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On the Cover

Joe Gamble with his family, son Forest and wife Suzanne Thompson, live in a geodesic dome, so their PV array couldn't be easily installed on the roof. Instead, they opted for a ground-mounted array (see page 50 for details).

Photo courtesy Joe Gamble

Top to bottom: (this page): Courtesy Joe Gamble; joeychung; Trojan Battery Co.; Coda Automotive; (opposite page) Tom Hardisky; PowerHouse Dynamics; U.S. DOE

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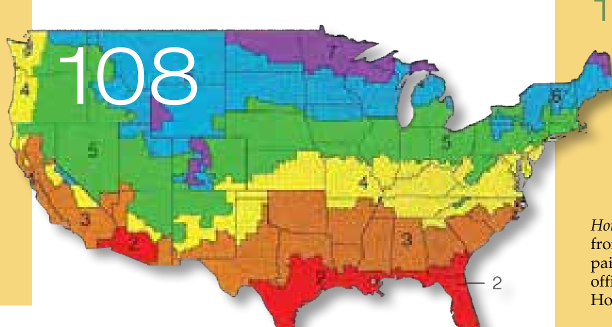

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In Back

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Energizing Innovations

Home Power is gearing up for the next industry show—Solar Power International in Los Angeles—and anticipating seeing the latest, greatest gear and catching the solar buzz on the conference floor.

Last year, PV module maximizers caught our attention. They help solar-electric systems in non-optimal installations get the most energy possible out of each PV module. Complete, packaged solar hot water systems also made an appearance, promising easier, less-costly installations with components that are designed to work together. New ground-mount racking options were showcased, some even obviating the post-hole digger and pouring concrete (see "Ground Mounts for PV Arrays" in this issue). And software solutions for monitoring both solar-electric and solar thermal systems were entering the limelight (see "Keeping Tabs on your PV System" in this issue).

So, what's it going to be this year? Despite the gloomy forecast for the global economy, the sun is shining on renewables and the time is ripe for innovations. According to the Renewable Energy Policy Network for the 21st Century, the PV industry "has grown by 60% annually, wind by 27%, and solar hot water by 19%."

Investments are driving the market and new developments will help expand it. And *Home Power* will be following the progress, providing coverage on what works, so you can make smart decisions about your future renewable energy systems and energy-efficiency upgrades.

—Claire Anderson, for the *Home Power* crew

Get in Gear!

Find these articles and more at HomePower.com:

Microinverters/Module Maximizers

- *The Circuit: Gear* (*HP133*)
- "PV Micromanaging" (*HP129*)
- "Distributed MPPT" (*HP137*)
- "Microinverters Make a Simple DIY Installation" (*HP136*)

SHW Kits & Integrated Components

- *The Circuit: Gear* (*HP135*)
- "Solar Hot Water Storage: Residential Tanks with Integrated Heat Exchangers" (*HP131*)
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Think About It...

A PV module is the closest thing we have to perpetual motion
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—Joel Davidson, SOLutions in Solar Electricity

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Brightest Days Ahead for Hybrid Gas-Electric Cars

To paraphrase Mark Twain, recent reports of the death of hybrid cars have been greatly exaggerated.

In the past few months, the reliability and safety of cars that use both a gas engine and an electric motor have been called into question. If you believe the headlines, you'd think that hybrids are running out of gas (and electrons). But a study of product plans from major car makers reveals that hybrids are just getting started.

The worst of the antihybrid press took place in March, when a San Diego, California, man claimed that his Toyota Prius sped up and couldn't be stopped. After a harrowing 23 minutes—recounted in detail by major national media outlets—a highway patrolman coached the man to safety by having him simultaneously apply the parking brake and foot brake. Investigations by Toyota, the National Highway Traffic Safety Administration, and even NASA, failed to produce any explanations. No matter. The incident struck fear into the public's hearts and, along with Toyota's other safety publicity, undermined the once-spotless reputation of these hybrids as the most reliable and fuel-efficient cars on the road.

Hybrids have also come under attack from the other side of the gas-electric divide. At least one auto reviewer sees hybrids as dead in the water now that a new age of electric cars is upon us. In late April, Warren Brown of *The Washington Post* wrote, "Hybrids are merely a way-station until we get proper electric cars and infrastructure…. The Prius's dominance seems to be almost over." Indeed, fans of pure electric cars have a lot to be happy about these days with the Nissan Leaf, Ford Focus Electric, Coda Electric Sedan, Mitubishi i-MiEV, and other EVs scheduled to arrive this year (see "The EV Revolution," this issue). But electric devotees eager to dance on the grave of any vehicle with an internal combustion engine might have to wait a bit longer.

Most forecasters believe that relatively affordable gas-powered engines—especially ones employing strategies like direct injection and turbocharging—will become increasing efficient and will be a long-term winner when it comes to the economics of saving fuel. Of course, these downsized gas engines can be combined with an electric motor and a battery pack to turn them into hybrids—and boost efficiency even more.

In fact, tougher fuel economy regulations requiring automakers to reach an average of 35.5 mpg by 2016 will practically legislate more hybrids. In the next five years, the number of hybrids—both the ones that can plug in and the ones that can't—will grow from 25 to perhaps 60 or 70 models.

What should we expect?

- Toyota plans to double hybrid production in 2011, and will introduce an entire family of Prius cars in the next few years. Their plans reportedly include a subcompact Prius, a Prius plug-in hybrid, and a hybrid minivan.

- Ford's electrification strategy includes the all-electric Ford Focus and Transit Connect, but also the Ford MKZ hybrid (due later this year), a plug-in hybrid Ford Escape, and a pair of next-generation hybrids by 2013. The company is also crossing the pond with a set of hybrids and plug-in hybrids for Europe.

- Hyundai will introduce its first hybrid, the Sonata hybrid, and says that it's working on a new hybrid to compete against the Prius.

Courtesy Ford Motor Company

- Honda is re-investing and re-engineering its future hybrids in a quest to take the lead on fuel economy. It will introduce the small and sporty CR-Z hybrid coupe this summer, and use the technology on a hybrid minivan and in its Acura luxury division.

- General Motors is on track to introduce its Chevy Volt, a plug-in hybrid, late this year and will follow with a plug-in hybrid crossover SUV. GM executives continue to assert that mild hybrid technology is a critical strategy for making future hybrids affordable.

- It's rumored that Mercedes is planning to convert its entire S-class to hybrid technology in the next few years.

- Nissan stands alone in its belief that pure electric cars are a single-point solution. Yet, its luxury division unveiled the Infiniti M35, its first hybrid, at the 2010 Geneva Motor Show. UK's *Autocar* reported that all Infinitis will be hybrids within 10 years.

Connect these dots to get a hybrid-rich picture of the road in 2013 or 2014: a 50-mpg Prius next to a 50-mpg Honda, next to a 50-mpg Hyundai, next to a 90-mpg Prius plug-in hybrid, next to the plug-in hybrid Chevy Volt…

—Bradley Berman

Courtesy Infinity


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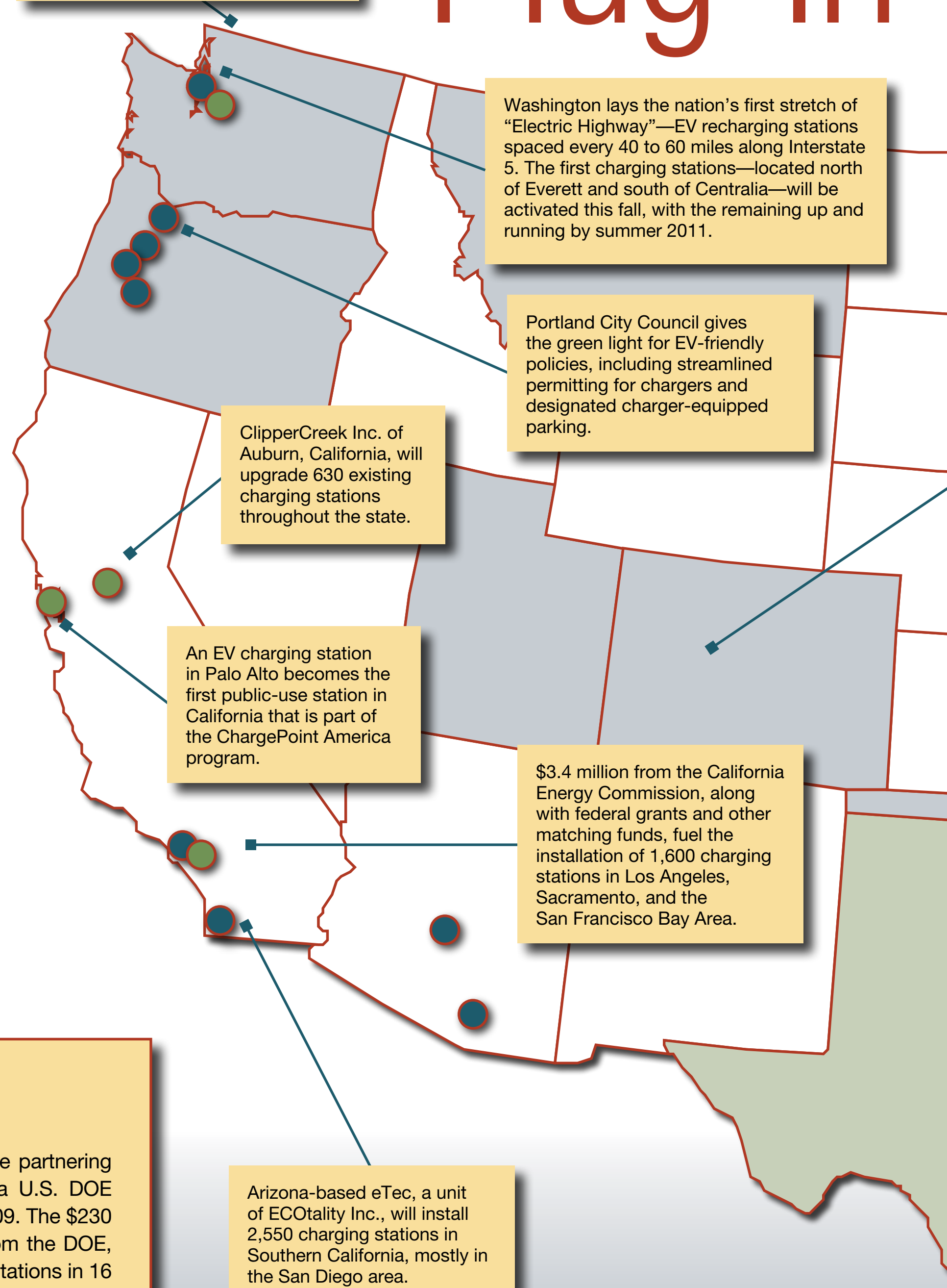
Plug-In

With GM's Volt, Nissan's Leaf, and other electric vehicles expected on the market in the coming months, the race is on to develop the charging infrastructure to support America's growing fleet of plug-in vehicles.

Federal stimulus grants are paving the way for the installation of more than 16,000 recharging stations nationwide—many of which are being made possible through the ChargePoint America program and The EV Project. We've mapped out the hot zones.



The EV Project

Nissan North American and General Motors/Chevrolet are partnering with ECOtotality North America on "The EV Project"—a U.S. DOE program that rolled out in major cities starting October 2009. The $230 million program, funded in part by a $99 million grant from the DOE, aims to deploy nearly 15,000 public and private charging stations in 16 cities (www.theEVproject.com).

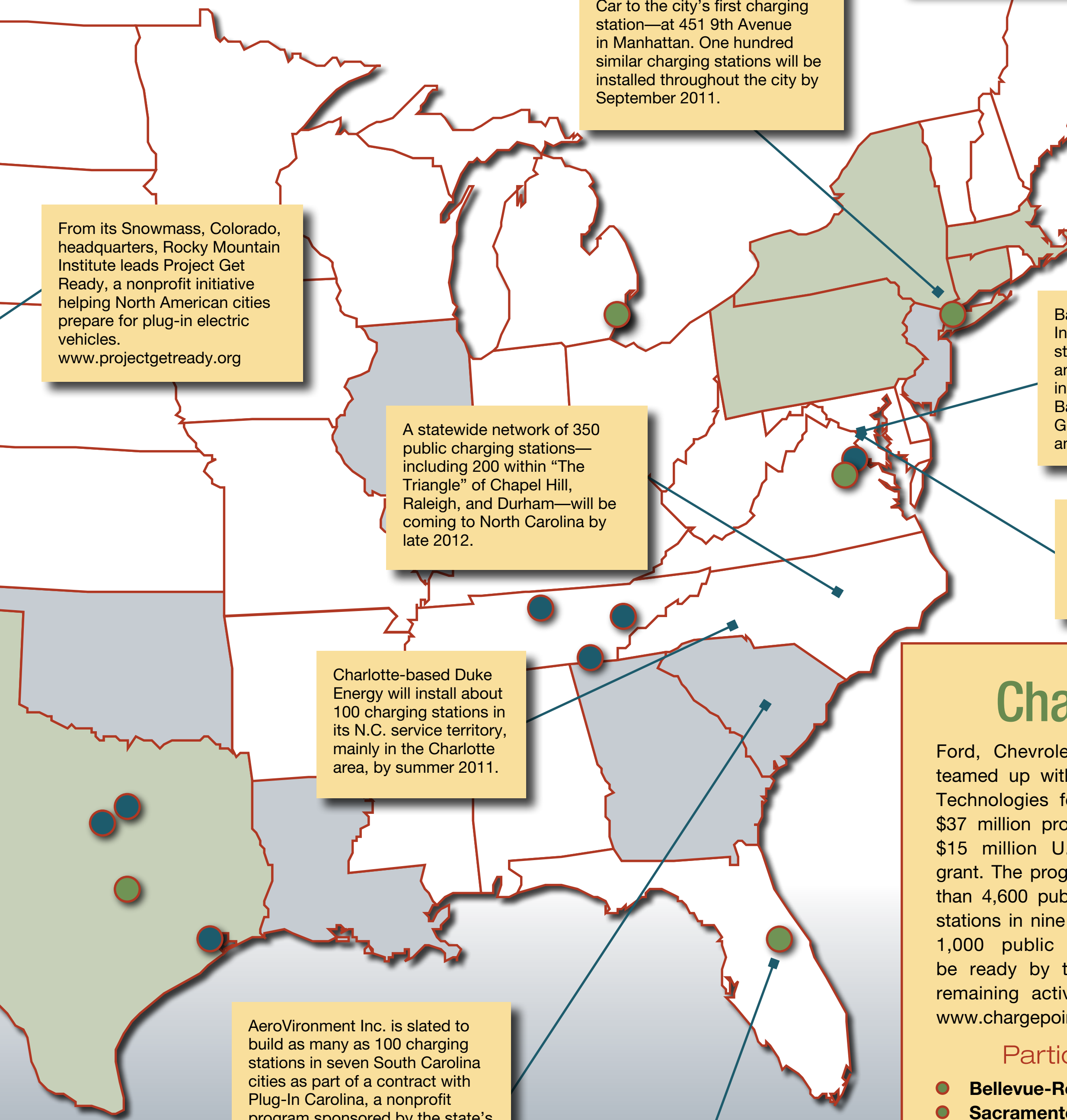
Participating Cities

- **Phoenix, AZ**
- **Tucson, AZ**
- **Los Angeles, CA**
- **San Diego, CA**
- **Washington, DC**
- **Corvallis, OR**
- **Eugene, OR**
- **Portland, OR**
- **Salem, OR**
- **Chattanooga, TN**
- **Knoxville, TN**
- **Nashville, TN**
- **Dallas, TX**
- **Fort Worth, TX**
- **Houston, TX**
- **Seattle, WA**

America

Federal

In Congress, the Electric Drive Vehicle Deployment Act of 2010 gains momentum. If passed, the bipartisan initiative would foster the widespread adoption of electric vehicles and infrastructure by supporting comprehensive programs to deploy up to 700,000 EVs over the next six years, as well as by extending and enhancing tax credits for consumers who purchase EVs or plug-in hybrids.



New York City's mayor Michael Bloomberg plugs in a Smart Car to the city's first charging station—at 451 9th Avenue in Manhattan. One hundred similar charging stations will be installed throughout the city by September 2011.

From its Snowmass, Colorado, headquarters, Rocky Mountain Institute leads Project Get Ready, a nonprofit initiative helping North American cities prepare for plug-in electric vehicles. www.projectgetready.org

Baltimore Electric Vehicle Initiative will install 55 charging stations along Interstate 95 and throughout the state, including sites in Cecil, Harford, Baltimore, Anne Arundel, Prince George's, Montgomery, Charles, and Frederick counties.

