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Neighbors Go All-In
On a Community-Scale Solar Project

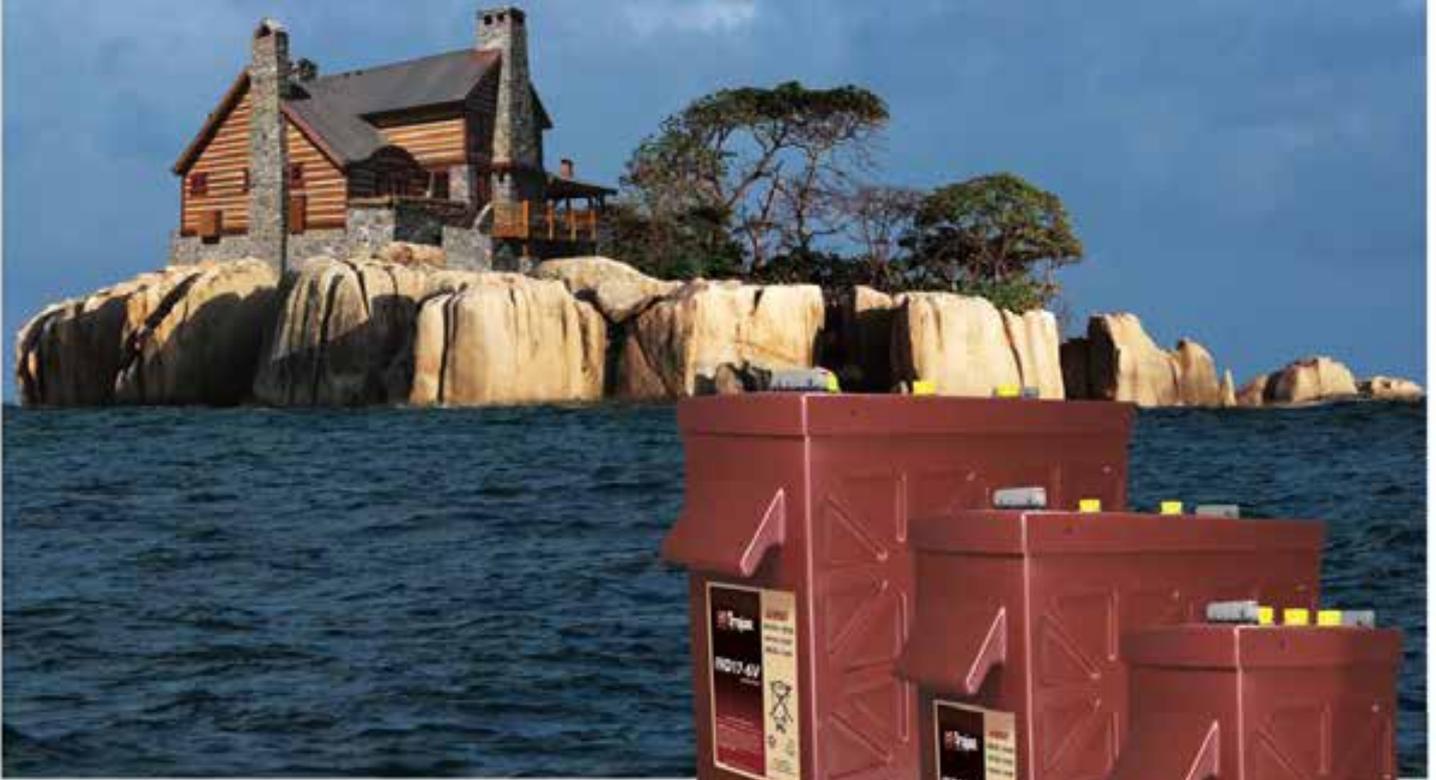
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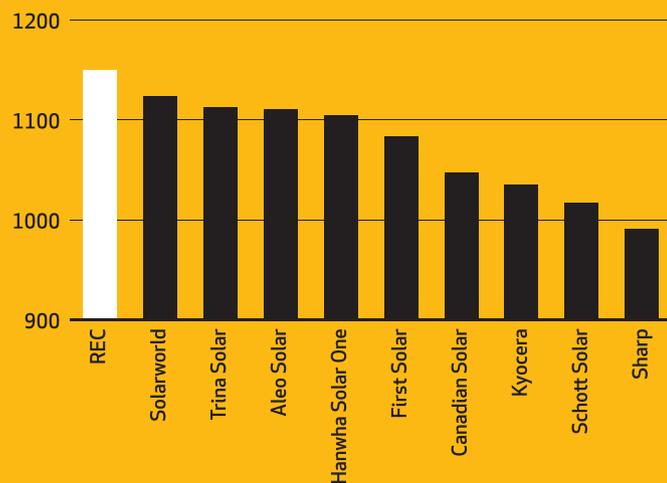
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- 6% more energy produced than average
- Competitors include multicrystalline, monocrystalline and thin film



Yearly comparison Photon Test 2011 leading brands

Yield kWh/kW





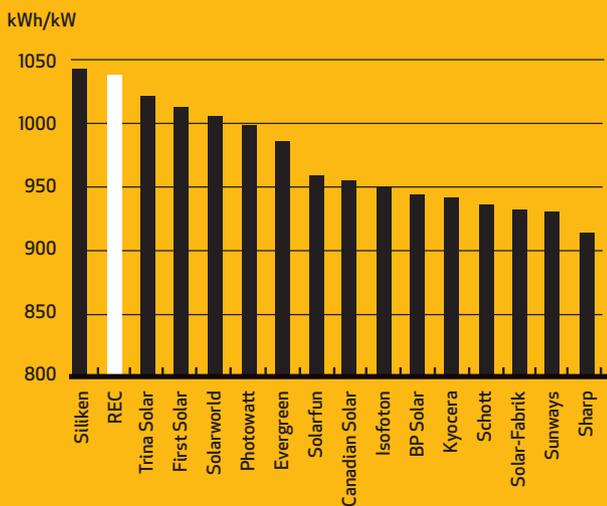
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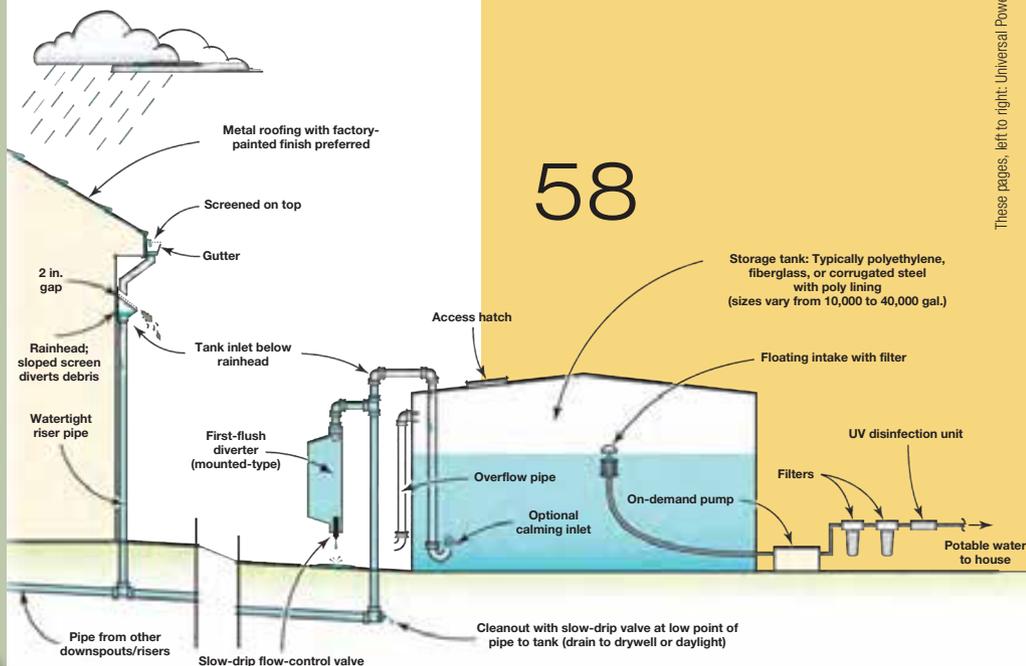
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With her Voltaic PV-powered pack, Ana Neff can still hit the woods in high-tech style.

Photo: Shawn Schreiner



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Home Power (ISSN 1050-2416) is published bimonthly from offices in Phoenix, OR 97535. Periodicals postage paid at Ashland, OR, and at additional mailing offices. POSTMASTER: Send address corrections to Home Power, PO Box 520, Ashland, OR 97520.

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The Numbers Are In...

According to the latest U.S. Solar Market Insight report published by the Solar Energy Industries Association (SEIA) and GTM Research: "The U.S. solar energy industry installed a record 1,855 megawatts (MW) of photovoltaic (PV) capacity in 2011, more than doubling the previous annual record of 887 MW set in 2010." That's enough to power more than 370,000 homes, signifying a 109% increase for 2011, and is the first time U.S. solar installations have exceeded 1 gigawatt in a single year.

2011
Increase in
PV Installations:
109%

This growth was partially due to the decline in PV system costs, which, according to this report, fell 20% last year. But much of this installed capacity was due to anticipating the expiration of the 1603 Treasury Program (grant in lieu of tax credit) on December 31, 2011, and the resulting rush to get projects commissioned beforehand.

Regardless of the reasons behind the growth, we now have a lot more PV systems pumping clean energy onto the grid. It appears that we are indeed headed in the direction of a renewable energy future.

According to Rhone Resch, president and CEO of SEIA, "The solar industry is the fastest-growing industry in America for the second year in a row. What we are seeing in the United States is that policies are working to open new markets and remove barriers for solar. The industry is now poised for years of multigigawatt growth and the creation of tens of thousands of new jobs."

For 25 years, *Home Power* magazine has been on a mission to change the way people generate and use energy, one system at a time. We have become the in-print and online venue for homeowners, business owners, and renewable energy professionals to exchange experiences and information about solar equipment and system design, installation, and performance. We're proud to be a part of the information exchange that has helped shape this growing industry.

2011
Reduction in
Weighted Average
System Cost:
20%

And whether we are talking about using solar cells for charging your laptop, powering your home, or discussing large megawatt installations, each is a step in helping us reach the common goal: Reducing the use of polluting conventional energy technologies and replacing them with the infinite supply of renewable energy that surrounds us.

—Justine Sanchez, for the *Home Power* crew

Number of PV Systems Greater Than 10 MW Installed:

2
2009

8
2010

28
2011

Think About It...

What we need to do is really improve energy-efficiency standards, develop in full scale renewable and alternative energy, and use the one resource we have in abundance—our creativity.

—Lois Capps, U.S. politician



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Home Power magazine

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Solar Sales Consultant
Benton Electric



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The Stimulus Act's "Buy American" Provision for Solar

Red, White & Blue-Washing?

The ARRA provision is an attempt to increase domestic benefits by requiring "buy American" for projects it funds on public buildings. Just how American does "American" have to be? Only your PV module manufacturer knows for sure.

The American Recovery and Reinvestment Act (ARRA) of 2009 requires that solar projects on public buildings be developed "buying American" materials and products. While "buying" is uncontroversial, it turns out that "American" can be more international, foreign, worldly, cosmopolitan, and/or legalistic than you might first think.

Section 1605 of ARRA (aka the "Stimulus" or "Recovery" Act) mandates, "None of the funds appropriated or otherwise made available by this Act may be used for a project for the construction, alteration, maintenance, or repair of a *public building or public work* unless all of the iron, steel, and manufactured goods used in the project are *produced in the United States*" [emphasis added].

To implement this congressional mandate, the White House's Office of Management and Budget (OMB) issued guidance to federal agencies. Plainly enough, "produced in the United States" means the states or territories. According to the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy, "a domestically manufactured good for the purposes of the 'buy American' provision of the Recovery Act, is one that has undergone 'substantial transformation' in the United States or its territories."

So what does this mean? EERE says, "Substantial transformation occurs when, as a result of manufacturing processes, a new and different article emerges, having a distinctive description, character, or use, which is different from that originally possessed by the article or material before being subject to the manufacturing process. The mere finishing or modification of a partially or nearly complete foreign product in the United States will not result in the

substantial transformation of such product and it remains the product of a foreign country."

EERE developed several multipart questions to determine the "substantial transformation" status of goods. Turns out, where PV modules are concerned, some are "more" American-made than others.

In an attempt to clarify and simplify this legalistic morass to facilitate PV installations on public buildings, EERE issued a "Solar Public Interest Waiver" that waives the American-made formal requirements for purposes of ARRA for:

- domestically manufactured modules, even though they are made of foreign manufactured cells;
- foreign manufactured modules, if they are "completely composed" of domestically manufactured cells; and
- ancillary items and equipment (essentially the balance of system components, save for inverters and batteries).

According to the EERE guide, it doesn't matter, for ARRA's "buy American" provisions, if the U.S. manufacturing facility is foreign-owned. (For instance, SolarWorld's manufacturing facility in Hillsboro, Oregon, is German-owned, and Schott Solar, which is also German-owned,

has a manufacturing plant in Albuquerque, New Mexico.) If it costs more than 25% more to "buy American," the provision does not apply. If the total value of the project is \$7,804,000 or greater *and* the grant recipient is "party to an international agreement" (there is an official and exclusive list in the regulations), one doesn't have to "buy American" to get the ARRA grant.

The Solar Energy Industries Association, a U.S. trade group, distinguishes for distinct parts of the PV module manufacturing process.

Polysilicon Production. Highly purified polysilicon is the feedstock for ingot and wafer production. According to Greentech Media, 25% of the world polysilicon production in 2010 came from three U.S. facilities.

Ingot/Wafer Production. Ingots are large bricks of polysilicon. Wafers are very thin slices of the bricks. "Global wafer



production is dominated by Asian manufacturers, particularly those in China and Taiwan,” says Greentech Media. “Only 3% of PV wafers manufactured worldwide in 2010 were produced in U.S. facilities.”

Cell Production. The basic unit of PV energy production, cells are made from processing wafers. The United States produces only 3% of the world’s PV cells.

Module Assembly. Typically, 60 to 72 cells comprise a PV module. “Overall, 31% of U.S.-installed crystalline silicon modules were assembled domestically in 2010,” says the Greentech report.

When considering an entire PV system, 71% of the value is domestically produced. Module mounting structures, inverters, and other electronics and hardware, along with site preparation, labor, and other (permitting, legal, engineering, financing, distribution, profit, etc.) make up the vast majority of the value chain.

To get a practical handle on what “American-made” modules were available, *Home Power* examined the product listings of Civic Solar, which is aggressively marketing the portion of its module offerings that are “American-made.” Of the 191 different PV modules from 19 manufacturers Civic Solar offered in late 2011, 46 were classified as “ARRA-qualified.” The remaining 145 were not. The average price (single-module

pricing) of all PV modules was \$2.16 per watt. The ARRA-qualified modules averaged \$2.43 per watt; non-ARRA-qualified modules averaged \$2.06 per watt. The \$0.37 per watt difference between “American” and non-“American” made PV modules on a 50 kW system for a public building is \$18,500.

According to Civic Solar, some or all of its PV module offerings from Kyocera, Schott, Schuco, Sharp, SolarWorld, and Solon are ARRA-qualified. Civic Solar’s website offers some Kyocera modules that have identical technical specifications and even identical model numbers, but only those made in “Japan, Mexico, USA” are ARRA-compliant, while those labeled just “Mexico” are not.

Since it was enacted in early 2009, ARRA has spent \$749 billion on tax benefits, contracts, grants, loans, and entitlements. As of January 2012, EERE had funded \$435 million for 462 solar-related projects subject to ARRA’s “buy American” provisions.

The Act’s provisions pertaining to “buy American” indeed result in an advantage to U.S.-manufactured solar goods and materials—and therefore U.S. workers, as ARRA intended. But given global supply chains, exemptions and waivers allowed by ARRA and its regulations, and other factors, maybe not as much as politicians who touted the provisions led us to believe.

—Andy Kerr

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Working Toward a Better Bottom Line?

Across the nation, a better way of doing business is catching on, as more and more companies adopt a new corporate structure intended to create greater public good. It's called a Benefit Corporation (B Corp for short), and unlike its conventional counterparts that have one bottom-line goal—to create profits for shareholders—a B Corp is obligated to adhere to a triple bottom line: people, planet, and profits.

The new corporate class marries nonprofit ideals with for-profit motives, according Richard Edlin, public policy director at the American Sustainable Business Council, a nonpartisan advocacy group representing more than 100,000 businesses nationwide. "Profits and social responsibility are not mutually exclusive. Any well-managed company can only do what they can afford, but the idea behind the Benefit Corporation is to induce for-profit companies to find better ways of doing business—to maximize profits while growing opportunities in environmental stewardship and community investment," Edlin says.

A B Corp is identical to a conventional corporation with a few exceptions. A B Corp writes socially conscious goals, of their choosing, into their articles of incorporation and agrees to make measurable progress toward those goals. Such progress must be reported annually in "benefit" reports that are audited by an independent third-party chosen and paid for by the company. A company can adopt the B Corp model either through legal incorporation in states where it is recognized, or by certification from a third party. One third-party is B Lab, the Philadelphia-area nonprofit that developed the B Corp framework and brought the idea to the marketplace through its certification program.

To become a certified B Corp, a company must earn a minimum of 80 points (out of 200 available) on an annual assessment that scores the company's accountability, employees, consumers, community, and the environment, and pay an annual certification fee that is based on the company's

annual net sales. Once certified, B Lab randomly selects 10% to 20% of B Corps companies for an on-site review every two years. Failure to uphold the standards results in the loss of certification. Consumers and investors can track a company's annual progress by checking scores on B Lab's website.

"Measuring a company's bottom line is easy—either they're making money or they're not. It is not as easy to evaluate other areas of performance. That's where B Lab comes in. We distinguish the companies with truly good practices from those with just good marketing," says Erik Trojian, B Lab's policy director.

Since the program's launch in 2007, the organization has certified 518 private companies in 60 industries—including a number of leading renewable energy outfits like Sungevity, Namaste Solar, and Southern Energy Management. And the program is expected to continue growing, especially now with B Corp legislation gaining ground in several states.

In 2010, Maryland became the first state to pass legislation that recognizes Benefit Corporations as a legal corporate structure. California, Hawaii, New Jersey, New York, and Vermont followed suit. Bills are now pending in Colorado, Michigan, Pennsylvania, and North Carolina. This year, Georgia, Illinois, Oregon, and the District of Columbia are slated to introduce similar legislation.

The general legislation is the same from one jurisdiction to the next, with some variation in the fine print. Fundamentally, the law establishes a fiduciary duty to create both social and shareholder value, and better protects the company's social and environmental mission through changes in management, capitalization, and ownership. Currently there are no tax breaks or procurement incentives for B Corps, with the exception of a \$4,000 tax break in Philadelphia—though there's talk of incentives in Portland, Oregon, and Washington, D.C.

While a publicly traded company may become certified or even legally restructure as a B Corp through shareholder





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Courtesy IMC Instruments

IMC Instruments

Solar Water Heating Controls

IMC Instruments (imcinstruments.com), of Wittenberg, Wisconsin, received an Intertek (ETL) listing for its solar water heating controls. IMC manufactures the Eagle series of differential controls for solar water, space, and pool heating. The company also makes controls for hot air collectors and PV-pumped hot water systems. The EAGLE 2 WEB has a built-in interface for connecting to the Internet. IMC also has a full line of sensors, cables, adapters, and flow meters that integrate with its controls.

—Chuck Marken

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MidNite Solar Surge Protector



Courtesy, MidNite Solar

MidNite Solar (midnitesolar.com) released its surge protector to safeguard RE system equipment from damaging voltage surges from lightning or the utility. The unit is mounted on the outside of electrical enclosures using a 1/2-inch knockout. Its components are visible to see if the unit is functioning (via two blue LEDs) or has absorbed a surge. It is available in 115 V for low-voltage equipment (12, 24, and 48 V PV arrays, for example), and 300 V and 600 V for high-voltage grid-tied arrays. It is capable of clamping surges up to 115,000 A and protecting equipment by reducing the voltage to a level system electronics can handle without damage. The devices are designed to protect both DC and AC electrical equipment and come with a five-year warranty.

—Justine Sanchez



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A close-up photograph of SnapNrack solar panels installed on a roof. The panels are dark blue with white grid lines and are mounted on a grey shingled roof. The background shows a clear blue sky and some greenery.

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Is It OK to Love a Programmable Thermostat?

Programmable thermostats (PTs) can save energy. If a conditioned space's temperature is automatically adjusted for when the occupants are not home, adjusted for bedtime conditions, and is allowed to rise in the summer or decrease in the winter, less energy will be required to cool or heat the house.

But because of human meddling, most programmable thermostats aren't saving much energy. Overriding settings and then forgetting to turn the temperature back at a later date or failing to program settings in the first place is problematic. In fact, several studies by the Environmental Protection Agency and Department of Energy have led to the Energy Star label being revoked for PTs.

Most PTs are just a clock with digital switches. For a typical PT to work flawlessly, your life needs to be predictable. They are available with different configurations like 7-day (each day can be uniquely programmed); 5-2 (the weekend days are different than the weekdays); or 5-1-1 (Saturday differs from Sunday). But today's PTs have more features, are much easier to program, and can be controlled via a Web portal or smartphone app.

Nest Learning Thermostat (\$249; nest.com) programs itself by tracking user interaction and adjustment patterns, usage activity and temperature sensors, and monitoring weather. Change the temperature a couple of days in a row and the Nest will adjust its programming accordingly. It takes the Nest about a week to learn and set up a temperature protocol. You control the Nest by turning or pushing the outer dial in response to its full-color screen's questions or prompts. You can also control the Nest remotely online.

Before you buy, visit the company website and answer a few questions about what thermostat wires you have and it will tell you whether or not the Nest will work with your HVAC system. You can buy the Nest online, or through Best Buy, where you can have it installed by their Geek Squad for \$120.

Nest encourages do-it-yourself installation, even providing a screwdriver and all the mounting hardware for installation in any kind of wall, including cover plates if the hole left by your previous thermostat is too big for the Nest to cover. I was planning to install the Nest myself, but since I pre-ordered very early, they offered free installation. The tech was in and out in 25 minutes, and that included me picking his brain for this article. He had installed at least 100 already.

As for problems, he said that one came with a dead battery that he recharged via a USB cable from a laptop computer. He had also cleaned up after do-it-yourselfers, who had neglected to turn off the power to the furnace as directed in the manual. The 24-volt thermostat circuit hurt neither the do-it-yourselfer nor the Nest, but crossing some wires can burn out the HVAC transformer. The tech liked Nest Lab's factory support, though he preferred the paper manual over the online version. I thought my Nest might be misbehaving and leaving the heat on at night, but in fact it was accurately sensing my insomniac house guest walking by on the way to the kitchen to make a pot of midnight tea.



Courtesy Nest Labs



Courtesy Nest Labs

It may be time to re-apply Energy Star ratings for PTs—at least for the Nest. While the newer and more expensive PTs are easier to program, only the Nest does the programming itself. It's as close to idiot-proof as you can get.

—Andy Kerr

Thermostat Potential

Energy Star estimates that the average U.S. household spends \$2,200 per year on heating and cooling bills. Further assuming a typical single-family home with a 10-hour daytime setback of 8°F in winter and set-“up” of 7°F in summer, along with an 8-hour nighttime setback of 8°F in winter and a setup of 4°F in summer, they estimate a savings of about \$180 per year, or a little more than 8%.

The experts at BuildingGreen.com say that for every 1°F you turn down the thermostat, you save about 2% on heating costs. So, if you normally keep a house at 70°F and drop the setting to 65°F, you'll reduce heating costs by about 10% ($5 \times 2\%$). If you lower the thermostat for a portion of each 24-hour day during the heating season, say at night when many people like it cool for sleeping, there will be proportional savings. For example, if your thermostat is set to reduce your house temperature by 10°F for eight hours each night (one-third of the 24-hour day), your annual savings would be about 7% ($10 \times 2\% \div 3$).

Although the Energy Star program no longer labels PTs, the program has good information about them and how they can save energy, *if* you set them up and use them properly (energystar.gov). You can also download an Excel file that will estimate your potential savings.

After you determine your estimated annual savings, divide it into the cost of buying and installing a PT to determine simple financial payback. If you are persistent and disciplined, you can buy a cheap PT and get some energy savings. But for the best savings, if you're like the rest of America, you may want one that does the programming—and maybe also the thinking—for you.

solar trackers



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Justin McComas, Baker Electric Solar

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When licensed electrician and veteran PV installer Justin McComas became general foreman with Baker Electric Solar in 2011, he selected Quick Mount PV as the preferred mount on every solar installation where they could be used. “At my previous employer we used a cheaper mount, and one of our installs developed a leak that led to mold,” Justin said. “The cost in money, reputation, and cancelled jobs was enormous.”

Baker Electric Solar crews use Quick Mount PV’s Classic Composition and Universal Tile Mounts on about 20 jobs each month. “We love the installation speed of the Classic Comp, and its clean sleek look,” said Justin. “What sold me on the Universal Tile Mount was its reinforced base. Superior shear strength is critical on arrays sitting seven inches above a tile roof.”

Justin also appreciates saving labor and avoiding mistakes by getting all parts, hardware and instructions in a single box. “Now I walk away from every Quick Mount job with 100% confidence that it won’t leak,” Justin said. “**Quick Mount PV is the best protection I can buy.**”

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The Power of the Crowd

New Financing Model Makes Solar More Accessible for Small Nonprofit and Community Groups

For the nonprofit People's Grocery, solar power is a natural fit. The Oakland, California-based organization manages an urban farm and supports programs that make sustainable, healthy food available to the city's low-income population.

"There is an obvious connection between farming, food, and the sun, and it seemed only fitting that we use solar energy to power our office," explains Nikki Henderson, the group's executive director.

Like so many nonprofits, People's Grocery must manage its limited resources wisely and faced the challenge of finding affordable financing to realize its solar dream. The group worked with the building owner and explored different options. Discouraged by the high rates and fees of traditional lenders, People's Grocery turned to Berkeley-based Solar Mosaic (solarmosaic.com) for help.

The People's Grocery project is one of the first to be "crowd-funded" through Solar Mosaic's online platform, which pools individual small amounts of funding from a large group of backers to provide low-interest leases for solar

projects. For People's Grocery, the goal was to raise \$38,800. It took about seven weeks and 70 investors—including one anonymous celebrity donor who covered half of the cost—to fully fund the 8.3 kW rooftop installation.

Kickstarter (kickstarter.com), a popular fundraising website, brought the idea of crowd-funding to the mainstream, using the power of multiple donors to fund creative projects like independent films and art installations, but Solar Mosaic is the first company to apply the approach to solar projects. Another popular program, KIVA (kiva.com), crowd-funds a wide spectrum of projects mostly in developing countries, including solar and other renewable projects.

So far, Solar Mosaic has raised more than \$320,000 for three solar installations. In addition to its work with People's Grocery, Solar Mosaic completed a 28.8 kW system at the Asian Resource Center in Oakland and a 1.5 kW system at the home of artist Shonto Begay, one of the 18,000 homes without electricity on the Navajo Reservation in Arizona. Other projects—including a 25.7 kW system for the Society of St. Vincent de Paul in Oakland and an 8 kW system for

Courtesy Solar Mosaic



the Murdoch Community Center in Flagstaff, Arizona—are featured online and are close to being fully funded.

