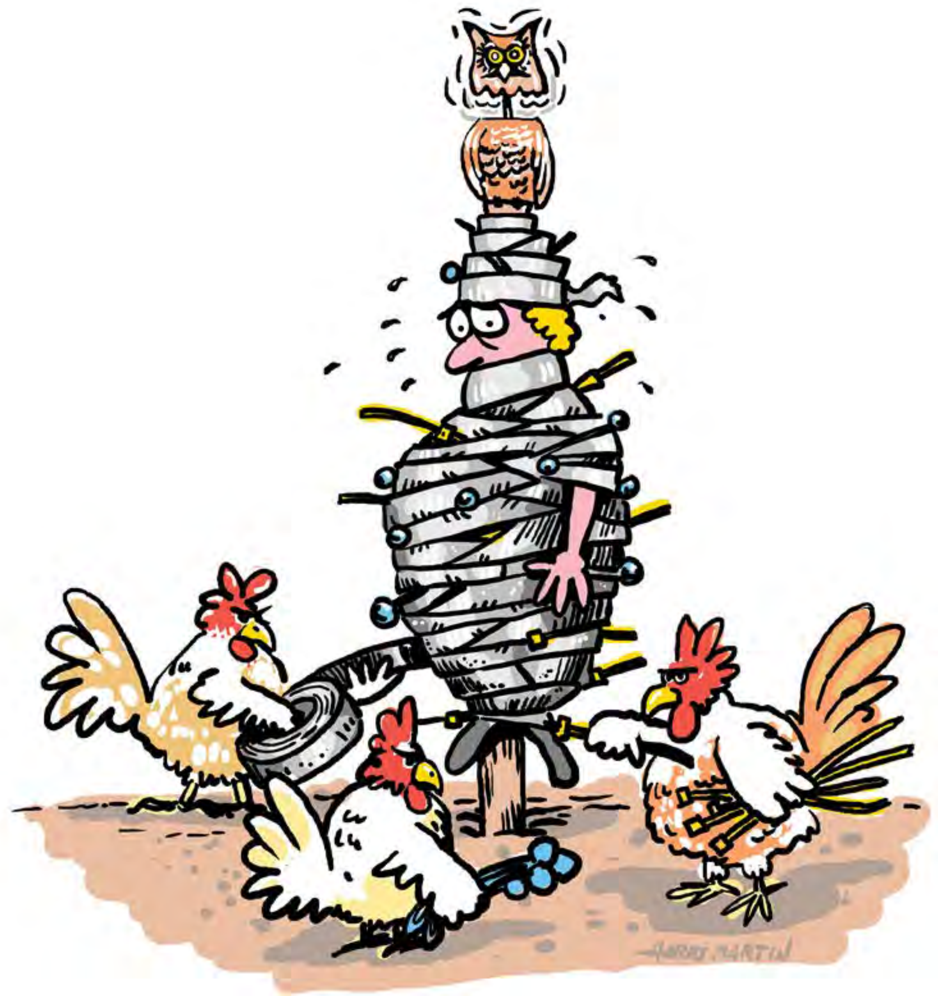

by Kathleen Jarschke-Schultze

I love tools. But who doesn't? A tool can make any job shorter, easier, and more efficient. The right tool multiplies that goodness. In my household, my husband Bob-O and I have a system—I get any old hand tools when Bob-O upgrades. That is, except for my hammers and my cordless power drill—I bought those new.

Tools

"A tool is a device held in and manipulated by the hand and used by a mechanic, plumber, carpenter, or other laborer to work, shape, move, or transform material." So says my desktop dictionary. Well, that covers a lot of ground. I have all sorts of tools here at the homestead and I love building things. Admittedly, I'm not very good at it, but that has never stopped me.

There are many instances where I have to "build" (and I use the term loosely) some sort of temporary setup, like a larger chicken pen for when the grapes are ripe and we don't want the flock in the vineyard chowing down—the two or so weeks my free-range hens are not so free. I build a temporary pen, then deconstruct it into the separate materials, to be used again for that or another purpose.

Trinity of Tools

This type of off-the-cuff construction and destruction is probably my favorite kind of activity. I've found there are three tools that I use a great deal, and make sure I always have on hand.