A statewide network of 350 public charging stations—including 200 within "The Triangle" of Chapel Hill, Raleigh, and Durham—will be coming to North Carolina by late 2012.

The city of Baltimore and Baltimore Gas & Electric will install 9 to 16 charging stations in parking garages around town.

Charlotte-based Duke Energy will install about 100 charging stations in its N.C. service territory, mainly in the Charlotte area, by summer 2011.

AeroVironment Inc. is slated to build as many as 100 charging stations in seven South Carolina cities as part of a contract with Plug-In Carolina, a nonprofit program sponsored by the state's major utilities. Stations should be operational by December 1.

The sunshine state kicks off its ChargePoint America program with an EV charging station at Orlando City Hall Plaza. Orange County will add 300 to 500 stations by 2012.

ChargePoint

Ford, Chevrolet, and SmartUSA recently teamed up with California-based Coulomb Technologies for ChargePoint America—a $37 million program partially funded by a $15 million U.S. Department of Energy grant. The program's goal is to install more than 4,600 public and private EV charging stations in nine metropolitan regions. About 1,000 public charging stations should be ready by the end of 2010, with the remaining activated by September 2011. www.chargepointamerica.com

Participating Cities

- **Bellevue-Redmond, WA**
- **Sacramento, CA**
- **San Jose/San Francisco Bay Area**
- **Los Angeles, CA**
- **Austin, TX**
- **Detroit, MI**
- **New York City, NY**
- **Washington, DC**
- **Orlando, FL**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Courtesy Siemens Industry

Siemens Industry 600 VDC Disconnect

In June, Siemens Industry (www.sea.siemens.com) released its Type VBII 600 VDC solar safety switch ($530 to $2,284), UL listed to disconnect three separate PV input strings. It is available in 30-, 60-, and 100-amp fusible and non-fusible versions, for indoor (Type 1) and outdoor (Type 3R) use. The switch has a factory-installed ground bar, and comes with the *National Electrical Code* (Article 690.17) required warning label. This product is built for the grid-tied PV DC disconnect niche, which has been commonly filled by the Square D HU series safety switches, but is not made to work with positive-grounded PV arrays. (Square D safety switches are self-certified—but not UL-certified—to disconnect up to three input strings.)

—Justine Sanchez

SunReports Apollo 1 PV & SHW Systems Monitoring

Courtesy SunReport (2)

Interested in monitoring the performance of your PV and thermal systems (SHW or pool heating) with the same device? Then check out SunReport's Apollo 1 (www.sunreports.com). The monitor uses your Internet connection and results can be accessed by any Web browser. For thermal systems, temperature sensors monitor system performance and current transducers detect when the pump is energized. Easy setup features include inverter detection, current transducers, and Internet connections. Plus, the wiring is color-coded. No Internet configurations are needed after correct component installation and wiring.

Apollo 1's thermal monitoring requires an estimated flow rate; this will rarely be as accurate as a Btu meter working with an inline flow meter, but it's the next best solution. For more information on SunReport's PV system monitoring, see "High-Tech Solutions for Keeping Tabs on Your PV System" in this issue.

—Chuck Marken

PowerCost Monitor Goes WiFi

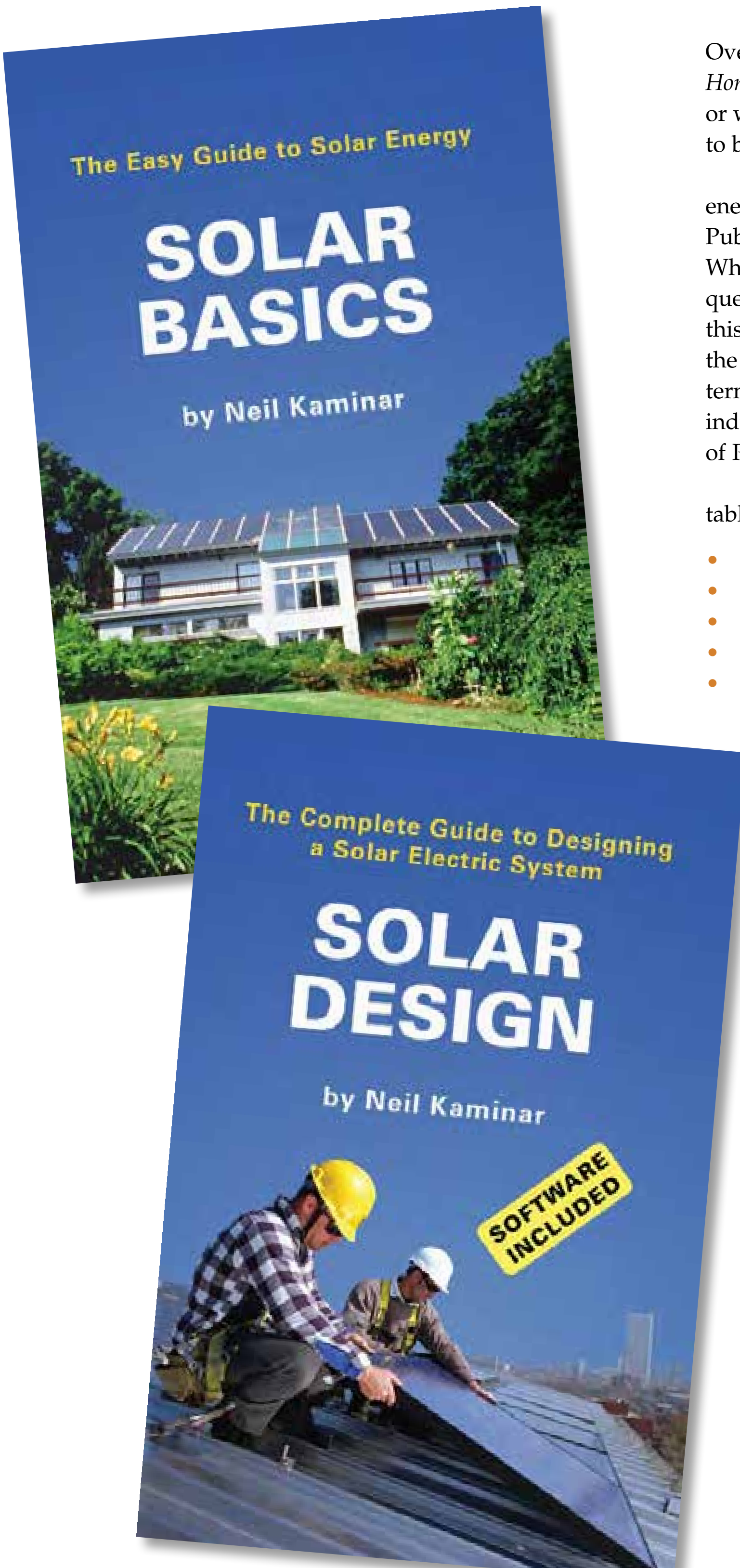
Plus Microsoft's Hohm Web Portal

CourtesyBlue Line Innovations

Blue Line Innovations (www.bluelineinnovations.com) released its PowerCost Monitor (full kit, $268), a new energy monitor that couples with Google's free PowerMeter Web portal (www.google.com/powermeter), entering the market alongside the TED 5000 energy monitor (www.theenergydetective.com). The PowerCost Monitor straps around your utility kWh meter, reading the meter wheel optically. (It also works with digital meters.) Opening the breaker box is not required. Data is sent by Bluetooth to a gateway and your Internet router, which sends it to the Microsoft Hohm free Web portal (www.microsoft-hohm.com). The Hohm portal helps consumers with energy-saving tips, tracks your energy usage and compares it to historical patterns. Plus, you can learn how others have saved money and energy—including your neighbors. Users enter data about their home and energy usage, and Hohm then offers efficiency recommendations. The monitor currently has no provision for reporting grid-tied renewable energy generated or exported, unlike the TED/PowerMeter system.

—Guy Marsden

Solar Basics by Neil Kaminar



Over the years, lots of books about PV systems have come to *Home Power's* mailbox. Many have lacked either completeness or were so far over the heads of the intended reader's level as to be difficult to wade through.

But for folks who are just getting their renewable energy start, Neil Kaminar's new *Solar Basics* (McNeill Hill Publications, 2009) explains solar electricity in simple terms. While most books on the subject require a leap of faith that questions during the reading will eventually be answered, this book's organization does a pretty good job of sequencing the information. My only beef with it is that sometimes terminology is used that is not well standardized in the industry, such using the word "panel" to describe an array of PV modules.

The book is nicely illustrated with photographs and tables, and covers:

- How solar modules and solar cells work
- PV applications
- Batteries, inverters, charge controllers, and more
- Solar water systems
- How to find funding
- How to buy modules and other equipment
- The basic steps in sizing a system
- How to figure costs
- System installation, testing, and maintenance
- Safety

Kaminar has been in the solar industry since the early 1970s, and his credentials include early solar engineering, as well as PV module development and manufacturing. But those lofty credentials have not gotten in the way of his communication capabilities, and RE newbies should find the book very helpful.

Kaminar has also published *Solar Design* (ISBN 978-0-9840510-1-4), intended to take would-be professionals and dedicated DIY readers of *Solar Basics* to the next level, offering details on system sizing, component choices, and other subjects important to system design. *Solar Design* includes a CD-ROM disk of software and spreadsheets helpful in designing PV systems. Both books are available at www.thesolardesignbook.com.

—reviewed by Michael Welch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Small Changes, Big Success

After graduating with her MBA from Northeastern University, Jenean Smith began climbing the corporate ladder, working her way up to a management position at a dot-com company in San Francisco.

Even though she had made it close "to the top," Smith says, "I just couldn't shake this hollow feeling, like I was missing something." So she decided to figure out just what that was. A year later, after applying to the Peace Corps, she was living in the rural community of San Lorenzo, Nicaragua.

"The experience made me realize that I could do a lot of good as an individual. I didn't need to work with an NGO or a government project. I just needed to set a goal and work at it," she adds.

Her time in Nicaragua convinced her that one person can make a difference. "I joined the Peace Corps thinking I needed a structured program and lots of support to have any real impact on people's lives, and while I have tremendous respect for the program, I was surprised by how little help I was given," Smith says.

Smith's latest endeavor is Power to the People (PTTP), a nonprofit organization that works with communities in rural Nicaragua to install solar-electric systems on community buildings, such as schools, health-care centers, libraries, and orphanages.

Having relied upon kerosene lamps for lighting while living in Nicaragua and Honduras, Smith learned firsthand of kerosene's problems—its high cost, unhealthy fumes, and flammability hazards. Recognizing the need for a clean, renewable source of

Above: A Las Cuchillas community volunteer cuts the EZ mount rack for the battery-based PV system.

Below: Schoolgirls in front of the 680 W PV system on the school in Las Cuchillas, Nicaragua.

Courtesy Power to the People (2)

electricity in rural communities, PTTP started with the mission of raising enough money to install a 1 kW PV system on the roof of a public school in El Pedregal, Nicaragua.

Although Smith didn't have the technical expertise to install PV systems on her own, she leveraged what she did have—marketing savvy. Upon her return to the States, she solicited donations from businesses and organized fundraising activities—silent auctions, concerts, and even "green" speed-dating events, where "eco-conscious" people donated $25 for the opportunity to meet other like-minded folk.

She assembled a team of volunteers, calling on members of a renewable energy discussion group that she hosted when living in Los Angeles. Before long, she had convinced an energy consultant, a city planner, a solar engineer, and a host of other talented individuals to donate their time and resources to the cause. The group raised funds to cover the project's cost, including the expenses for a six-person volunteer crew to travel to the site and install the off-grid, battery-based system.

In March of 2009, the school's system was installed. "The PV system not only brought light to the small community," says Smith, "but it also provided a place to hold community meetings and night classes for adults. It made it possible for people of all ages to attend televised distance learning classes, and it created income for the school by selling electricity to charge cell phones."

Since then, PTTP has raised more than $75,000 and solicited nearly $25,000 in equipment donations. The group also stepped up its fundraising efforts with a "voluntourism" program, in which people pay for the opportunity to travel to Nicaragua and work on a PTTP project.

In April 2010, the group completed its second project in Las Cuchillas, Nicaragua—a 680 W PV system for a rural, two-room school and a 225 W PV-powered battery charging station at a small library.

Next up is an installation in the central Nicaraguan community of Las Lajas—a 1.4 kW PV system and a 450 W PV battery charging station at the elementary school, and a 340 W PV system at the health care center. Future projects include an ambitious plan to power an entire town in Nicaragua with a batteryless PV system.

—Kelly Davidson

web extra

To learn more about PTTP and how you can help, visit **powertothepeople.org**.

Saving Energy with LED Lighting

For a recent project at a shopping plaza in Manchester, New Hampshire, the property manager's goal was to address the whopping electricity bill generated by 22 high-pressure sodium (HPS) and six metal halide parking lot lamps. Each year, the lighting was racking up about $8,000 in energy costs, plus an additional $11,000 in bulb replacement and maintenance costs. The goal was to cut total energy consumption from parking lot lighting—51.1 megawatt-hours per year—by 50%.

LED lighting was selected to retrofit the parking lot, reducing electricity consumption in the first phase to 19,000 kWh per year (approximately a 62% reduction). The second phase should reduce electricity consumption by an additional 7% to 10%.

In the first phase, 13 poles and 28 400-watt metal halide and HPS fixtures were replaced with 25, "two-level" (217- and 78-watt modes) LED fixtures, equipped with motion sensors for reducing energy consumption when the lot is in low use, such as late at night. Phase two will replace existing canopy down-lighting with LED fixtures, reducing the bulb wattage by 75%.

Courtesy BetaLED

The new LED lighting provides excellent visibility and better control throughout the site, reducing security concerns. The original projected return on investment (ROI) for this project was four years, but rising energy costs, a deviation from projected run-times, and maintenance savings have reduced the projection to less than three years.

When business costs are a constant consideration, especially for property owners and retail tenants, LED lighting can be effective in decreasing long-term operational expenses. LEDs also have an extremely long life—depending on the fixture, they can last more than 100,000 hours without maintenance. Plus, LED technology provides lighting options that are manufactured in the United States from recycled materials; do not contain mercury or lead (reducing the danger and cost of disposal); do not emit infrared or ultraviolet radiation; and are compliant with Energy Star's Dark Sky initiative, which requires streetlight shielding to reduce lighting intrusion on night skies.

The U.S. Department of Energy accepted this project as a Solid-State Lighting GATEWAY Demonstration Project—the first in the Northeast. For more information, visit www1.eere.energy.gov/buildings/ssl/gatewaydemos_results.html.

—Cass Thurston

Efficiency vs. Renewables

While this energy-efficiency retrofit appears expensive ($46,640), the payback time is short, resulting in cost savings for more than 15 years—the expected life of the lighting. And many states or utilities have incentives programs that reduce retrofitting costs even more.

Energy-efficiency measures almost always offer a better return on investment than turning first to renewables. A PV system designed to offset the same amount of electricity as this retrofit (about 32,100 kWh each year) would need to be about 26 kW with a cost of about $143,000 (assuming $5.50 per watt for a commercial PV system, and without taking the 30% federal tax credit).

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POWERING YOUR FUTURE

To Tilt, or Not to Tilt

In a perfect world, the sun's rays would always be perpendicular to your PV modules. In reality, the sun's location changes throughout the day and across the seasons and, unless you have a tracking system, modules are in a fixed position. Should you adjust the module tilt for the seasons? Maybe.

Using Charlotte, North Carolina, as an example, the greatest *average* radiation for a fixed-tilt array is with the tilt equal to latitude (35.22°) with 5 kWh per m^2 per day. PV modules set at a tilt equal to latitude plus 15° (50°) get more sun from October to February. From April to August, PV modules tilted at 15° *less* than Charlotte's latitude also see more solar radiation than those set equal to latitude. Certainly, you can ignore all this and decide to live with the average of 5 kWh/m^2/day. But if you decide you want to squeeze out a few more kWh from your array, you will have to put some effort in. For an off-grid system, those few extra kilowatt-hours are often worth it, particularly in the colder months. (But off-gridders may choose to permanently set their tilt to the ideal winter angle, often not needing all possible production in the summer.)

Pole-mounted arrays are easiest to adjust seasonally because the pivot point is at the center of gravity. Roof-mounted arrays are the most complicated—and dangerous—to adjust.

According to NREL's PVWatts calculator, a 2 kW array tilted equal to the latitude in Charlotte would produce approximately 2,636 kWh annually. Going for maximum monthly production requires adjusting the array angle monthly, and may yield 5% more in production. However, just adjusting it twice annually (in March, to latitude minus 15°, and in October, to latitude plus 20°) will eke out 4% more production. Over 25 years, the extra energy adds up.