Crowd-funding is filling a niche in solar financing, appealing to nonprofits, schools, places of worship, small businesses, and homeowners with relatively small-scale projects that are often overlooked by traditional lenders. “Projects up to \$2 million are having a hard time. Banks haven’t been lending to this segment of the market because the amount is not enough to justify the expense of performing due diligence and going through the underwriting process,” says Billy Parish, president of Solar Mosaic and author of the new book, *Making Good: Finding Meaning, Money and Community in a Changing World*.

Frustrated by the lack of progress in clean energy financing and policy, Parish and his partners—Dan Rosen, Arthur Coulston, and Steve Richmond—decided to take matters into their own hands and launched Solar Mosaic in October 2010. The company embraces social responsibility, combining nonprofit sensibilities with for-profit enterprise and is no stranger to the solar movement—Parish co-founded and helped grow the Energy Action Coalition (energyactioncoalition.org) into the world’s largest youth organization focused on clean energy and climate solutions. And Rosen was named one of the “30 Under 30 in Energy” by *Forbes*.

Currently, Solar Mosaic is working almost exclusively with nonprofits but hopes to scale up and diversify its solar projects after attaining the necessary clearance to pay 6% to 10% annual returns on its solar investments. Due to securities laws, Solar Mosaic’s current projects operate under a zero-interest loan model—meaning that if someone puts \$100 in, they get \$100 back over the number of years specified in the project. However, Solar Mosaic is working with the U.S. Securities and Exchange Commission and hopes to launch its return product by the end of summer 2012. It remains to be seen how the returns will work into the equation and affect the rate structure for leases.

But Parish maintains that the model will still come out ahead of traditional lenders. “As an online marketplace, we don’t have the same overhead costs that banks do, so we can offer attractive returns to investors and still provide capital to develop solar projects at a lower cost than banks are able to,” he says.

As it stands now, projects benefit from leases that take advantage of available incentives, and are structured with lower interest rates than traditional bank financing—on average, 2% to 4% lower. Even after Solar Mosaic takes a developer fee from installers and a small percentage of lease revenue for the duration of the project, host organizations should see long-term savings—money that can be rolled back into their programs. With electricity rates predicted to rise 5% to 8% per year and the solar lease cost increasing by 3.5% annually, Solar Mosaic estimates that People’s Grocery should save more than \$30,000 in utility bills over its 20-year lease, even after paying back the investors.

Piecing Together a Solar Mosaic

Anyone—professional solar developers or private citizens—can bring an idea to Solar Mosaic, but not every project will qualify. Solar Mosaic vets each project on several parameters, most importantly the project’s potential to create jobs and clean energy. Another key factor is geography—projects in states where third-party financing is not allowed are automatically ruled out. Beyond having a good roof, the system host must have the financial security to pay the monthly lease payments to Solar Mosaic, which are then used to pay back the “crowd.”

Once approved, Solar Mosaic “coaches” the organization through the process of crowd-funding. Solar Mosaic works with the host and a NABCEP-certified installer to determine the system design and the level of funding required. With a design in place, the project goes live on the company’s website. There, people can read about the project, track the funding progress, and click to invest.

The minimum investment is \$25 and investors can pay using a credit card. In turn, they receive a portion of the proceeds from the system’s net generation until the original purchase price is reimbursed. Several protections help ensure that investors receive their target return, but as with any investment, there is some risk that investors will lose their principal purchase—either as a result of the system not performing as expected or the failure of the host to make their lease payments.

After 10 years, once all the investors have been paid back, the host site has the option to buy the system. In 20 years, Solar Mosaic will automatically transfer ownership to the host site. All of Solar Mosaic’s leases are structured such that the host site begins saving money on day one and makes lease payments at a significant discount to their normal utility bill.

Solar Mosaic is a for-profit, mission-driven company that was recently certified as a B Corporation (see article in this issue’s Circuit News & Notes). By negotiating lower costs with installers and ensuring capital efficiency, it is able to provide services without adding to the overall cost of projects.

With no return on investment for the short term, why would someone “invest” their money in a Solar Mosaic project? The idea is that people have the opportunity to support change. Member Ayla Schlosser, who invested in a now-completed 29 kW PV system for Oakland’s Asian Resource Center, says, “As a renter, I don’t have the option of installing solar panels on my own home. Yet I can still invest in the renewable energy solutions that I believe in with Solar Mosaic.”

—Kelly Davidson



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New Energy for an Old Barn



Courtesy Zeke Yewdall

My company, Mile Hi Solar, was hired to install a grid-tied PV system at an old homestead near Loveland, Colorado. It is one of the original turn-of-the-century farms in the area—its few acres now largely surrounded by suburban houses.

The only catch was that large cottonwood trees made just about all areas subject to too much shading for the size of the specified array. Only two suitably sunny locations existed—right in the middle of the front yard and on the roof of an old barn, built around 1910. The front yard was quickly ruled out, since it would block views from the house. So the question became whether the old barn structure could support the weight of a large PV system.

A structural engineer found the structure to be sound. Its rough-cut beams of high-quality wood even foiled some of our attempts to drive nails into them to build interior scaffolding to work from. The steep slope of the barn roof—36° on the shallow topmost section and 55° on the steeper section—also reduced the snow load engineering requirements.

With the engineer's stamp in hand, the second hurdle was how to work on a steep corrugated metal roof. Since we would be connecting our safety harnesses to the racks and walking on them a lot while building the array, they needed to be stronger than typical aluminum PV mounting rails. We designed a system using steel Unistrut bolted through the roof to another piece of Unistrut on the inside of the rafters, sandwiching the roof between them. For the topmost section, where the slope was not as steep and the force on the rails wouldn't be as great, Spax engineered lag screws secured the Unistrut Rails to the rafters. Where each bolt penetrates the metal roof, a steel spacer holds the rail off the roof surface; a neoprene washer, sealed with silicon sealant, is used against the metal roof. This is not suitable for a residential roof (we always use fully flashed feet rather than relying on sealant), but for the roof on this barn, which already had hundreds of random nail holes, our lack of flashing wasn't too concerning.

The three rows of modules each feed an SMA America SB2500 inverter. Since one row has a different slope (and thus will also experience a different insolation and temperature), having individual multiple power point tracking was advantageous. The three inverters tie into a subpanel, which is fed via a new, 400-foot-long, underground feeder that ties in at the utility meter at the pole. The existing feeder at the barn was at least 30 years old, and making it *Code*-compliant was more difficult than adding a new feeder solely for the PV.

—Zeke Yewdall • Mile Hi Solar

Overview

Project name: Parton PV Barn

System type: Batteryless grid-tied PV

Installer: Mile Hi Solar

Date commissioned: April 2012

City: Loveland, Colorado

Latitude: 40°N

Average daily peak sun-hours: 5.5

System capacity: 6.7 kW STC

Average annual production: 10,300 AC kWh estimated (PVWatts)

Average annual utility bill offset: 80%

Equipment Specifications

Number of PV modules: 30

PV manufacturer & model: Sharp 224 W polycrystalline

Module rating: 224 W STC

Inverters: Three SMA America SB2500 HFUS

Inverter rated output: 2.5 kW each; 7.5 kW total

Array installation: Custom mount on south-facing roof

Array azimuth: 180°

Tilt angle: 55° and 36°

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Sizing a Battery-Based Inverter

The battery-based inverter buyer's guide (in this issue) has a comprehensive list of inverters, and discusses how each specification affects system design. Here we detail the basic inverter *sizing* steps to select an inverter that has the capacity required to power to your AC loads.

The primary inverter specifications to consider for sizing are the inverter's continuous output rating and its surge capability. Inverter sizing is also affected by whether the application is off-grid or grid-tied with battery backup.

Off-Grid

For off-grid sizing, we simply sum the wattage of all AC appliances that might run simultaneously (the base load). Then we consider any appliances that might surge and add the cumulative surge watts to our base load to estimate the surge capacity requirement. Here is a simple example scenario. (You can either measure these individual appliances' power with a watt-meter, use their nameplate ratings, or contact the manufacturers.)

Inverter Loads

Load	Operating W (Base Load)	Surge W
10 CF lights, 15 W each	150	-
LCD TV	135	-
DVD player	15	-
Stereo	25	-
Refrigerator	100	300
Laptop computer	70	-
Microwave	1,400	3,000
Front-loading washing machine	600	2,400
Totals	2,495	5,700
Running Loads + Surge Load	6,095	

In this case, a 2,500 W inverter capable of surging to 50 A or greater at 120 VAC is needed ($6,095 \text{ W} \div 120 \text{ V} = 50.8 \text{ A}$). It is unlikely that all loads will be on and surging at the same time, so some folks may be less conservative in their surge estimates, especially if they can easily provide some load management—for example, not running the washing machine while using the microwave. With a household of more than one, this gets harder to control.



Courtesy Schneider Electric

Some inverters, such as this Schneider Electric XW model, can operate in either an off-grid or grid-tied system with batteries.

Battery-Based Grid-Tied Inverter

We need to consider the inverter's two operating modes: when the grid is connected, and when there is a utility outage. When the grid is available, these inverters will be limited to processing the PV array's power, so the inverter needs to be large enough to pass the available array wattage.

Let's say we have a 4.5 kW PV array. This array rating is at standard test conditions (STC), and actual output will likely be lower due to higher module temperatures and system inefficiencies. If that full power is available (say during cool, clear weather), it is desirable to have an inverter large enough to process all of it. Otherwise, a portion of the available power will be lost. We'd need an inverter with a minimum continuous output rating of 4,500 W.

When the grid is down, these battery-based grid-tied inverters will switch into off-grid mode to power only a critical load subpanel—which does not normally include all of a home's loads. Let's assume that the critical load subpanel has the same load profile as our off-grid system. An inverter with a 4,500 W continuous output rating will meet our critical base load requirement of 2,495 W. As long as the 4,500-watt inverter has a surge rating of about 50 A or greater, we are covered.

—Justine Sanchez



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Solar Charging

I decided to add a solar charger my 1956 Chevy truck—a 2-ton flatbed used for hauling firewood and brush. It will hold five cords of wood in one load, and two loads is good for my year's heating. I hope that after some better insulating of the house, one load will be sufficient. The truck gets used maybe six to eight days a year, so it spends most of its time just sitting. The starter battery tends to go dead after a few months, and I decided to do something about that.



Courtesy Zeke Yewdall

I added an old 75-watt solar-electric module (late 1990s vintage, from an upgraded system), a deep-cycle AGM battery to replace the starter battery, and a Morningstar Sunlight-10 charge controller. This charge controller is a PWM charge controller and also has a built-in lighting controller, using the PV as the light sensor. We've used a number of these on driveway lighting systems; they can be set for various numbers of hours of light after darkness, or both in the evening and morning (it remembers when morning was the previous day and bases the pre-dawn activation on this). I've hooked the DC output of the lighting control to the input of a small (100-watt) inverter, which powers a string of LED lights around the top of the truck.

While I was at it, I added a Square D QO-series breaker box, since this truck had *no* fuses in it anymore. These breakers are rated for up to 50 VDC, so they work great on a 12-volt system. On a truck this big, it was no problem finding room under the hood to stick the box.

It's not the most efficient scheme in the world, because, rather than optimizing the design, I used a lot of parts I already had. The charge/lighting controller was the only new purchase. The inverter has a cooling fan that runs all of the time, so it's drawing around 4 watts by itself, about the same as the string of LED lights. The 75 W module is overkill for running an 8-watt load all night, though, so it works out fine.

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Since 1999, SunDanzer has built and sold refrigeration products especially designed for use with solar power. To learn more about SunDanzer products, including our new battery-free unit, contact your solar products dealer or find us online at www.sundanzer.com.

Setups like this—usually with around a 5 W to 10 W module, and Morningstar’s tiniest Sunguard charge controller, if you were to buy new components—are very good for maintaining starter batteries on rarely used farm vehicles. The cost of a small module and charge controller is similar to a new battery for many tractors and larger trucks, so if it saves replacing the battery once, it has paid for itself. Of course, you can always take the battery out during the off-season and bring it into the shop for trickle charging. But having a module mounted on the vehicle is a much less labor-intensive way of making sure that old truck or tractor you keep out in the back 40 will start six months from now, the next time you need it.

Zeke Yewdall, Mile Hi Solar •
Loveland, Colorado

Sun Data

Now that there are many solar-electric (PV) systems with data acquisition systems, it should be possible to paint a picture with real data of kWh per year production per rated watt of PV. Here in southwest Michigan, one of our systems just recorded 1.4 kWh per year per rated watt! (Disproving the notion that solar “does not work” in Michigan!)

It would be helpful to know how this compares with other places. Perhaps other readers could share their direct experiences.

Dan Alway • via email



Early Home Power Author Uses RE 'Til the End

Just dropping y’all a line and letting the ol’ timers on your staff and readers know that my father, Gerald L. Ames Sr., passed away at his renewably powered home in Okanogan, Washington, earlier this year at the age of 75.

He wrote “A Working Wind/PV System” in *HP4* and “Charging Batteries Can Be A Gas” in *HP6*.

The system he built is still operational. It has had a few battery changes along the way, but the main system is still going at 24 years, folks. Keep up the great work, and long live *Home Power* magazine.

Jay Ames (Gerald L. Ames Jr.) • via email

write to:

mailbox@homepower.com

or Mailbox, c/o Home Power
PO Box 520, Ashland, OR 97520

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altE customer, Jesse, began his solar powered cabin, over half of it made from recycled/reclaimed materials, as a home-school "senior project" in 2007. He has been adding to and improving his cabin ever since, turning it into a year-round home in Maine. Jesse's next plans for his system include an MPPT charge controller and four additional PV modules!

"My hope is to inspire other young people to build their own homes too, as a means of survival and learning useful skills, but also to discover how much (or how little) a person really needs to live," says Jesse.



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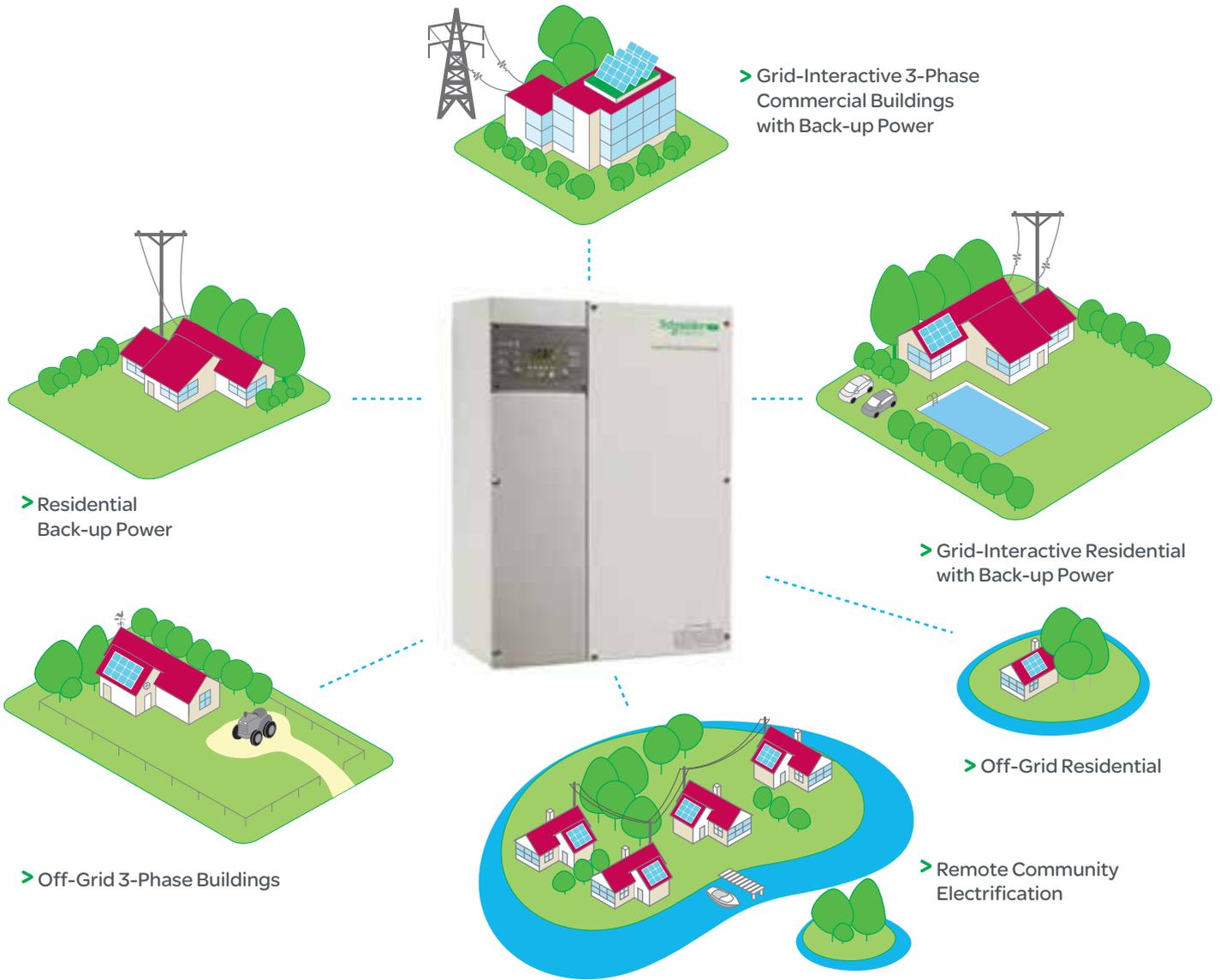
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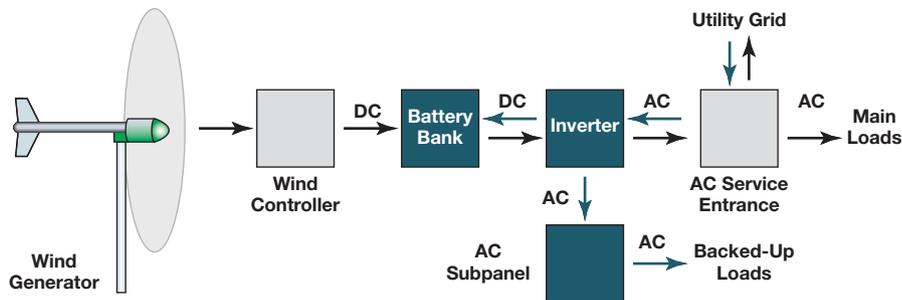
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Grid-Tied Wind with Battery Backup

I am searching for information about a grid tied wind-electric system that also has battery backup. There doesn't seem to be a lot of information out there on this particular setup. Have you heard of people doing this?

Zac Luhellier • via email



Any battery-charging wind generator can be part of a grid-tied battery-backup system, and this is very common. The models in our “Wind Turbine Buyer’s Guide” in *HP137* that show 48 volts as an option will be best for a modern North American home.

Perhaps you are already familiar with *batteryless* grid-tied systems, which couple a specific wind generator to a specific inverter—the two *must* be matched. Only a handful of wind generator manufacturers have done the design work to customize a specific inverter to work safely and effectively with their wind generators. Batteryless wind is definitely *not* a situation where you can buy a wind turbine and then go shopping for an inverter. You should buy the two together, from a reputable source.

But you asked about *battery-based* grid-tied systems, which is a very different situation. In that case, the charging source is not directly matched to the inverter. It simply charges a battery bank. You’ll want to size your battery bank for your backup needs, and make sure the charge controller for your charging source has an output voltage compatible with your battery bank.

The inverter in a battery-based grid-tied system is not directly coupled or matched to the charging sources. It only needs to be large enough to handle the total charging wattage of your sources, so it will be able to send excess energy back to the grid even in times of peak production. The inverter, of course, also needs to be able to have the capacity to run all the backup loads you might want on at one time (see “Sizing a Battery-Based Inverter” in this issue).

You could have multiple charging sources putting energy into the battery bank and one inverter selling to the grid. You could also have one charging source and multiple inverters selling to the grid. The specific configuration will depend on your situation.

Batteryless systems require expertise and education to design and install; battery-based systems need even more of both, since these systems and their electronics can be quite complex. Work with an experienced designer and installer to get what you want.

Ian Woofenden • *Home Power* senior editor

Off-Grid Source Choice

I am getting ready to build on my off-grid property in New England. The property has abundant renewable resources, and I’m having a hard time deciding on how to prioritize. Here are some facts and estimates I’ve gathered:

- 3.3 average daily peak sun-hours, with minimal shading at my site
- 8–9 mph average wind speed estimated on a 120-foot tower, 40 feet above the tops of the mature trees
- A stream with 30 feet of head over 400 feet, about 40 gpm available year-round, with the potential turbine location about 750 feet from the house site

I’ve heard and read in *Home Power* and elsewhere that hydro is “best,” wind is really hard to keep going, and solar electricity is more expensive up-front, but very reliable and perhaps the best buy in the long run. Of course, since I’m off-grid, I may need multiple sources.

My load is not firmly determined, but I’m pretty thrifty with energy, using only 8 kWh per day in my small city home. I intend to buy super-efficient appliances; I don’t need every gadget; and I expect that my off-grid home’s usage will not exceed my city usage, but may be somewhat less. I’ll heat with wood exclusively, unless there’s excess energy from the renewable energy system.

I’m getting ready to crunch some numbers, but without a great deal of experience at this, I’m wondering what I’m missing, and

seeking expert advice. Perhaps you could use my example to give *Home Power* readers some perspective on the choices involved, so others can avoid costly mistakes and misconceptions. I’m wondering where my dollars will best be spent, what will be the best for my personal environment and the global environment, and what will give me the most personal satisfaction.

James Barber • via email

It’s a pleasure to deal with such a clearly documented case. The most important design parameter is target energy (8 kWh per day), although it’s also important to allow for losses. Energy is lost in the wires, battery, inverter, and dump loads, so you may need to generate, on average, about 12 kWh per day. If the cost of the system becomes daunting, check where exactly this energy is going—you may find it’s cheaper to save some of that energy than to generate it.

Hydro is likely to be the lowest-cost source. Plus, it also works at night and in winter, reducing battery usage. You can estimate the power available from hydro (in watts) by multiplying the head by the flow and dividing by 10. For your scenario, a well-built system could yield 120 watts. Over 24 hours, this would amount to $120 \times 24 \div 1,000 = 2.88$ (or conservatively 2.5) kWh per day. I suspect that you may have access to twice that flow for useful periods of time, and the extra cost of pipes and wires that can handle 300 watts would be small in relation to the benefits. If you go with a solar/hydro-electric hybrid system, the extra kWh in wet weather would be especially welcome as your solar production decreases. Popular brands of Pelton or turgo turbines have multiple nozzles so you can set the flow to a level that the source can sustain.

Although a 3-inch bore pipe will work well at 40 gpm, a 4-inch pipe would reduce the pipe loss from 12% to 3%, and also open the door to 100 gpm or more, when available. With only 30 feet of head, you can probably use a thin-walled pipe to reduce cost.

The transmission cable is quite long at 750 feet, so losses due to resistance have to be considered. A 48-volt battery system has one-fourth the wiring loss of a 24 V one. Consider using an even higher-voltage turbine connected via a maximum power point tracking (MPPT) controller, provided you have a voltage clamp to prevent the turbine voltage from going wild. MPPT also deals automatically with changes in flow, avoiding the need for manual adjustments to tune the alternator for changing conditions.

Solar electricity (PV) is the next option, and the good news is that the prices are falling. A PV system will complement the hydro system, as it works best in dry, sunny weather, but production could be disappointing midwinter. Assume you will get about 70% of the "peak" rating. For example, with 3.3 peak sun-hours on a 3 kW array, expect about 7 kWh per day. Again, MPPT can help improve this picture somewhat.

Wind power would be interesting and might be fun for you, but in your case it has little

else to recommend it. The 120-foot tower is likely to be expensive and the energy produced at your wind speeds won't be much. Wind is an erratic energy source that puts big demands on the batteries and the backup generator. You need more energy for your system, especially in winter, but in terms of the effort and cost, wind is the more expensive and difficult choice for your site.

Check the *Home Power* wind buyers' guides for 2010 and 2011 for a comparison of turbines, but be aware that manufacturers' energy production figures tend to be optimistic. Note that you would get twice the energy in a mean wind speed of 11 mph compared to your 8 or 9 mph. You can find the daily average kWh by dividing the annual production by 365. However, on many days you will get next to nothing; other days you may be dumping surplus energy.

Whatever sources you choose, you will need an efficient backup engine generator. Try to minimize its use, but you may need it to rescue your batteries and keep the system up and running when conditions conspire against you. If your hydro source is truly year-round, and you are willing to drastically reduce your usage at times, you might avoid using a backup generator.

The final decision about how to split your investment between these different sources will take more research. Use the wisdom of your local installers, and check out their pricing for the systems to figure out the costs per kWh. Your biggest decision, whether a wind turbine suits your marginal site, perhaps belongs more to your heart than your head (but make sure you know what to expect before taking the plunge). It's much more satisfying to watch the battery voltage rising on a windy night and not to hear the drone of an engine.

Hugh Piggott, Scoraig Wind-Electric • Scoraig, Scotland

Overheating SHW System

I have an evacuated tube (30-tube) solar water heater that produces more hot water in the summer than we need. I have a Steca differential control that has a setting to circulate the antifreeze to cool the tank if it gets too hot. According to the control instructions, it is supposed to circulate the fluid at night to cool the tank. It seems to turn on and circulate for hours but it loses very little, if any, heat overnight like the instructions claim. Do you have any idea what is wrong?

Bill Noyes • Winnipeg, Manitoba

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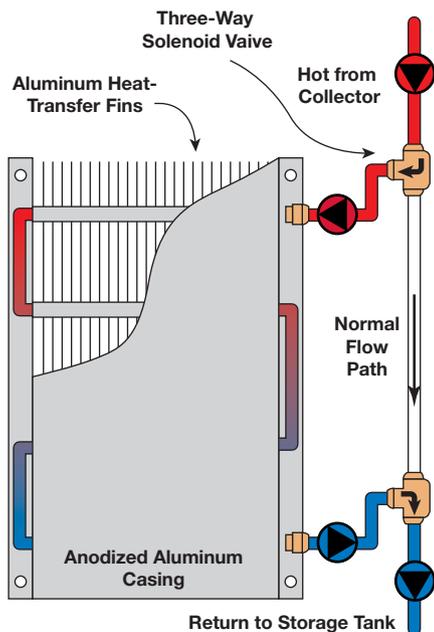
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Apricus Heat Dissipator



The vacation mode built into some hot water controls does work—but *not* with evacuated tubes. The recirculation heat dissipation is effective with flat-plate collectors because they only have a single sheet of glass as insulation on the front of the collector, and the plates can readily lose the excess heat.

The vacuum insulation in evacuated tubes that provides enhanced performance in cold, cloudy weather hinders reradiation losses. In addition, most tubes sold in North America

today use a heat pipe inside the tube to collect the solar energy and transfer it to the manifold at the top of the collector. The heat-transfer fluid is then circulated to a heat exchanger and into the storage tank. Heat pipes don't work in reverse, and this prevents any reradiation in tubes of this type.

Apricus makes a heat dissipator to help prevent summer overheating in evacuated-tube systems. The heat-transfer fluid from the collector(s) is diverted to the dissipator/radiator (liquid-to-air heat exchanger) when the fluid temperature is above 170°F. The dissipator and other overheating solutions are the subject of an article in *HP142*.