Hippie Chrome. I don't know when we started calling duct tape "hippie chrome," but the name has stuck. Always have a roll or two on hand. One thing to remember about duct tape is that whatever you do with it will be, to some degree, temporary. If your tape job is out in the sun, the tape will have a shorter life.

I have made ice chest hinges from duct tape. Just before the old plastic hinges completely gave way on our cooler, I reinforced them with the tape. That was four months ago, and the tape is still holding. Our ice chest gets a lot of use, going on every shopping trip to town, which is an hour away. Hippie chrome is also good for emergency shoe repairs. For a more permanent fix, however, I recommend Shoe Goo adhesive.

When Bob-O goes to replace or install a set of batteries for clients, he wears his "battery pants." At first I tried to patch the inevitable battery-acid holes in these pants. It was a job for mythical Sisyphus—a never-ending, futile task. I discovered a repair method—turn the pants inside out and generously use duct tape over the holes, then turn them right-side out and repeat the taping on the outside, pressing firmly. The tape job on these now-wearable pants will last through about three washings.

We use a Melitta coffee maker for our morning coffee, but I broke the 8-cup glass carafe that the filter sits on. When we found out we would have to buy the whole machine again just to get the carafe, I went to a thrift store and bought a similar carafe for $2. But the opening on the carafe was bigger than the filter base.

Bob-O suggested I modify a plastic lid to fit the carafe top and set the filter on top of that. I found a plastic container lid with grooves in it that just fit the glass rim. Set firmly in place, there was no slipping back and forth. I carefully cut a hole in the plastic lid and placed the filter over the hole. I then tore thin strips of duct tape and meticulously connected the two pieces with a tidy circle of duct tape.

The next morning when Bob-O made coffee, he said that really liked the new coffee pot and asked what sort of glue I had used to seal the two pieces together. Offhandedly I replied, "hippie chrome." That was eight months ago, and my tape job is still holding.

The most unusual use I ever heard for duct tape was from my brother-in-law Rick. Seems he had a wart on his hand that he couldn't get rid of. At his yearly physical, his doctor would burn it off or freeze it off, but it would always grow back.

Then he got a new doctor. She told him to wrap the wart with duct tape for six days, and then remove it for one day and to do this for six weeks. It didn't even take six weeks for the wart to disappear and it has not returned.

Ball Bungees. I became aware of these handy tools when we purchased a tarp carport kit to use as a wood shed (see "Home & Heart" in *HP87*). A six-inch loop of bungee cord with a small plastic ball at one end, they are made to slip through a tarp grommet, wrap around a pipe, and loop over the plastic ball to secure and hold tension on the tarp. They are also called "tarp bungees."

I use them to seal my pant legs when I work the bees. I carry some in my car, since I never know what I might be lashing to my car to bring home. In the garden, I use them to construct trellises, using lengths of bamboo or PVC pipe. I can lash a hose up onto a fence so I can see and easily reach the connections there. There is nothing better for making seasonal gate hinges: Pound a fence post into the ground, set your chicken-wire gate upright alongside the post, and use ball bungees to tightly secure your gate to the post in three or four places. Voilà ! A gate you can open and close with one hand.

When the grapes in our hillside vineyard start to ripen, I bring out an old plastic barn owl with a bobble head. By sticking the owl on top of a 10-foot piece of PVC pipe, I can get it to a nice height. Then I use a couple of ball bungees to secure the PVC to a vineyard post. The owl's head bobbles in the breeze as he guards my crop from the birds. This ploy only works if you move the owl daily. Undoing the bungees and walking to a new post takes a couple of minutes. I really can't think of how I could easily do it otherwise.

I wore out the first set of ball bungees I bought. Eventually, the elastic cord gave out. I removed the cord from the plastic balls. Bob-O was able to find rolls of elastic cord at our local hardware store. All I have to do is cut the cord into lengths, knot one end, pull the loop end through the hole in the plastic ball, and a ball bungee is reborn.

Zip Ties. I guess it's inevitable that an electrician's wife would latch onto zip ties as a favorite tool. They are just so darn handy. Be sure to get the UV-resistant kind—they last longer.