Some mounting spots and hardware configurations are more suited to tilt adjustment than others. Modules mounted on pitched roofs, for example, present challenges in accessing the array. Wind loading on the building—caused by arrays tilted up from the roof surface—can be a concern. Additionally, aesthetic preferences may rule out an adjustable array on a pitched roof—many people favor an array that's mounted parallel to the roof plane, rather than modules sticking up at an angle.

Accessible, flat roofs may be decent candidates for tilting, but adjusting the tilt of the modules will change the shadows they cast, and unless the row spacing was designed to handle the steeper winter tilt, adjusting one row may shade the row behind it. However, for most roof situations, it is probably easier and less expensive to increase the size of the array by 5% than to address the mount type and additional space required for manual tilt adjustment.

Ground-mounted and pole-mounted systems offer a greater accessibility and adjustability of tilt, with a variety of applicable products. Just be aware that ground-mounted and pole-mounted projects require more material and site preparation—digging, placing forms and anchors (or poles), and pouring concrete—which increases the cost. A large, top-of-pole mount will likely have some built-in adjustability, although an array larger than 2 kW may require two people to safely adjust the tilt angle. Some multipole installations divide the modules into adjustable groups to make the arrays more manageable.

Take the same 2 kW array and move it north to snow country—then, the conversation about tilt changes from improving production to guaranteeing *any* production in winter months when snow can accumulate above 3 feet. If your array is set at 30° versus 60°, it will accumulate more snow, and it will take longer for the snow to slide off.

So, to tilt or not to tilt? It all depends on:

- Off-grid or utility-intertied;
- PV array size;
- Roof type;
- Snow country; and
- the amount of effort you wish to put in.

—Erika Welickzo

Blast from the Past

In 1980, after living without electricity for five years in the woods of Vermont, I bought my first PV module. Responding to an ad in a back-to-the-land magazine, I sent a check to Joel Davidson, an urban refugee who was facilitating a bulk purchase of PV modules. From his off-grid acreage in Pettigrew, Arkansas, Davidson was selling 33-watt Arco Solar modules (model 16-2000) for $275 each.

That was more than three decades ago, and I was curious about how 30 years in the Vermont sun and snow would impact a module's performance. So to mark the anniversary of my first PV module, I decided to climb up on my roof and bring it down for testing.

The module was designed to charge a 12 V battery at a maximum voltage of about 16 V. When new, the 33 W module produced 2 A in full sunlight.

So, how did the old module measure up?

Better than Factory Specs

I decided to test the module by connecting it directly (with no battery) to two different 12 V loads: a 35 W incandescent light, and a blower rated at 4.5 A (about 54 W).

I ran the test in my backyard, on a sunny day at 11:30 a.m. The outdoor temperature was about 50°F.

The old PV module easily powered up the light; my Fluke multimeter showed that under a full load of 2.015 amps, the module's voltage was an impressive 14.93 volts.

Next, I hooked up the 54 W blower directly to the module. Almost immediately, the blower started spinning at a fast clip. According to the Fluke, the blower was drawing 2.5 A from the module—more current than would be expected from the factory specs.

I described my test to Raju Yenamandra, the North American head of sales and marketing for SolarWorld, the current owner of the old Arco Solar factory in California. "That's unbelievable," said Yenamandra.

"Your module is still performing to factory specifications—or perhaps a little better. We usually tell people to anticipate a performance degradation of 0.27% per year." Yenamandra informed me that my module—serial number 256387—was manufactured in 1979, during the very early years of Arco's PV manufacturing history.

Joel Davidson, the PV dealer who sold me the Arco from Arkansas, now lives in California. When I called him, he said, "Your test results don't surprise me. Solar modules are the most reliable electricity generation source in the known universe. A PV cell is a rock that makes electricity. Unless something corrodes the electrical contacts, it will still keep working."

Davidson was happy to reminisce about the early days of PV. "I was selling to a range of people: back-to-the-land hippies, right-wing extremists and survivalists, engineers, hobbyists, and Christian missionaries on their way to Africa," said Davidson.

Good for a Few More Decades

My old module shows no signs of browning, electrical corrosion, or water intrusion. Since I bought my first module three decades ago, PV manufacturers have made many improvements. While my old Arco panel has simple electrical lugs on the back side for wiring, newer modules have sturdier junction boxes. Manufacturers have also improved encapsulation and the lamination materials. It certainly looks as if it's ready to perform for another decade—or two, or three.

—Martin Holladay, adapted with permission from www.greenbuildingadvisor.com

Courtesy Noah Manning

web extra

Want to see how your modules measure up? See our detailed instructions on testing and verifying module voltage and current at www.homepower.com/webextras


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Khalid J. Harbi • via e-mail

Ultimate Recycling

We have lived off-grid in southwestern Costa Rica for more than 30 years. We started out in a thatched shack with a dirt floor, which flooded every rainy season, cooking on driftwood, and using candles and kerosene for lighting. The first time we went swimming, we looked back at the shack from the beach and it was sitting at the end of a rainbow (this actually happened). Talk about an omen!

Three decades later, we live in a concrete-block house with tile floors and steel roofing. A 1,500-watt solar-electric system provides our energy needs and *Home Power* has been my bible. Of course, it didn't all happen overnight.

The candlelight slowly evolved into a fuel-fired lantern—you know, the ones with the fragile mantels. The next step was a car battery and a couple of car tail lights mounted through a hole in a coconut shell wrapped in tin foil. We would take the battery to the gas station every month or so for charging. I honestly can't remember where the first solar-electric module came from, but I could see immediately that this was the answer.

We brought some modules on one of our few visits to the states, and had friends and family bring them down when they visited. Ditto the other goodies required as the system grew, such as charge controllers and the first, small modified-square-wave inverters. At one point, we got pretty serious, and along with a friend, imported a pallet of modules, which we distributed to other people.

Courtesy Ron MacAllister

Recycling is second nature to us, and the materials in these modules are just too valuable to throw away—and I always wanted one of those fancy stainless steel, glass-topped coffee tables. It must have been a dream—or maybe it was my pocketbook—but putting four legs on a solar-electric module seemed the way to go. I had not only built all the structures on our property, but all the furniture as well.

The solar-electric module is an old Kyocera (LA 361 J51) that doesn't fit into my present system. The legs are wooden and shaped from some pieces of 1 by 3. The aluminum frame on the module was easy to drill, and the legs can be attached with screws or small bolts. After a few months of my dog crashing into the table, I reinforced the legs with some fiberglass and resin. The module will still produce a few amps, and I've often thought about adding some small fan or toy just for kicks. This 10-year subscriber says thanks for all the help.

Ron MacAllister • Golfito, Costa Rica

Ohm & Home

I enjoy your magazine, but have just a small nit to pick in the *HP138* article, "Beyond your Utility Meter." The "Power vs. Energy" sidebar on page 58 says you can use Ohm's law to calculate power: Volts × Amps = Watts. Ohm's Law describes the relationship between voltage, current and resistance: V = IR.

I'm a retired electrical engineer who spent 32 years making electricity by burning coal, and I always dreamt about doing it with solar energy. My wife Joanne and I completed our solar-electric installation in October 2007. It consists of eight Evergreen 180s, wired four in series and two strings in parallel into an OutBack MX60, charging a 24 V Rolls battery bank (twelve, 2 V, 1,766 Ah). It's inverted and grid-tied via two OutBack GVFX3524 inverters wired for 120/240 VAC. We also had to reinforce our garage roof to accommodate the modules and Unirac racking.

We have had some prolonged outages at my house, and although I originally had a gasoline-powered generator, the solar-electric system has a much higher geek factor. And the gen-set was still fossil-fueled! So all my essential loads—oil-fired water heater, septic pump, well pump, fridge, computers, and, of course, the microwave—are set up to run on battery backup when my supplier and former employer lets me down. Unfortunately or fortunately, however you look at it, since the system's been in, we've had few outages, and none more than three or four hours. Nevertheless, I'd do it again. It's a hobby, and my small contribution to the environment. I figure my system will have paid for itself about 30 years after I'm gone.

Mike Curran • Chagrin Falls, Ohio

Battery Voltage Decision

I would like to share a different point of view on battery voltages and system sizing than stated in "Ask the Experts: Change Battery Voltage" (*HP137*). The *only* voltage I would consider for a home system is 48 V. One of the main reasons is the voltage drop from connection resistance. Any resistance in a battery or DC-side connection will drop twice the voltage if a 24 V system is used instead of 48 V.

Say there is 0.01 ohm resistance in a battery connection. A current (either during charging or discharging) of 20 A in a 48 V system would represent a voltage drop of 0.2 V—0.416% of total battery bank voltage. With a 24 V system, the current will be twice that of a 48 V system when the same power level (wattage) is at work. Consequently, the same 0.01 ohm resistance will cause a voltage drop of 0.4 V or 1.66% of total battery bank voltage—about a 300% increase. This loss occurs in both directions—during charging and discharging.

Measure the total battery bank voltage and connection—put one probe on the terminal of the battery itself and the other probe on the battery jumper wire (not the connector terminal). There will likely be some voltage differential, but it should be small—maybe 10 mV for a 48 V system. If the reading from a 48 V system is in the hundreds of millivolts, then there is a problem. A good rule is to look at the best connection you have (lowest voltage drop)—that should be a reasonable goal for all the battery connections.

This exercise brings to light the weaknesses of battery jumper cables versus copper bar. With jumper cables, there is a connection between the battery terminal and the terminal lug, and another connection between the terminal lug and the wire, which doubles on the opposite end of the cable as well. With copper bar, the only contact is between the bar and the battery terminal. With fewer mechanical points of contact, bus bars offer less resistance.

Beyond losses, there is much debate about battery-based system sizing in general. Personally, I do not want a large battery bank that gives me several days of backup power. I would much rather take those thousands of dollars and invest in generation capacity. With a relatively small battery bank and a large generation capacity, the battery bank will rarely get discharged because of the larger PV system. Even on cloudy days, a large solar array can charge a small battery bank to near full capacity. If sized correctly, the battery can operate smaller loads throughout the night. With prices of solar-electric modules dropping, this has become a very reasonable approach.

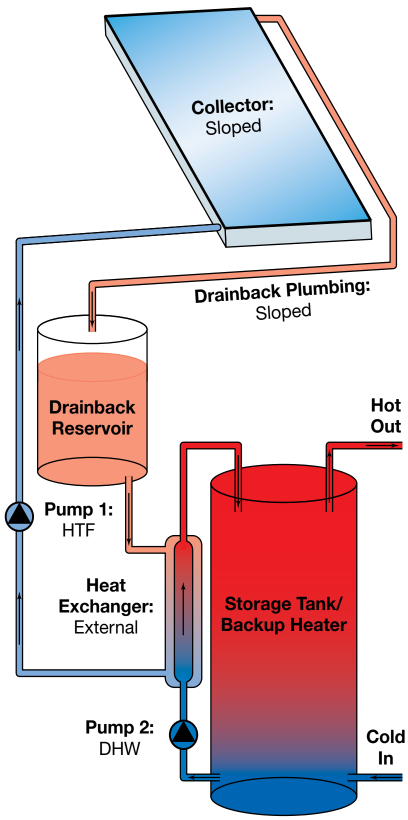
Courtesy Rick Zuber

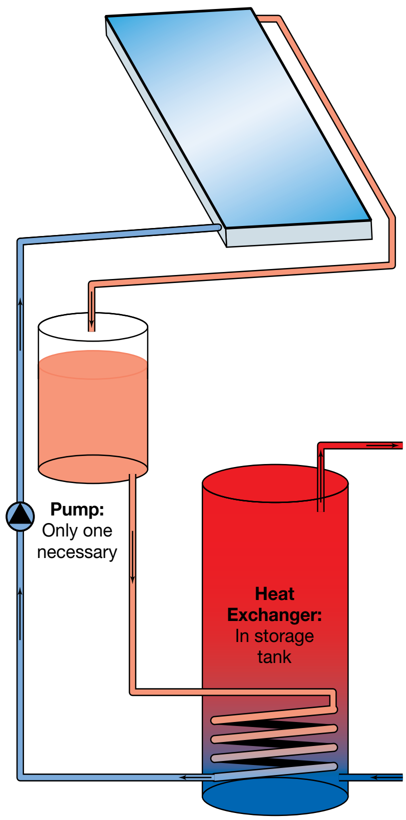
Rick Zuber • SolarWind Energy,
Sterling, Alaska

Errata

The drainback system article starting on page 78 in *HP138* had a few errors and omissions.

Drainback (DB) systems are almost always piped in 3/4-inch copper tubing or larger to prevent freezing by draining the system quickly.





The size of a DB tank with an internal heat exchanger should always be at least twice the volume of the collectors and piping in the system—this will keep the internal heat exchanger immersed when the DB tank is half-filled with air.

Finally, it is extremely important that the hot return pipe from the top of the collector(s) terminate above the water line in the top of the DB tank to allow air to rise to the top of the collector, break the vacuum and allow the system to drain. Most of the collector loop fluid will drain back through the high head pump. The air will travel up the return pipe at the same time the collector loop fluid drains into the DB tank. The two drawings on the right hand side of page 83 did not reflect this critical piping configuration, and the drawings here are one way of correctly plumbing these systems.

Chuck Marken • Solar Thermal editor

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Radiant Floor or Forced Air?

We are considering an eight-collector solar domestic water/space heating system for our 10-year-old, ranch-style home in central Wisconsin. The home, including a full basement, is about 3,000 square feet. A corn stove in our basement and a wood-burning heater in the upstairs living room provide most of the space heating. A propane forced-air furnace provides the rest. We use about 150 to 200 gallons of propane per year.

About 85% of the upstairs flooring is carpet; the rest is tile. We have about 1,000 square feet of unfinished basement with exposed ceiling. My plan was to install PEX tubing in the ceiling to provide some extra heating in that part of the house.

Two of the installers I talked to thought that my PEX plan would work OK. The third installer suggested a water-to-air exchanger installed into the ductwork and a whole-house circulating fan to extract the heat. He was concerned that the subfloor and carpet above would inhibit heat transfer.

The radiant heating retrofit would cost about $1,000 to install; the other method would cost less. Any ideas as to which method is best and would extract the most heat from my proposed system?

Jason Lang • Medford, Wisconsin

If you were building a new home, a solar-assisted, low-temperature radiant heating system would be the most comfortable, quiet, and efficient system. The problem with your existing home is that to use solar-heated water effectively, you need a low-temperature radiant floor system, which doesn't need more than a 120°F water temperature on the coldest day of the year. Low-temperature radiant heat is typically paired with concrete slabs, thin slabs, or above-the-subfloor applications just below tile or hardwood flooring.

Stapling PEX under the subfloor and under carpet is rarely a low-temperature radiant option. Often, these systems have trouble keeping you warm on very cold days—even with high radiant water temperatures. To find out for sure, you need to know the R-value of the carpet and pad, and then use radiant design software to run a heat loss calculation. Then, you can identify what your load and water temperature needs actually are. You may want to hire a certified radiant and solar heat designer to do this for you.

One option, though it would add to your costs, would be to remove the carpet and install a thin slab or above-the-floor radiant board system under tile or wood flooring. If that is not possible, the warm-air ducted system may make more economic sense. Placing a solar hot water coil in the furnace would be the least expensive strategy. You could improve the comfort and control of the warm air system by adding zoning, controlling each floor with its own thermostat.

I would also recommend upgrading the blower motor to an electronically commutated motor (ECM), which qualifies for a tax credit and, sometimes, utility rebates. The ECMs are much more efficient than other blowers and can run at very low airflow (CFM) using little energy to move heated air around your home. One possible system is Arzel Evergreen Zoning (www.arzelzoning.com), which includes both zoning and ECMs in the package. You could also look at extending your return air ducts to just behind or above your stoves to pull the warmest air off these units and move it to the cooler parts of your home. Use the very low speed setting on your new ECM blower to reduce the chance of feeling a cold draft.

Getting solar to work with a heating system can add a lot of complexity to piping, wiring, and control systems. Make sure your installer has done this before or has help from someone experienced. Download Caleffi's *Idronics* No. 3 & No. 6 journals on solar combination systems (www.caleffi.us) for some piping and control ideas. Several manufacturers are offering integrated solar thermal domestic water and space heating systems. They come with all the components, collectors, tanks, controls, and piping and wiring diagrams. This can take a lot of the guesswork out of getting all the parts to work together, and is worth considering.