An Apricus heat dissipator.



Courtesy Chuck Marken

Chuck Marken •
Home Power thermal editor

write to:

asktheexperts@homepower.com

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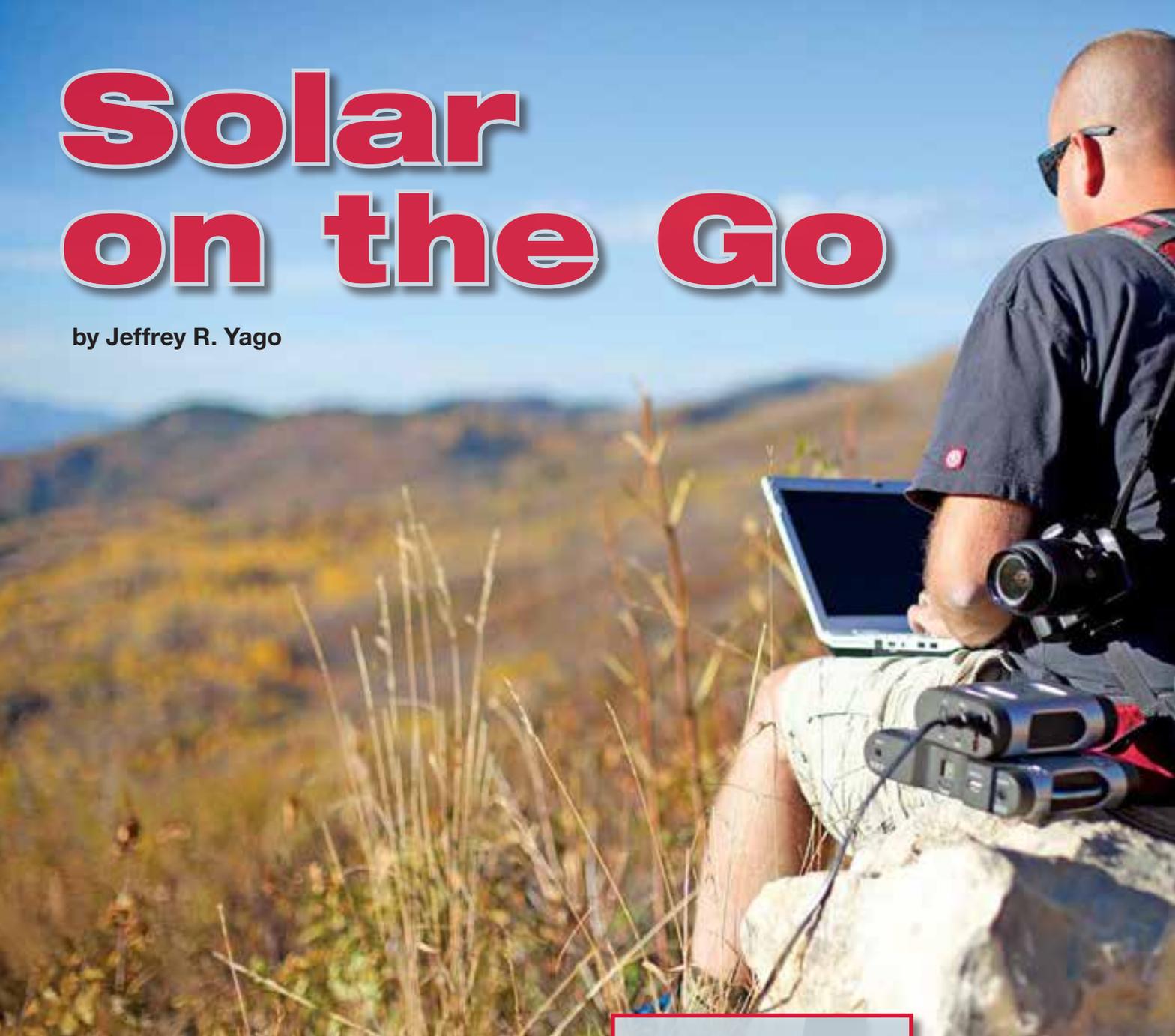


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Solar on the Go

by Jeffrey R. Yago



When PV modules were first introduced to the mainstream market, the only electronic equipment most of us carried around was a transistor radio. Today, our tablespots are starting to look like miniature power substations, with electronic appliance battery chargers filling every wall outlet.

PV technology can meet the demand for keeping our electronic tablets, e-readers, digital cameras, media players, games, cell phones, and laptops operating during a power outage, or while traveling on business or tromping around the back woods.

PowerFilm

60 W Solar Charger

Power rating: 60 W

Price: \$1,000

Weight: 3.19 lbs.

Size: 13.25 x 7 x 2 in. (folded);
51.5 x 47.5 x 0.125 in. (unfolded)



Courtesy PowerFilm Solar

GoalZero

Guide 10 Plus Adventure Kit

Power rating: 7 W

Battery capacity: 10 Wh

Price: \$160

Weight: 1 lb.

Size: 6 x 9 x 1 in. (folded); 17 x 9 x 0.1 in. (unfolded)

Fold-Up PV Modules

Some reasonably priced, off-the-shelf flexible PV modules can run or charge small appliances or keep a few battery-powered LED lights operating whether you're trekking in the city or backpacking. These fold-up modules do not have a battery, so are used to recharge the batteries in devices that can accept 12 VDC.

Fold-up solar modules in the 5 to 10 W range are used to recharge smaller electronic devices including cell phones, e-readers, and media players. Those in the 25 W range are well-suited for powering tablets and small laptop computers. Several manufacturers now offer fold-up PV modules in sizes over 60 watts to power larger loads, including radio and satellite communication equipment when hiking or camping in remote locations.

Portable Solar Power

"Pocket Panel" Portable USB Phone Charger

Power rating: 6 W

Price: \$100

Weight: 13.2 oz.

Size: 7 x 4.52 x 1.37 in. (folded);
7 x 21.65 x 0.12 in. (unfolded)



Courtesy Global Solar

Courtesy GoalZero

Global Solar

Sunling Series

Power rating: 2 – 62 W

Price: \$100 – \$1,000

Weight: 0.25 – 3.2 lbs.

Size range: 9 x 5 in. to 8.5 x 14.5 in. (folded);
9 x 14 in. to 30 x 52.5 (unfolded)



Solar-Powered Backpacks

Several manufacturers are incorporating flexible PV modules into almost anything—including jackets, backpacks, fanny packs, purses, and briefcases. Even the smallest versions include adapters to charge multiple electronic devices, and there are lots of colors and styles to choose from.

A typical backpack or briefcase has limited surface area to attach a flexible solar module, keeping most to about 10 W. However, backpacks have interior space to include a built-in battery, which is being charged when not energizing other devices. Some store enough energy to be used even at night to recharge smaller electronic devices. Solar backpacks also include a cigar-lighter-type auxiliary socket. This is the standard connector for powering portable electronic devices, which often come with a 12 V vehicle charging plug.



Courtesy Innovus Designs

Innovus Designs

Eclipse Solar Backpack

Power rating: 4 W

Price: \$180

Weight: 2.5 lbs.

Size: 18 × 14 × 8.75 in.

Suitable for charging: Portable handheld electronics, smartphones

Voltaic Systems

Array Solar Laptop Charger

Power rating: 10 W

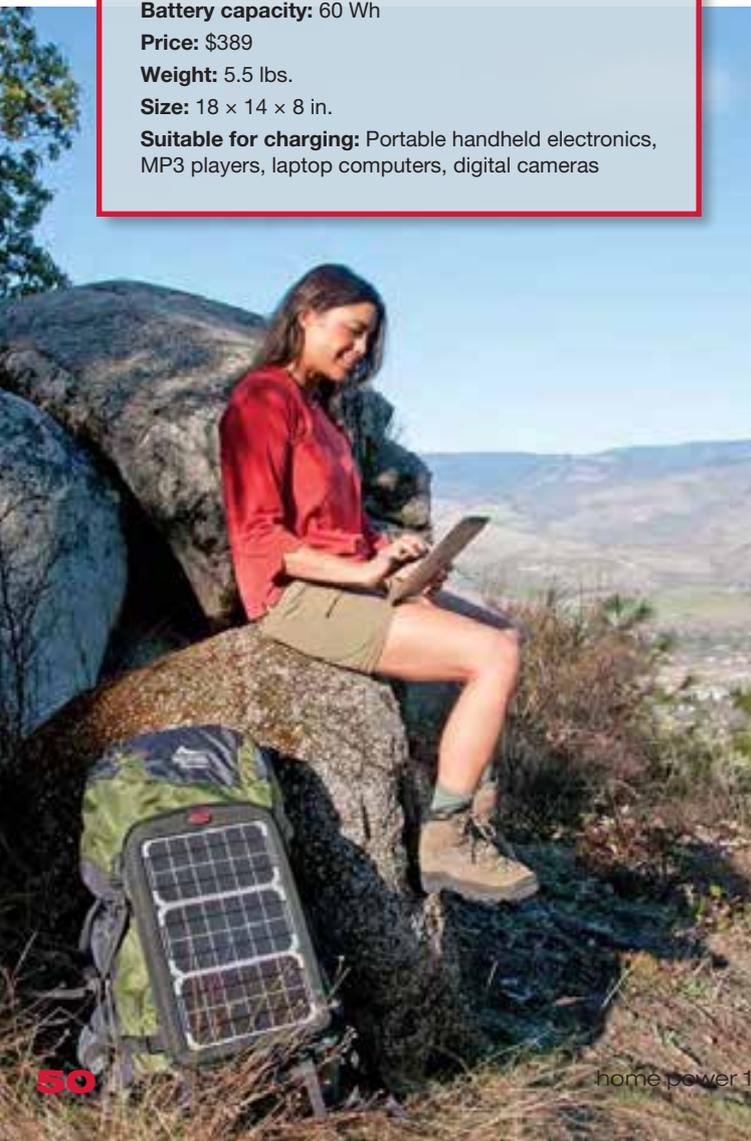
Battery capacity: 60 Wh

Price: \$389

Weight: 5.5 lbs.

Size: 18 × 14 × 8 in.

Suitable for charging: Portable handheld electronics, MP3 players, laptop computers, digital cameras



Shawn Schreiner

PV Carts

Adding a deep-cycle battery to any portable PV system can extend its utility. However, batteries with enough energy to operate larger tools, computers, and small appliances for a significant amount of time are heavy. In addition, some electronic appliances may have built-in battery chargers that require 120 VAC.

Portable solar systems in this midsize range are mounted on a hand cart or suitcase with wheels, as their batteries can weigh 60 pounds or more. Adding an inverter gives the ability to power AC loads. Since a cart-mounted PV system could be in a variety of positions and be used in a confined area, sealed batteries are typically used to avoid spilled acid and vented gas.

Recent electric-vehicle research to reduce battery weight and increase energy density has produced batteries that are also suitable for PV carts. Lithium-ion batteries allow a full discharge and fast recharge time for thousands of cycles. The amazing amount of energy that these lightweight batteries can store means they are ideal for portable systems.

Until now, condo or apartment dwellers have been unable to use PV systems, either due to lease restrictions on installing permanent arrays or having battery banks in buildings shared by others. Now if the grid goes down, they can roll outside a PV cart from the closet and use an extension cord to energize their TV and lights after a power outage.

Universal Power Group

Ecotricity Eco 1800S

Inverter power rating: 1,800 W

Battery capacity: 720 Wh

PV module rating: 90 W

Solar-charging time: 12 hrs.

Price: \$1,595

Weight: 120 lbs.

Size: Modules—42.75 × 24.5 × 1.37 in.;
generator—19.5 × 8 × 11.5 in.



Courtesy Universal Power Group

SunRNR

Sun110

Inverter power rating: 3,500 W

Battery capacity: 2,952 Wh

PV module rating: 135 W
(expandable to 270 W)

Price: \$3,800

Inverter/battery enclosure weight: 260 lbs.

Inverter/battery enclosure size: 28 × 15 × 30 in.

Module size: 56 × 26 × 2 in.

Module weight: 27 lbs.



Courtesy SunRNR

Xantrex

XPower Powerpack 1500

Inverter power rating: 1,350 W

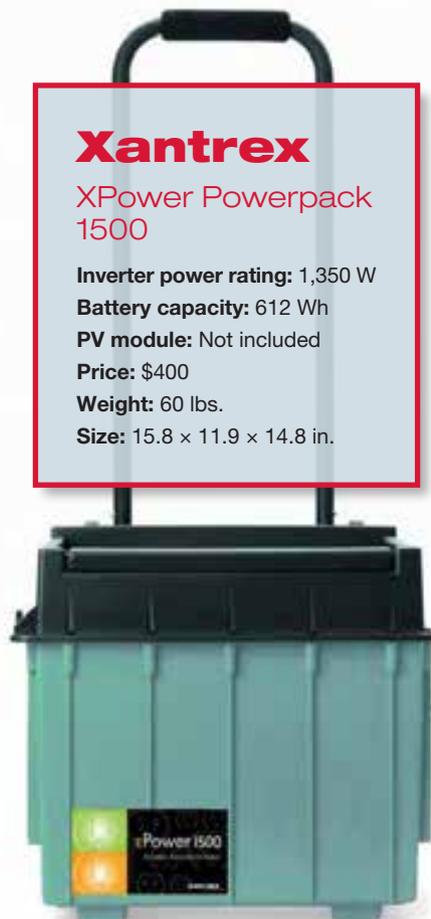
Battery capacity: 612 Wh

PV module: Not included

Price: \$400

Weight: 60 lbs.

Size: 15.8 × 11.9 × 14.8 in.



Courtesy Xantrex

Sol-Solutions

SolMan Classic

Inverter power rating: 1,500 W

Battery capacity: 3,600 Wh

PV module rating: 420 W

Price: \$5,000

Weight: 275 lbs.

Size: 51 × 32 × 45 in.



Courtesy SolSolutions

PV Trailers

If your portable solar power needs are larger, some manufacturers offer PV-powered trailers that can even include a backup generator. The smaller units are usually the size of a pop-up camper.

Smaller solar trailers cost less than \$5,000. Their array and battery are sized to be towable by a car or SUV. These trailers are ideal to power smaller 120 VAC loads that may be needed for extended camping trips, remote construction sites, or emergency power for lights and communications equipment.

For heftier needs, there are manufacturers that custom-build solar trailers in sizes that require a large pickup truck to tow and can cost \$90,000 or more. They are better suited for commercial and government emergency power needs, or used as rental units which are towed from event to event to help offset their high initial cost.

The largest solar power trailers have tons of deep-cycle batteries and a heavy-duty backup generator to recharge the batteries when the sun is not available. These units are great for emergency communications equipment at disaster areas, remote television broadcasts, or for temporary lighting and audio/video equipment.

GreenTow

GT916

Inverter power rating: 7,200 W

Battery capacity: 24,768 Wh

PV modules: Twelve 135 W modules

Price: \$57,900

Weight: 4,100 lbs.

Size: 9 ft. long x 5 ft. 10 in. wide x 6 ft. tall (with modules stowed)

*120/240 VAC output; optional onboard diesel generator



Courtesy GreenTow

Mobile Solar Power

MS-150

Inverter power rating: 3,500 W

Battery capacity: 15,048 Wh

PV modules: Three 220 W modules

Price: \$19,450

Weight: 2,000 lbs.

Size: 8 ft. long x 5.5 ft. wide x 6 ft. tall (with modules stowed)



Courtesy Mobile Solar Power

Patriot Solar Group

Andromeda 2000

Inverter power rating: 2,500 W

Battery capacity: 9,600 Wh

PV modules: Two 240 W modules

Price: \$12,730

Weight: 2,000 lbs.

Size: 116 in. long x 62 in. wide x 37 in. tall (with modules stowed)



Courtesy Patriot Solar Group

The Smallest Solar Chargers

Beyond backpacks and trailers, PV modules are showing up in other interesting places—from pocket-sized solar chargers to bicycle rack bags—making charging on the go suited to almost any lifestyle. A few of these products caught our eye:

- **Innovus Designs'** Eclipse Solar Gear Nomad Bicycle Trunk Bag (\$100) and **G24i's** Bicycle Panniers (\$150)—Made to mount to a standard rear bicycle rack, the Nomad solar charger can top off your smartphone or spare batteries while you ride. G24i's products mount just like typical panniers.
- **Power Traveller's** Solargorilla (\$220) and Solarmonkey (\$50) and **Solio's** Bolt (\$70)—A tough, rubberized casing protects

the PV modules inside the Solargorilla. Pop it open, plug in your portable electronic device, and place it in the sun to start charging. At 1.8 pounds, it won't weigh you down. The tiny Solarmonkey will keep your mp3 player or cell phone charged on the fly, and it's small enough to slip into your pocket. The Bolt is another little solar module that can charge your personal electronics. Inserting a pencil through the center hole gives it a stand and makes it into a sundial to help orient the unit for optimal solar charging.

- **Simply Brilliant/SolLight** makes a handheld solar charger (Solicharger-SP, \$60), but its LightCap 300 (\$30) solar-powered lantern/water bottle/waterproof container is strictly for light.

Solar Gorilla



Courtesy Power Traveller; Solio

Bolt



Solicharger-SP



LightCap



Courtesy SolLight(2)

Understanding Your Needs

Before purchasing (or building) a portable PV system, it's important to estimate the battery drain for the loads you want to power. For systems that include a 120 VAC inverter, you must first convert the power requirements from "watts" into a battery "amp" load. This battery draw can be high for a microwave oven or hair dryer. Any electrical load operating at 120 VAC will require 10 times the amperage at 12 VDC, and the inverter's efficiency losses must be accounted for.

The table provides both the watts and corresponding battery amp draw for the most common appliances, lights, and computer equipment used with portable PV systems. You will find these values to be more accurate for estimating your true solar battery run time, as they are based on real measurements.

For example, an iPad consumes 11 W of 120 VAC, which is a 1.06 A drain on a 12 V battery, the most common battery voltage for smaller portable PV systems. You can divide the amp values by 2 for systems having a 24 V battery, or by 4 for a 48 V battery bank to find their current draw.

Powering the iPad for four hours requires 4.24 amp-hours of battery capacity (1.06 A × 4 hrs.). (The table values already include a 15% inverter efficiency loss.) To meet this daily electrical load, let's assume you have six hours of bright

Typical Appliance Power Requirements

Appliance	Power (Watts)	Measured 12 V Battery Draw (Amps)*
DVD player	4	0.38
Cell phone charger	4	0.38
Radio	5	0.48
Light, 7 W LED	7	0.67
Tablet computer	11	1.06
Satellite receiver (off = 13 W)	15	1.44
Printer, inkjet (idle = 2 W)	15	1.44
Light, 13 W CFL	15	1.44
Computer monitor, LCD	22	2.10
Light, 25 W CFL	27	2.59
Laptop computer	34	3.26
TV, 21 in. LCD	38	3.70
Battery charger, drill	62	5.90
Light, incandescent	75	7.20
Wood heater blower	90	8.60
Light, incandescent	100	9.60
Fridge/freezer, 19 c.f. (peak = 300 W)	125	11.90
Desktop computer (idle = 85 W)	140	13.40
PA amplifier, 300 W	150	14.40
Computer projector (idle = 16 W)	260	24.90
Well pump, 1/2 hp (surge = 1.1 kW)	535	51.30
Hair dryer	745	71.40
Microwave, compact	1,030	98.70
Coffee maker, drip	1,070	102.50
Microwave, standard	1,350	129.40

*Assumes 15% losses through inverter supplying 120 VAC power from a 12 VDC battery.

Portable Power Products

Manufacturer	Small Solar Chargers	Flexible PV Modules	Backpacks/ Briefcases	Small Wheeled Units w/Integrated Battery	PV Trailers
Brunton Outdoor Group bruntonoutdoor.com	✓	✓			
Ecowatt ecowatt.com			✓		
G24 Solar Innovations g24i.com	✓		✓		
Global Solar Energy globalsolar.com		✓			
Goal Zero goalzero.com		✓	✓	✓	
GreenTow greentow.com					✓
Horizon Fuel Cell Tech. horizonfuelcell.com	✓				
Humless Power humless.com	✓				
Innovus Designs eclipsesolargear.com	✓		✓	✓	
Mobile Solar mobilesolarpower.net					✓
Patriot Solar patriotsolargroup.com	✓		✓		✓
Portable Solar Power Biz portablesolarpower.biz	✓	✓		✓	
Power Traveller powertraveller.com	✓				
Powerenz powerenz.com		✓		✓	
PowerFilm Solar powerfilmsolar.com	✓	✓			
Reware rewarestore.com		✓	✓		
Sol Solutions sol-solutions.com				✓	
Solar Components solarjoos.com	✓				
Solio solio.com	✓				
SolLight sollight.com	✓				
Solutions from Science solutionsfromscience.com				✓	
SunRNR sunmr.com				✓	
Universal Power Group universalpowergroup.com				✓	
V-Dimension v-dimension.com			✓		
Voltaic voltaicsystems.com	✓		✓		
Wagan wagan.com	✓			✓	
Xantrex xantrex.com				✓	

sun to recharge the battery. This means you will need a PV module that can provide a minimum of 0.71 A output (4.24 Ah ÷ 6 hrs.). However, to account for the miscellaneous efficiency losses during this charging process, I have added a 15% loss factor, which rounds this up to 0.8 A. Since the nominal 17 V PV module voltage will vary between 14 and 17 V as the battery voltage starts to rise, this means that the PV module will need to be rated at a minimum of 14 W (0.8 A x 17

Early Portable PV

My first experience with portable PV goes back to the 1990s, when I was designing off-grid residential PV systems. Most of the installations were in remote areas, and we wanted generator-free temporary power for tools. I took a 6- by 12-foot enclosed utility trailer and installed a 1,000 W PV array on the side with hinges along the roofline, which allowed easy fold down for travel. An interior wall-mounted 2,500 W inverter, charge controller, and eight L-16 deep-cycle batteries completed the trailer. I later added a SunFrost DC refrigerator, microwave oven, work counter, utility sink, and composting toilet. Spending days working on a remote mountaintop suddenly became much more civilized.

Although I only intended to use this solar trailer for temporary power at construction sites, a year later I received a call from an agent of a well-known actor who was hosting a rally at his rural property to protest the utility's plan to run a high-voltage power line through the area.

The actor and his neighbors understood the irony of using the power company's electricity to power an event to protest against the same power company and were looking for alternatives. They were also concerned that a noisy generator might interfere with the speeches and live music. They had heard about my PV trailer and called to see if they could use it to power the tent lights and sound system for their two-day event.

The solar trailer was also used to power the public address system at an outdoor energy fair. I recall to my horror how the solar batteries were losing charge much faster than I expected, right in the middle of the featured speaker's presentation. I feared a total system failure was only minutes away, and headed out to follow the multiple extension cords from the solar trailer to the distant event's tent. Halfway along this path I discovered a recently added extension cord—heading off in a totally different direction. As I stumbled through the dark following the wire, I finally reached a brightly illuminated doughnut concession trailer. The fry cook was happily making piles of hot doughnuts in the electric deep fryer for the hundreds of attendees, and had no idea he was running off my batteries!

Since this early experience with making solar doughnuts, my PV trailer has been loaned out to national scouting events and energy fairs, and is still used occasionally at remote construction sites. Through these experiences I have learned the importance of identifying the energy and power limitations of a portable PV system.

If you're planning to purchase or build a portable PV system, first decide exactly what will be powered and for how long. Most organizers will seriously underestimate the event's actual power requirements so be sure to take a careful inventory of their loads before taking on a project of this kind.

Have you built a portable PV system? Email your photos & story to submissions@homepower.com

V). For small electronic devices, it is always more efficient to use a 12 VDC charger, if available, to avoid inverter efficiency losses. A PV module twice as large will cut the charge time in half—from six to three hours—so keep this in mind when comparing systems with different wattage modules.

Watching Watts

Selecting a portable PV system can be confusing, since there are no standards for rating this type of equipment. In addition, some people just do not understand how much electrical energy an appliance consumes when it operates, since their only experience with electricity is plugging into a wall outlet—a practically unlimited amount of energy.

Some marketing hype claims that their products can power all kinds of household appliances, including refrigerators, microwave ovens, desktop computers, and household lighting. Although it may be theoretically possible to power these large loads if the inverter is large enough, the actual battery capacity may be for minutes—not hours or days. To keep production costs low, some manufacturers may provide a very small PV module to recharge their higher-capacity battery, which means it may take days to recharge the battery after it powers a large load for only a few minutes.

When trying to sort out all these advertising claims, you will find few terms in common. Some product advertising includes helpful amp-hour ratings for battery capacity, others may provide battery capacity in “joules,” or worse, may not provide any battery capacity information at all.

That large “joule” rating advertised for one system’s battery seems hundreds of times higher than the watt-hour ratings listed for the competition. However, a joule is just a “watt-second,” so a battery that provides 30 watt-hours of standby power would have a rating of 108,000 joules (30 Wh \times 60 min./hr \times 60 sec./min.). The same 30 Wh rating for a 12 V battery equals 2.5 Ah if totally discharged, but only 1.25 Ah if discharged to a more realistic 50% rate, so you can see how this can be very misleading.

Regardless of which portable solar power system you need, there are now many different sizes to pick from. The recent drop in the cost of PV modules is making them even more affordable, and newer battery types are helping to keep the weight down.

Access

Jeff Yago (pvforyou.com) is an engineer and certified energy manager in Virginia, and has more than 35 years of experience in the solar and emergency preparedness field. He is a NABCEP-certified PV installer, and has authored numerous articles and texts.



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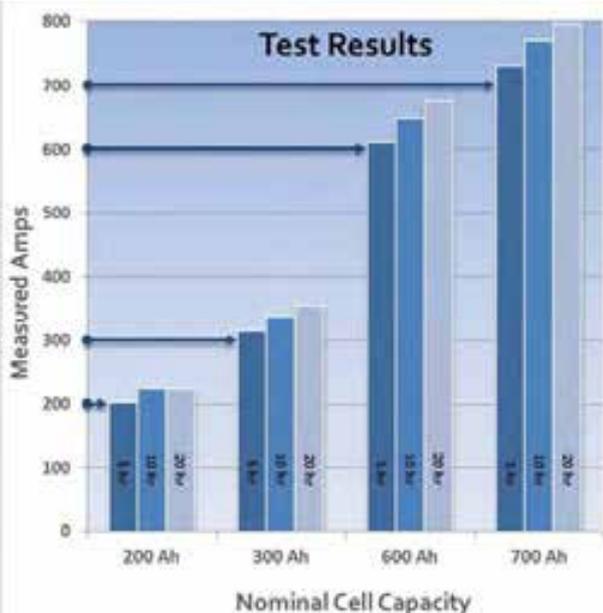
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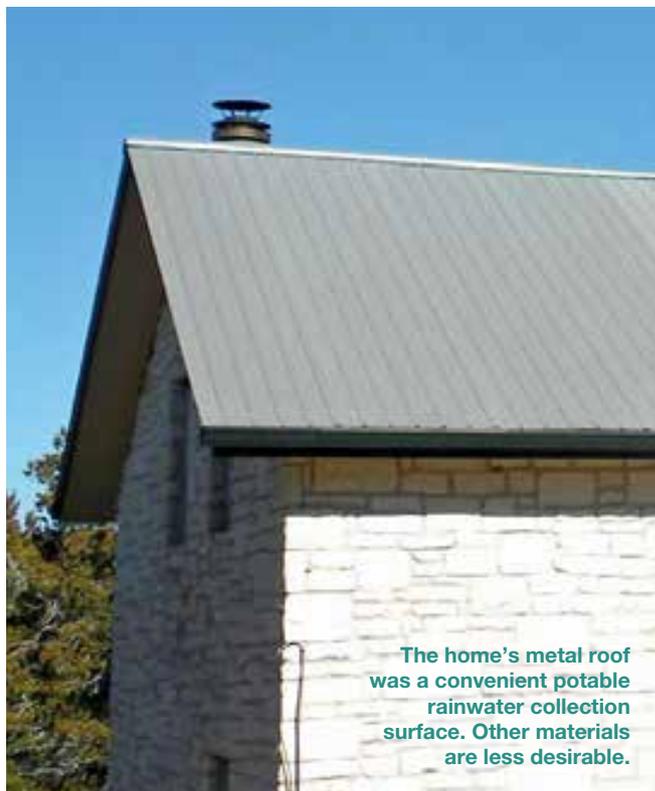
by Stephen Hren

Nancy Poage-Nixon's 5,000-gallon rainwater storage tank provides potable water throughout the year.