Every year, I have to construct—and destruct—fences to keep my free-ranging chickens out of gardens. We have a large, permanently fenced main garden. We also have several smaller areas that we use to grow corn, squash, melons, and pumpkins—plants that get big and like to ramble. We also plant cabbages in these beds. My chickens would wreak havoc if allowed to range there. Any place damp from watering would be scratched up and young plants killed.

My chicken defenses are those orange plastic fences sold by the roll. I stretch it out between posts and secure it with zip ties. My gates are as described above. I have a pipe structure in the garden proper that I cover with a shade cloth every year to grow spinach and lettuce as long as possible in our summer heat. The shade cloth is attached to the pipe frame with zip ties and ball bungees.

I discovered that you can reuse zip ties, too. It is kind of tricky, and you have to be careful. If you can stick a very thin wedge (I use my Swiss Army knife) under the tiny toothed ratchet and lift it, the zip band can be pulled back through the opening. Some zip ties come with a tiny lever attached to the ratchet to make them easily releasable and reusable.

It's funny how some tools just become indispensable parts of your work repertoire. I certainly haven't exhausted the possibilities of this trio. And I could do without a cell phone much easier than any of these three tools.

Access

Kathleen Jarschke-Schultze (kathleen.jarschke-schultze@homepower.com) is enlarging her chicken coop with a pallet-built feed storage room at her off-grid home in northernmost California.

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Shading & Solar-Electric Systems

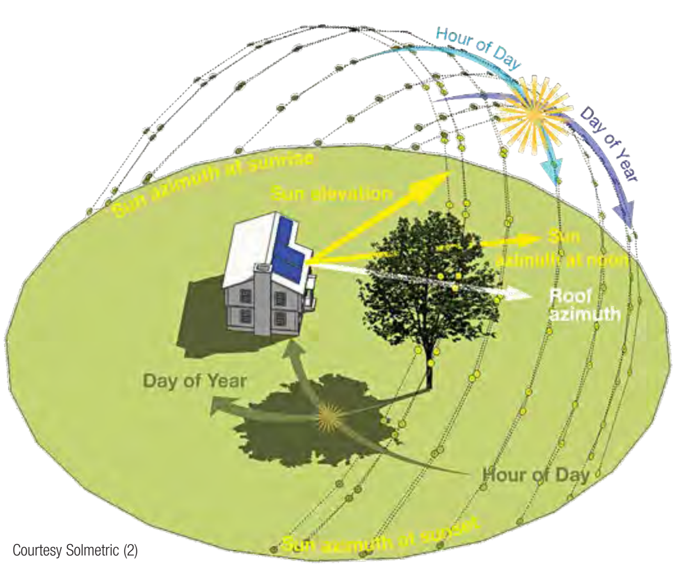
There are many factors that can reduce the production of a solar array. Shade is often the biggest.

A PV system's yield is a large factor in whether the financial investment pays off. Anything that blocks the sun, even if partial shading, will affect output. That's why accurate shade measurements and system planning are essential to maximizing the system's production.

Shade can be caused by obstructions such as chimneys, trees, or nearby buildings. The sun's trajectories through the sky (sun paths) are determined by the array site's latitude/longitude and the season. The shape and location of a shadow is determined by the shape of the obstruction, the location of the array, and the location of the sun.

A small amount of shade may, at first, seem like a small problem, but because cells within a PV module are wired in series, this enables shade on a cell to block the path of current flow. Thus, a little shade can cause a disproportionate reduction in PV energy production. Bypass diodes are used within modules to limit the impact to a portion of a module, and microinverters and power optimizers can confine the impact to the individual shaded module(s). However, the reduction in energy is still typically many times higher than the percentage of shaded area.

Solar professionals use shading analysis tools, such as a Solar Pathfinder (manual) or Solmetric SunEye (digital), to assess a site's shading for the entire year. These tools capture an image of the sky, including the horizon and any obstructions, as seen from the perspective of the array. They superimpose the sun paths for that latitude/longitude, identify obstructions in the image, and calculate the solar access.



Courtesy Solmetric (2)

Terms

- **Irradiance** is the sun's power in kW/m^2.
- **Insolation** is the sun's energy (power integrated over time) measured in kWh/m^2.
- **Solar access** is the percentage of insolation available to an array—shading versus no shading. Only insolation and shade within the array's field of view is considered in calculating solar access.
- **Azimuth angle** is a compass heading.
- **Elevation angle** is the angle above the horizon.
- **Magnetic declination** is the deviation of true south from magnetic south.