Eight solar collectors is a large system. Each square foot of collector area usually requires 1.25 to 1.75 gallons of water storage in Wisconsin, which translates to a 300- to 450-gallon tank for your system. I recommend a drainback system to avoid overheating your heat-transfer fluid when the tank is up to temperature and the sun is still shining. This is especially important with a large system like you are proposing. A large heating load like a pool or outdoor hot tub can be put to use with all of the extra solar energy that'll be stored in your tank in the summer. If you use a glycol system, you will need a reliable heat dump such as a fan-coil hydronic unit heater, outdoors, and piped and wired into your solar collector glycol loop and control.

Bob Zima • Radiant Panel Association certified trainer

Back-Up Generators

I have an off-grid house in a roadless area, accessible only by boat. I need an automatic backup (not standby), propane-fueled generator to charge batteries during winter, when sunlight is minimal and I'm away. The generator needs to draw no energy when off, have a two-wire autostart on a signal from the inverter/charger, and be configured for full power at 120 volts. Honda portables won't work—they're not propane-powered and, for safety reasons, the dealer strongly warned against aftermarket fuel modifications. Current models of Kohler, Baldor, and Onan/Cummins standby generators won't work because they have always-on power requirements and are not reconfigurable to full 120 V output. The only choice I'm aware of is to adapt an RV generator, but I'd prefer a unit made for off-grid use—without modification. Since others must also face this problem, I'd appreciate any input you have.

John McMurry • via e-mail

You have hit a common problem in the off-grid world. As far as I know, what you're seeking isn't available. This is a point I

Courtesy Generac

addressed in my article on generators in "Engine Generator Basics" (*HP131*). All of the features that you are seeking are reasonable—and *used* to be available. The main generator manufacturers have moved toward "residential standby" models that are 120/240 V only. They need grid power to maintain starting battery charge and some even have an electric carburetor heater.

You might seek out a good used Kohler 6.5 RMY (1,800 rpm; twin; discontinued around 1999), 8.5 or 11 RMY (took the 6.5's place; 3,600 rpm, twin) or the 10 or 12 RY (1,800 rpm, water-cooled, four; discontinued about five years ago). All of these are two-wire start and field-configurable to straight 120 V output. Older Onans, such as the 6.5 Commercial, will also work as long as you include their two-wire start (TWS) auxiliary module. In fact, I would look for one of these older units in good shape with reasonable hours before I would consider most new units.

I have spoken with a few major generator manufacturers about the need for a product that does just what you're asking. Recently Generac, one of the largest industry names in other generator applications, told me they are developing just this product. It hasn't been tested yet by our industry, and, historically, Generac has a weaker reputation in the off-grid RE industry, so there's no word on how well it fills the bill. But this might well be a reason to wait and watch—if it proves out, it might be a good solution to your problem.

Allan Sindelar, Positive Energy • Santa Fe, New Mexico

Local Motivation?

I live in Washington State, and the production incentive here pays a premium for solar electricity produced with components made in the state. I'm trying to decide whether to pursue using these components, which are more expensive and less efficient. How's a person to decide?

Sarah Wexler • Kirkland, Washington

The Washington state production incentives, also called "feed-in tariffs," seem quite attractive. Systems with no Washington-made components, such as inverters, get 15 cents per kWh. Systems with only a Washington-made inverter get 18 cents per kWh. Systems with only Washington-made solar-electric modules get 36 cents per kWh. And systems with both modules and inverter made in Washington receive 54 cents per kWh. This is in addition to the net metering value of 3 to 12 cents per kWh, depending on your utility.

Before you make your buying decision, look at your motivations, at the specifics of your situation, at the equipment you are considering, and at the long-term picture.

While getting a value of 54 cents per kWh might seem compelling, many people do not approach renewable energy from a financial perspective. Other very common motivations are environmental, energy reliability, independence, and "cool factor." Your motivation may have a strong influence on your decision.

Your site characteristics—especially the space available for an array—may also be influential in your decision. The only

Washington-made modules available are less efficient (they are about 40% less efficient, so they take up about 40% more space for the same production) than the best on the market. They are also built only in a 4- by 4-foot configuration.

These two factors can combine to limit the size of your system significantly if you have a small roof that is the wrong size to handle 4-foot modules. I have seen cases where using these modules cuts the system wattage almost in half compared to the most efficient modules available. In this case, using the Washington-made modules will serve someone with a financial motivation better than someone who has an environmental motivation. The question becomes, "Do you want to make more money or more solar electricity?"

It's also important to be clear that the Washington-made modules are produced by a small company without a long track record. The module warranty is shorter than industry standard (20 years instead of 25). But to some people, this might be entirely offset by the attractiveness of buying from a local company that provides local jobs.

When you are dealing with systems that "earn" up to 66 cents per kWh, it's not hard to calculate simple returns in the 10% range. But it's important to understand the key factors. For instance, you must have a federal tax liability to take advantage of the 30% tax credit. And the Washington production incentive sunsets in 2020, so the longer you wait to buy your system, the lower the long-term return is. We won't know until closer to that year whether the incentive will be extended. Examine your motivations, your site, and your financial picture, and make a decision that serves your own needs. One way or the other, you'll be helping yourself, your community, and the planet.

Ian Woofenden •
Home Power senior editor

Courtesy Ian Woofenden

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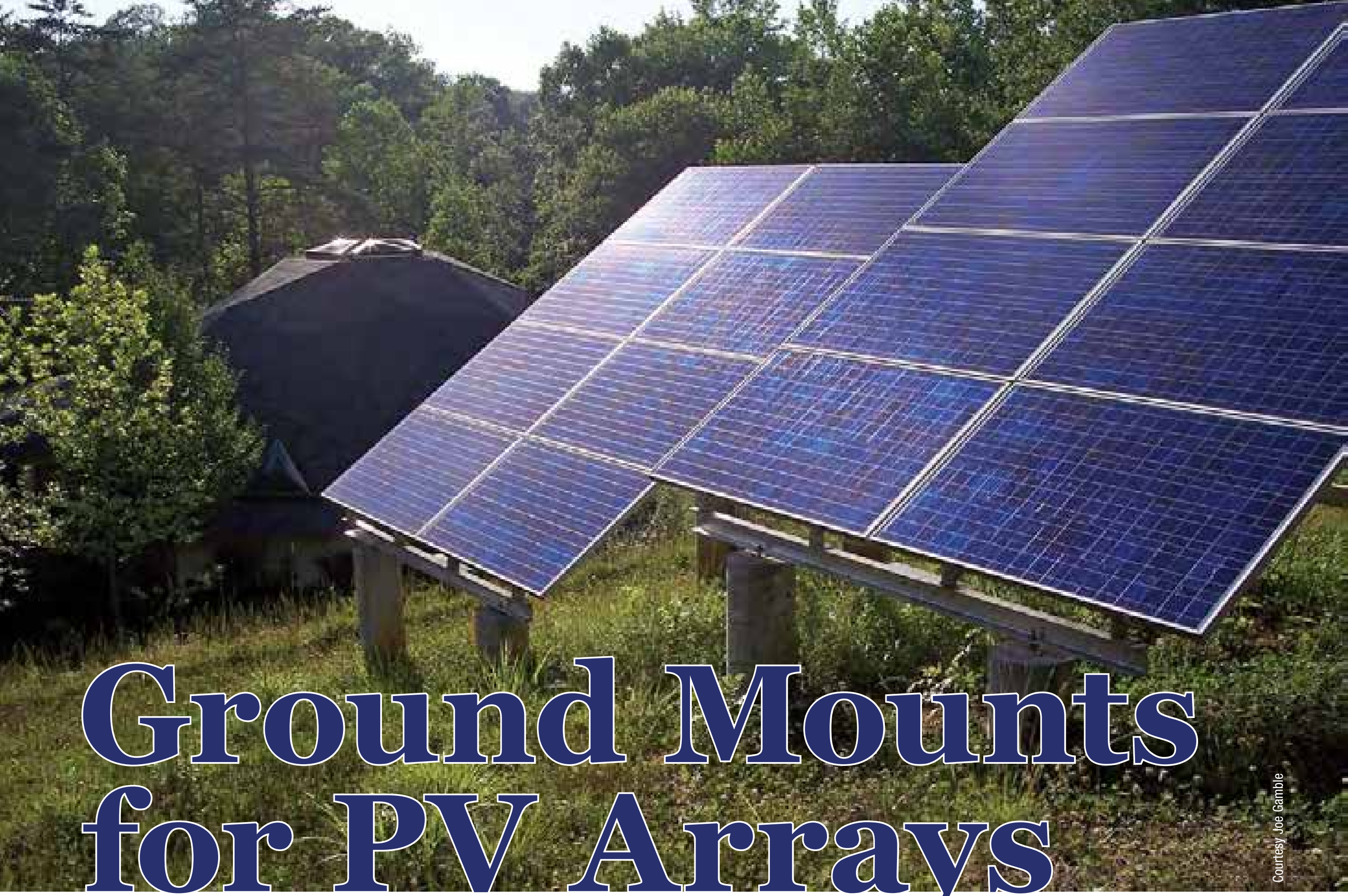


Courtesy Joe Gamble

Ground Mounts for PV Arrays

by Rebekah Hren

Roofs aren't the only places for PV systems—ground-mounted systems offer their own unique advantages.

Choosing the structure to secure your PV array—roof, pole, or ground mount—is a process of weighing the pros and cons of each. Cost or energy-production comparisons might yield an answer, but sometimes the site speaks loud and clear.

Ground mounts, like pole mounts, can often accommodate larger PV arrays, as they are not limited to the size of the roof and can take advantage of the best solar window a site offers. Array installation and maintenance is done on terra firma—no climbing, no safety roping. There are no roof penetrations to leak, and with increased airflow around them, modules can operate at lower temperatures—yielding higher performance. Being able to choose the perfect tilt angle and azimuth also results in optimum performance. And while PV arrays don't *have* to be cleaned, spotless modules do produce more energy; ground-mounted modules can be more easily washed of dirt, dust, and bird droppings. So if a site has wide-open, unshaded space to use for a PV array, ground-mounting can be the best option.

Courtesy Honey Electric Solar

Above: Ground mounts can work in situations where roof mounts won't.

Right: Working from ground level, rather than on a roof, is often safer and easier.

Schletter racks are typically used for large, utility-scale ground-mounted installations.

Rack Details

Ground-mount racks are made of a mix of aluminum and steel poles, rails, and channel attached to ground-anchoring structures—working together to provide the strength to resist live loads (like wind and snow that exert variable uplift and downward pressure) and dead loads (the weight of the rack and modules). While it's possible to scratch-build a ground-mount, it is rarely advisable. The engineering and testing that go into manufacturers' designs take the guesswork out of ground-mounting a PV array, and the end result is likely to be

Zilla racks can use their Helical system, avoiding the use of concrete pier footings.

Courtesy Next Generation Energy

Engineering Variables

The information that a custom ground-mount manufacturer will need includes:

- **Maximum design wind speed.** This is the highest wind gust speed probable in 50 years, averaged over a 3-second gust at a height of 33 feet. Because wind speeds vary (they are generally higher close to the coast and at high elevations), this is critical information for an engineer. Maximum design wind speeds can be found in the American Society of Civil Engineers (ASCE) Standard 7-10, "Minimum Design Loads for Buildings and Other Structures." However, your local building authority can provide the wind design speeds they require.
- **Snow load.** Measured in pounds per square foot, the weight of snow on a structure can stack up, depending on your location. Snow can be five to more than 15 times heavier than a PV module, and the rack must hold the additional weight. ASCE Standard 7-10 includes common snow-load values, but your local building authority will provide their requirements.
- **Exposure category.** This is related to wind loading and takes into account the turbulence at the site due to surrounding objects (trees, buildings, etc.). There are three main ASCE categories that relate to ground mounts: Category B (lower wind loading)—dense urban and suburban area; Category C (medium wind loading)—open terrain with occasional obstructions; Category D (higher wind loading)—flat and unobstructed terrain. (Category A refers to "large city centers" with at least 50% of the buildings with heights more than 20 meters.)
- **Site slope.** Again, the engineer will be concerned with the physical dimensions of the rack and the maximum slope the racking can accommodate. You'll need to provide the average slope and slope direction.
- **Soil class.** This is necessary for determining specifics for anchors, which behave differently in different soils. Soil classifications are derived from Table 1804.2 of the *International Building Code,* which classifies five general soil types—type 1: crystalline bedrock; type 2: sedimentary and foliated rock; type 3: sandy gravel and/or gravel; type 4: sand, silt, or clay sand, silty gravel, and clayey gravel; and type 5: clay, sandy clay, silty clay, clayey silt, silt, and sandy silt. If there is a mix of soil types, pick the dominant type. The USDA Natural Resources Conservation Service publishes soil surveys which contain maps and a description of each major soil in the survey area. Your local cooperative extension agent can provide you with maps and help determine your soil type. See www.csrees.usda.gov/Extension/ to find your local office.
- **Module type and quantity.** Acquire a specification sheet for your modules for the rack manufacturer, who will need at minimum the number of modules, plus module depth, height, width, and hole layout, to size the rack correctly.
- **Desired tilt angle.** This will be based on your location's latitude and the seasonal variation in solar gain (see "Specifics to Consider" for more details).
- **Ground clearance.** This is the height to the lower edge of the first row of modules (2 feet is typical). This basic design decision should be based on site conditions: potential snow accumulation, ground covering, aesthetics, etc.
- **Number of modules in a string.** This information can help the rack manufacturer design an efficient layout, with strings contained within a row or subarray for less trenching and conduit.

cheaper, sturdier, longer-lasting, better engineered, and quicker to install than a homemade rack.

Ground-mount manufacturers offer versatile designs for PV arrays, from two modules to upwards of 2,000 modules. The manufacturer typically provides a site-specific engineered design, layout, and prefabricated components, along with a list of what needs to be provided locally. The locally sourced parts will vary according to design—some systems come so complete that only concrete needs to be locally sourced. Although some rack manufacturers focus only on larger arrays (20 kW and up), nearly a dozen manufacturers provide smaller array (500 W to 20 kW) solutions, delivering fully engineered mounts with 10- to 15-year warranties.

Courtesy Next Generation Energy

In areas with no vegetative growth or snow shed, racks can attach to concrete at ground level.

Ground-mounted PV modules are arranged in one or more rows, in either a landscape or portrait configuration. A common layout for larger arrays is two rows of modules in a portrait configuration, but smaller array layouts vary substantially, depending on the number of modules. Care should be taken when specifying a design to match the number of modules and series strings with the layout to ensure a symmetrical final product with the shortest possible cable and conduit routes.

Securing the Rack to the Ground

A variety of methods are used to anchor the rack to the ground: poured footings made with concrete column forms; driven steel piles of beam or pipe (or, rarely, wood); "earth screws" (also called "anchors" or "helical piers") and even ballast (see "Ballast Mounts" sidebar).

Most smaller ground-mounted arrays use concrete footings because no special equipment (like a pile driver) is necessary. As more manufacturers join the industry and R&D accelerates, ground-mount anchor installation options are expanding. For example, Next Generation Energy's Helical System uses hot roll steel plate and steel tubing to make a sturdy anchor that quickly "drills" into the soil. The anchors cannot be used in hardpan soils or soils with larger than 6-inch rocks. The depth, diameter, height, and spacing of the ground-mount support anchors, as well as the design of the rack itself, will be specified by the rack manufacturer on a site-by-site basis. The manufacturers engineer the design to the most conservative building code standards for the site specifics, so you must provide accurate inputs for the engineer, or the rack design might not be built to withstand the particular environmental conditions of the site, with potentially catastrophic consequences.

Ground-Mount Planning Checklist

Preliminary

- ☐ **Siting:** Review property lines, shading, setbacks, right-of-ways, or easements; and check for underground utilities.
- ☐ **Civil engineering:** Will grading, storm water runoff mitigation, or environmental reviews be needed? Check with local permitting, planning, and inspection agencies.
- ☐ **Site access:** Is the site accessible to heavy construction machinery if needed?
- ☐ **Accessibility:** Will the array need fencing for security from theft and/or animals, and to comply with *NEC* 690.31A? Be sure there is sufficient space so the fence will not shade the array.

Design

- ☐ **Site-specific info:** Catalog wind speed, snow loads, soil conditions, etc.
- ☐ **Electrical interconnection:** Determine distance and route to the interconnection point, and placement of electrical equipment including combiner boxes, disconnects, inverters, and other BOS components.
- ☐ **Orientation:** Choose a tilt for the array that balances maximizing production and maximizing usage of the area (steeper tilts mean rows of modules must be further apart due to interrow shading).
- ☐ **Height:** Consider snow buildup and vegetation growth to determine the minimum height to the array's lower edge.
- ☐ **Layout:** For multiple rows, plan spacing according to shading calculations, access requirements, and trenching routes.
- ☐ **Maintenance:** Plan for dealing with vegetation growth and access to the modules for cleaning.