What do you do when your well runs dry? This proverbial question had real consequences for Nancy Poage-Nixon in Oak Hill, Texas, in the Hill Country outside of Austin. Development was encroaching from the east, and new subdivisions were drilling wells, tapping the already-stressed Edwards Aquifer. Although in its 28 years Nancy's 438-foot-deep well hadn't had any problems, in the summer of 2006, not a particularly dry year, its flow stopped.

Until then, Nancy had survived just fine with her well, although she'd never been particularly fond of the water that came out of it. The presence of sulfur meant that the tap water would often smell like rotten eggs. The water coming out of the karst limestone aquifer is also very hard, with a large amount of calcium and magnesium carbonates dissolved in it. This can have deleterious effects on household plumbing by building up in pipes and appliances, from hot water heaters to coffee pots, often shortening their lifespan. Hard water also doesn't take soap well (it is "hard" to lather), making cleaning more difficult.

Previous to the drought, Nancy had installed a 1,200-gallon above-ground storage tank with an aerator to help pull the sulfur out of the well water and make it more palatable. Also before the drought, she had replaced her asphalt roofing with a new metal roof to help reflect sunlight and reduce home cooling costs. These two installations were going to be



The home's metal roof was a convenient potable rainwater collection surface. Other materials are less desirable.

Courtesy: Nancy Poage-Nixon (2)

Courtesy Innovative Water Solutions LLC. (2)

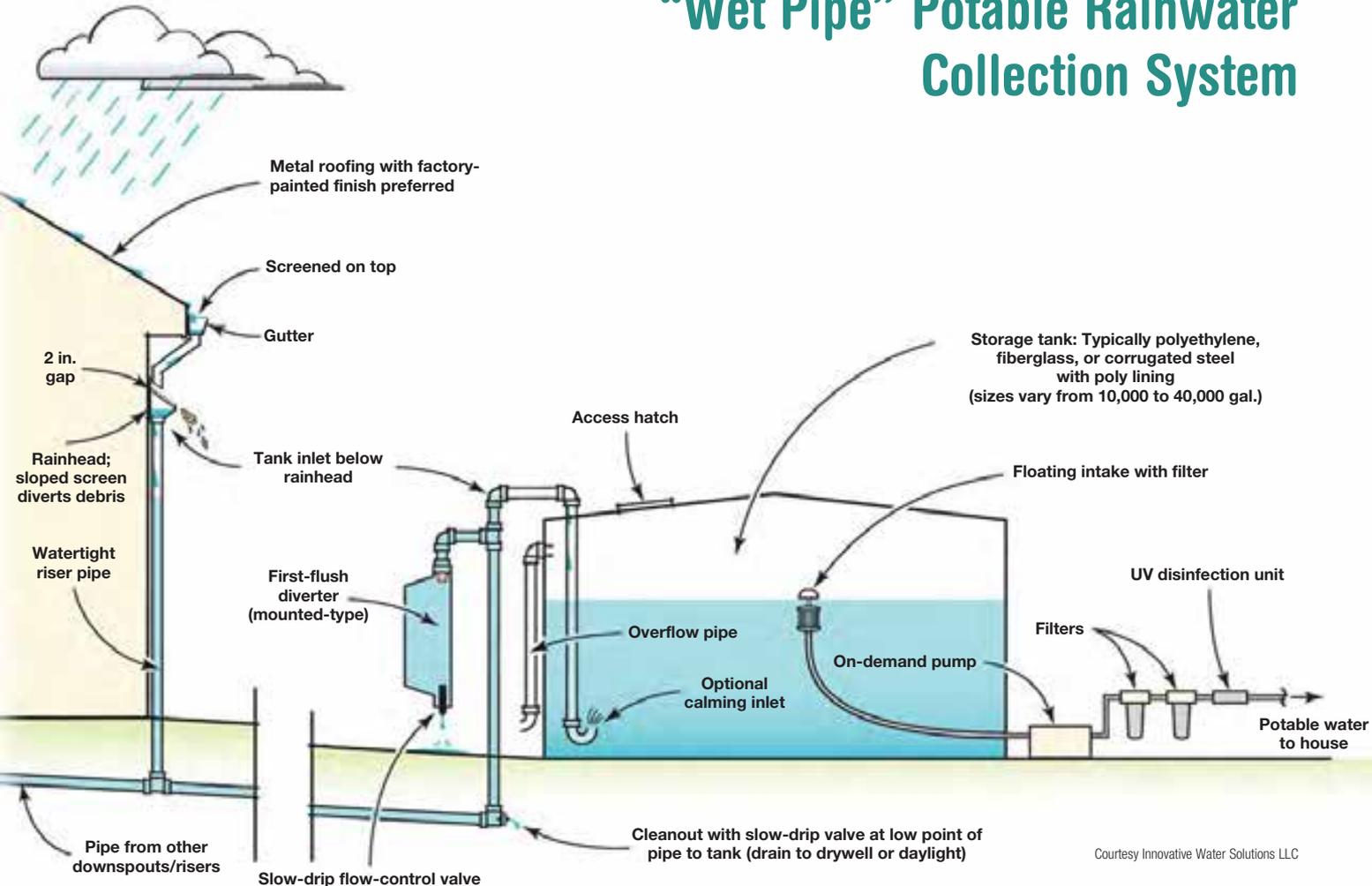


The first line of defense against contamination is to prevent debris from entering the system.

Left: One strategy is to place a metal or plastic screen over the gutter. Right: Another strategy uses permeable foam inserted into the gutter. (Note that the asphalt shingles on both of these roofs signify nonpotable water systems.)



“Wet Pipe” Potable Rainwater Collection System



Courtesy Innovative Water Solutions LLC

A rainhead is the second typical line of defense against contamination.

For this home, the roof height and lack of surrounding vegetation make this component optional.



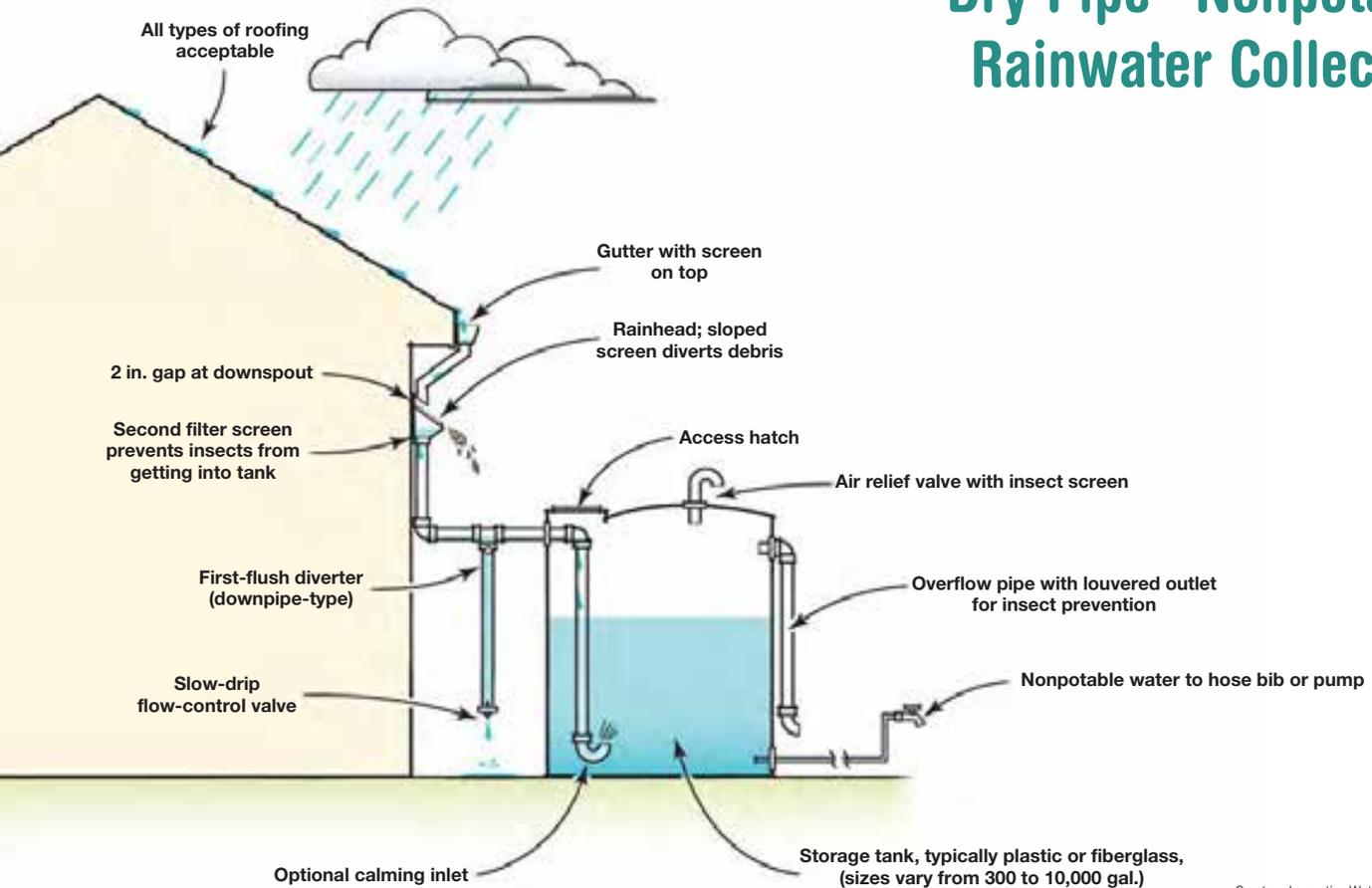
Courtesy Innovative Water Solutions LLC

propitious when it came time to decide how to get water into her home after her well ran dry.

One local well-drilling company quoted \$12,000 to drill through the limestone to the next layer of water in the aquifer. Of course, with new housing still going up and old wells going dry as the water table continues to fall, there was no guarantee that this deeper well would not dry up in the future.

Fortunately, drilling deeper was not the only solution. In the last decade, a few Austinites had set up whole-house rainwater catchment systems to provide all of their home's water needs. Nancy teaches science at the local middle school, and she makes environmental ecology a part of her curriculum. Using rainwater for her home's water needs would square with what she was teaching in the classroom and make a great example for her students.

“Dry Pipe” Nonpotable Rainwater Collection



Courtesy Innovative Water Solutions LLC

Sizing a Whole-House Rainwater System

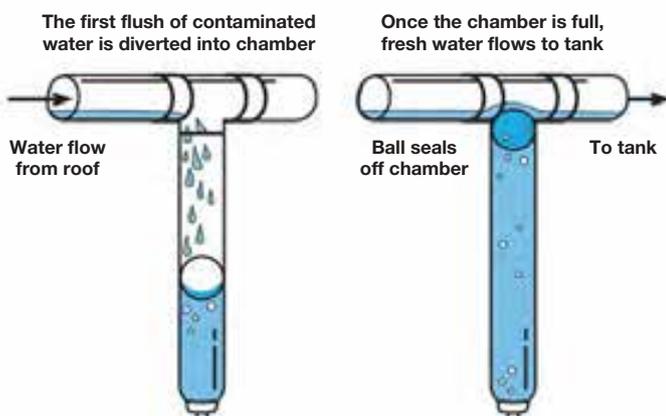
Your home's (or other building's) footprint determines its rainwater collection potential, not the square footage of its roof, because only horizontal area matters. For 1 inch of rain, 623 gallons of water can potentially be collected from a 1,000-square-foot horizontal roof area. But some loss occurs in even the best of systems, so 90% efficiency is considered a maximum.

First, consider whether it is possible, given your family's water consumption (look at a water bill or make an estimate based on plumbing fixtures), to live off your area's annual rainfall. Two water-conscious people will consume about 70 gallons per day. If they were living in a home with 1,000 square feet of horizontal roof area, they would need about 1 inch of rain per week (7 days x 70 gallons = 490 gallons per week consumed versus 561 gallons collected). It's possible to increase collection area by harvesting from nearby outbuildings as well.

Of course, all of this rain might not fall evenly throughout the year. In many areas, much of the rainfall comes only during a few months, so even if there is enough annual rainfall overall, collecting it and having enough storage capacity can be a challenge. Generally, you need to have a tank that is large enough to tide you over through your climate's three driest months. To calculate this, find your area's median rainfall amounts (from the National Oceanic and Atmospheric Administration's website) for the three driest months and assume two-thirds of that rainfall.

In three months, at 35 gallons per day each, two adults will consume 6,300 gallons of water. If supply during the dry months could be as low as 1,000 gallons, for example, then a 5,300-gallon tank would be the *minimum* you should consider installing. More storage means less risk of running out of water. Assuming two-thirds of normal rainfall might not be sufficient—Austin received only one-third of its median rainfall during its recent drought. So, the more people in a household and the longer the dry spells in your climate, the larger the tank. The more efficient your plumbing fixtures (and water use) and the greater your collection area, the smaller the tank can be. Polyethylene tanks are the least expensive and are used in most whole-house rainwater systems.

Function of a First-Flush System



Courtesy Innovative Water Solutions LLC (2)

System Sizing & Extreme Events

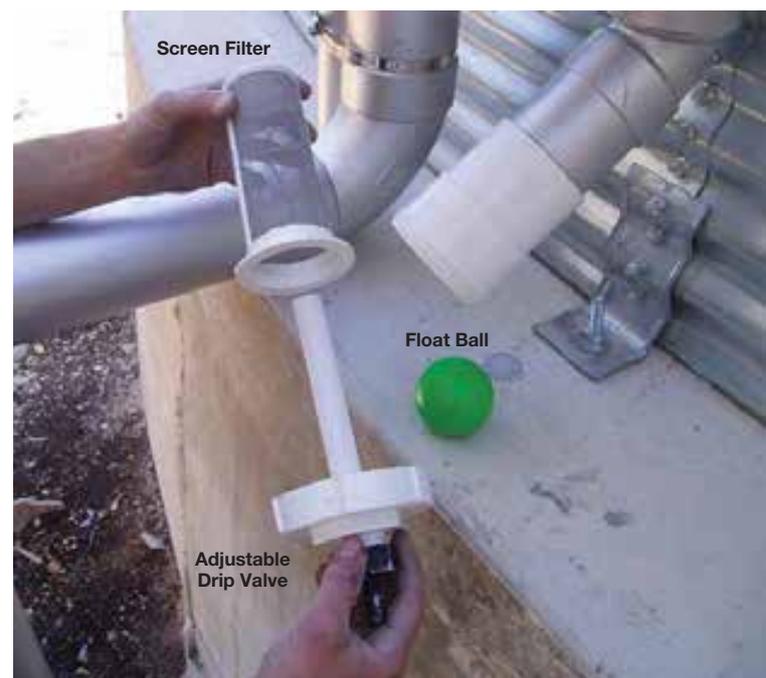
October 2010 to September 2011 was the driest year on record in central Texas, with only 11.2 inches of rain—about one-third of the 33-inch average. It also had the hottest summer since record keeping began in 1860, with 89 days hotter than 100°F. All this puts further strain on the already-stressed Edwards Aquifer. Aquifer replenishment is further hampered because rainfall now often occurs in larger bursts, rather than slower trickles—creating runoff and flash floods instead of recharging the aquifer.

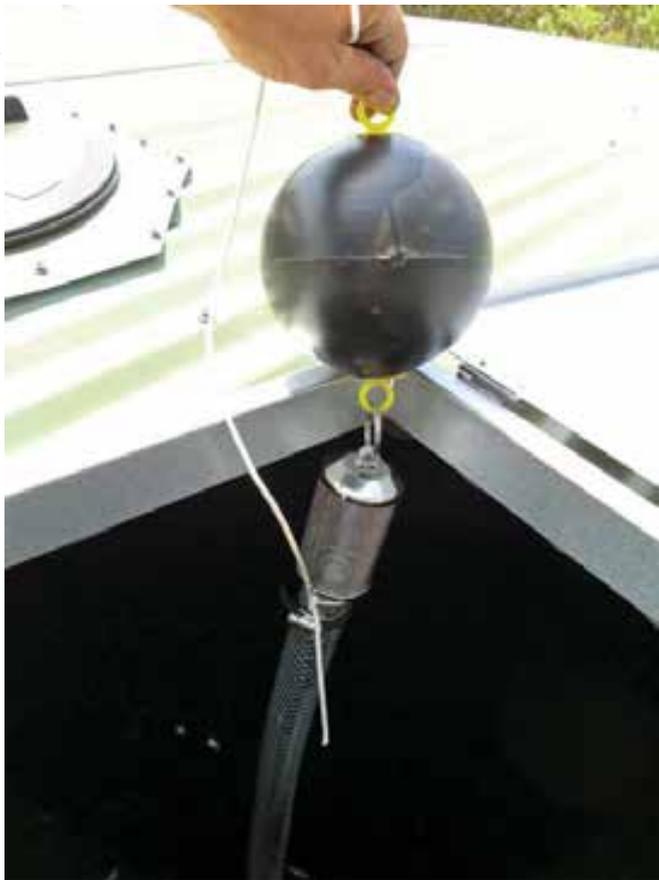
Drought and heavy rainfall events also make living with a rainwater collection system like Nancy's more complicated. Nancy's system has a total of 6,200 gallons of storage, and for five years this was plenty. But the drought forced her to hire a water service company to fill her auxiliary tank with 1,200 gallons of water each month during the summer—just enough, if she scrimped, to get by.

Sizing your water storage system for "extreme" events, such as historic droughts, can be very difficult. It's often a give and take between the willingness of the homeowner to sacrifice their independence in times of extreme weather and the significant cost of much-larger storage systems. At \$75 per month for trucked-in water, it wouldn't take too many similar summers to make it cheaper to have installed a larger tank at the outset, with additional storage in a larger tank costing about \$0.50 per gallon at this size.

Rainwater catchment improves aquifer replenishment—heavy rains are caught by the catchment system and stored, and then released slowly into the ground as it passes through the household and septic system. Some of this groundwater flows into nearby streams, but much leaches into the aquifer. Nancy can take satisfaction that her home has gone from an impervious surface that contributes to runoff, to a building that helps rainwater percolate down to the water table.

A first-flush system is the third line of defense, discarding the first wash of a new rain, including small particles and water-soluble contaminants.





The intake screen in this primary tank floats just below the surface, avoiding both “floaters” at the top and sediment at the bottom.

After a bit of sleuthing, she found Chris Maxwell-Gaines at Innovative Water Solutions, who was happy to work with her existing well equipment and convert it to a rainwater collection system. Her metal roof was ideal for collecting water, as it leaves no residue in the rainwater it sheds. And the 1,200-gallon tank was a good start for storage. With these components—and if Nancy was willing to maintain her water-thrifty ways—the complete system would cost around \$6,000, about half the cost of drilling a deeper well.

System Components

Nancy already had the metal roof, gutters, and 1,200-gallon tank. From there, Innovative Water Solutions opted for a “wet pipe” system that collects water in a similar fashion to a house’s typical drainage system. The downspouts are connected to sealed 4-inch PVC piping, which feed a large underground p-trap located between the house and a cistern. This is common practice when the cistern is located more than a few yards away from the house, so there are not elevated pipes traversing the yard. In contrast, a “dry pipe” system enters the cistern from above without going underground—when it is not raining, the pipes hold no water, negating concerns about harboring mosquitoes. Nancy’s wet pipe system includes a 2-inch pipe at the low point in the collection

Considerations for Rainwater Systems

Although harvesting rainwater is very satisfying, installing a complete system for all of your home’s potable water needs should be weighed against the myriad other sustainable upgrades you could invest in, like a solar water heater or an electric car. If your home is already connected to a functioning well or city water system, then it probably makes more sense to install just enough rainwater collection for your landscaping needs and keep it simple.

That said, there are renewable energy considerations involved with how you get and use water. In some situations where water needs to be pumped long distances and/or heights, like in parts of southern California and other mountainous areas, water treatment and delivery consumes the equivalent of about one-third of the average home’s electricity use to deliver water to your pipes. In situations like this, installing a whole-house rainwater system could save the energy equivalent to that produced by a multikilowatt PV system.

If you’re in a situation where access to water is in jeopardy because of drought, earthquakes, or lack of infrastructure maintenance, there are a few things to consider before proceeding. Firstly, reduce your home’s water consumption as much as you can. This means installing, at a minimum, low-flush toilets, front-loading washing machines, and low-flow shower heads (things we should all be doing anyway). Further reductions may be achieved by installing composting toilets and using greywater treatment systems for landscape watering. Fifty gallons a day per person is the most any household considering whole-house rainwater catchment should be consuming, with 35 gallons as a common goal.

Beyond your plumbing fixtures, other components of your home will make it easier—or harder—to incorporate a rainwater system. The biggest component is roofing. Prepainted metal roofing is the best material for most systems because it doesn’t leach toxins. Plus, almost all of the water is shed from the roof rather than being absorbed by the material. Tile and slate are good options (although they absorb some water). Cedar shingles work, although they collect lots of dirt and mold, and hold a lot of moisture. The most common roofing material, asphalt shingles, is generally nixed by rainwater authorities (like the Texas Rainwater Commission) because of concerns about toxins leaching out of them. Extensive studies haven’t been done (to my knowledge), so the jury is still out. Likewise, tar, treated wood shingles, copper, and gravel-based roof surfaces are out since the contaminant levels are too high. The other major concern about existing home infrastructure is older gutters that may be soldered with lead, which will need to be replaced.

system that has a faucet with a slow drip to empty the pipe after a day or two of no rain, which reduces insect concerns.

Since her home has two stories, the gutters generally sit well above the tree line, so maintenance for tree debris isn’t a big concern. There’s no need for screens or other covers on the gutter, and her system doesn’t include a rainhead—an open box that separates out leaves and other debris from the



A float switch in the secondary tank controls the pump that draws from the primary tank.

The 1,200-gallon secondary tank served as the original water storage. Now, it provides additional capacity and a place for incoming water to cool in the shade before entering the house.



Courtesy Nancy Poage-Nixon (2)

rainwater. Eschewing gutter screens and the rain head saved money initially, but meant the frequency of cistern cleanouts likely needs to be increased (something done on a typical rainhead-based system about once a decade).

At the cistern, the pipe comes above ground, stopping at a “first-flush” diverter that siphons off the first 50 gallons or so from each rainfall event and directs it to the surrounding landscaping via a slow-drip irrigation system. Small leaves, bird droppings, dead insects, and other unwanted bacteria-containing debris that have built up on the roof since the previous rainfall come off in this first flush. Keeping it out of the cistern greatly reduces sediment buildup and potential water contamination. The first-flush diverter has a rubber gasket at its bottom with a small hole in it for dripping out the water between rainfall events, as well as a 4-inch cap that unscrews for debris removal.

Keeping light out of the cistern is crucial, or else microorganisms such as algae can flourish. The polyethylene tank exterior is UV-resistant, with an expected life of 30 years or so. This can be extended if the tank is shaded, saving the top from becoming brittle and potentially broken by hail or downed branches. An overflow outlet drains off excess water and an access hatch on top allows periodic cleaning and maintenance. Sunlight heats up the water in the tank in the summertime to upwards of 90°F, but Nancy is able to cool the water by first routing it through her original, shaded 1,200-gallon tank. While hot drinking water coming out of the tap is not ideal, preheated water reduces the energy load for her water heater.

Water is pumped from the main 5,000-gallon cistern to the smaller 1,200-gallon auxiliary tank, activated by a float switch in the auxiliary tank. A screened floating intake valve—reinforced vinyl tubing attached by a short chain to a black-plastic floating ball—pulls water from a few inches below the surface, thus avoiding floating debris and bottom sediment.

From the smaller cistern, a Grundfos MQ3-45 pressure-booster pump with built-in bladder tank provides household water pressure. Before entering the house, the piped rainwater is forced through a two-stage filtration system—a 10-micron sediment filter and a 5-micron carbon filter. Nancy’s water is then purified by an ozone injection system. Once thoroughly mixed with the water, the extra oxygen molecule kills any bacteria and viruses.

Reacting to the Drought

Although Nancy hasn’t increased her potable rainwater storage, she has added two 250-gallon tanks for use in landscaping. She also switched from grass that dies in drought to purple prairie clover for her small yard. This perennial native is drought-tolerant once established, with

A Grundfos pressure-booster pump (bottom) provides the house’s water pressure through a two-stage filter and ozone purification system (top).



Courtesy Chris Maxwell Gaines

Rainwater Regulations

Several states and communities have enacted regulations and guidelines for dealing with rainwater harvesting, including Tucson, Flagstaff, Chino Valley, and Pason (in Arizona); Seattle and Friday Harbor, as well as King County (Washington state); and Atlanta, Georgia.

The American Rainwater Catchment Systems Association is working with several national organizations to come up with general ordinances that communities can revise and adopt. Texas has state legislation dealing with rainwater harvesting and, along with Hawaii and Virginia, offers rainwater harvesting guideline booklets (see Access). The Uniform Plumbing Code has an appendix dedicated to rainwater systems, with sizing guidelines for gutters, downspouts, and lateral pipes.

Beware, though, not every locale is rainwater-system friendly, so if you want to keep to the letter of the law, you'll need to check with your local authority having jurisdiction to see what, if any, rainwater harvesting regulations are in place.

a deep root system capable of subsisting off erratic rainfalls and septic system discharge. As others fret over their wells running dry, Nancy can relax, knowing she has a more steady supply of water, and that she is helping recharge the diminishing aquifer.

Access

Stephen Hren (stephenhren@gmail.com) is a writer and builder 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*. Find out more at www.earthonaut.net.