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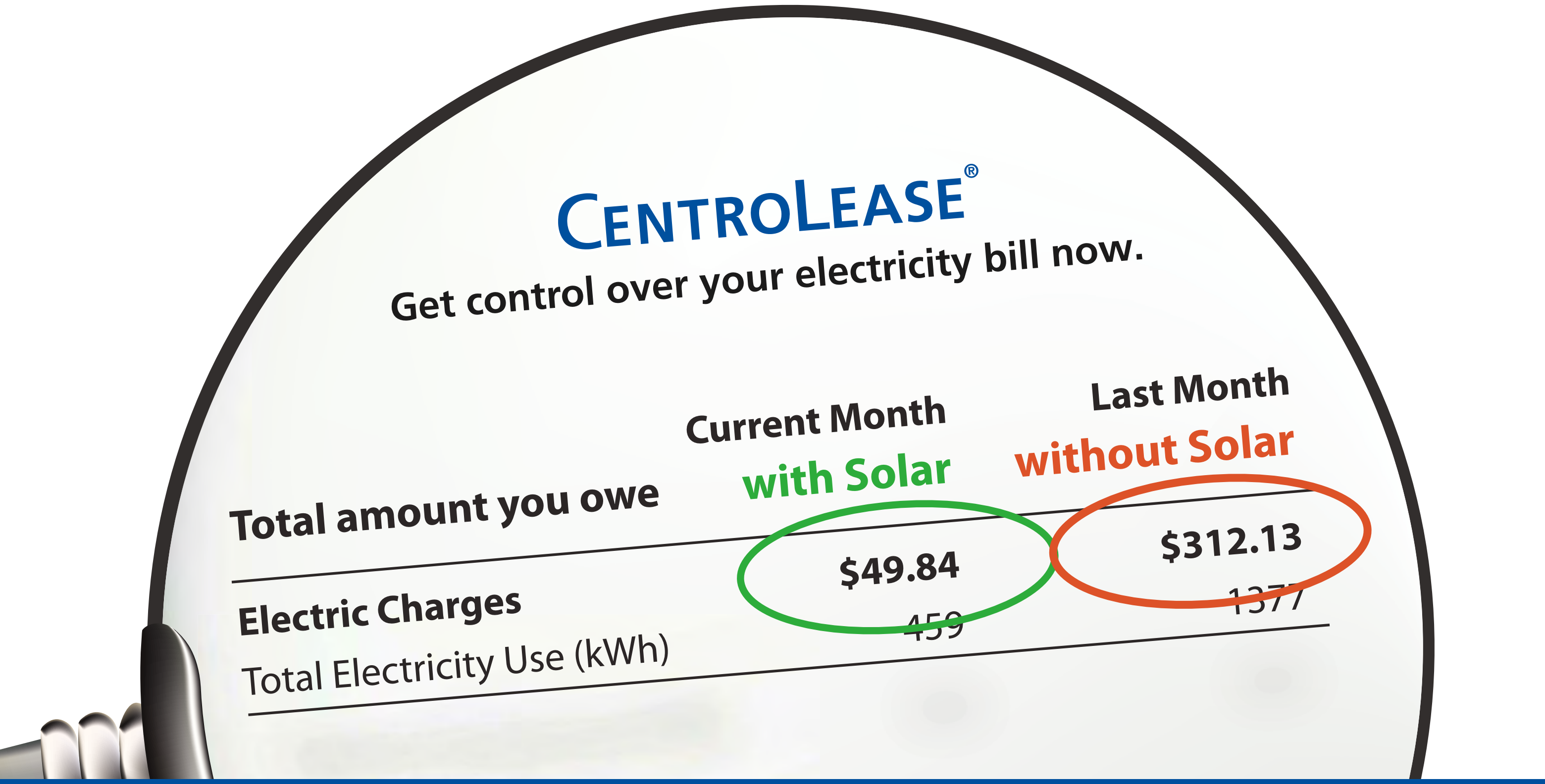

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