A Ground-Mounted Solution

Down a quiet gravel road in a small community in the piedmont of North Carolina, Joe Gamble and Suzanne Thompson's house often loses utility power during too-common hurricanes and ice storms. Their first priority was PV-powered battery backup for the well pump, but they also wanted to power as much of their residence as possible with renewable energy.

Their home—a geodesic dome—was particularly problematic for a roof-mounted PV system. The multiple azimuths and tilt angles of the curved dome would have meant installing modules at wildly different orientations or with a complicated rack attachment system—not usually a wise PV design decision (although microinverters or module maximizers might help alleviate the energy production aspects of this problem).

The siting focus turned to a field behind the house. But the field had its own issues: it was covered with brush, included a perilously steep western slope, and was bordered to the north by a utility right-of-way and on the south side by a row of evergreen trees.

Type of Mount

For PV arrays situated in fields like Joe and Suzanne's, there are two choices—pole mount or ground mount. Pole-mounted PV arrays sit atop a heavy, steel pole (usually 6 or 8 inches in diameter) that is anchored in yards of concrete. Ground-mounted racks have multiple smaller supports that secure the array, and usually sit closer to the ground. The slope of their field was too steep for concrete trucks or other heavy equipment, ruling out the pole-mounted solution.

Courtesy Honey Electric Solar (2)

DPW Solar provided the engineered rack system, which Honey Electric Solar installed on the steep slope.

Honey Electric Solar designed and installed the 2.8 kW PV system with two, side-by-side ground-mounted DPW Solar racks. Each rack accommodates eight, 180 W Evergreen PV modules that power an OutBack battery backup, grid-tied inverter. The Gamble array was limited to four modules in a series string, due to the module voltage, temperature extremes, and charge controller voltage window. If the strings had been limited to three modules instead of four, it would have meant splitting a string across the two racks.

Footers were reinforced with rebar and inspected prior to pouring concrete.

Poured concrete piers provide solid footing for mounts and BOS components.

Courtesy Honey Electric Solar

Cross-bracing keeps the plane of the modules from flexing under wind or snow loads.

Courtesy Joe Gamble

Courtesy Peltz Power

Compared to roof-mounted arrays, which are typically installed inches above and parallel to the roof plane, ground-mounted arrays have access to greater airflow, resulting in cooler operating temperatures and higher production.

Specifics to Consider

Every site is unique, and every mount design will be, too. For example, an array located in an area that receives heavy snowfall should have ample ground clearance so that snow can slide off, accumulating below without shading the modules.

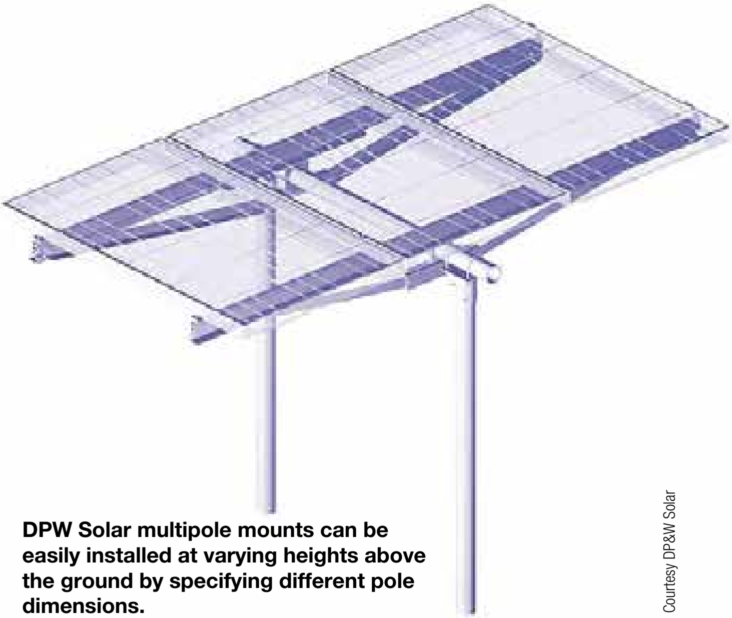
In addition to site-specific considerations, the tilt angle of the array is a key factor. While adjustable legs are a common option with many ground-mounts, it isn't nearly as easy as adjusting a pole-mounted array. Most pole mounts are balanced and have a single point of tilt adjustment, which a person can handle alone. Ground-mounted racks have multiple bolts, and the weight of the modules is resting on legs that have to be adjusted simultaneously or each leg a little at a time. This means at least two people can be needed for adjustments, or the process becomes arduous.

For a design starting point for a single-row, grid-tied array—that most commonly has a fixed tilt—use NREL's online PVWatts calculator to find the angle that gives the highest possible annual energy (kWh) estimate for your site. Deciding on a fixed tilt angle for the array can be tricky if you're off-grid or have multiple array rows within close proximity.

For setting the tilt of off-grid arrays, consider when loads are heaviest or the fewest sun-hours are available and choose an angle close to perpendicular to the sun's rays for that time of year. If no set tilt angle can meet the consumption demand year-round, then calculate what fixed tilt will most likely reduce generator run time via a comparison of seasonal production at different tilts versus seasonal loads.

For ground mounts with multiple rows in close proximity, the choices become even more complicated. An array set at lower tilt angles means interrow spacing can be narrower, since the shadow cast by each row is shorter—and more rows can fit into a smaller footprint. The trade-off is that as module tilt decreases below the optimum, array energy production will decrease as well. A good starting point that balances the two goals for a multirow array is to set the tilt at latitude minus 10°. Manufacturers can assist in calculating interrow shading and spacing where necessary.

Positioning the inverter(s) and other balance of system (BOS) components is another critical design decision, especially when the goal is to keep voltage drop to a minimum. Higher voltages with lower currents allow smaller wire sizes, which means money saved. For high-voltage, grid-tied residential arrays using string inverters, the DC voltage will nearly always be higher than or about the same as the inverter AC-side voltage—which means keeping the longer runs of conduit and wire on the DC side of the inverter can be a good design decision. The



DPW Solar multipole mounts can be easily installed at varying heights above the ground by specifying different pole dimensions.

Courtesy DP&W Solar

Ballast Mounts: Not Just for Flat Roofs Anymore

Ballasted mounting structures have traditionally been used on flat commercial-style roofs, where penetrating the roof surface is undesirable or impossible. Instead, a heavy ballast, often concrete blocks, sits in trays attached to the mount to firmly hold the array in place. Ballast weight is based on the site's design wind speed and other factors that affect the wind loading and pressure on the system. The building also must be structurally sound to support the added ballast and system weight.

Ballasted mounts are now being used on the ground, too. In places like brownfields that have contaminated soil, or landfill sites that have been capped, a ballasted system can be the only way to secure an array without penetrating the soil—turning a previously unusable site into a clean energy generation plant! Ballasted systems also work well in places where the soil is extremely rocky. For environmentally sensitive sites, a ballasted system can be more easily moved. Even abandoned parking lots can accommodate ballasted PV arrays without needing to tear up the paving. Ballasted ground mounts do not accommodate sites with more than a 5% slope.

The ballast used for ground-mounted arrays is locally sourced, and can be sand bags, paver blocks, or a precast concrete form specifically designed for the mount. Depending on the ballast racking system used, the site may not require heavy machinery or concrete pouring, and may require only minimal surface prep during installation.

Courtesy Tom Barnes

Concrete pavers or other blocks can be used to keep a ground-mounted array from being lifted by wind.

positioning of array BOS components will directly impact where conduit will be buried and how the array can be accessed for maintenance.

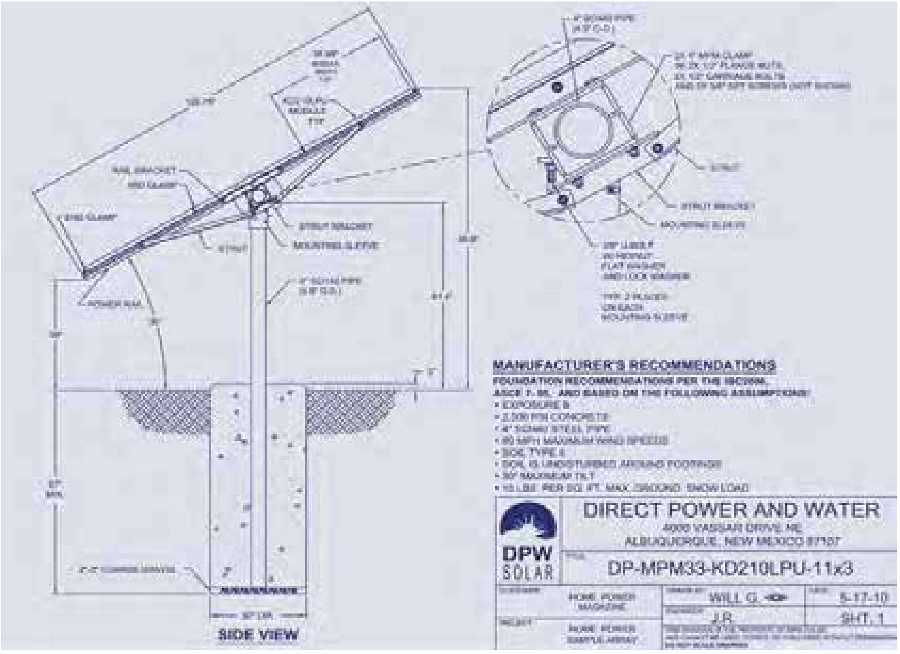
Code & Maintenance Considerations

Section 690.31A of the 2008 *NEC* specifies that PV wiring should not be readily accessible. For ground and pole mounts, that means either containing it in a raceway (which is possible when the modules have junction boxes that accommodate conduit) or by other means—the usual solution being locating the array behind a fence that does not shade the array. A fence can be a good choice for other reasons, such as in high-profile areas where theft or vandalism might be an issue. Several ground mounts have wire-management channels, into which PV wires can be safely tucked. These channels are either integrated into the design or offered as an option. These are not frequently UL-listed as a raceway, so the authority having jurisdiction over the installation might question their use for wire management.

The grounding for ground-mounted arrays also should be carefully considered. *NEC* Section 690.47D requires grounding electrodes connected directly to the array structure at the location of the ground mount. Exposed, non-current- carrying metal parts that may become energized in a fault situation, like module frames and rack rails, also must be grounded and connected to the grounding-electrode system. It is best to verify your grounding techniques with your inspector beforehand.

One of the biggest challenges for ground-mounted systems is keeping the surrounding area free of array-shading vegetation. Solutions include gravel, landscape fabric, and mowing. Sheep have been successfully used to keep the area around the array clear (but don't use goats, which will climb on the array and try to chew on conductors)! Mowing or

All rack manufacturers should be willing to supply custom drawings of their engineered systems. If needed for the local inspector, stamps from professional engineers can be provided.



Courtesy DPW Solar

string trimming should be done carefully, as thrown rocks can damage the panels. Another factor to consider is the permanence of the installation—some sites, especially in land trusts or farmland, require a plan for future removal of concrete piers and associated structures.

Finding a Manufacturer

Some manufacturers design mounting structures only for "larger" arrays or split their product lines into residential, commercial, and utility-scale solutions. If in doubt, check their Web site, and get in touch with them. A manufacturer should be easily accessible by phone or email, so it is worth the trouble to call a few and discuss upcoming projects to get a feel for how responsive they will be.

Access

Rebekah Hren (rebekah.hren@o2energies.com) is a licensed electrical contractor and NABCEP-certified PV installer living in Durham, North Carolina. Rebekah teaches PV system design and installation classes, and co-authored *The Carbon-Free Home*, a book on residential energy efficiency retrofits. Her newest book, *Solar Buyer's Guide for Home and Office,* will be available in October.

Manufacturers:

AEE Solar • www.aeesolar.com

Applied Energy Technologies • www.aetenergy.com

Conergy • www.conergy.us

DPW Solar • www.power-fab.com

HatiCon Solar • www.haticonsolar.com

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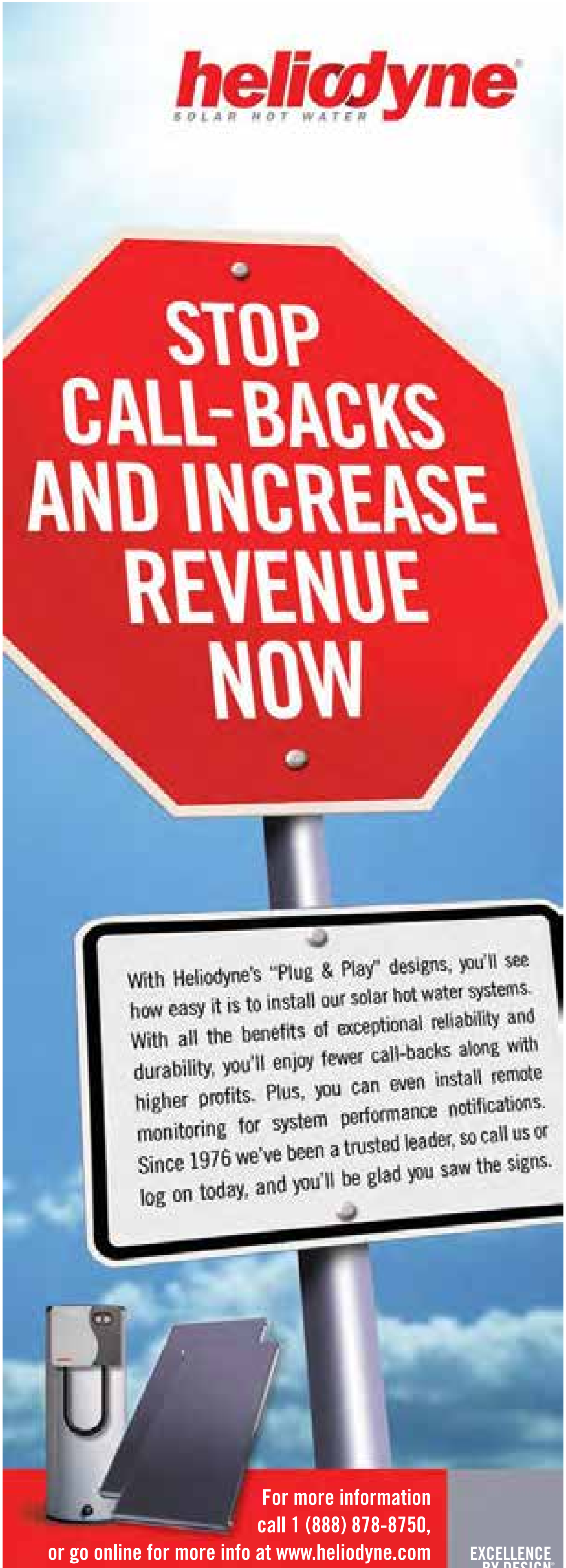
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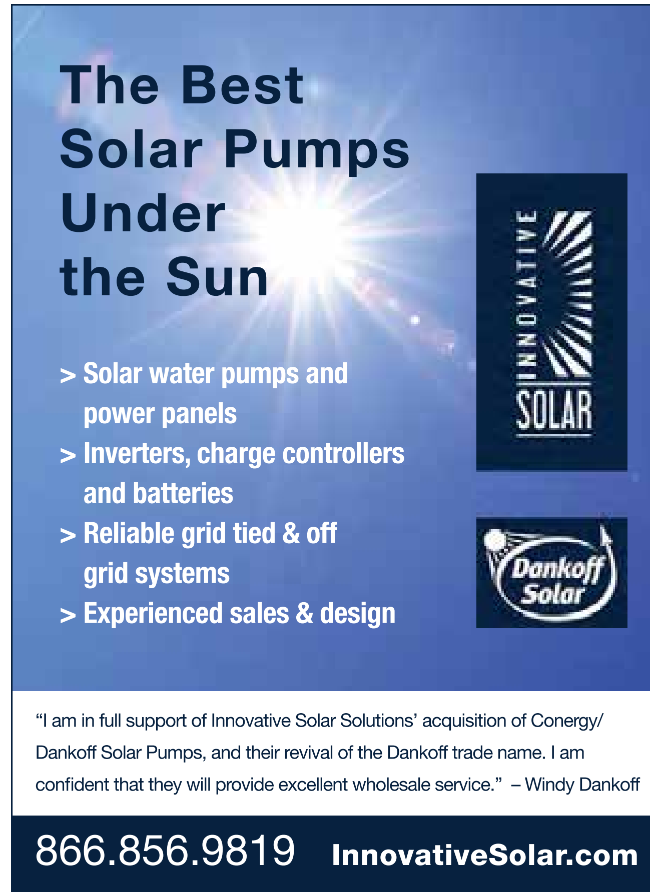
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GRID-TIED ...with Backup!

by Flint Richter

WOULD BATTERIES BENEFIT YOUR GRID-TIED SYSTEM?