Further Reading:

"Catching the Cloudburst" by Heather Kinkade in *HP125*

"Free Rain: High-Tech, Hands-Off Rainwater Collection" by Doug Pushard in *HP115*

"Harvesting Rainwater" by Michael Durland in *HP107*

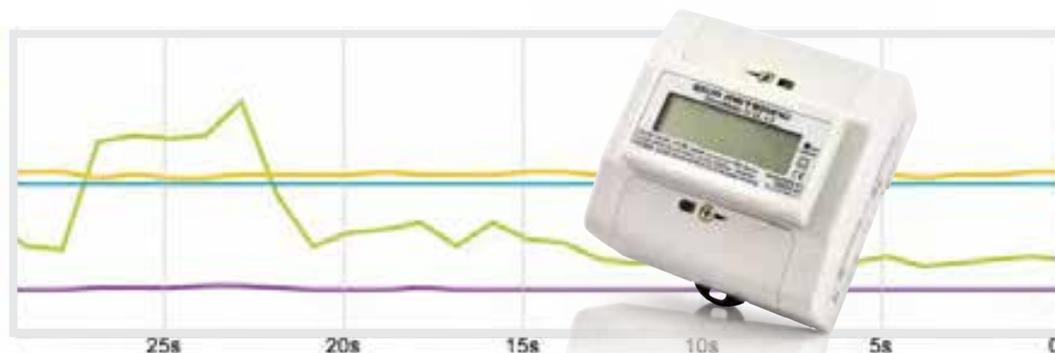
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CHOOSING

a Battery-Based Inverter

by Justine Sanchez

A residential battery-based inverter has a primary task of accepting DC electricity and changing it into standard, household AC electricity. This seems simple enough, but wading through the inverter specifications can be overwhelming if you don't understand what they mean and how they pertain to your system.

Your system may have other requirements (such as battery charging from an engine generator or the grid), and figuring out which features will be advantageous often depends on the system type and specifics. With no access to utility power, an off-grid system has to supply all of the electricity at all times. A grid-tied battery backup system has access to utility power, can use the inverter to export excess electricity back to the grid, and usually supplies electricity only to specific "critical" loads during a utility outage. These are some of the differences that make certain inverter features desirable in one system type but not necessarily in the other. As you go through the specification descriptions, you will see how these differences influence the inverter selection process.

This guide includes a specifications table for available battery-based, sine-wave inverters that are listed to the Underwriters Laboratories 1741 standard and commonly used in residential applications (2 to 8 kW). The compiled data is from manufacturers and their specifications sheets.

The Specs

Off-Grid, Grid-Tied, or Both tells us what system type(s) this inverter is built for.

Rated Continuous Output Power represents the inverter's capacity. For example, a 2,000 W inverter is rated to supply 2 kW of AC power continuously. In an off-grid system, this value determines the total wattage limit of AC loads that can be run simultaneously. You must specify an inverter with an output power rating large enough to handle all of your simultaneous AC loads.

Let's say we want to power the following at the same time:

- a 1,400 W microwave
- six 15 W lights
- a 100 W refrigerator
- a 120 W TV

In this case, an inverter with a continuous output power rating exceeding 1,710 W would suffice (1,400 + 90 + 100 + 120). Surge ratings are discussed separately.

For grid-tied battery-based inverters, the power rating is examined under two scenarios—when the grid is available and when there is an outage. When the grid is up, the inverter's job is to convert all available DC power from the

renewable energy system to AC, which is used in the home. If the array output exceeds household demand, the excess is sent to the utility. The inverter capacity must be large enough to accommodate the RE system size. For instance, an inverter for a 4,000 W PV array will generally be sized at that same power rating. (However, because climate factors such as warm temperatures will limit PV array output, the array-to-inverter ratio may vary.)

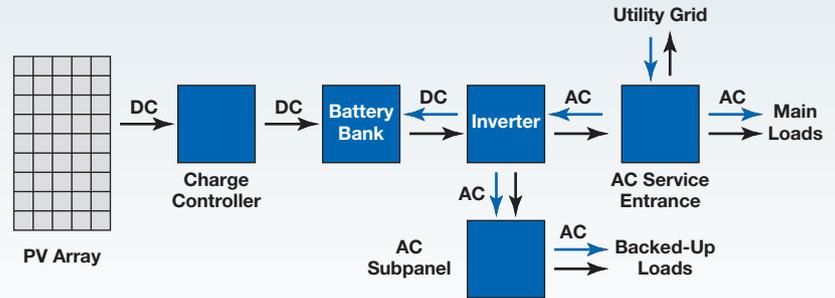
When the utility is down, the inverter’s job is to supply power to all the AC loads connected to it. Most of these systems include a “critical load subpanel” so that not all of a home’s loads have to be energized, which keeps battery and system costs down. The inverter capacity must be large enough to meet the total requirement of all connected AC loads that might be run simultaneously, and large enough to handle the RE output. (See “Sizing a Battery-Based Inverter” in the *Circuit: Methods* in this issue.)

Nominal Battery Voltage dictates the battery bank configuration. Only a few inverters (such as those from Exeltech) can accommodate multiple battery bank voltages.

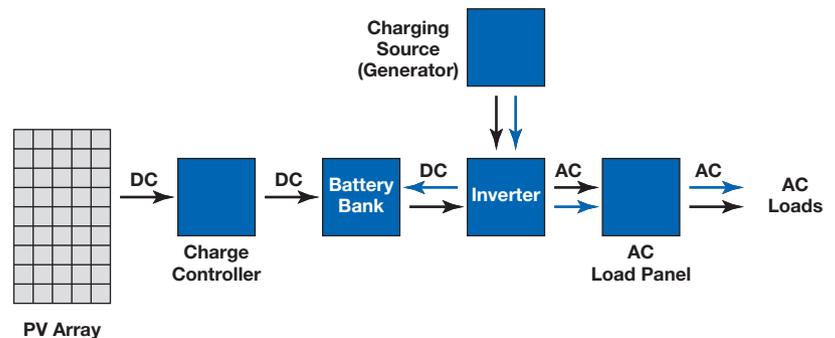
Most household-sized inverters require either 24 or 48 V battery banks. There are a few 12 V inverters on our list, but these are usually for smaller systems (think cabin-sized) that serve only a few AC loads.

AC Output Voltage has been limited to 120 VAC for a single inverter until the last few years. Now, several inverters have split-phase 120/240 VAC to power both standard 120 VAC loads and 240 VAC loads (such as a well pump). These inverters also have battery chargers to charge the battery bank using both legs of a 240 VAC generator. This saves generator run time and avoids having to include a 120/240 step-up/down autotransformer. Split-phase inverters also negate problems with wiring a single inverter to a load center that has multi-wire branch circuits, since this can possibly overload the neutral conductor. Additionally, several inverters on our list can also be connected in groups of three to supply three-phase 208 VAC output, commonly used in small commercial systems. (To see which models have this functionality, see the “Stackability” column in the table and look for “3Ph.”)

Battery-Based Grid-Tied System



Battery-Based Off-Grid System



magnumenergy.com (2)



Magnum Energy's off-grid inverters have optional remote metering and now carry a standard three-year warranty. A standard five-year warranty is offered, but only if the inverter is wired and mounted on Magnum BOS systems.



The OutBack Power off-grid FX series inverters come in vented (shown) and sealed models. The sealed model is recommended for harsh environmental conditions (high humidity and corrosive salt air). The vented model supports high AC output power in hot environments.

OutBack Power's new Radian series inverter can be installed in off-grid or grid-tied systems. It has an 8,000-watt output rating, and offers split-phase 120/240 VAC output and dual AC inputs.



outbackpower.com (4)



OutBack Power's line of GT inverters are built strictly for grid-interactive usage and are not designed to be used with a generator. Like the off-grid series, the GT models are offered in sealed and vented models.

Peak Surge ratings reflect the inverter's capability to supply significantly more than its continuous power rating for short periods of time. Certain appliances (i.e., those that have motors, like washing machines, refrigerators, and well pumps) will briefly draw more power upon initial startup. To find the surge requirement for a particular appliance, check the appliance spec sheet for the "start amps," or contact the appliance manufacturer. Alternatively, you can measure it with a recording clamp-on ammeter.

Stackability is the capability to connect multiple inverters together to create 120/240 VAC output (series stacking) or increase output current (parallel stacking). Historically, the ability to series stack was handy for systems that needed to power 240 VAC loads, using inverters with 120 VAC-only output. Now that more split-phase inverters are available, stacking is usually done to increase inverter output capacity (amps). Stacked inverters can be programmed to activate only if needed so that when there is low power demand, standby losses are reduced (see "No-Load Draw").

Inverters can be stacked for higher voltage, more current, or for multiple phases. This OutBack Flexware 1000 system integration hardware supports up to four inverters and accommodates the charge controllers and all required AC and DC balance-of-system components.



Peak Efficiency is the ratio of AC power out of the inverter to power in from the DC power source. The higher the efficiency, the less energy that is wasted in the inversion. Actual operating efficiency will vary depending on how much power is being pulled through the inverter, so inverter efficiency curves can be more helpful than the peak efficiency specification, and are often available in inverter manuals. On-grid systems spend most of their time processing RE-generated power to send to the home/grid, so high efficiency at the RE system's power output rating is best. Since off-grid systems can spend much of their time requiring significantly lower power (when only a few loads are running), consider an inverter that has high efficiency at lower power output.

No-Load Draw (aka "Idle," "Standby," or "Tare" Loss) tells how many watts each inverter consumes simply by being "on." This power needs to be accounted for when performing a load analysis for an off-grid system. Multiply the no-load draw by 24 hours to calculate the daily energy (watt-hours) consumed by the inverter.

SMA America's Sunny Island inverters can be used in both off-grid and on-grid systems, and support AC coupling to Sunny Boy batteryless grid-tied inverters. (Note: Two Sunny Island inverters are required for 240 VAC output to AC-couple to Sunny Boy inverters with 240 VAC output.)



Automatic Generator Start

Autostart generators can be started by an external signal, such as one that might come from an inverter when it detects a too-low battery voltage. The control over the generator's operation—that is, when to run and when to stop—is external to the generator, while the generator provides its own safety protection, such as shutoff for low oil level, overheating, and other factors. Among remote-start generators, the simplest is the "two-wire start," in which a closed contact tells the generator to start and run. When the contacts open, the generator stops.

All inverters with generator-start capability can do this, as can other system components such as a manual switch, a voltage-controlled relay, a threshold signal in some system monitors, and even a signal triggered by a big load. Automatic generator operation is at best a mixed blessing. In theory, the inverter calls for the generator to provide backup charging power whenever the RE source is insufficient. However, numerous real-world bugs can interfere with such seamless operation. Automatic operation can lead to a system owner failing to perform regular maintenance, and neglecting something as simple as checking oil levels can cause catastrophic generator failure, which might not be noticed until the system shuts down due to low battery voltage.

Poor programming can lead to excessive run time and fuel consumption, yet not guarantee that batteries are adequately charged. The most likely path to eventual failure is total dependence on a generator in an unattended system.

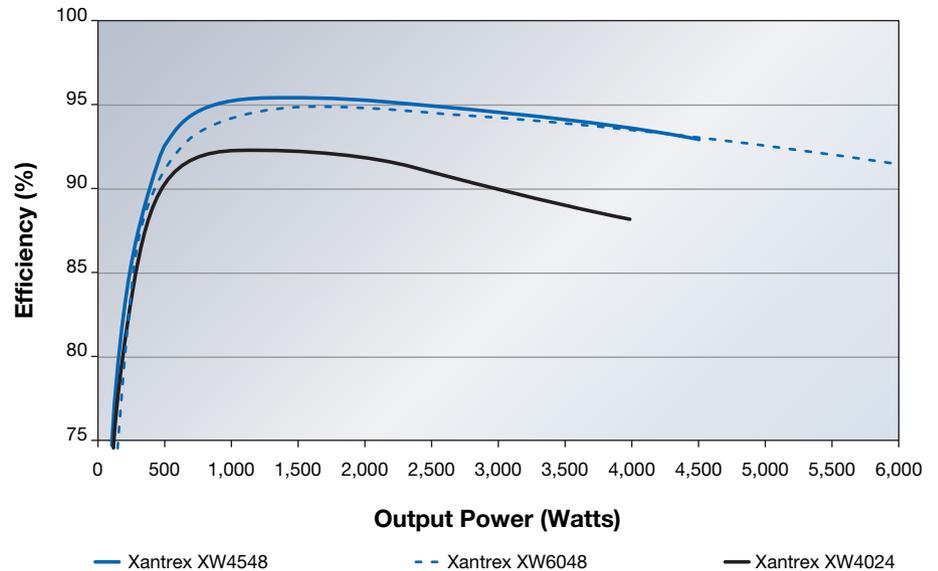
—Allan Sindelar (from *HP131*)

The Schneider Electric XW series inverter also can be used in either off-grid or grid-tied systems. It has 120/240 VAC split-phase output and dual AC inputs. The complete XW system shown here includes AC and DC balance-of-system equipment on the power distribution panel.



Search Power ratings reflect the energy-saving “search” or “sleep” mode available in most off-grid inverters. This mode allows the inverter to nearly shut off during times of no-load draw. While the inverter still consumes some power to monitor household loads, the search power consumption is commonly about 75% less than the no-load consumption. Depending on the inverter “wake-up” wattage threshold, there may be some small AC loads that will no longer work if nothing else is turned on. Small, always-on AC loads (security systems, clocks, answering machines, etc.) can keep the inverter awake, consuming energy all of the time. For small loads, one tactic that can work is to shift to a consumer battery (like AA rechargeable) counterpart. Another tactic is to include a small, always-on inverter that is dedicated to those household appliances.

Inverter Efficiency (Typical)



Integrated Battery Charger/Maximum DC Amps—Most of the inverters in the table include battery chargers that work on an AC power source (see the “Integrated Battery Charger” sidebar). The battery charger has a maximum DC current rating that will limit how much from the available charging source can be used. While the generator may be adequately sized, a lower battery charger limit can increase generator run time. One strategy is to install multiple inverters/chargers, which increases battery charger capacity. Ideally, the generator will be sized according to charger capability (see “Engine Generator Basics” in *HP131*).

The Apollo TSW inverters offer 120/240 VAC split-phase output/input.



Exeltech MX inverters can be configured in 1 kW increments up to 20 kW at 120V; in 2 kW to 40 kW at 240 V; and in 3 kW to 60 kW at 208 V three-phase. Up to 5 kW will fit into a “cage” at 120 V. Two cages are required for 240 V (one cage for each phase), which are bolted together as a single unit. Three cages are used for 208 V three-phase.



Off-Grid Inverter Selection Guide

Manufacturer	Model	Off-grid, GT or Both	Rated Continuous Output (W)	Nominal Battery Voltage	AC Output Voltage	Peak Surge (AC Amps @ Time)	Stackability	Inverter Peak Efficiency (%)
Apollo Solar www.apollosolar.com	TSW3224	Off-grid	3,200	24	120/240	80 A @ 1 ms, 120 V	P & 3Ph	93
	TSW4048	Off-grid	3,600	48	120/240	80 A @ 1 ms, 120 V	P & 3Ph	94
Exeltech^b www.exeltech.com	MX	Off-grid	4,000	12, 24, 32, 48, 66, 108	120/240	4 x 17.1 A @ 3 s	S & P	90
Magnum Energy www.magnumenergy.com	MS4024PAE	Off-grid	4,000	24	120/240	120 A @ 1 ms, 120 V	P	93
	MS4448PAE	Off-grid	4,400	48	120/240	120 A @ 1 ms, 120 V	P	94
	MS2012	Off-grid	2,000	12	120	50 A @ 1 ms	No	89
	MS2812	Off-grid	2,800	12	120	70 A @ 1 ms	No	88
	MS4024	Off-grid	4,000	24	120	120 A @ 1 ms	S	87
	MSH4024RE	Off-grid	4,000	24	120	120 A @ 1 ms	No	87
OutBack Power Systems www.outbackpower.com	FX 2012T	Off-grid	2,000	12	120	56 A @ 1 ms	S, P, 3Ph	90
	FX 2524T	Off-grid	2,500	24	120	70 A @ 1 ms	S, P, 3Ph	92
	FX 3048T	Off-grid	3,000	48	120	70 A @ 1 ms	S, P, 3Ph	93
	VFX 2812	Off-grid	2,800	12	120	56 A @ 1 ms	S, P, 3Ph	90
	VFX 3524	Off-grid	3,500	24	120	70 A @ 1 ms	S, P, 3Ph	92
	VFX 3648	Off-grid	3,600	48	120	70 A @ 1 ms	S, P, 3Ph	93
	GTFX2524	Grid-tied	2,500	24	120	70 A @ 1 ms	S	92
	GTFX3048	Grid-tied	3,000	48	120	70 A @ 1 ms	S	93
	GVFX3524	Grid-tied	3,500	24	120	70 A @ 1 ms	S	92
	GVFX3648	Grid-tied	3,600	48	120	70 A @ 1 ms	S	93
	GS8048	Both	8,000	48	120/240	200A @ 1 ms @ 120 V	P	90 ^c
SMA Solar Technology www.sma-america.com	SI 4248-US	Both	4,200	48	120	140 A @ 5 s	No	94.5 ^c
	SI 5048-US	Both	5,000	48	120	180 A @ 60 ms	S, P, 3Ph	95
Schneider Electric www.schneider-electric.com	XW4024	Both	4,000	24	120/240	70 A @ 20 s, 120 V	P & 3Ph	91 ^c
	XW4548	Both	4,500	48	120/240	75 A @ 20 s, 120 V	P & 3Ph	93 ^c
	XW6048	Both	6,000	48	120/240	105 A @ 15 s, 120 V	P & 3Ph	92.5 ^c

a) Via T80 charge controller AUX relay; b) Four MX inverters configured as 4 kW; configurations available in multiples of 1 kW for 120 V, multiples of 2 kW for 240 V, and multiples of 3 kW for 208 V three-phase. Surge, no-load draw, and weight specs change with number (N) of MX units: Surge = N x 17.4 A; No-load draw = N x 14 W; Weight = N x 7.5 lbs; c) CEC weighted efficiency

Generator Start enables inverters to remotely start and stop a generator. Users can select a low battery voltage value that triggers the inverter to initiate a generator start and run sequence to charge the batteries. Other parameters can also be set to run the generator during times of high power consumption and/or during specific times of the day. While this feature can be handy, there are drawbacks (see “Automatic Generator Start” sidebar).

Dual AC Inputs allow users to use more than one AC power source, such as the grid and a generator, for battery charging. This is useful in grid-

Integrated Battery Charging

In battery-based systems, a power source besides PV, wind, or microhydro is usually needed to provide battery charging during times of cloudy weather, no wind, or low stream flow. Engine generators are commonly used in off-grid systems; the utility (and sometimes generators) is often used in grid-tied systems.

Both are AC power sources, but the batteries are DC, so AC to DC conversion is needed. Battery-based inverters commonly include integrated battery chargers that convert AC to DC and control the charge flowing into battery bank.

Inverter/chargers eliminate the need for an external battery charger, reducing system cost and complexity. Just like with other multistage charge controllers, users can program bulk and float voltages and absorption time to accommodate their particular battery bank. Additionally, users can adjust the maximum charge rate flowing into their battery bank, which is crucial since the maximum rate is different for various battery banks.

No-Load Draw (W)	Search Power (W)	Charger Max. Current (DC Amps)	Generator Start	Dual AC-inputs	Remote Display	Prepackaged w/ BOS Available?	Dimensions (In.)	Weight (Lb.)	Standard Warranty (Yrs.)
<29	4.5	100	Optional ^a	No	Optional	Yes	22.5 x 9 x 7.25	49.0	5
<35	4.5	70	Optional ^a	No	Optional	Yes	22.5 x 9 x 7.25	49.0	5
56	—	N/A	Optional	No	Optional	No	Rack mount	30	1
27	<6.0	105	Optional	No	Optional	Yes	13.75 x 12.65 x 8	55.0	3
25	<6.0	60	Optional	No	Optional	Yes	13.75 x 12.65 x 8	55.0	3
25	7.0	100	Optional	No	Optional	Yes	13.75 x 12.65 x 8	42.0	3
30	7.0	125	Optional	No	Optional	Yes	13.75 x 12.65 x 8	55.0	3
25	7.0	105	Optional	No	Optional	Yes	13.75 x 12.65 x 8	55.0	3
25	7.0	105	Optional	Yes	Optional	Yes	13.75 x 12.65 x 8	55.0	3
20	6.0	80	Yes	No	Optional	Yes	16.25 x 8.25 x 13	62.0	5
20	6.0	55	Yes	No	Optional	Yes	16.25 x 8.25 x 13	62.0	5
23	6.0	35	Yes	No	Optional	Yes	16.25 x 8.25 x 13	62.0	5
20	6.0	125	Yes	No	Optional	Yes	16.25 x 8.25 x 12	61.0	5
20	6.0	85	Yes	No	Optional	Yes	16.25 x 8.25 x 12	61.0	5
23	6.0	45	Yes	No	Optional	Yes	16.25 x 8.25 x 12	61.0	5
20	6.0	55	No	No	Optional	Yes	16.25 x 8.25 x 13	62.0	5
23	6.0	35	No	No	Optional	Yes	16.25 x 8.25 x 13	62.0	5
20	6.0	85	No	No	Optional	Yes	16.25 x 8.25 x 12	61.0	5
23	6.0	45	No	No	Optional	Yes	16.25 x 8.25 x 12	61.0	5
30	9.9	115	Yes	Yes	Optional	Yes	28 x 16 x 8.7	125.0	5
22	4.0	100	Yes	Yes	Optional	Yes	15.35 x 23.23 x 9.65	86.0	5
25	4.0	120	Yes	Yes	Optional	Yes	18.4 x 24.1 x 9.3	139.0	5
24	<8.0	150	Yes	Yes	Optional	Yes	23 x 16 x 9	116.0	5
26	<8.0	85	Yes	Yes	Optional	Yes	23 x 16 x 9	118.0	5
28	<8.0	100	Yes	Yes	Optional	Yes	23 x 16 x 9	122.0	5

ted systems with battery backup, since it allows charging batteries from the grid when it is available and from an engine generator during times of utility outages (and low RE-system output), offering another source of backup power.

Remote Display is useful for keeping tabs on the system from a convenient location (such as the kitchen). These displays usually include user buttons to turn the inverter on and off, and to adjust programmed settings.

Prepackaged with Balance of System Equipment can be a time-saver when it comes to installing a battery-based inverter, since these systems have *many* components that need to be wired and located in the vicinity of the inverter and battery bank. These additional components are required in battery-based systems because there are multiple power sources (such as a PV array, batteries, generator, and the utility

grid), and it is required to have disconnects and overcurrent protection between each system component and each power source. Other components can include charge controllers, meters (and shunts), ground-fault protection devices, inverter bypass assemblies, and communications hubs. Additionally, all of these components need a backplate to be mounted on and neatly fitted and wired together, further increasing the time and hassle savings offered by optional prepackaged power-panel assemblies.

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.



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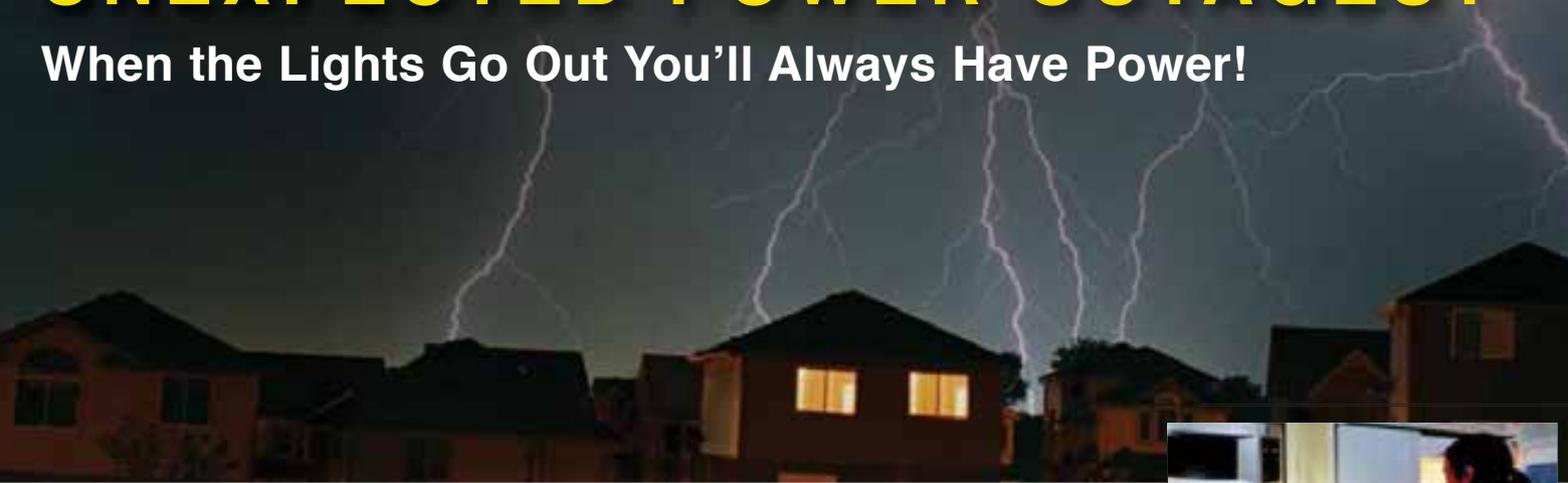
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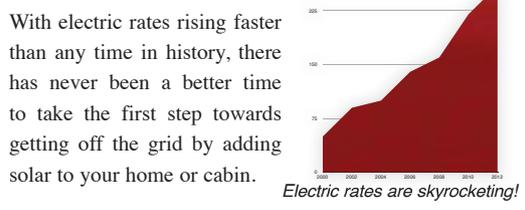
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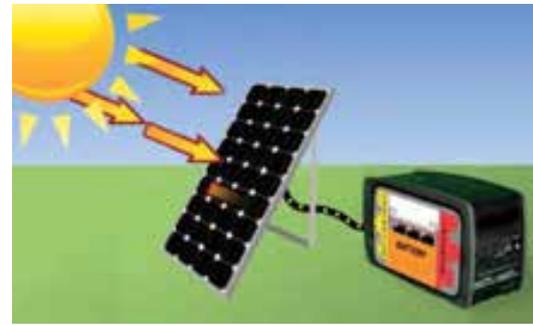
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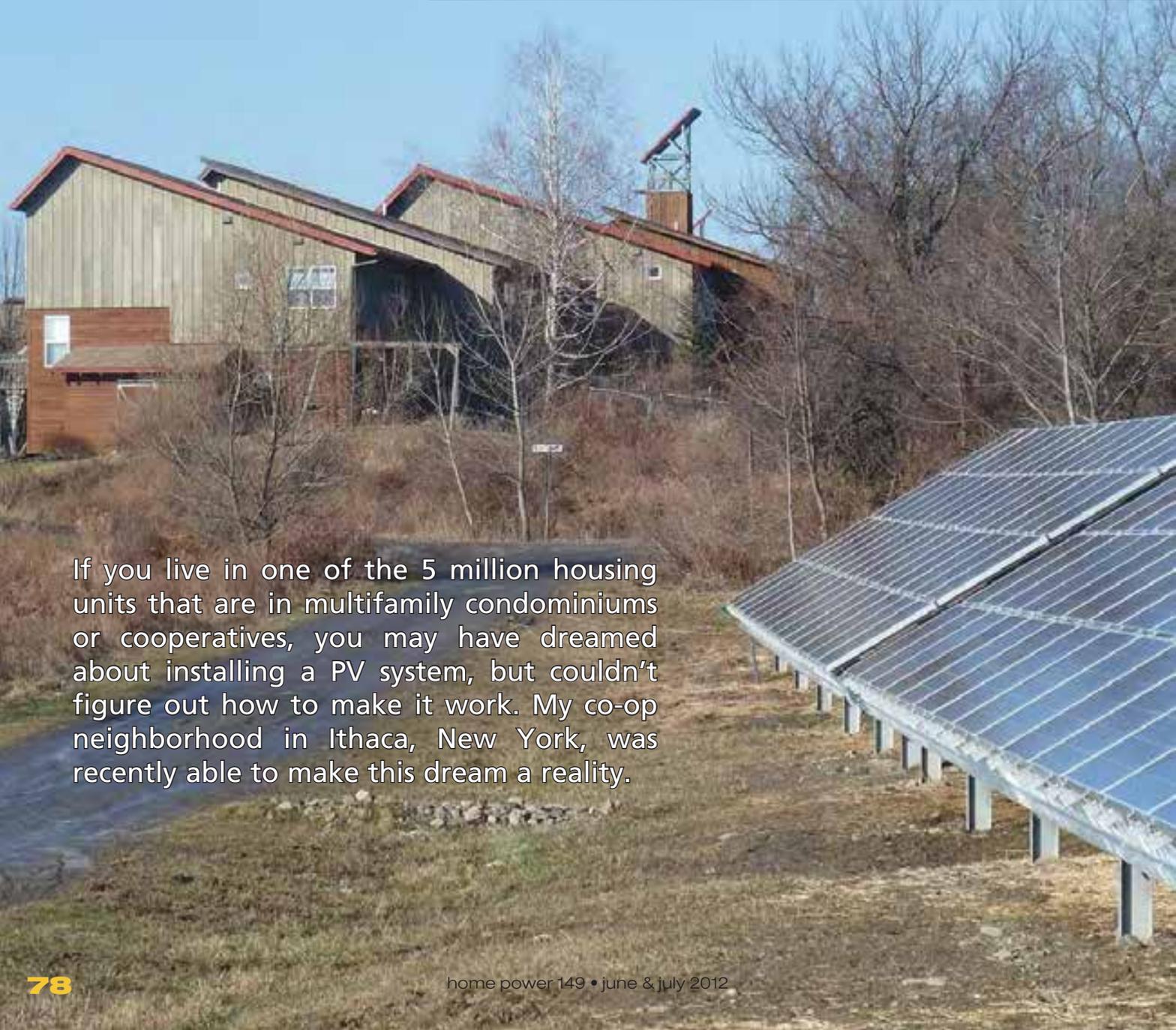
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Story & photos
by Jeff Gilmore



If you live in one of the 5 million housing units that are in multifamily condominiums or cooperatives, you may have dreamed about installing a PV system, but couldn't figure out how to make it work. My co-op neighborhood in Ithaca, New York, was recently able to make this dream a reality.

at Ecovillage at Ithaca



Challenges

There are many benefits to living cooperatively or in a condominium, but the ease of installing a solar-electric system is not one of them. The first problem is that you don't own the roof and walls—so a PV installation requires permission from your neighbors and the homeowners' board. In addition, there are wiring, metering, utility connections, and aesthetic considerations that come into play. For example, your electrical service connection may be located some distance away from your unit, you may need access to a neighbor's roof or attic for attaching modules or routing wiring, or you may find that some of your neighbors don't share your delight in seeing solar collectors gleaming on the roof.

An alternative is to expand the PV project into a neighborhood effort. In this scenario, the condo association or co-op owns the system, and the system benefits all of the residents. That solves a few problems, but brings up several more.

One of the thorny problems is the way most utilities implement net metering. Usually a utility will allow you to hook up a PV system only to your own utility connection. Under an annualized net-metering agreement, the utility credits your household only for PV production *up to* your total usage for that year. Usually, any surplus generation is given to the utility for free or at a low wholesale rate. Since the homes in most multifamily neighborhoods are individually metered, this necessitates having many small PV systems (one per unit), rather than one large, more efficient, cost-effective system.

If this can be overcome, the remaining challenges are how to pay for the system; how to meter and divide the output; and getting approval from utilities, planning departments, rebate providers, and other agencies. Oh yeah, and you have to get everyone in your neighborhood to agree to all of this.

Daunting? Yes. Achievable? Definitely! My community, Ecovillage at Ithaca (EVI) in Ithaca, New York, successfully navigated these obstacles and constructed a 50 kW grid-tied PV system that was financed with local capital and is expected to meet more than half of our community's electricity needs.

One of the design elements of the Ecovillage was the creation of a car-free zone between the rows of townhouses.



Background

EVI is a community of 60 energy-efficient homes in two distinct neighborhoods (soon to be three) clustered in the center of a 176-acre parcel on the outskirts of town. My neighborhood, built in 1997, has 30 compact townhouses and was designed according to cohousing principles: Homes face onto a meandering, car-free central corridor and share access to a large common house that provides space for community gatherings and meals, playrooms, laundry facilities, and offices. The average townhouse is 1,225 square feet, and up to 40% more energy efficient than typical homes in the area due to extensive insulation and sealing, triple-pane windows, a shared hydronic heating system, and passive solar design.

In tune with ecological design, residents were very interested in adding PV systems to the townhouses when they were originally built. At that time, though, it was prohibitively expensive and there were few incentive programs to help out. For many years after, residents discussed adding solar-electric systems, but couldn't find an approach that addressed all the challenges in a cost-effective way. In 2010, that changed, partly because we devised a new approach.



The common house's south-facing roof already showcased a 6 kW PV system.

Ecovillage System Costs

Item	Cost
PV system	\$232,416
Metering system changes	18,871
Site prep, drainage, etc.	9,257
Construction financing	7,385
Land easement	5,000
Protective fencing	3,000
Misc. expenses	1,983
System design	800
Total Cost	\$278,712
NYSERDA rebate	\$90,160
Federal tax credits	51,355
State tax credits	42,796
Total Incentives	\$184,311
Net Cost	\$94,401

Revisiting our desire for solar electricity began with a bit of friendly conflict among neighbors. My wife Kristen and I, feeling frustrated by the lack of progress implementing renewable energy in our community, wanted to install a small solar heating system on the roof of our unit. When we asked for permission, several neighbors objected, citing the long-standing desire to use our shared roofs to implement a comprehensive PV strategy.

Feeling grumpy about the roadblock, I set out to demonstrate why such a PV system was impractical on our difficult roofs. As I was trying to prove this, it occurred to me that we didn't need to use the roofs—we could ground-mount the PV system.

I quickly switched gears and roughed out a possible design for a 50 kW array located a few hundred feet from the neighborhood. Some initial calculations of costs and available rebates and tax credits, as well as some ideas about financing, made it seem feasible. So I started meeting with other residents to get their feedback. Enthusiasm for the idea ran high, and the group quickly agreed on some core goals:

- All residents should benefit equally from the system;
- Monthly electricity costs should remain similar to existing utility charges;
- Residents are not required to contribute up-front capital;
- The system should be big enough to be worth doing, but small enough to manage.

We assembled a small project team, requested a small amount of seed money from the co-op board, and got busy.



Ground-mounting away from the village allows the PV arrays to receive full sunlight and allows each home in the Ecovillage to receive equal portions of credit for the energy.

Making Tax Credits Work

Tax credits are important elements to help make PV systems more affordable, but taking advantage of them can be tricky for co-ops and condominium associations, which don't typically owe a lot of income tax. Fortunately, tax credits can be passed on to residents to reduce their personal taxes. To do this, the association assigns in writing a proportional share of the PV system's cost. The residents claim the credits when they file their tax returns, and then the co-op collects the amount of the tax savings from the residents. Issuing letters and collecting funds can be cumbersome, but can save up to 30% on federal taxes, and more if your state also has tax credits. Work with a qualified tax professional to ensure compliance with the law.

Figuring Out the Financing

We needed to get an accurate cost estimate, so I contacted my neighbor Tony Henderson, who has spent the last few years managing large PV projects around the Northeast. Tony was able to quickly validate and improve my design, and gave us an estimate of about \$6 per watt, or \$300,000, for the system. The DSIRE website (see Access) provided information on available rebates and tax credits, and we determined a final out-of-pocket cost of about \$100,000.

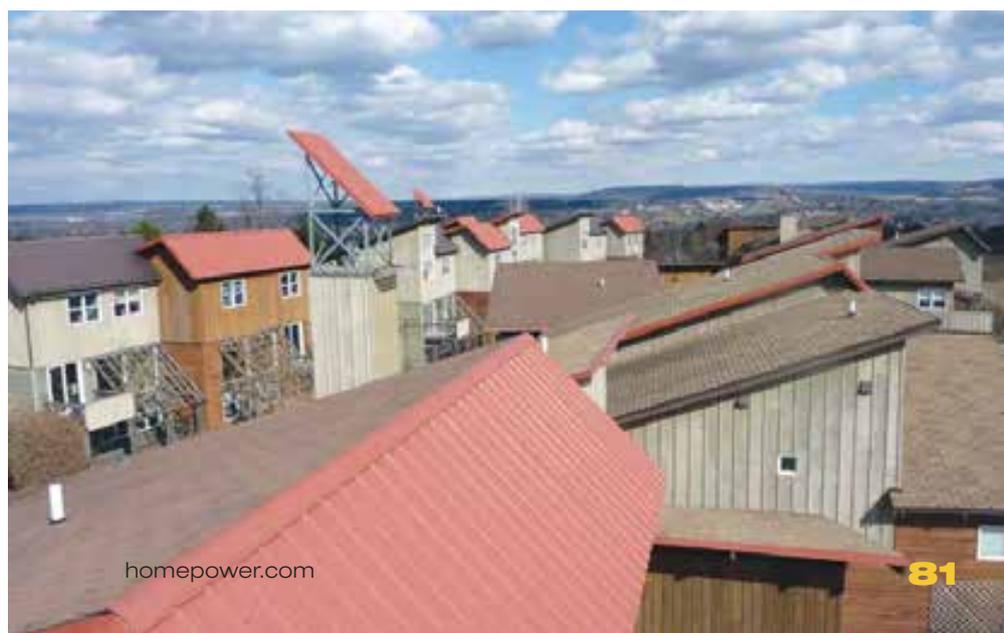
With that estimate in hand, we started working out how to pay for it. We decided that it made sense for the co-op to own the system and that it should borrow the money. We doubted we would find a bank that would lend the co-

op money for such a project, so we proposed borrowing it directly from individuals in the community.

With banks paying interest rates of 2% or less, some neighbors were open to lending if the co-op could pay a higher rate. We ran the numbers at an interest rate of 5% and a loan period of 20 years to calculate the monthly payment—the amount we would need to raise each month. To meet the goal of keeping monthly electricity costs similar to what residents were currently paying, that meant that the PV system would need to generate savings equal to the loan payment.

We used PVWatts to estimate the system's annual output and gathered up a year's worth of utility bills to estimate our neighborhood electricity usage in dollars and kWh. The PV

Tricky roofs and lack of individual ownership can complicate adding a PV system to multifamily buildings.



Tech Specs

Overview

System type: Batteryless, grid-tied solar-electric

Location: Ithaca, New York

Solar resource: 4.2 average daily peak sun-hours

Record low temperature: -25°F

Average high temperature: 80°F

Average monthly production: 59,464 AC kWh

Utility electricity offset annually: 55%

Photovoltaic System Components

Modules: 224 Trina TSM-230PA05, 230 W STC, 29.8 Vmp, 7.72 Imp, 37.0 Voc, 8.26 Isc

Array: Four subarrays of two 13-module series strings (387 Vmp, 7.72 A Imp, 481 Voc, 8.26 Isc) and three 10-module series strings (298 Vmp, 7.72 A Imp, 370 Voc, 8.26 Isc) for 12.9 kW STC per subarray

Array combiner box: Crouse-Hinds CCBF03 with 15 A fuses

Array installation: RBI Solar mounts installed on south-facing ground mount, 30° tilt

Inverter: Eight Sunny Boy SB6000US, 6,000 kW rated output, 600 VDC maximum input, 250-480 VDC MPPT operating range, 240 VAC output

System performance metering: EKM Metering Omnimeter I; Centron CL200 glass meter

system would generate about 55% of all the electricity used. By examining the average residential electricity rate, we determined the approximate dollar value of the PV-generated electricity. If residents continued to pay the same amount as their current monthly electricity bills, the PV system would generate enough income to pay the loans. In fact, the loan period was adjusted to 15 years, instead of 20.

Metering

With a financing plan in hand, the next challenge was net metering. The co-op would only receive credit for PV electricity that offset the annual usage of one utility meter, and we had 30 separate meters. We needed to find a way to combine the meters into fewer separate utility connections.

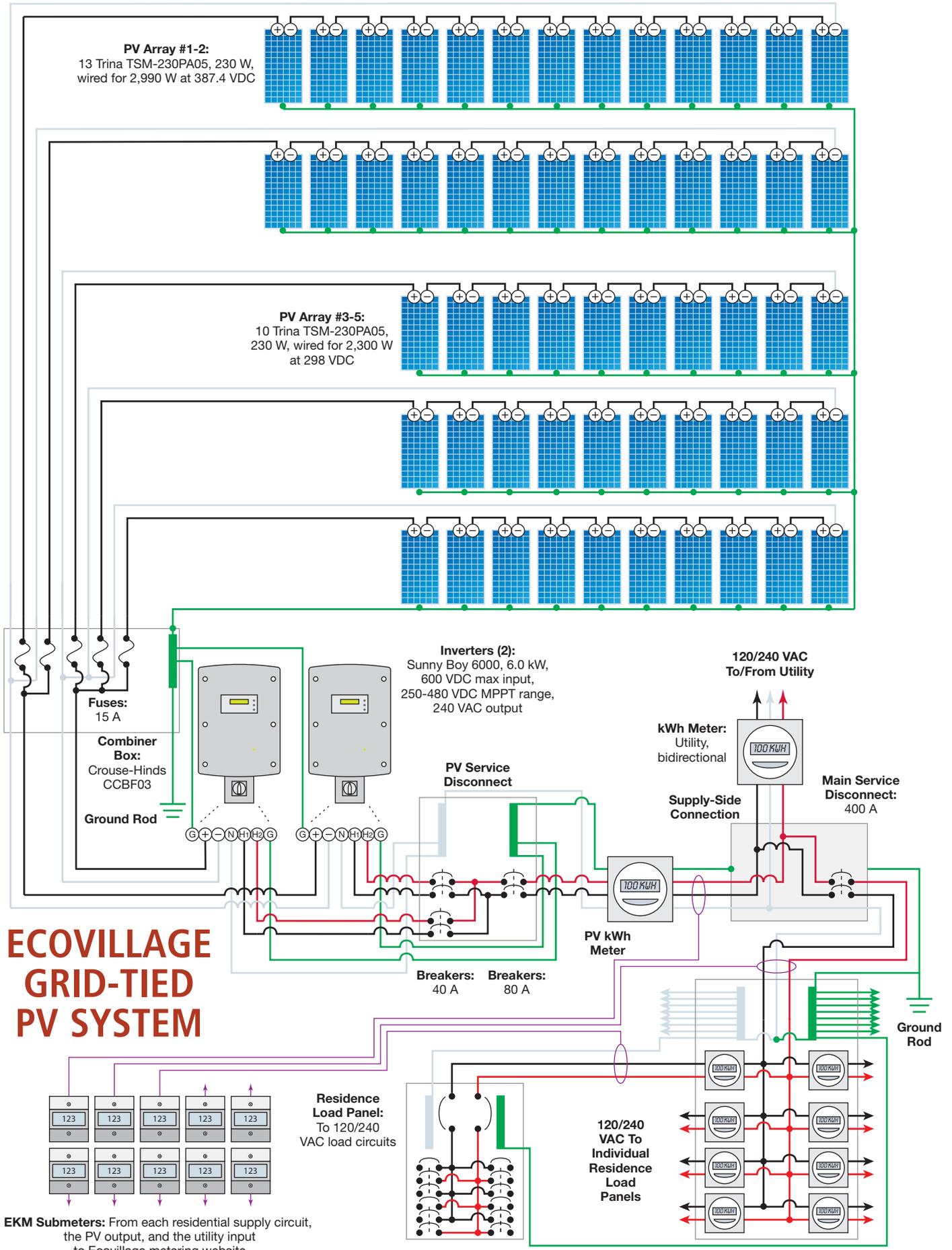
New York State has well-established procedures to allow the conversion of individual meters to master meters in multifamily dwellings. By following the procedures, we were able within a few months to get our local utility to agree to the conversion. We reduced from 30 separate meters to four—one for each quadrant of the neighborhood.

The EKM meters monitor the electricity consumption of each residence.



One of two power walls, which include performance metering, disconnects, the inverters, and the members' consumption meters.





ECOVILLAGE GRID-TIED PV SYSTEM



The second power wall. Each power wall holds the inverters for two of the neighborhood quadrants, with one set of AC outputs going underground to feed the remote quadrant.

Moving to master metering meant that the co-op would be responsible for metering and billing of residents, which required installing new submetering equipment. Our initial equipment survey was disappointing—most products we found were expensive and lacked key features. We wanted “smart meters” that would interface with our internal Internet-connected network that allows either wide or local-only access as we see fit. So far, we have chosen to make display data available only internally, but we could make it accessible to the outside world if residents feel comfortable about making their usage info public.

Most products with these capabilities work only with proprietary software and required significant monthly fees. Other smart meters are more suited to individual homeowners and not designed to be centrally installed and managed. Luckily, we found EKM Metering of Santa Cruz, California, which approached smart meters more like a computer startup company and less like a utility, creating inexpensive products that act as flexible building blocks to be “mashed-up” in various ways, rather than creating rigid systems that lock a customer into using only the capabilities provided by one vendor.

We were able to create a cost-effective smart-metering system with no monthly fees. Besides the basic meter reading, we developed software for graphical display of real-time power usage for individual homes as well as aggregate displays of use, PV generation, and purchased energy for each group of townhouses and the whole neighborhood. We are considering making this available for free as open-source software.

With the overall plan in place, we now had to get official approval from our 30 households to commit to the project. In our neighborhood, this happens through monthly meetings open to all residents, with decisions made by consensus after lots of discussion. Our group was challenged to explain the details of a complex project and answer many probing questions.

Changes to Public PV Policy

Some of the challenge of implementing multifamily PV systems relates to outmoded or overly restrictive policies by utilities and public service commissions. Two programs could help overcome some of these challenges.

Community net metering—Some locales allow “virtual net-metering” in which a utility customer buys a certain number of PV modules in a large array located somewhere off-site, and the utility tracks the PV production and subtracts the energy from the customer’s utility bill. It is a simple accounting transaction—no physical connection to the home is required. (See “Growing Solar in Your Community” in *HP143*.)

Feed-in tariff—This is the simplest of all. With a feed-in tariff, the utility is required by law to purchase all PV-produced electricity at retail or higher prices. The price premium paid to producers is funded by a small surcharge on nonrenewable energy usage. Using this approach, many countries, notably Germany and Japan, have grown their solar capacity immensely, and have provided green investment opportunities for millions of their citizens. In our case, we would have simply hooked up the system to the utility at the nearest location, and sold the power, crediting the money to residents to offset their utility bills.

Improved utility tariffs—Most states define a variety of tariffs or “service classifications” that define rates for different classes of power users. The structure of available tariffs can have an impact on community PV projects. For example, New York state does not have a tariff for multifamily residential service, so master-metered neighborhoods must use commercial tariffs, which tend to cost more. New York also lacks any applicable time-of-use or peak/off-peak tariff, so residents cannot take economic advantage of the fact that PV produces the most power during the time of day when utilities in other states are paying premium prices per kWh.

The Sunny WebBox is the communications hub between the inverter data and the Internet, so that users have online access to monitor the PV system remotely.





SMA's Sunny Portal is the online interface that users navigate to check PV system status and production data for each inverter.

By the end, it was clear that some aspects of the project, such as exact design requirements and pricing from the utility for master meter installations, utility tariffs, and extraneous permits, could only be confirmed as the project moved through the process. We were frank with residents about these uncertainties. The project was approved unanimously in April 2011.

Implementation

With approval in hand, the focus switched to Tony Henderson and his crew at Hayes Electric to get things rolling. Tony worked with us to obtain approvals for a zoning variance, building and electrical permits, and our application for PV rebates from NYSERDA (New York's state agency that manages RE rebates). By the end of June, we were ready to break ground.

This graph shows the PV generation, electricity purchased, and electricity consumed by one group of townhouses. When the green line drops below zero, it means the system is producing beyond usage, selling electricity to the grid.



The system consists of four subarrays of 56 Trina 230-watt modules. Each subarray is connected to a pair of Sunny Boy SB6000US grid-tied inverters. The array, about 200 feet from the nearest building, required trenching across backyards of the residences for more than 500 feet. We located the inverters at the residence-end of the trenches rather than near the array, sending the higher-voltage DC over the long conductors to reduce voltage drop.

We experienced a few big delays, particularly related to the foundation holes, rocks, and a couple of passing hurricanes, but were still able to meet our end-of-year deadline. The system came online on December 29, 2011.

After Construction

With the array complete and our new metering system in place, we set up the billing system. Previously, our residents all were billed at a residential rate, but by combining meters, our only option was to convert our account to commercial. We negotiated the service rate classification for the new master meters with the utility and we got the state public service commission involved as well. We contended that since the load was still all residential usage that we should be able to retain a residential (nondemand charge) tariff. However, New York's PSC regulations do not include a multifamily residential tariff (nor any time-of-use classes, except for large industrial customers), so we ended up on "SC2," a basic commercial tariff with demand charges.

This was not a big price difference, but it did require paying an additional monthly fee known as a demand charge, which reflects how *quickly* you draw power from the grid, in addition to *how much* you draw. It's as if you were charged for how hard you stomped on your car's gas pedal in addition to having to pay for the gas you use. In our case, demand charge is measured as the highest-drawing 15-minute period during the billing period on



Residents celebrate the new 50 kW PV system.

each of the four master meters. For example, in January and February 2012, the highest demand was 61 kW across all four quadrants, and at a fee of \$8.13 per kW the total charge was about \$495. The overall bill for that period (including demand) was \$1,327. Despite that big demand charge, it turned out that because some other charges (such as the delivery fee) are cheaper on the SC2 tariff, it only cost about 4% more. And we could have dropped that even lower had we done a better job managing our demand.

That gave us an economic incentive to minimize avoidable energy use during times of peak simultaneous usage, such as during normal meal times. Our smart-metering system gives residents the tools to examine their use and consider rescheduling things like dishwasher loads to be outside of the peak periods. Residents have been changing their energy habits, and even initiated discussion groups to share energy-saving strategies, such as using pressure cookers and slow cookers to decrease electric stove use.

Calculating monthly bills turned out to be more complex than we originally anticipated. Utility bills contain a bewildering number of separate charges, and we wanted to ensure that costs were being passed on fairly for both light and heavy electricity users. Our solution was to classify each of the various charges on the utility bill into categories of fixed, per-kWh, and demand charges, and apportion them to residents. Once these ratios/percentages were figured, we built a spreadsheet to automatically calculate charges for individual households.

The electricity generated by the PV system is divided evenly among the 30 households, giving each a kWh credit. This provides a target to see how close each household can get to “net zero” electricity usage. For the energy-thrifty households, that sometimes results in having no monthly charge for electricity.

Lessons Learned

The most important thing we learned from this project is the value of steadiness—to neither rush nor allow ourselves to be deterred. At every point, there were obstacles, surprises, and things we didn’t know how to do. Cultivating an attitude of relaxed determination kept us on track, and made the project satisfying.

We also became acutely aware of the ways public policy can impact the development of renewable energy. While our project was helped immensely by the generous incentives from state and federal agencies, we also had a lot of complications that would be unnecessary with some common-sense changes to law and regulatory policy.

For example, our array was actually situated only 50 feet from our site’s main utility feed. It would have been convenient and cost-effective to connect the array there, if we could have gotten a fair price for the power produced. Instead, since the only way to get a good price for PV power is to do net metering against a load served by a single utility meter, we had to trench more than 500 feet and rework our entire metering system. That added complexity to our

project and up to 30% of its cost. A few simple policy changes could greatly facilitate the expansion of PV deployment (see “Changes to Public PV Policy” sidebar).

Benefits

This project has many benefits for our community. The system has been paying for itself from day one. For the 15-year life of the loan, our neighborhood gets more than 50% of our electricity from a local, carbon-free source at utility rates. After the loan is paid, our utility bills will drop by more than half for the system’s lifetime. At no point will we pay extra for having a PV system. In addition, the interest from the loans remains among neighbors, helping community families rather than disappearing into the corporate financial system.

Our residents also have new tools to monitor electricity use, which numerous studies have shown can lead to energy savings approaching 10%. We can also track changes over time, allowing us to evaluate the effects of investments in more-efficient appliances and lighting, or behavioral changes.

There are also less tangible benefits. We learned that everyday people can come together to respond in an active way to the problems of living on a finite planet. We don’t have to wait for others to provide solutions.

Now, when the sun shines, we feel something more than its warmth on our faces. We’re also aware that it’s powering our homes, cooking our food, running our computers, and

even spreading over the grid to feed clean energy to others, while putting a little change in our pockets. By tapping the sun’s ongoing daily flow, rather than further drawing down nonrenewable stores, it feels like we’re on a more robust path than before. And that may be the biggest benefit of all.

Access

Jeff Gilmore (jeff@thegilmores.net) is a former computer engineer with a long-time interest in renewable energy and community projects. He currently helps manage a variety of technology projects at Ecovillage at Ithaca, where he lives with his wife and three sons.

Database of State Incentives for Renewables & Efficiency (DSIRE) • dsireusa.org

Ecovillage at Ithaca • ecovillageithaca.org

Hayes Electric • 607-279-6964

PVWatts • nrel.gov/rredc/pvwatts

PV System Components:

EKM Metering • ekmmetering.com • Smart metering

RBI Solar • rbisolar.com • Racking

SMA America • sma-america.com • Inverters

Trina Solar • trinasolar.com • PV modules



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A typical heat pump can deliver two to four times the amount of energy it takes to operate. It can act as a boiler, furnace, and air conditioner—all in a single unit.



HEAT PUMP PRIMER

Why Electric Heating Finally Makes Sense

by Alex Wilson

I used to think that electric heating could never be justified—for any reason. As energy guru Amory Lovins said in the 1970s, using electricity for heating was “like cutting butter with a chain saw.” It just didn’t make sense to use such a high grade of energy for such a low-grade energy need.

But since then, electric heat pumps have become widely available. This has changed my mind and I find myself recommending electric heat all the time. In fact, a new house that my wife and I are planning in southern Vermont will have electric heat—from a heat pump. Let’s find out what heat pumps are, and why they make sense.

Electric Heating Basics

What I thought about as electric heat in the 1970s, when Lovins’ preaching was ringing in my ears, was electric-resistance baseboard heating. With electric-resistance heat, electric current is converted directly into heat. Special “resistance wire” is used that resists the flow of electrons, producing heat in the process. Electric-resistance heat is most commonly delivered through baseboard “radiators,” but it can also be delivered through radiant ceiling panels, fan-driven convection heaters, and radiant-floor systems.

Electric-resistance heating is 100% efficient—each kilowatt-hour (kWh) of electric energy is converted into a kWh of heat. However, that only considers the conversion efficiency in the unit—and does not factor in the utility transmission losses or the efficiency of the source (see “Improving Source & Site Efficiency” sidebar).