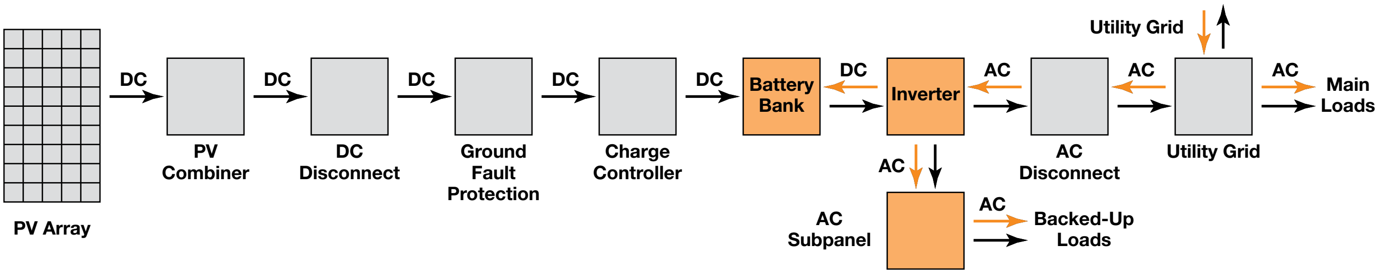
Most grid-tied solar-electric systems are "batteryless" and require the utility grid to function. The grid provides a "signal" for a grid-tied inverter to follow, creating an AC waveform from the DC PV system output. Once that signal disappears or goes too far out of voltage or frequency specifications, the inverter stops operating. That is the most efficient way to produce PV-made energy—more watts can be converted.

Conceptually, a PV array could produce useful energy any time the sun shines. So why can't we use it if the grid does not operate? It's because a PV array is a constant-current energy source—it cannot cut back or increase the energy available depending upon how much the household needs at any moment. For example, there might be a fridge motor that draws 9 amps while running. A PV system putting out 9 A could keep up with that, except for one problem. When the fridge starts running, the motor surges to possibly double or triple its running amperage. Since the PV system is limited to 9 A, it can never start the motor.

When hooked up to the utility, this same PV system has the grid available to make up for any deficiencies, like during appliance start-up surges. The grid also provides a place to go for any excess energy produced by the PV-powered home.

Including a battery in the system adds a source of energy that can vary according to the needs of the home. Special battery-based, grid-tied inverters are designed to disconnect

Basic Energy Flow: Grid-Tied with Battery Backup



from the grid, instantaneously switching internally to draw needed energy from the battery instead of the grid. These inverters still disconnect themselves from the grid when the grid goes down, so that they don't inadvertently energize the grid while utility workers are working on it—a potentially shocking hazard.

High frequency or long durations of electrical outages are the most common reasons to have battery backup. Many rural homeowners want battery backup with their systems because they live with a low-quality grid or have affecting circumstances—trees near power lines, a long power line extension, wind or snowstorms—that make outages more frequent or of longer duration.

If you do suffer consequential outages, or if there are appliances that absolutely must run all the time, you'll need backup energy during an outage. You may have medicine or food that needs to be kept cold; lights and computer equipment for work; an oxygen generator for your health; radios and TV for access to news; or a lift for alter-abled access.

A detailed worksheet listing loads and their usage is necessary to size a battery-backup system (see "Sizing a Grid-Tied PV System with Battery Backup" in this issue). Any improvements in load efficiency that can be made prior to sizing the system will reduce costs. Sizing a battery backup system usually takes several attempts—you need to weigh the cost of backing up loads with the loads' importance, while paring down the list or increasing efficiency to stay within your budget.

Battery backup system sizing is much more critical than grid-tied sizing, so details are a must. If you size a grid-tied system too small, the extra energy needed comes from the grid—no problem, except for a higher bill. If you size your battery backup system too small, you may run out of electricity during an outage, defeating the point of having battery backup.

A typical *batteryless* grid-tied PV system's cost is $6 to 8 per rated watt. A grid-tied system with battery backup can cost $10 or more per watt, because of adding batteries and the extra equipment needed to charge them. The total size of the critical loads and duration of outages dictates the size of your battery, inverter, and charging source (PV array, wind generator, micro-hydro generator, etc.)—and your system's cost. Rewiring your service panel adds another cost, since backed-up loads must be separated from non-backed-up loads and placed in a dedicated service panel. This work can lead to remodeling, further adding to the labor and cost involved.

System Operation

A battery-based grid-interactive system requires a specialized inverter. Most of the time, the inverter operates in its grid-tied function, converting DC energy (from a PV array, for example) into grid-quality AC energy that can

Besides a battery-based grid-tied inverter and batteries, these systems require a charge controller, new load panel, and various additional components, driving the total cost up 20% to 40%, while reducing overall system efficiency.

Courtesy Honey Electric Solar

Outages Infrequent? Consider Unplugging

Most urban homeowners rarely experience power outages. And when they do, it's typically for only a few minutes. Instead of spending money on a battery-based system that would be rarely, if ever, needed, consider the "candle and bottle of wine" plan: a potentially fun respite from being "plugged in" all the time.

Maintenance, Environment & Efficiency

Photovoltaic systems are very reliable, and batteryless systems are nearly maintenance-free. Adding batteries increases maintenance costs and responsibilities. Flooded lead-acid batteries—still the most common energy-storage medium—require checking electrolyte levels periodically to see if distilled water must be added. Sealed batteries require no electrolyte checks, but still have connections and terminal posts that must be periodically inspected and cleaned of corrosion, as is the case with any battery.

Batteries also come with environmental issues that you may want to consider—mining, chemical manufacturing, and spills. The owner's responsibility continues beyond the batteries' life cycle, since this potentially hazardous element must be disposed of properly or recycled into new batteries. There are battery recyclers that reuse or recycle all parts of a battery: lead plates, electrolyte, and plastic case.

A consequence of adding batteries to a grid-tied system is a drop in overall system efficiency. A *batteryless* grid-tied inverter will be from 90% to 97% efficient at turning the available PV input power into grid-quality output—the bulk of most tested inverters hover around 95% efficient. Introducing batteries drops the inverter efficiency to about 92%.

In addition, there are battery inefficiencies. A lead-acid battery is about 80% efficient, with 20% of the energy wasted as heat during the battery's chemical reactions. Better efficiency can be had by charging and discharging a battery slowly; quick charging and discharging means lower efficiency. But once the battery is full, almost all of the energy from the inverter is directed to the grid or loads, although a little energy will be used to keep the battery at float level (full).

With the inverter sending energy to the grid, the main efficiency difference between battery-based and batteryless systems is how well the inverter processes energy from a renewable source and delivers it to a load. When the grid is down, the battery efficiency comes into play during the cycle of charging and discharging the battery to power your backed-up loads.

Courtesy Sun Xtender

Even sealed batteries require maintenance and have a shorter life-span than most other components in a system, which come at an efficiency and economic cost.

be consumed on-site or—if the loads do not use all the energy—exported to the grid. The inverter's second function is as a backup power supply, which handles battery charging when the grid is available and seamlessly switches to battery backup mode when grid power drops out.

In the more-common grid-interactive mode, the inverter is exporting energy from the charging sources to the household loads and any excess energy is pushed on to the grid. If the home consumes more energy than the charging sources can supply, that energy is pulled from the grid. Specifically, if the backed-up load center demand exceeds what the charging source can supply, the inverter will pass grid electricity through its internal transfer switch to its output circuit (i.e., to the separate backed-up loads subpanel).

During a utility outage, the inverter switches to converting DC from the battery to AC for the backed-up loads panel. The means of feeding the grid during grid-tied mode is disconnected when the grid is down, and all loads in the main panel are de-energized. Once grid power returns, the inverter will wait five minutes to make sure the grid is stable and then switch the backed-up loads panel from inverter power to grid power and start recharging the battery with whatever power sources are available—grid, solar, etc. Then the inverter resumes sending excess energy to the grid.

When the grid is out-of-spec but not out, the inverter will disconnect from the utility and send power to the backup panel. The loads inside the main panel will continue to run as long as the loads are getting enough voltage from the grid. Inverters have a very tight spec and may disconnect from the utility even when there isn't a major problem. In this scenario, the inverter wouldn't be able to send power back to the grid if the PV array was producing excess power.

While the complexities and design factors for a battery backup system may be daunting, the rewards can make up for it. Few battery-backup customers ever say they regret the system choice—while some *batteryless* grid-tied customers fantasize about using their appliances while the grid is down. Usually, the financial outlay for a battery-based system is the determining factor. These systems, like all home RE systems, are becoming more affordable thanks to falling module and other PV equipment prices—and the generous 30% federal tax credit that even applies to battery-based systems.

Access

Flint Richter (flint@rockygrove.com) lives and writes off-grid in Arkansas' Boston Mountains. He is a partner and NABCEP-certified PV project manager with Rocky Grove Sun Company and a contracted instructor for Solar Energy International. He is teaching his young daughters the difference between a solar module and a solar panel.

Sizing a Grid-Tied PV System ...with Battery Backup

by Flint Richter

Courtesy Honey Electric Solar

A professionally installed grid-tied PV system with battery backup using the Schneider (Xantrex) XW inverter and BOS package, with a custom battery box.

Once the decision has been made to include batteries in your grid-tied system (see "Grid-Tied…with Backup!" in this issue), next is estimating the backed-up loads' energy consumption, selecting the inverter, sizing the battery bank, and considering other balance-of-system (BOS) components.

System sizing starts with the loads, which determine system components and cost. Sizing a simple batteryless grid-tied system starts with a year's worth of household energy use data (usually from electric bills) and a budget (see "Sizing Batteryless Grid-Tied PV Arrays" in *HP138*). Sizing the PV array (or other RE source) of a battery-based grid-tied system is done similarly, but sizing the inverter and battery bank requires more information and calculation.

Estimating/Measuring Backed-Up Loads

If you want a battery-based system, you'll need to decide what loads will be backed up and how long you need them to operate.

Nameplate ratings—volts, amps, and possibly watts—are printed on most appliances. Remember: amps (A) × volts (V) = watts (W). Watts is an instantaneous measurement of how much power is needed (or produced) at a given moment. You'll need to know how much energy (kWh or Wh) your loads use while operating over a period of time. Multiplying watts by the number of hours the load runs gives you its energy use in watt-hours (Wh) per day—then dividing by 1,000 will translate it to kWh.

Although nameplate ratings can be used for system sizing, they may lead to overestimating a load's power needs, since amp ratings are sometimes given for surge peaks—not continuous draw. A more accurate way to measure a load is with a watt meter (see "Beyond Your Utility Meter" in *HP138*). These tools measure volts, amps, watts, and cumulative kWh for each load. Measuring each load you're considering for backup will provide a better foundation for system sizing.

Inverter Sizing

The inverter in a grid-tied battery-based system must be sized to do two things: power all of the backed-up loads simultaneously and pass the energy from the renewable sources (PV array, wind generator, etc.) to the grid. To calculate the inverter power rating, sum the total backup loads. If surge loads (pumps, compressors, induction motors) are anticipated, the inverter should be sized to also handle the maximum combined surge loads. Most inverters can handle a surge twice their rated output for a few seconds. If more power is needed than a single inverter can supply, you can stack the outputs of multiple inverters to increase the total connected power and surge capabilities, or multiple inverters can separately feed separate loads.

The voltage and frequency of the inverter must also match the loads. Inverters for the United States are available in 120 and 240 VAC output at 60 Hz. If you only need to back up 120 V loads, then a 120 V inverter will be your most economical choice. However, purchasing a split-phase, 120/240 V inverter (or stacking two 120 V inverters for 120/240 V output) gives the flexibility to power both 120 and 240 V loads.

The second inverter selection factor is the ability to send renewable-made energy to the grid. If you have a PV array rated at 4,000 W, the inverter needs to be able to process the full amount. While it is true that the PV array will produce less power under normal operating conditions (due to module heating, dust/dirt, wiring inefficiencies, etc.), there are conditions (cold temperatures and clear skies) when the array can produce full power. Select an inverter that will handle the larger of the two factors: Array output and maximum combined backup loads.

Battery Bank Sizing

After sizing your inverter to fit the loads and RE sources, next size the battery bank to power the loads for a given amount of time, making sure to match the battery and inverter's DC voltage.

Begin battery bank sizing by determining how many days you want to power your backed-up loads without a charging source (days of autonomy). Since the grid will be your primary energy source, for this calculation, you only need to consider the amount of time the grid won't be available. Using historical information, you can estimate the average length of time your site experiences utility outages. You can also add in a safety factor to account for extreme situations. In arriving at a number, assume that there won't be a source of energy to recharge the batteries. Finally, if the days of autonomy exceed three, consider adding an engine generator as a third energy source. This will help keep overall system costs down, and result in a more reasonably sized and better utilized battery.

Above: Two stacked inverters are the core of this OutBack system, which integrates charge controllers and other BOS components.

Below: An SMA America Sunny Island system uses AC coupling to integrate battery charging with a second batteryless inverter.

Courtesy Honey Electric Solar (2)

Available Battery-Based

Three manufacturers dominate the grid-tied, battery-backup inverter market: OutBack Power Systems, Schneider Electric (formerly Xantrex), and SMA America. Each company offers an inverter—some with different AC outputs or in different configurations—that is listed to UL Standard 1741 for grid interconnection and has battery-based capabilities.

Courtesy OutBack Power Systems (2)

Above: GTFX/GVFX inverter.

Left: SmartRE inverter.

OutBack Power Systems

OutBack Power experienced early adoption in the off-grid market because its equipment had features and operations not yet filled by other inverter manufacturers. It soon became a player in the grid-tied with battery backup market niche with its GTFX, GVFX, and, more recently, SmartRE products.

The GT stands for grid-tie; the GV is the higher-powered, vented model—both are variations of the rugged off-grid FX inverter. The sealed GT versions are available in 24 V, 2.5 kW and 48 V, 3 kW models. The vented versions come in 24 V, 3.5 kW and 48 V, 3.6 kW models.

All versions have single-phase 120 V output. Two G-series inverters can be "stacked" for 120/240-volt split-phase output. OutBack also produces AC and DC FLEXware panels that hold all BOS components, overcurrent devices, shunts, and bypass breakers. There are many versions of OutBack-inverter-based power panels that are pre-assembled, and tested to save labor costs and on-site assembly. At least one third-party manufacturer makes power panels that integrate with the FX series of inverters.

OutBack's newest product—the SmartRE—provides easy installation with a quality battery backup grid-tied system. The SmartRE incarnation of the GTFX includes two AC inputs—much like the Xantrex XW. The combination of grid and backup engine generator inputs make this a very flexible unit. All four of the SmartRE models are 48 V with 2.5 or 3 kW and either 120 V or 120/240 V versions.

Grid-Tied Battery-Backup Inverters

Company	Model	Power	Battery Voltage (VDC)	Surge Power[1]	Output Voltage (VAC)	Stacking	Multiple AC Inputs	Generator Control	Integrated Battery SOC Meter	Integrated Charge Control
OutBack Power www.outbackpower.com	GTFX2524	2.5 kVA	24	4.8 kVA	120	Up to 2	No	No	No	No
	GTFX3048	3.0 kVA	48	4.8 kVA	120	Up to 2	No	No	No	No
	GVFX3524	3.5 kVA	24	5.0 kVA	120	Up to 2	No	No	No	No
	GVFX3648	3.6 kVA	48	5.0 kVA	120	Up to 2	No	No	No	No
	SmartRE 2500-120	2.5 kVA	48	4.8 kVA	120	N/A	Yes	Yes	Yes	Yes
	SmartRE 2500-120/240	2.5 kVA	48	4.8 kVA	120 / 240	N/A	Yes	Yes	Yes	Yes
	SmartRE 3000-120	3.0 kVA	48	5.0 kVA	120	N/A	Yes	Yes	Yes	Yes
	SmartRE 3000-120/240	3.0 kVA	48	5.0 kVA	120 / 240	N/A	Yes	Yes	Yes	Yes
Schneider Electric www.schneider-electric.com	XW4024	4.0 kW	24	8.0 kW	120 / 240	Up to 3	Yes	Optional	LED display	No
	XW4548	4.5 kW	48	9.0 kW	120 / 240	Up to 3	Yes	Optional	LED display	No
	XW6048	6.0 kW	48	12.0 kW	120 / 240	Up to 3	Yes	Optional	LED display	No
SMA America www.sma-america.com	Sunny Island 5048US	5.0 kW	48	11.0 kW	120	Up to 4	No	Yes	Yes	Yes

[1] Surge duration: OutBack & SMA America: 5 seconds; Schneider Electric: 10 seconds.