Instead of using electricity directly to produce heat, the electrical energy can be used to *move* heat from one place

Courtesy: WaterFurnace

to another—like from outdoors to indoors. That’s the basic principle of a heat pump: it extracts heat from the outdoor air (air-source heat pump) or from the ground (ground-source heat pump) and delivers that heat inside the building.

The idea of moving heat from a cooler to a warmer place is counterintuitive, but it’s exactly what your refrigerator does. Peter Temple, an architecture professor at Keene State College, refers to this concept as “pumping heat uphill.” While electric resistance is 100% efficient at converting electricity into heat, a heat pump can deliver (move) two to four units of heat for every unit of electricity it consumes.

Every substance that is at a temperature above absolute zero (about -460°F , where all molecular motion stops) contains heat energy. Cooler objects have less heat energy (energy of motion of the molecules) than warmer objects. But even air molecules at 0°F have enough heat so that we can extract some, and leave the air just a little cooler than it was before.

A heat pump’s coefficient of performance (COP) is the ratio of energy delivered compared to the operating energy. A heat pump with a COP of 1 delivers 1 unit of heat for each unit of electricity consumed—no better than electric-resistance heating. A COP of 2 provides twice as much heat from the electricity consumed. That can be thought of as 200% efficiency—though it really isn’t a measure of efficiency, since the electricity is used for moving, rather than generating, the heat. Some heat pumps, in some situations, can have a COP as high as 5 or 6.

Understanding Heat Pumps

Heat pumps work by altering a refrigerant between its liquid and vapor phases in a closed loop. This phase change process releases and absorbs heat, enabling the heat pump to move heat from one place to another—even if the heat source is colder than the heat sink. This refrigerant cycle or vapor-compression cycle is the principle behind nearly all air conditioners, heat pumps, and your kitchen refrigerator.

There are four main components to a heat pump—compressor, condenser, expansion valve, and evaporator, plus heat exchangers to deliver heated or chilled air to the living space. Gaseous refrigerant is mechanically squeezed in the compressor—a process that also raises its temperature. This hot vapor then enters the condenser, where the hot vapor cools and condenses into a liquid state. A heat exchanger in this part of the heat pump transfers heat to the surrounding air (because that air is cooler than the refrigerant), and that heated air is delivered to the house.

Next, the condensed liquid refrigerant flows through an expansion valve, where it experiences a sudden pressure drop. This further cools the refrigerant, which at this point is mostly liquid. From there, this liquid refrigerant flows into the evaporator, where it evaporates into a vapor, a phase change that requires absorption of a large amount of heat. The heat exchanger uses air to warm that vapor and, in the process, chills the air.

“The key idea,” says Temple, “is that we have a loop and there are two phase changes every time the refrigerant goes around that loop.” Heat is absorbed on one side of the loop (evaporation) and dissipated on the other (condensation).

IMPROVING SOURCE & SITE EFFICIENCY

When we refer to electric resistance heat as being 100% efficient, we are referring to the efficiency at converting the electricity coming into your home into heat. If we look at the *source energy* used to produce this current, though, the efficiency is much lower. Most coal and nuclear power plants are only 30% to 35% efficient at generating electricity. Most of the rest is lost as heat; some is lost in transmission.

Thermoelectric power plants, which account for 89% of U.S. power generation, use a fuel to heat water to produce high-pressure steam. That steam spins a turbine, generating the electricity, and the leftover heat gets dumped into the environment, such as a nearby waterway, as thermal pollution.

The overall efficiency of power plants can be improved dramatically through cogeneration or combined heat and power (CHP), in which waste heat is captured and utilized, but that is rarely done in this country.

When electricity for heating is site-generated with renewables, a very different picture emerges. With solar-, wind-, and hydro-electric systems, there are no transmission lines or steam turbines with their inherent production of waste heat. This isn’t to say that renewable power generation is 100% efficient, but the lost energy is not derived from fossil fuel combustion or nuclear fission, both of which carry environmental impacts.

Air-source heat pumps are easy to install and are beginning to rival the performance of ground-source heat pumps, at a fraction of the cost.



Courtesy Alex Wilson

HOW A HEAT PUMP WORKS

Electrical Load:

Heat pumps use freely available heat energy by moving it to where it's needed. But moving it takes some energy. The components of the system that require power include the compressor, fans, pumps, and controls.

Exterior Heat Exchanger:
Cold liquid refrigerant is warmed by outside air and evaporates as its temperature increases

Air from Outside:
Warmer than liquid refrigerant

Fan:
Draws outside air through heat exchanger

Compressor:
As the pressure of the gasified refrigerant increases, the temperature increases.

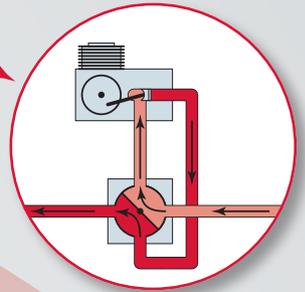
Reversing Valve:
Changes refrigerant direction for heating or cooling cycles

An Air-Source Heat Pump in Heating Mode

Expansion Valve:
As the pressure of the liquid refrigerant drops, the temperature drops further

Heat Pump Cooling Mode:

The reversing valve allows the whole system to run in reverse, extracting heat from the home's interior and releasing it to the outside.



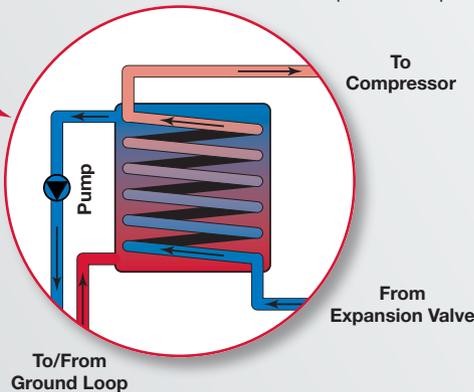
"Interior" Heat Exchanger:
Hot gasified refrigerant releases heat to the inside air and condenses to a liquid as it cools

Air from Inside:
Cooler than gas refrigerant

Fan:
Draws interior air through heat exchanger

Ground-Source Heat Pumps:

Use a heat-transfer fluid and a liquid-to-liquid heat exchanger to extract heat energy from the earth or a water source.



Split Systems:

The "interior" heat exchanger can be located outside, using ducting to move hot air to the inside space, or it can be located inside, in a separate "split" unit that uses refrigerant to move heat between the two heat exchangers.

Heating Water with Heat Pumps:

Like the liquid-to-liquid heat exchanger on the exterior side of a ground-source heat pump system, an interior heat exchanger can heat water for domestic use and/or hydronic space heating.

Every heat pump has a heat source and a heat sink, and these can be swapped. In the winter, the heat source is the outside air (air-source heat pump, ASHP) or the ground (ground-source heat pump, GSHP), and the heat sink is the house that is being heated. In the summer, that is reversed, with the house air being the heat source and either the outdoor air or ground being the heat sink. The same coils are used, but in one season they serve as evaporator coils and in the other season they serve as condenser coils. A heat pump's reversibility is one of its key benefits.

Imagine removing the door on your refrigerator. In the winter, you position the refrigerator in a doorway, with its opening facing the outside. In this configuration, the refrigerator works like a heat pump to *heat* your house—extracting heat from

the outside air and transferring that heat to the room through the coils on its back. In the summer, you turn the refrigerator around and fit it back into the doorway so that its cool interior now faces the room. Now it works like a heat pump to *cool* your house.

A real heat pump doesn't have to be physically moved, but uses valves to accomplish the same effects—the condenser becomes the evaporator and the evaporator becomes the condenser.

Confused? Don't worry. The refrigerant cycle is complex and not very intuitive. But it works—as it has since Willis Carrier first perfected its use in 1900. In a heat pump, the components are elegantly housed in a box located inside the home or in separate indoor and outdoor units. The user doesn't see those thermodynamic processes happening, but can just enjoy the results.

GROUND-SOURCE HEAT PUMPS

Ground-source heat pumps have been a darling of the green building movement—and for pretty good reason. Temperatures underground remain much more constant year-round than air temperatures. This makes the ground a better heat source in winter and a better heat sink in summer, boosting the efficiency of a GSHP compared to an ASHP.

Most GSHPs are closed-loop systems, in which long coils of plastic tubing (usually polyethylene) are buried in horizontal trenches or vertical bore holes. This tubing serves as a primary heat exchanger, transferring heat between the ground and an antifreeze (glycol) solution, which is brought to the heat pump where another exchange of heat with the refrigerant happens.

A specialized type of closed-loop heat pump uses the coil of tubing sunk in a body of water. The heat transfer to and from the water is very rapid, so the coil doesn't need to be as long. However, this type of system is uncommon, since most homes don't sit next to usable water sources.

Open-loop GSHPs are also referred to as groundwater or surface-water heat pumps, depending on the water source. Water is pumped from the ground or a body of water, circulated through the heat pump, where heat is either extracted from it or added to it, then returned to the source. If the water is extracted from a well (most common), it is usually returned to the ground through a separate injection well. Open-loop heat pumps present a greater risk of contaminating either the aquifer (groundwater) or the surface water from which the water is drawn, and are prohibited in some states.

Ground-source heat pumps extract heat from the earth using a well, several bore holes, or loops laid in shallow trenches.



**CLOSED-
LOOP
HORIZONTAL
TRENCH**



**CLOSED-
LOOP
VERTICAL
BORE**



**CLOSED-
LOOP
WATER
SOURCE**



**OPEN-LOOP
WATER
SOURCE**

Courtesy WaterFurnace (4)



Courtesy zhome



Courtesy WaterFurnace (2)



The WaterFurnace 502W12 hydronic heat pump is capable of delivering 150°F water, and is suitable for baseboard radiator systems, underfloor and overfloor radiant applications, and fan-coils that transfer heat to a forced-air heating system.

The WaterFurnace 500A11 ground-source system provides forced-air heating and air conditioning, and can contribute to a home's domestic water heating.

Rather than circulating an antifreeze solution through the ground, direct-exchange (DX) GSHPs circulate the refrigerant directly. These heat pumps are simpler and more efficient because they don't use a secondary heat exchanger in the heat pump cabinet to transfer heat between the ground-contact antifreeze and refrigerant loops. But DX heat pumps require copper tubing, which is more expensive than polyethylene. They require a lot more refrigerant, and the copper may corrode and eventually leak.

Some GSHP manufacturers claim COPs as high as 6 for their systems under certain conditions, and COPs of more than 3 are common. High COP claims may be exaggerated for real systems in the field—the performance of GSHPs drops as the heat-exchanger loop warms or cools the soil over time.

GSHP Performance

One of the only long-term studies of GSHP performance is a field study of 83 heat pump installations in the United Kingdom by The Energy Saving Trust, with support from government agencies, utility companies, and manufacturers. Published in 2010, the study examined 54 GSHP installations and 29 air-source heat pump installations.

Only a handful of the GSHPs (13%) performed at a COP of 3 or higher. About the same number had measured COPs of less than 2. The largest number performed with COPs in the 2.2 to 2.4 range—below the expected performance of GSHPs.

One of the problems appears to be poor installation or lack of commissioning (inspecting, testing, and tweaking the installation after completion). Operation was another problem, with some homeowners telling researchers that they did not understand the operating instructions.

GSHPs also alter the ground temperature, causing a drop in performance. "You end up cooling the ground a lot in the winter and warming it up a lot in the summer," says Temple. In climates such as New England, where heating loads dominate, cooling of the ground from GSHPs may accumulate over multiple years—dropping the GSHP performance from year to year. In cooling-dominated climates, a similar drop in performance may occur over time as the ground warms up from year to year. More testing is needed to understand these seasonal and year-to-year performance issues with GSHPs.

GROUND-SOURCE vs. GEOTHERMAL

Ground-source heat pumps are often referred to as *geothermal* heat pumps, reflecting that the heat comes from the ground. Using "geothermal" to refer to heat pumps creates confusion with true geothermal energy systems, which pull heat from the Earth's mantle deep underground. With a ground-source heat pump, the stored heat it takes from the earth comes primarily from seasonal (solar) warming of the ground.

AIR-SOURCE HEAT PUMPS

Air-source heat pumps have long been popular in some parts of the United States. Until recently, they only made sense in milder climates where winter temperatures rarely drop below about 40°F.

Unlike their ground-source cousins, ASHPs have separate indoor and outdoor units where different parts of the vapor-compression refrigerant cycle take place. But like GSHPs, they can be switched from heating mode to cooling mode seasonally.

ASHPs rely on the outside air as the heat source in winter and as the heat sink in summer. When outside temperatures are low, it's harder to extract heat from the air, and efficiency drops. In fact, at temperatures below 30°F, most older U.S. ASHPs would automatically switch to electric-resistance heating, so the benefit of the refrigerant cycle was lost.



A minisplit air-source heat pump puts the second heat exchanger inside the house, moving refrigerant (rather than air) between the two.

The outdoor unit of a minisplit air-source heat pump can be small and inconspicuous. The refrigerant lines going to the inside minisplit unit are protected inside of the shown chase.



Courtesy Environmental Comfort Systems (2)

In the past 10 to 15 years, there has been a revolution with ASHPs, as Japanese companies have brought variable-refrigerant-flow (VRF) or “minisplit” heat pumps into the U.S. market. Most VRF heat pumps can operate down to 0°F (or even lower) without significant loss in performance. In southwestern New Hampshire, for example, these systems have been successfully heating houses without any other heat source, even with outside temperatures as low as -18°F.

VRF heat pumps vary the flow of refrigerant in ways that significantly boost performance, while the older, standard heat pumps operate at a constant flow—either on or off. VRFs also benefit from improved refrigerants and sophisticated electronic controls.

The indoor unit can be wall- (most common), floor-, or ceiling-mounted. Small-diameter refrigerant lines connect the indoor and outdoor units. They are relatively easy to install and elegant in their simplicity. They cost a lot less than GSHP systems, because trenching or well drilling isn't required, nor are long lengths of tubing .

ASHP Performance.

The best VRF ASHPs operate with COPs that are close to those of GSHPs, and their performance doesn't change over time due to long-term changes in ground temperatures.

Costs of both GSHPs and VRF ASHPs vary widely depending on available installers and system popularity, but the pricing differences can be dramatic. It is not unusual for GSHP installations to cost \$25,000 to \$35,000, while \$10,000 to \$15,000 is more common for the VRF units. With simple installations in places where a lot are installed, VRF heat pump installations can cost as little as \$5,000.

Heat Pump Water Heating

Both ground- and air-source heat pumps can be configured to heat water along with space heating and air conditioning. In the summer operation mode, water heating can be almost free—as a byproduct of the cooling cycle. In this mode, heat is extracted from the indoor air, but instead of simply dumping it into the ground or outside air, a “desuperheater” diverts the waste heat for water heating. Only a few heat pumps incorporate water heating, but this will become increasingly common as heat pump advances continue.

Heat Pumps & Photovoltaic Power

If we can reduce space-heating loads—through high levels of insulation, well-insulated windows, and airtight construction—and provide some heat with passive solar design, then it makes sense to provide the small amount of needed heat with solar electricity. And it makes sense to use heat pumps, rather than electric-resistance heat, since heat pumps are far more efficient.

PV systems can allow achieving net-zero-energy use in homes. With the heating loads low enough and using a heat pump to deliver more heat from each kWh, a simple roof- or ground-mounted PV system with net metering should be able to satisfy those needs. For example, a well-built, well-insulated, and well-sealed 1,500-square-foot house in southern New Hampshire, for example, could require about 9,500 Btu per square foot per year for heating, or about 14.25 million Btu per year. That converts to about 4,175 kWh, which in New England could be supplied by a 3.5 kW PV array.

CONSERVATION VS. CONSUMPTION

There’s a disconnect between investing in conservation and investing in consumption. Rather than spending \$35,000 on a GSHP or \$20,000 on a radiant-floor heat-distribution system, it often makes more sense to put those dollars into energy conservation, passive solar design, and retrofits, like extra insulation, weatherstripping, and high-performance windows. For new construction, in cold climates, get the wall R-values to R-40 or higher. Then install high-performance windows with low-e coatings that provide R-5 or higher, and use air-sealing strategies to provide a tight envelope (1.5 air changes per hour at 50 pascals of pressure is recommended).

In an efficient house, having a high-performance envelope may eliminate the need for a central heating system. A VRF air-source heat pump or a wood heater may be able to meet all of your space-heating needs. It just doesn’t make sense to spend tens of thousands of dollars on a heating system to provide a few hundred dollars’ worth of heat per year.

Most early net-zero-energy homes used GSHPs for heating because they offered the highest COPs. But today’s VRF ASHPs are nearly as efficient, and that efficiency is less likely to drop over time. Plus, because of the significantly lower installation cost of VRF heat pumps, the economics can be far better than with GSHPs, allowing you to invest the savings into a bigger PV system.

PV-powered heat pumps can provide a truly renewable source of heating (and cooling). Avoiding all combustion in the home eliminates the risks inherent with fossil fuel and wood combustion—long-term health problems from air, soil, and water pollution; explosions; etc. This is why more and more, leading energy engineers and builders are now examining VRF air-source heat pumps more closely.

Access

Alex Wilson is the founder of BuildingGreen in Brattleboro, Vermont, and executive editor of *Environmental Building News*. He is the author of *Your Green Home* (2006) and coauthor of the *ACEEE Consumer Guide to Home Energy Savings* (ninth edition, 2007).



COMPARING FUEL COSTS

Comparing the economics of a heat pump to other heating systems can take a little work since we’re not comparing apples to apples. Different fuels are sold (and priced) in different units: therms or hundred cubic feet (ccf) of natural gas; gallons of propane; gallons of heating oil; tons of pellets; cords of wood; and kilowatt-hours (kWh) of electricity. These different fuels have very different heat values.

Online fuel-cost calculators allow you to plug in the current price of the fuels being compared. The more sophisticated calculators allow you to vary the efficiency with which the fuel is burned (or converted into heat) and even the efficiency with which the heat is distributed, then output a comparison of costs in consistent units—such as dollars per million Btu of delivered heat.

Of course, energy prices fluctuate, so such a comparison is only accurate in the present. But running through these calculations can help you make an informed decision about the costs (and savings) of various heating systems. BuildingGreen’s online calculator (buildinggreen.com/calc/fuel_cost.cfm) was used to create the comparison table below.

Home Heating Costs

Heater Type	Fuel Type	Efficiency or COP	Fuel Cost	Operating Cost per Million Btu
Hydronic heat (boiler)	Heating oil	83%	\$3.50 per gal.	\$31.03
Pellet heater	Wood pellets	80%	250.00 per ton	18.94
ASHP	Electricity	2.25	0.15 per kWh	19.94
GSHP	Electricity	3.00	0.15 per kWh	14.95
Central furnace	Natural gas	90%	1.25 per therm	14.17

Source: buildinggreen.com/calc/fuel_cost.cfm

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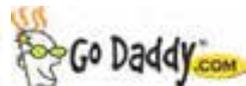
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10 Considerations for Smart Solar-Heating System Design

Off-the-shelf solar heating systems don't always fill the bill. This is where good design and smart planning come in.

by Kurt Koegel

1 System Type

Determine the type of heating your system will be supplementing.

Solar thermal can be used for many applications, from water heating to air conditioning to biodiesel processing, but the most common are domestic water heating, pool heating, and space heating. "Combisystems" cover more than one of these applications.

Solar heating systems can be an efficient, economical method of space heating, domestic water heating, and pool heating. With attention to careful design and sizing for your household's needs, they can provide decades of productive service.

istockphoto/Barcin



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istockphoto/skymesher

2

Backup Source

Figure out what type of backup source will be used.

When your solar heating system can't take care of the whole load, there are many backup heating choices. The energy source your backup water heater uses will determine the choices you have. For natural gas or propane, traditional tank-type and tankless are the most common. For electricity, you can choose from tank-type, tankless, or heat pump/hybrid water heaters. Gas or electric boilers can also be used to heat water, which is then pumped to an indirect water heater (aka coil tank) or even a plate heater.



Courtesy Alex Wilson



Courtesy Ben Root



Courtesy Kurt Koegele

A natural gas or propane-fired furnace and water heater take care of DHW and space heating in the absence of sun.

Far left: Heat pumps can heat water for both DHW or space heating, as well as provide stand-alone space heating.

Left: Gas or electric on-demand water heaters can act as backup for DHW and space-heating applications.

For space-heating backup, natural gas, propane, or electric boilers can be used as well as air, ground, or water-sourced heat pumps. The key to selecting is in the heat delivery—the lower the required temperature, the more solar can contribute. Solar thermal is most efficient when the desired water temperature is in the 70°F to 140°F range. Radiant heating works at temperatures from 90°F to 120°F, so this makes it a great match with solar thermal. Next is forced air that works at temperatures from 100°F to 140°F. Last is hot water baseboard heating that works at temperatures between 120°F and 190°F.

In most cases, the solar system ties into the existing space heating system and assists it by preheating the HTF before it gets to the boiler, but after it has left its heat in the floor loop. In this way, solar can contribute the most because the HTF will be at its coldest. If the solar system can produce hotter HTF than comes out of the load, then solar is contributing. If it cannot, then the boiler operates normally with no solar contribution.

Checks & Balances

To keep costs down and performance up, certain checks and balances should be applied to your solar heating system design.

- Keep it simple. The most successful systems work well for a long time because of their simplicity.
- Solar is usually supplemental—there will be cloudy days, so always include a backup energy source.
- Solar is site-specific. It will only work if the sun is able to shine on the collectors.
- The system must be appropriately scaled—it should have a reasonable return on investment, whether monetary or environmental.
- Aesthetics can be important. A well-designed solar thermal system can be visually unobtrusive, while providing good performance.

3 Solar Loop Type

Specify the solar loop type that will work best for your application and climate. The main choices are direct, glycol, or drainback systems.

A direct system routes potable water directly through the solar collectors. These systems are only used in year-round warm climates (like Hawaii) where the ambient air temperature never drops below freezing.

In a glycol or pressurized closed-loop system, the solar loop and collectors are filled with a glycol antifreeze solution. The collectors can be mounted in any orientation and be located above or below the solar storage because they require pumps. Some drawbacks are antifreeze maintenance and potential summertime overheating.

A drainback system circulates antifreeze or, more typically, plain water through the collectors only when they are warmer than the load or solar tank. The rest of the time, the collectors and outside pipes are “drained back” and empty—the fluid drains to a holding tank. Advantages are less or no fluid maintenance, higher efficiency, and no possibility of overheating. Drawbacks are that larger circulating pumps are needed, and the orientation of the collectors and pipes must allow unfettered draining back to the holding tank.

Pump energy type is another factor in solar loop choice. The most common circulating pumps are 120 or 240 VAC. DC pumps are also available that can be energized by PV modules or batteries. AC pumps come in hundreds of sizes and are easy to find at most supply houses or home centers. More expensive DC pumps are available in fewer sizes, but can provide a grid-free solar heating system.

Closed-loop systems using an antifreeze heat-transfer fluid are best for cold climates, but require more maintenance than other system types.



Courtesy Ben Root



Courtesy Edward Marie

PV-powered DC pumps are a perfect match for SHW circulation, since they run when the sun shines.

An open-loop system sends potable water through the collectors. Simple and inexpensive, these systems are best in nonfreezing climates.

Drainback systems allow the collectors to drain to prevent freezing or overheating.



Courtesy Cardinal Heating



Courtesy Kurt Koegel

4

Space Available

Calculate how much space is available for the solar thermal collectors. For optimum performance, you will need a shade-free south-facing area for your collectors. It is best to have no shading from 9:30 a.m. to 3:30 p.m. throughout the entire year. If you have any doubts, this can be verified by using a shade analysis tool such as a Solar Pathfinder. Also consider future shading from tree growth or new construction.

Facing the collectors south is important but not critical. If your collectors are 30° east or west of true south, there will only be a 5% to 10% performance penalty—though some areas have late or early fog to consider. Keep in mind that the roof is not the only option—collectors can be mounted on the ground, the side of the building (like awnings), or even pole-mounted.

Wall-mounted collectors can be vertical for winter-specific exposure or awning-mounted for year-round exposure and shading beneath.



Courtesy Kathleen Root

A ground mount can get your collectors in the sun when orientation, space restrictions, or shading prevents roof-mounting.



Courtesy Powerfully Green

Shading isn't always a bad thing: Here, winter sun cuts through deciduous branches, while summer foliage will help prevent overheating.



Courtesy Kurt Kregel

Courtesy Cardinal Heating

Roof mounting is common for solar heating systems. Collectors can be angled for optimum exposure or set flush for streamlined aesthetics with only a minor decrease in efficiency.



Courtesy Warren Tessler

A simple one-tank system may meet your family's needs at a reasonable price. In most climates, solar hot water systems have a quick payback.

5

Budget

What's your budget? This is often the biggest limiting factor. Decide what makes financial sense for you, while still meeting your goals, such as specific building standards like Passivhaus or LEED; carbon dioxide offsets; or total energy offset. Utility grants, state rebates, tax incentives, the anticipation of reduced utility bills; and private or government financing options can help you more accurately arrive at a final up-front cost.

Installation costs vary widely from region to region because of differences in labor cost, permit fees, code requirements, climate-specific equipment, and other region-specific factors. Get estimates from reputable solar contractors to gauge what the cost will be. You can dramatically reduce your system costs by taking advantage of local and state government incentives or utility programs. Also, if you have a federal tax liability, you can take a 30% tax credit on the entire installation cost. Check dsireusa.org for available utility, local, state, and federal incentive programs.

6

Storage Size

Calculate how much solar storage you need—a place to park extra heat until it's needed. If the sun is shining and there is no immediate load, there is no need to let it go to waste. Water is the most common heat storage medium because of its ease of use and ability to transfer heat easily to a load.

Hot water use is usually sporadic. Solar tanks are usually sized to store a full day's worth of hot water. A good rule is 1.25 gallons of storage for every square foot of collector in the Northeast and Northwest; 2 gallons per square foot in the Southwest; and 1.5 gallons most everywhere else. Even in locations with excellent winter insolation (like the Southwest), most designers use a 1:2 ratio. Having too much storage can result in the collectors not raising the tank temperature enough each day.

For space heating, it's a little more complicated. If your building needs a lot of heating even when the sun is out, little storage is needed. But if you also have passive solar heating in your building, you might not need all of the harvested solar hot water until the evening. Storage sizing for space heating systems can be from 1 to 3 gallons per square foot of collector area—it depends on when you will need the heat and when it is available. Thermal mass—such as extra sand under the slab or the concrete slab itself—can also be used for storage by hydronic floor space heating systems.



Courtesy Kurt Koegel

Storage tank volume choice is a factor of climate and collector area: too much storage and water will never come up to temperature; too little storage and overheating becomes a problem.

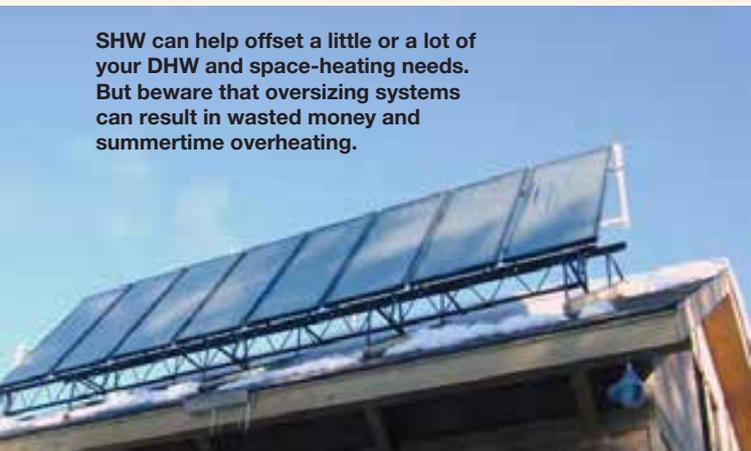
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Percent of Load

Calculate your heating loads. Each person in the home will typically use about 20 gallons of hot water per day. This usually covers bathing, cleaning, and laundry. But “typically” does not fit all: If you have a big bathtub, add accordingly. If you are more conservative than most, then subtract accordingly. If you're not sure how much hot water you use on a daily basis, install a water meter on the cold water line that feeds your existing water heater. Master Meter makes quality water meters (about \$60) that can be bought online.

Determining your space-heating load is more complex. First, do *not* use your current heater's size—your boiler may have a 100,000 Btu per hour input, but this does not mean it consumes 100,000 Btu per hour since it cycles on and off. This could be one cycle lasting two minutes every hour in the spring and fall, to one cycle lasting 50 minutes every hour during the height of the heating season. This fluctuating load makes determining the heating load difficult.

SHW can help offset a little or a lot of your DHW and space-heating needs. But beware that oversizing systems can result in wasted money and summertime overheating.



Courtesy Northland Builders

The best way to calculate heating load is to use your monthly heating bills or have a heat loss calculation done for your building for every month of the heating season. This information will help you determine how much energy is needed to keep your building comfortable. Next, determine how much of this heating load you want to cover with solar during the winter months. Some people choose to cover all of the winter heating load, but for a more moderate and efficient system, most people aim for covering the spring and fall seasons. This is a common practice where the winter months bring cloud cover. In areas like the Southwest, however, a high solar fraction is possible even in December.

For pool heating, knowing the pool's surface area is most important, because this is where the majority of heat loss occurs. Is it an outdoor or indoor pool? What months of the year will it be heated? Outdoor pools can gather heat from the sun but can also lose heat to cool ambient temperatures, wind, and evaporation. Indoor pools lose less heat because they are sheltered, but depending on the ventilation system of the building, a lot of heat could be pumped outside to keep the humidity levels low inside the pool room. Another big factor is using a pool cover, which can save up to 50% of the daily heating energy. It works like a comforter, keeping the pool cozy and warm, and, at the same time, slowing evaporation. Armed with this information, you can use a sizing program provided by most solar pool heating manufacturers to determine how many collectors you will need. If you have a separate electric or gas meter for your existing pool heater, you can look at your utility bills to determine the amount of energy it currently consumes.

8

Collector Type

Choose your collectors. The common types are unglazed, glazed flat plate, and evacuated tube. Each works best for a certain job in a certain climate. Unglazed collectors are generally used for year-round pool heating in a warm climate or for seasonal pool heating in cooler climates. Flat plates can be used for many jobs, such as year-round indoor pool heating and domestic water and space heating in most any climate. Evacuated tubes can be used for the same jobs as flat plates, but work best for higher-temperature applications in cloudy or very cold climates.

Once you have decided on a collector type, you will need to choose the model. Many factors should go into your decision, such as sizes available, energy output, and the quality of the components and finished product. Consider the collector's (and manufacturer's) reputation, its country of origin (if you like to keep it local), warranty, and, least of all, price. If you simply shop by price, more than likely you will end up disappointed with your purchase. What you are really looking for is the most Btu you can get per dollar. If your collector is cheap, but only lasts a few years, it has not paid you back. Select a collector that balances performance and cost.



Courtesy www.solarexpert.com

Because swimming pools require lower temperatures, less expensive, unglazed pool-specific collectors can be used.

Flat-plate collectors are the most common type, and are available in styles for open- and closed-loop systems, and in horizontal and vertical orientations.



Courtesy Kurt Koegel (2)

Evacuated tubes are more expensive, but can perform better in situations that require higher temperatures.



Collector Thermal Performance Rating

Solar Rating and Certification Corporation OG-100 sheets are issued to solar manufacturers for certified collectors. These sheets contain lots of information, but most useful are the performance tables, which show predicted collector output in kilowatt-hours per day and Btu per day under 15 different conditions. Three insolation levels—a clear sunny day; a mildly cloudy day; and a cloudy day—are shown across the top of the chart. The insolation or amount of sun hitting the collector under each condition is shown in kilowatt-hours per square meter per day and Btu per square foot per day. Down the side are the temperature categories, shown in Celsius and Fahrenheit. Each category is classified by a letter and a temperature. The temperature shown is the difference between the incoming water temperature to the collectors versus the ambient air temperature around the collector. The key at the bottom of

the chart suggests applications for each category. For example, for outdoor seasonal pool heating in a warm climate, you would likely use performance numbers for category A, since the incoming pool water temperature would be lower than the ambient temperature. If you were designing for winter water heating, you'd check out the numbers that correspond to category C or D since the outdoor ambient temperatures will be lower than the fluid entering the collectors.

When using the performance tables, remember that these ratings are for referencing and comparing different collectors. The given ratings are what the collector is making at that exact moment, under these exact conditions. In the field, a collector could experience all three insolation levels and three temperature categories in just one day.

SRCC Collector Performance Data

Kilowatt-Hours Per Panel Per Day

Category (Ti-Ta)	Insolation Level		
	Clear Day (6.3 kWh/m ² •day)	Mildly Cloudy (4.7 kWh/m ² •day)	Cloudy Day (3.1 kWh/m ² •day)
A (-5°C)	15.2	11.5	7.8
B (5°C)	13.8	10.1	6.4
C (20°C)	11.6	8.0	4.3
D (50°C)	7.0	3.7	0.8
E (80°C)	2.7	0.4	0.0

Thousands of Btu Per Panel Per Day

Category (Ti-Ta)	Insolation Level		
	Clear Day (2,000 Btu/ft ² •day)	Mildly Cloudy (1,500 Btu/ft ² •day)	Cloudy Day (1,000 Btu/ft ² •day)
A (-9°F)	51.9	39.2	26.6
B (9°F)	47.2	34.5	21.9
C (36°F)	39.6	27.1	14.8
D (90°F)	23.7	12.6	2.8
E (144°F)	9.2	1.3	0.0

A. Pool Heating (Warm Climate); B. Pool Heating (Cool Climate); C. Water Heating (Warm Climate); D. Water Heating (Cool Climate); E. Air Conditioning

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9 Frequency of Use

Determine frequency of use—when will your system be used and how often? This is often overlooked when designing a system. Frequency will determine the type of collectors used, solar loop type, and storage tank size. If you want year-round domestic water heating, then this will not be a concern. If you want to heat water for a summer camp, then you know the load will be pretty constant throughout the day for showers and food service—components for warm weather and minimal storage are called for. If you want space heating, maximize your system's winter performance and incorporate summer heat-dumping capability.

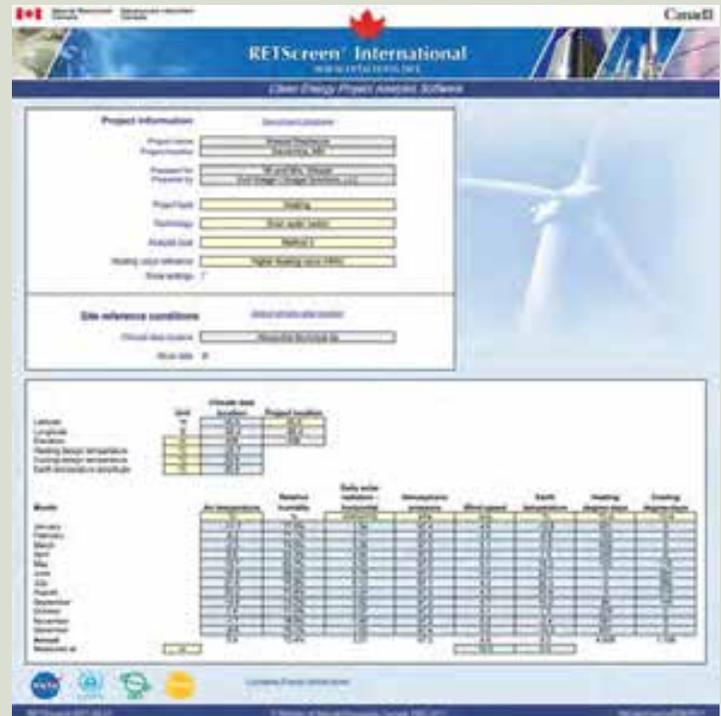
Whether a system is installed to provide winter space heating or summer water heating affects collector area and tilt angle, and storage tank size. Good system design is critical to optimize performance and meet needs without undue cost or excess heat production.



Courtesy Solar Farm LLC

Evaluating Your Designs

Energy modeling programs, such as RETScreen (free; shown at right), T-Sol (\$1,000+), or F-Chart (\$400), allow simulation of solar heating system performance before any equipment is purchased. You enter information such as the collector model, location, size of load, months the system will be used, collector tilt and azimuth, amount of proposed storage, efficiency of heat exchanger, and so on. Then you can change factors to see what will work best. The program report will give you a very good idea on how your system will perform in the real world because it uses actual weather data and actual collector performance in the calculations.



10 Mechanical Room

Measure the space available for mechanical equipment. Solar thermal systems require tanks, pumps, controllers, and heat exchangers. In most cases, the building's mechanical room can house the solar equipment. If that space is already full, you will have to be creative. Is there a closet or corner of another room that can be used? If you live in the deep South, what about the attic or crawl space? Can an outdoor shed be insulated and made into a remote mechanical room? Other options are to use a one-tank system with an integrated backup electric element or a single storage tank with a tankless backup heater that can be wall-mounted.

For solar water-heating systems, you will need room for the existing water heater and the new solar tank. If you plan on replacing an old tank-type water heater with a solar tank with an integrated heat source, then no extra space will be needed.

For space-heating systems, the floor space needed for equipment depends on how the solar heat will be stored. The size of storage tank will determine the space needed. If the slab of a radiant floor system is the storage medium, no space needs to be set aside.

Pool systems do not have separate storage, as the pool serves as the storage. All of these systems will need pumps, controls, and, possibly, small drainback or expansion tanks. These components are usually mounted on a wall (even above the solar tank), so they normally don't take up much space. Always leave enough room for future servicing.

System components can take up a lot of space, especially in large combisystems.



Courtesy Kurt Koegel

Access

Kurt Koegel (kurt@koegelsolutions.com) has more than 25 years of experience in the plumbing and heating industry, and holds a master plumber's license in multiple states. He is one of the first 10 professionals in the nation to be certified through the North American Board of Certified Energy Practitioners (NABCEP) as a certified solar heating installer.





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Article 250

Grounding and Bonding

by Ryan Mayfield

Article 250, “Grounding and Bonding,” is a very important *Code* article that receives a lot of attention in PV installations. If you ever get a group of solar installers together, or electricians for that matter, and merely bring up grounding, you are likely to have a lively discussion ensue. Grounding and bonding is a broad and difficult topic to be covered in a brief article—my attempt will be to break the topic down into small, manageable sections that will make the overall topic more user-friendly over multiple *Code Corners*.

I encourage readers to have their *Code* books handy and jump from my explanations to the specific *Code* language. Additional resources include *Soares Book on Grounding and Bonding* and Mike Holt’s *Understanding NEC Requirements for Solar Photovoltaic Installations*.

Purpose, Scope & Arrangement

The first section of Article 250 outlines its scope. The article as a whole covers the general requirements for grounding and bonding, as well as six specific requirements listed in 250.1. Table 250.3 lists other *Code* articles and specific sections for installation requirements that may modify the 250 requirements, with Article 690 being one of many. This means that you need to be aware of not just the rules as defined in 250 but also how 690 may override some of those requirements for PV installations.

Section 250.4 covers the general requirements for grounding and bonding and helps give some insight into the purpose for the requirements. In this section, both grounded and ungrounded requirements are outlined. Our focus will be on grounded systems. Ungrounded PV systems are becoming more common and they will be detailed in future articles.

Systems are grounded to “limit the voltage imposed by lightning, line surges, and unintentional contact with higher-voltage lines.” Another major purpose of the grounding and bonding requirements is to establish an effective ground-fault current path. The installed conductors create a low-impedance circuit that allows the overcurrent protection or ground-fault detector to safely operate.

Definitions

I’ve heard it said that if you understand grounding, then you haven’t been taught properly. While the statement is good for a chuckle, most of the confusion can be cleared up by understanding a few definitions.

Article 100 contains definitions for many terms in the *Code*. Several definitions specific to bonding and grounding are included in both Articles 100 and 250. The “PV System Grounding” diagram helps illustrate these definitions.

- **Ground**—The Earth. I have to say, I love the simplicity of this definition. While it may seem obvious to some, the ground definition is the basis for all other definitions

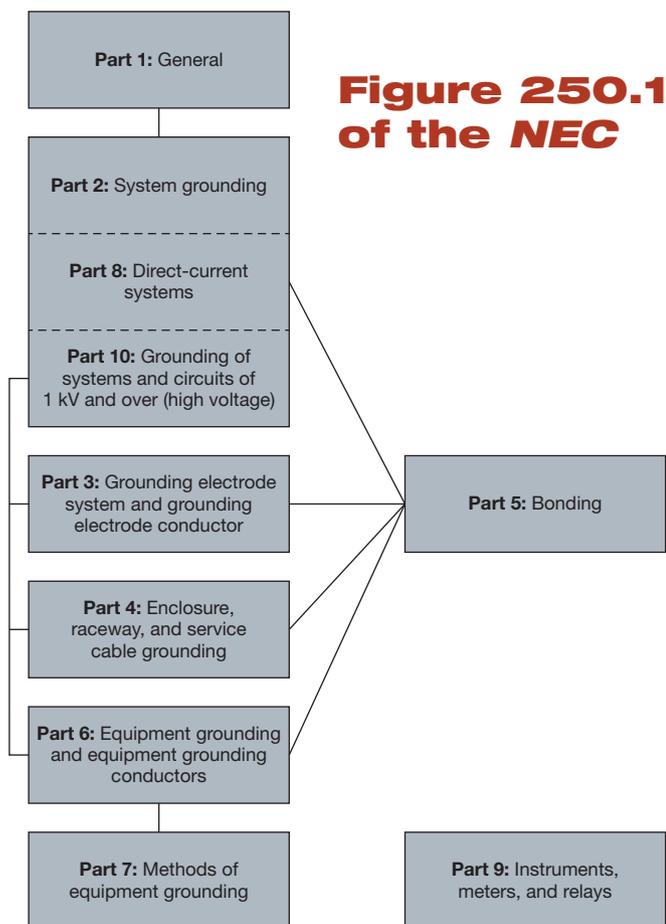
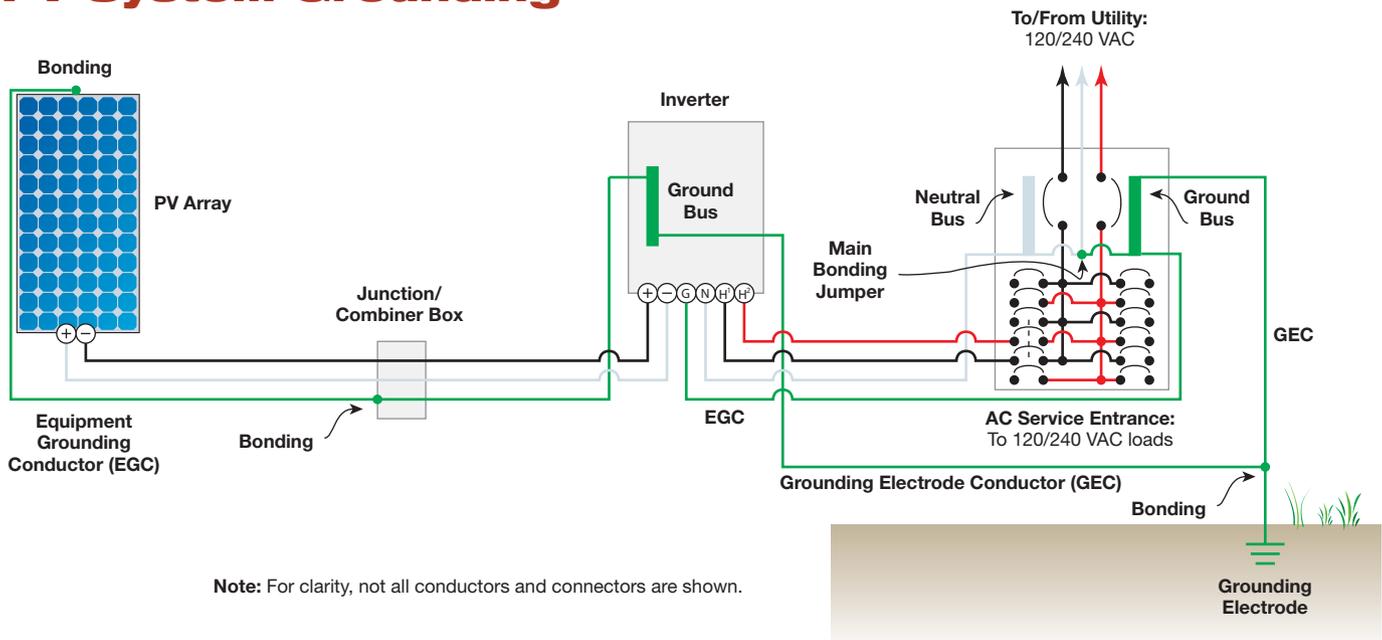


Figure 250.1 of the NEC

The flow and relationship of each part within Article 250.

PV System Grounding



Note: For clarity, not all conductors and connectors are shown.

surrounding grounding, so clarifying it in the beginning is important.

- **Ground fault**—An unintentional, electrically conducting connection between an ungrounded conductor of an electrical circuit and the normally noncurrent-carrying conductors, metallic enclosures, metallic raceways, metallic equipment, or the earth.

A ground fault occurs when current is flowing through the metallic components of an electrical installation instead of being contained within the conductors as intended. In PV systems, this can happen for a number of reasons, commonly as a result of conductor insulation being abraded until the copper conductors come into contact with a metallic component, such as the racking system.

In PV systems, ground faults have received a fair amount of attention lately as some fires associated with PV installations have been traced back to ground faults. Nearly every grid-tied inverter is shipped standard with built-in ground-fault protection to reduce the possibility of such faults.

- **Grounded (grounding)**—Connected (connecting) to ground or to a conductive body that extends the ground connection.

This refers to the physical connection between the earth and the material we are using for the ground reference: the grounding electrode (defined next). The diagram helps illustrate where the grounding connection, as opposed to the bonding connection, happens.

- **Grounding electrode**—A conducting object through which a direct connection to the earth is established.

The grounding electrode is how our electrical system makes its connection to the earth. Common types of grounding electrodes include ground rods and concrete-encased electrodes, known as an “Ufer grounds.” A ground rod is typically a ⁵/₈-inch-diameter by 8-foot-long copper rod driven into the ground. A Ufer ground uses the rebar installed in a building’s foundation and encased in concrete. Section 250.52 defines other acceptable types of grounding electrodes.

- **Bonded (bonding)**—Connected to establish electrical continuity and conductivity.

This is a term used repeatedly throughout the *Code* and in our everyday PV language. A common use describes the action we take when establishing a low-resistance connection between the PV modules’ aluminum frame and the support rails. This connection can be made using a variety of methods, but in all cases, the goal is to create a long-term and reliable connection between the metallic components. This connection is made with a bonding conductor or jumper as defined in the *Code*.

- **Grounding conductor, equipment (EGC)**—The conductive path(s) installed to connect normally noncurrent-carrying metal parts of equipment together and to the system-grounded conductor or to the grounding electrode conductor, or both.

This is the conductive path, in PV systems typically accomplished with a conductor, that makes an electrical bond to all of the metallic components. The *Code* defines the acceptable EGCs in 250.118. The purpose is to create an effective ground-fault current path, reducing risks associated with faults.

- **Grounded conductor**—A system or circuit conductor that is intentionally grounded.

This is a current-carrying conductor that has an intentional bond to a grounding conductor, establishing a reference to ground. In AC circuits, this is the neutral conductor. The current-carrying conductor-to-ground bond is typically established in one location—the main service panel—with a conductor known as the main bonding jumper. For PV systems, the grounded conductor is most often the negative conductor and the bond between it and the grounding conductor, in batteryless PV systems, is within the inverter, across the ground-fault protection device.

- **Grounding electrode conductor (GEC)**—A conductor used to connect the system-grounded conductor or the equipment to a grounding electrode or to a point on the grounding electrode system.

This conductor makes the connection from the grounding electrode to the electrical system. In traditional AC systems, the GEC is commonly a copper conductor that originates in the main service panel and is bonded to the grounding electrode. In PV systems with transformer-based inverters, the GEC is required to connect the inverter to a grounding electrode. A variety of methods are allowed for this connection in PV systems; the diagram illustrates just one of those methods.

Because many terms use similar language, yet refer to different portions of the system, it is important to understand the definitions of each. A simple misstatement can lead to confusion or misapplication of the *Code*.

Access

Ryan Mayfield (ryan@renewableassociates.com) is the principal at a design, consulting, and educational firm with a focus on PV systems. He is an ISPQ Affiliated Master Trainer and has been accused of talking about bonding and grounding too much in class.



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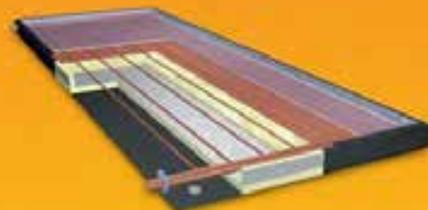


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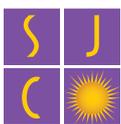
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Roads Scholar

by Kathleen Jarschke-Schultze



For my husband Bob-O and myself, part of being beyond the grasp of the power lines and the pavement means our 1.8 miles of dirt road need regular attention. The county does not maintain the road. It is a private access road for many land owners, only a few of which live here full time or visit their property regularly.

On the Road Again

When working on a dirt road, timing is everything. The ground must be damp, not wet with puddles or dry with dust. There is a narrow window of opportunity to make your roadwork effective.

I stayed in our home office so Bob-O, my partner in all things, could take the tractor out to fill a few potholes a couple of days after the last rain. The phone rang and, of course, it was for Bob-O.

"I'm sorry," I said, "I'll need to have him call you back. We have the only tractor in the neighborhood, so Bob-O's out working on the road."

"Tag," the guy said, "you're it!" I immediately knew this guy had lived on a dirt road at some time in his life. He knew they have to be maintained. You have to pay attention to a dirt road or it will go away. Dirt roads swallow gravel and rocks whole.

Road Gang

When we moved here 22 years ago, there were only three families living here full time. We all worked on the road. We trucked in gravel from the quarry for the road repairs. Although the gravel was not that expensive, it was the transport from the quarry to our remote road that took a monetary toll on us all.

We put out signs at strategic places along the road so the truck driver would know where to dump the piles. That way, Bob-O wouldn't have to drive too far with the tractor to reach a pile of gravel.

We only worked on the stretch of road we used. So our neighbor down the creek did not work on the road in front of our house. Our neighbor at the very end of the road, however, worked on the entire length of the road.

But whenever there was a big project to take care of, we all showed up—no matter *where* the repair was. If a dead standing tree was threatening to fall into the road, Bob-O would cut it down and we would all help split it into firewood and then divvy it up.

Once, super heavy rains, known locally as toad-stranglers, washed out the road at a place we call Dutch Oven Creek. When the water receded, we all helped rebuild the road base atop the exposed culvert.

Road Warrior

In the years since, neighbors have moved out, moved in, or moved away. Bob-O is almost the lone road wrangler now. But he knows that maintaining the road means keeping our vehicles in better repair.

He understands the road—and the dedication it demands to keep it passable. After you fix a really bad section in the road, it becomes the nicest place on the road—and another problem area is then the prominent problem. It is a continuing and constant dance to keep our road passable.

You can fill a pothole with gravel just when the ground moisture is perfect and it may stay. But if drivers see this as an invitation to go fast, their tires will squeeze the gravel up and out of the pothole, soon rendering your repairs useless. Speed is also the enemy when the pothole has standing water in it. The proper thing to do is to go very slowly through the pothole or, better yet, avoid it all together. The absolute wrong thing to do is to see how big a rooster tail of muddy water you can produce while speeding down the muddy road. Regrettably, generations of four-wheelers see this as a fun thing to do. They drive home with their vehicles covered in the mud, leaving us to repair the road.

If you have the time, patience, and a good back, you can put a better fix on a pothole. Take your shovel and dig out the pothole in a straight-sided shape. The preferred option is to level out the hole to the depth of the original pothole. Fill this with your rock or gravel, whichever you have. This works better because it is harder for the repair rock to work its way out of a straight-sided hole than a shallow, bowl-shaped hole. If possible, avoid river rock—even when crushed, its rounded sides help it leap out of the hole.

If the road has any uphill stretches, it is common to see a washboard effect on the roadbed. This is caused mostly by two-wheel-drive vehicles—one tire slips on the roadbed and pushes up a little dirt. The next tire comes along and kind of bounces over the bump and pushes up a little more dirt. A washboard effect emerges as the two-wheel-drive rigs chatter up the hill, building the ridges over time.

Muddy Roads

Ditching and water bars are a seasonal treat. Without good ditching along the road, the rain and snow pool at the lowest points, or the flow can wash away the gravel and fines. I hate that feeling when the tires lose their grip and the Subaru starts sliding toward the edge of the road. It becomes much worse if you actually have to get out in the mud to, say, open and close a gate. Gumboots are advised.

Water bars are small, shallow ditches dug across a roadway to give water a place to cross and drain. Many

times I have found myself in the pouring rain with a shovel or Pulaski, Bob-O by my side, digging a water bar to prevent worse road erosion later on.

I honestly don't know what our neighbors or we would do if Bob-O did not have a tractor that he regularly uses for road work. As it is, we have friends with two-wheel-drive rigs that only visit us when the weather is fine. In winter, even driving a four-wheel-drive rig can be an adrenaline-pumping adventure. Lucky for us, our clay soils dry out fairly quickly, so the muck doesn't last long after the rain or snow stops.

Country Roads

Do I want my road paved? No, not really. In the dead of winter when I have to drive in bad weather I think I would. But that doesn't happen very often. Our dirt road is intimidating enough to keep out most tourists. A good portion of the year the road is just fine, if a bit dusty. There is something really wonderful about an after-dinner walk up a dirt road to watch the sunset. I do, however, want to get a bumper sticker made for the front of my car that says, "You Back Up. I Live Here."

Access

Kathleen Jarschke-Schultze (kathleen.jarschke-schultze@homepower.com) is trying out Tattler canning lids at her off-grid home in northernmost California.



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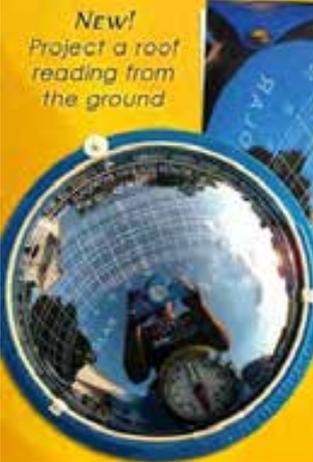
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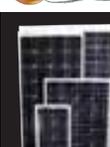
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