Grid-Tied Inverters

Schneider Electric

The company has a long history of reliable products that were the foundation of battery-based RE equipment. Its grid-tied with battery backup inverter is the XW, replacing the old workhorse SW, which was one of the first grid-tied with battery backup inverters.

The XW is a sine-wave inverter that offers split-phase (120/240 AC) voltage output and a 200% surge capacity for 10 seconds. The company offers 24 V, 4 kW; 48 V, 4.5 kW; and 48 V, 6 kW models. Any of these models can be stacked with one or two other inverters of the same type to double or triple the output capabilities. All models can accept two AC inputs—the first AC input will typically be the grid; the second may be a backup engine generator. Adding a generator can minimize battery and PV costs, since you can design for fewer days of autonomy and a smaller charging source.

The XW can be purchased with a complete integrated AC/DC power distribution panel for up to three parallel inverters and four XW MPPT 60-150 PV charge controllers.

Courtesy Schneider Electric

A Schneider XW inverter and power distribution panel.

SMA America

SMA America's Sunny Island is an off-grid inverter that can function as a battery backup grid-tied inverter—but that's not all. It can be installed with the company's Sunny Boy batteryless grid-tied inverter, allowing the Sunny Boy to continue to produce power even while the grid is down.

One of the Sunny Island's outputs is wired into the same subpanel containing the grid-tied inverter's output and all of the backed-up loads. The other Sunny Island output backfeeds a breaker in the main load center. When the grid is present, the Sunny Island can charge the batteries while the grid-tied inverter "sells" power to the grid. If the grid goes down, the Sunny Island disconnects from the main load center and starts to invert battery power to the backup panel. The grid-tied inverter sees the AC, and the Sunny Boy acts as if the grid is still present, continuing to produce power. The Sunny Island prioritizes powering the backed-up loads with the grid-tied inverter's output first and will then supplement with inverted battery power if needed.

The Sunny Island output is 120 V, so if your backed-up loads need 240 V or the output of your Sunny Boy inverter is 240 V, you will need two Sunny Islands or an 120 to 240 V autotransformer between the Sunny Island and backed-up subpanel.

The Sunny Island system may not be the most cost-effective way to install a battery-backup grid-tied system—but it is the only product that is engineered to allow an existing grid-tied batteryless inverter system to add battery backup.

Courtesy SMA America

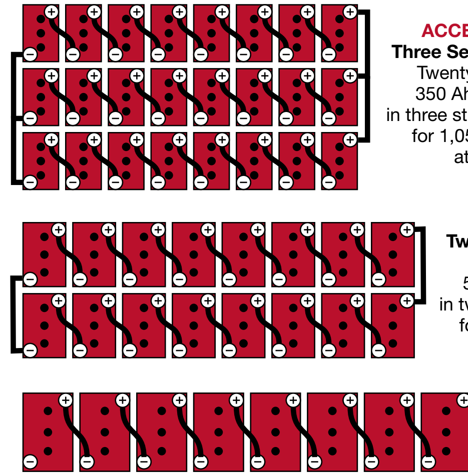
SMA America's Sunny Island inverter.

Flooded or Sealed Batteries?

Most batteries installed today are lead-acid batteries—either flooded or sealed. Flooded batteries are used extensively in off-grid situations, when frequent cycling is part of a battery's duty and maintenance is a given. To get maximum life from this type of battery, it's important to monitor electrolyte levels and state of charge, and run regular equalization charges.

Batteries in grid-tied systems will rarely cycle and require far less maintenance, so sealed lead-acid batteries can be a good fit. Compared to their flooded counterparts, there's also very little gassing, yet batteries should still be contained, kept out of living spaces, and have sufficient ventilation. Sealed batteries are more expensive, must not be overcharged, and have a shorter life expectancy, but their low maintenance and ability to handle the small number of cycles they will see in service still makes them an appropriate choice.

Battery String-Sizing Options



ACCEPTABLE
Three Series Strings:
Twenty-four 6 V,
350 Ah batteries
in three strings of eight,
for 1,050 Ah total
at 48 V

BETTER
Two Series Strings:
Sixteen 6 V,
500 Ah batteries
in two strings of eight,
for 1,000 Ah total
at 48 V

BEST
One Series String:
Eight 6 V,
1,000 Ah batteries,
for 1,000 Ah total
at 48 V

Batteries can only supply a limited amount of energy before they are depleted. Some deep-cycle batteries may be discharged up to 80% for about 2,000 cycles, or at 50% for about 4,000 cycles. A battery-based backup power system may undergo 10 cycles per year—often less. So sizing a battery based on an 80% deep discharge rate is appropriate for this type of infrequently cycled system. (For an off-grid home that cycles batteries often daily, a more conservative approach may be necessary.)

Once you know the desired days of autonomy, possible battery discharge level, and the energy requirements of your loads, you can size the battery. Start with the total Wh per day for backed-up loads and divide by 0.85 to correct for inverter loss (assumes an 85% efficient inverter). This results in DC Wh per day, which we will divide by our nominal battery voltage—usually 24 or 48 V (dictated by your inverter's nominal DC input). That computes the total DC amp-hours (Ah) per day. Divide this by 0.80 to account for the maximum DOD of 80% (i.e., to leave our battery 20% full after a day of discharge). Then multiply this total by your days of autonomy to get the adjusted DC Ah total.

Battery capacity in Ah is rated at several different discharge rates. For general sizing, use the Ah capacity at a 20-hour discharge rate; this is a realistic discharge rate for batteries in an RE system. Once a battery has been selected, divide your

The Trojan L16 is a classic flooded lead-acid battery used in renewable energy systems—420 Ah at 6 V.

This sealed gel-cell by FullRiver Battery requires less maintenance, but more delicate treatment than flooded batteries.

This 2 V flooded lead-acid battery by Surrette provides 1,766 Ah, giving high capacity with a single series string.

autonomy-adjusted DC Ah per day by the Ah capacity rating of your chosen battery to determine the number of parallel battery strings needed. If this number is greater than three, select a larger-capacity battery to promote a balanced charge across all strings. Each parallel string of batteries will contain as many individual cells as needed in series to reach your nominal battery voltage.

For example, assume that the backup load daily requirement is 8,000 Wh. First, correct for inverter loss by dividing by 0.85. This gives you 9,412 DC Wh per day. Dividing this by the nominal battery voltage of 48 equals 196 Ah per day. For an 80% depth of discharge, divide by 0.80, which equals 245 Ah per day. Multiply that by 4 days of autonomy (this home tends to be among the last reconnected to the grid after an outage) for a total of 980 Ah—the minimum size battery needed.

Eight 350 Ah, 6 V batteries in series yields 48 V at 350 Ah. Divide the 980 Ah total capacity by 350 Ah series battery capacity, which equals 2.8. Round up to 3 since batteries cannot be divided—the total bank (consisting of 24 batteries) will provide a capacity of 1,050 Ah. If the number of paralleled strings needed is greater than three, then source a higher-capacity battery as the basic building block.

Choosing a Charge Controller

A charge controller's main function is to keep the battery from being overcharged and potentially damaged. The two common styles of charge controllers used with these systems attain this goal differently. Either type can be used in battery backup grid-interactive systems.

Pulse-width-modulation (PWM) charge controllers regulate charging by adjusting the width and frequency of the full current pulses sent to the battery. The closer a battery is to full, the farther the pulses are apart, effectively lowering the charging current.

Maximum power point tracking (MPPT) charge controllers have several advantages. Their software algorithms can operate a PV array at its MPP over a wide range of operating conditions and at a voltage much higher than the battery voltage. This improvement increases power harvest by up to 30% (with greatest gains attained with cooler site temperatures) and allows longer distances or smaller wire sizes between the PV array and charge controller.

A charge controller should be sized to pass all the array's current to the battery. A 60 A controller charging a 12 V battery can only pass 750 watts but if configured to charge a 48 V battery, it can pass nearly 3,000 W. Oversizing the controller slightly can be beneficial since the controller will not have to work at the upper limits of its capabilities all the time and it can harvest any unexpected wattage that could come from extra irradiance or environmental conditions.

If the PV array is capable of producing more power than one charge controller can handle, consider upgrading to a larger-amperage controller, installing multiple controllers, or increasing the battery bank voltage to get more wattage out of each controller.

Both OutBack and Schneider Electric make MPPT charge controllers that integrate directly with their inverters. SMA America's AC coupling technology has built-in charge controlling.

BOS Components

Bypass breakers allow bypassing the inverter and battery-based system to power all loads directly via the grid. Most commonly, these are installed for inverter or other removal and repair. Bypass breakers are usually located in the battery/inverter power panel, and limited to 60 A or smaller.

A **battery meter** is critical to understanding a battery bank. Much like a fuel gauge in a car, a meter will report your battery's state of charge and help you determine the need for other charging sources or to conserve during an extended power outage. These meters are your window into your battery bank's world and commonly display the battery voltage, amperage in or out, and state of charge.

Schneider Electric's LinkLITE battery monitor.

Most systems include a **production meter** to measure the amount of energy produced by your renewable energy system. Incentive programs commonly require a utility-grade kWh meter. In a batteryless system, the production meter is installed between the inverter and the grid connection to measure all energy flowing between the inverter and the grid. But in a battery-based, grid-tied system, this would only measure the net difference between your system's renewable production and energy consumed by the backed-up loads.

To get a true reading of how much energy is being produced, a special kWh meter must be used. A "Form 12S" kWh meter measures both the grid input/sell circuit to the inverter, and the inverter to backed-up loads circuit. For 240 V systems, two of these meters are needed.

All electrically live parts are kept in **enclosures** of some type. The backed-up AC loads have their own panel; DC inputs or loads have another; and batteries are in their own enclosure. Batteries can discharge massive amounts of current if shorted—via a dropped wrench or other conductive materials—so their terminals must be protected. When charging to a high voltage batteries give off hydrogen gas, which must be vented outdoors to lower the risk of fire or explosion. The battery enclosure must be sealed but vented passively or mechanically from its high point. Incoming air should be introduced at the bottom of the enclosure, and wire conduit should also extend to the bottom.

Putting It All Together

A grid-tied with battery backup system is one of the most complicated RE systems to install—if you plan to hire a local installer, do your homework, and ask pointed questions about their related experience. The recent boom in PV installations has led to many new companies that have done *only* batteryless grid-tied work, which is much simpler and requires comparatively little design work. A North American Board of Certified Energy Practitioners (NABCEP) certification is good sign that the prospective installer has been tested on the basics of battery-based systems, but not a sure sign of an extensively experienced installer in that field.

Access

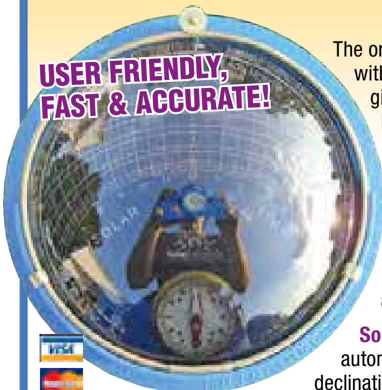
Flint Richter (flint@rockygrove.com) lives and writes off-grid in Arkansas' Boston Mountains. He is a partner and NABCEP-certified PV project manager with Rocky Grove Sun Company, and a contracted instructor for Solar Energy International. He is teaching his young daughters the difference between a solar module and a solar panel.

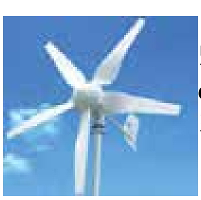
Battery Backup Inverter Manufacturers:

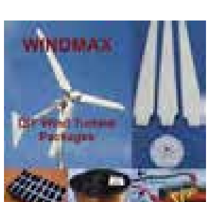
OutBack Power Systems • www.outbackpower.com

Schneider Electric • www.schneider-electric.com

SMA America • www.sma-america.com







the ev revolution

by Bradley Berman

Outrage over the environmental and economic devastation from the Gulf oil spill could represent a real turning point in long-term public attitudes about oil dependence.

Yet, the common knee-jerk response is to throw our hands into the air and say, "Yeah, but we have to drive—we have to get to work." That excuse is about to ring off the scale on the lame-o-meter, because a wave of mainstream cars that run on zero petroleum is about to hit the streets of California, Oregon, Washington, Arizona, Michigan, Texas, Tennessee, Greater New York and the D.C. area. Shortly after, EVs will arrive at dealerships across the country.

The electric car revolution is on: The Nissan LEAF and Chevy Volt are scheduled to debut later this year, and about two dozen more will arrive in the next few years.

Major car companies have had the technology to make practical and affordable electric cars for more than a century. Ever since hybrid gas-electric cars stormed on the scene a few years ago, green car buyers have been eager to take electric driving to the next stage. So, why has it taken so long for auto executives to get behind electric cars?

The complicated answer to that question was addressed in the 2006 documentary, *Who Killed the Electric Car?* On the eve of the re-birth of the electric car, I posed the same question to Chelsea Sexton, one of the key figures in the film. "Electric cars challenge the status quo on which auto executives have built their companies," Sexton said. "Aggressively committing to EVs is tantamount to acknowledging that these massive companies are not sustainable with what have always been their core products, and for some, comes uncomfortably close to saying 'maybe we were wrong.'"

Don't expect a mea culpa from Big Auto. Nonetheless, one by one, the biggest obstacles—some might say excuses—to the mass adoption of electric cars are fading away.

Propelled into the Limelight

Engineers are making steady advances in lithium-ion battery technology. These batteries provide all the necessary power, energy storage, and durability. The Chevy Volt and Nissan LEAF will come with warranties of 100,000 miles or eight years.

Worries about limited driving range also are being addressed. The next wave of plug-in cars will commonly offer a range of about 40 to 100 miles—more than needed by most Americans, who on average drive less than that each day. Moreover, car companies, municipalities, and other stakeholders are realizing that almost all electric car charging will happen at home—and can be accomplished overnight during electric grid "off-peak" hours.

In fact, according to Pacific Northwest National Labs, the current national grid has the capacity to accommodate up to 180 million plug-in cars, without a single new power plant, since most of the charging will occur off-peak.

Daytime public charging will be needed only in a pinch, but thanks to generous government grants, hundreds of thousands of public charging stations are scheduled to be built in the next five years, according to Pike Research, a Colorado-based clean-tech market research firm.

Consumers are clamoring for cleaner alternatives. The number of reservation deposits for the all-electric Nissan LEAF has blown away expectations. Three months after opening up its online ordering process, the number of pre-orders (with a $99 deposit) is approaching 25,000, essentially selling out the car months before the first U.S. LEAF owner takes possession of keys.

It's likely that demand will exceed supply for some time. And that's before early adopters report their experiences—and share the best-kept secret about electric cars: their low centers of gravity and linear acceleration makes them fast and fun to drive.

Nissan LEAF

There's a reason that Nissan is calling its new electric car "the world's first affordable, zero-emission car." The Nissan LEAF is priced at $32,780, minus a $7,500 federal tax credit and generous state-based incentives, such as California's $5,000 rebate toward the purchase of zero-emissions vehicles. That puts the LEAF just above $20,000—right in the sweet spot of mainstream buyers.

The LEAF is an all-electric, compact-sized hatchback that seats five adults and has a range of about 100 miles—and a top speed of 90 miles per hour. Its V-shaped design features long, slanted LED headlights and rounded, downward curves in the back. The prominent protruding headlights are designed to split and redirect airflow away from the door mirrors, thus reducing wind noise and drag. The shape says high-tech and aerodynamic, but with a sharpness that the Toyota Prius never had.

Despite its designation as a compact car, seating and headroom accommodates passengers who are 6'4", maybe even taller. The lithium-ion battery pack is tucked away under the cabin.

Like all of the upcoming electric cars, the Nissan LEAF comes standard with a system that connects to a global data center, to supply all kinds of info and entertainment to the dashboard—most critically maps showing the locations for nearby charging stations.

The initial rollout of the Nissan LEAF is limited to California, Oregon, Washington, Arizona, and Tennessee. Nissan filled its first-year reservation list only a few weeks after registration opened in May 2010. So, unless you've already submitted the $99 deposit, don't expect to take delivery on one until 2011. But don't lose heart. Nissan not only plans to dramatically increase production of the Nissan LEAF, but it also plans to release three more electric cars in the next few years.

Make: Nissan
Model: LEAF
Web site: www.nissanusa.com/leaf-electric-car
No. of passengers: 5
Battery size: 24 kWh
Range: 100 miles
Max. speed: 90 mph
MSRP: $32,780
Availability: December 2010

Make: Chevrolet
Model: Volt
Web site: www.chevrolet.com/pages/open/default/future/volt.do
No. of passengers: 4
Battery size: 16 kWh
Range: 40 miles all-electric, plus 300 miles per tank of gas
Max. speed: 100 mph
MSRP: $41,000
Availability: December 2010

Chevrolet Volt

General Motors calls the Chevy Volt an "extended-range electric vehicle," underlining this "hybrid's" crucial point of separation from pure electric cars like the LEAF, and from conventional hybrids like the Toyota Prius. The Volt operates entirely as an electric car for its first 40 miles after a full charge. It burns no gasoline during those miles, drawing energy from a 400-pound, 16 kWh lithium ion battery pack.

But a 40-mile range isn't enough to make a car practical, so the Volt also carries a 1.4-liter gas-powered engine that drives a generator—not the wheels—to charge the battery enough to give another 300 miles of range. And that only happens once the battery is exhausted to about 8 kWh of capacity.

When the Volt concept car was unveiled in 2007, it had a muscular, Camaro-like appearance. Since then, GM engineers have modified the car's shape for greater aerodynamics—resulting in something more similar to the new Chevy Malibu or Cruze. One important factor: The main column of Volt's T-shaped battery pack runs down through the center of the cabin's floorboard, limiting seating to four passengers.

GM continues to report that production Volts are on schedule, going on sale in November 2010. In late July, GM announced that the Volt will sell for $41,000, or lease for $350 a month for 36 months with a $2,500 down payment. Like other electric-drive cars that carry at least a 16 kWh battery, the Volt will receive a federal consumer tax credit of $7,500. Early availability will be limited to California; Michigan; Austin, Texas; New York City; and Washington, D.C.—with widening availability to follow in 2011.

Ford Focus Electric

Ford's plans for an electric version of its Focus compact are not aimed at buzz and sizzle. Instead, the company is focused on addressing the biggest obstacle between EVs and the mainstream: cost.

The Ford Focus Electric will be based on the next-generation Ford Focus, a capable if not head-turning car. By choosing an existing platform—not only for its pure electric cars, but also for its hybrids—Ford will save the expense associated with developing a unique design. Ford is gambling that the cool factor lies in the technology and price, not in the car's name or the shape of the sheet metal. It's hard to know if the strategy makes sense until pricing is announced—but trimming the cost should give Ford the ability to aim for affordability and long-term profitability.

The Focus Electric is targeted to have a range of 100 miles between charges, courtesy of a 23 kWh lithium-ion battery pack. The car will use a single-speed transmission. The power train, including the motor and gearbox, are packaged under the hood where you would expect to see a gasoline engine.

The Ford Focus Electric is due in 2011. In the meanwhile—timed for late 2011—the company will offer to fleet and a few individual buyers an all-electric version of its popular small delivery truck, the Transit Connect. That vehicle, ideally suited for use by small companies, will use a 55 kW electric drivetrain system and a 600-pound, 28 kWh lithium ion battery pack. The vehicle has a 75 mph top speed and can drive up to 80 miles on a charge—perfectly fine for the needs of a local delivery cycle.

Make: Ford
Model: Focus Electric
Web site: www.thefordstory.com/green/
No. of passengers: 5
Battery size: 23 kWh
Range: 100 miles
Max. speed: 85 mph
MSRP: Approx. $30,000
Availability: 2011

CODA

Coda Automotive's all-electric sedan, due late this year or in early 2011, is the underdog in the race for an affordable, mass-market pure electric car. As a new start-up company, Coda doesn't have the financial and marketing resources that Nissan and General Motors are putting behind the LEAF and Volt. (Unlike Tesla or plug-in hybrid-maker Fisker Automotive, Coda hasn't received big government loans.) So Coda is planning an innovative approach to sales and service—and a multinational production process. The vehicle's body will be assembled in China at a leased plant. The partially built car will be shipped to California for final assembly. Battery packs will be built in the United States, probably in Ohio.

The all-electric Coda sedan, with a range of about 100 miles, is expected to sell for around $40,000—although pricing has not been announced. The Coda sedan has a five-passenger chassis with a fairly nondescript design—although it was created by Pininfarina, the famed Italian car design firm.

The company will have a store in Los Angeles County, California, plus seven other locations across the state where customers can go for test drives. Each model will be built to order, so new purchasers can expect their vehicles to be delivered within eight weeks after they've been ordered. Ordering is expected to start before the end of 2010. Coda will contract to have technicians trained to do warranty work at 75 Firestone retail locations.

Make: Coda
Model: Sedan
Web site: www.codaautomotive.com
No. of passengers: 5
Battery size: 37 kWh
Range: 100 miles
Max. speed: 80 mph
MSRP: Approx. $40,000
Availability: 2011

Mitsubishi i-MiEV

The i-MiEV is the smallest electric car coming to market. Think of those cute Smart cars—but seating four instead of two. Although its size will be an issue for some drivers, it is a fully capable subcompact that can carry four adults—even if the ride is less than spacious.

The i-MiEV has been offered in Japan since 2009, and Mitsubishi has scheduled introducing the car in the United States for 2011. Before coming to America, the company will probably widen the track by 3 or 4 inches for stability at higher speeds. The maximum speed is around 80 miles per hour, and a driving range of about 75 miles.

Price is still up in the air—although the LEAF's price tag is putting pressure on Mitsubishi. In June, it was reported that the company could bring the price down to about $30,000, not including incentives.

Make: Mitsubishi
Model: i-MiEV
Web site: www.mitsubishi-motors.com/special/ev
No. of passengers: 4
Battery size: 16 kWh
Range: 75 miles
Max. speed: 80 mph
MSRP: Approximately $30,000
Availability: 2011

Other EVs on the Horizon

Make: smart
Model: ED (Electric Drive)
Web site: www.smartusa.com/electricdrive
No. of passengers: 2
Battery size: 16.5 kWh
Range: 80 miles
Max. speed: 62 mph
MSRP: TBD
Availability: 2012

smart ED

The electric version of the smart fortwo—with a top speed of 60 mph—is unlikely to shake the car's reputation for being underpowered. However, early reviews indicate that the smooth electric drive is a marked improvement compared to the gas-powered version's choppy feel. The lack of size, range, and oomph feeds into the perception of electric cars as glorified golf carts. Smart is promising a United States release by 2012.

Tesla Roadster & Model S

The two-seat Tesla Roadster, on sale since 2008, is credited with making electric cars fun and sexy. The Roadster is adapted from components of the Lotus Elise, and will do 0 to 60 mph in 3.9 seconds, besting cars that cost twice its $109,000 sticker price. The Roadster's audacious acceleration comes from a 185 kW (248 hp) electric motor powered by a 53 kWh Li-ion battery pack that provides 200 or so miles of range. Tesla has sold about 1,200 Roadsters—but production is slowing down as the company prepares to release its Model S in 2012 or 2013. The Maserati-looking four-door Model S is expected to sell for about $58,000, and offer a range of 150 or 300 miles, depending on which battery pack is selected.

Make: Tesla
Model: Model S
Web site: www.teslamotors.com
No. of passengers: 7 (two small seats for kids in back)
Battery size: 80 kWh (two battery packs will be avail.)
Range: 150 miles
Max. speed: 120 mph
MSRP: $57,400
Availability: 2012

BYD e6

According to China's BYD, the e6 can accelerate from 0 to 60 mph in 14 seconds, has a top speed of 100 mph, and has a range of 250 miles on a single charge. Compared to other electric cars from major auto manufacturers, these claims sound exaggerated. However, BYD is backed by billionaire investor Warren Buffett, giving it a bit of street cred. A wagon, the e6 could be among the most practical of EV offerings. But product delays, unproven vehicle quality, and tough economics have raised doubts about BYD's ability to deliver.

Make: BYD
Model: e6
Web site: www.byd.com/showroom.php?car=e6
No. of passengers: 5
Battery size: TBD
Range: 200 miles
Max. speed: 100 mph
MSRP: TBD
Availability: 2011

Volvo C30 Electric

The stats for the all-electric sedan may seem unimpressive: a range of about 90 miles, acceleration from 0 to 60 mph in 11 seconds, a top speed of about 80 miles per hour, and a leisurely eight hours to recharge the 24 kWh battery pack from 220-volt household service. But when it comes to performance and safety, Volvo is testing its plug-in prototypes perhaps harder and longer than anybody in the industry, and has indicated a long-term commitment to producing electric models.

Make: Volvo
Model: C30 Electric
No. of passengers: 4
Battery size: 24 kWh
Range: 90 miles
Max. speed: 80 mph
MSRP: TBD
Availability: TBD

Think City

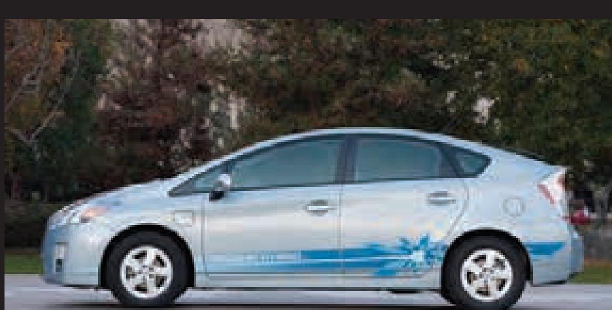
Rescued from the brink of bankruptcy, Think (formerly owned by Ford) re-emerged in late 2009 in Europe. With those in place, the company moved production of the plastic-bodied, two-seat microcar, capable of about 68 mph and 120 miles of range, to a manufacturing facility in Finland. The company is aiming for annual production of 5,000 units.

Make: Think
Model: City
Web site: www.thinkev.com
No. of passengers: 2
Battery size: 24 kWh
Range: 120 miles
Max. speed: 65 mph
MSRP: $22,000
Availability: 2012

Toyota FT-EV & Plug-in Prius

In 2009, Toyota hinted that it might offer an all-electric commuter vehicle in the next few years. It could take the shape of Toyota's FT-EV concept, which shares its platform with the company's new minicar, the Toyota iQ—sold as a Scion in the United States. The FT-EV on display at the 2009 Detroit Auto Show promised a driving range of 50 miles. Don't hold your breath for this mini-EV, but the company is planning to introduce the Toyota Prius Plug-in Hybrid—which will provide about 12 miles of all-electric driving before returning to the Prius's standard hybrid mode. That's expected in 2012.

Make: Toyota
Model: FT-EV
Web site: www.toyota.com/concept-vehicles/ftev.html
No. of passengers: 4
Battery size: TBD
Range: 60 miles
Max. speed: 70 mph
MSRP: TBD
Availability: 2012



Make: Toyota
Model: Prius Plug-in Hybrid
Web site: www.toyota.com/esq/articles/2010/Prius_Plug_In_Demo_Program.html
No. of passengers: 5
Battery size: TBD
Range: 12.5 miles in all-electric
Max. speed: 62 mph in all-electric (Conventional Prius has max. speed of 112 mph)
MSRP: TBD
Availability: 2012

Volkswagen EVs

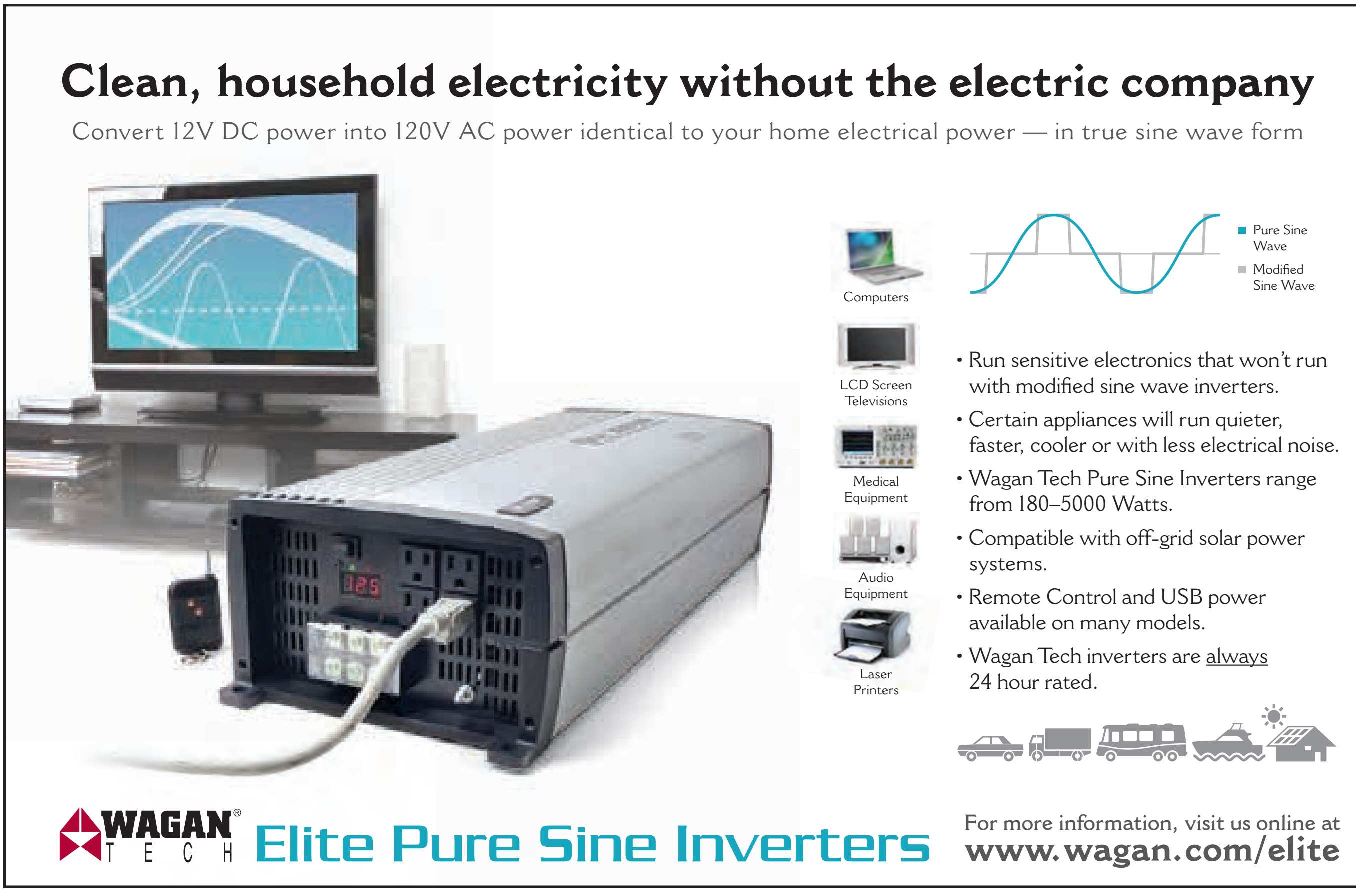
For a number of years, Volkswagen has been displaying its e-Up! concept, including an all-electric version of the 10.5-foot minicar that seats four—three in front and one in back. The e-Up! weighs about 2,400 pounds—with more than 500 pounds coming from the 18 kWh battery pack that can deliver about 80 miles of range. However, it appears that Volkswagen has shifted gears and instead will make the Golf Blue-E-motion its first electric car—by 2012 or 2013. The Golf's lithium-ion battery pack will have a range of about 90 miles, capable of delivering 0 to 62 mph acceleration in 11.8 seconds, with a top speed of about 87 mph.

Make: Volkswagen
Model: Golf e-Motion
Web site: TBD
No. of passengers: 5
Battery size: 26.5 kWh
Range: 90 miles
Max. speed: 85 mph
MSRP: TBD
Availability: 2013

Make: Volkswagen
Model: e-Up!
Web site: TBD
No. of passengers: 4
Battery size: 18 kWh
Range: 80 miles
Max. speed: 85 mph
MSRP: TBD
Availability: 2013

Access

Bradley Berman is the editor of PluginCars.com and HybridCars.com. He writes about alternative cars for *The New York Times*, *Detroit Free Press*, Reuters and other publications. Mr. Berman is a tireless researcher of the green car market. He speaks directly to industry insiders and participates as a panelist at numerous professional conferences.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LCD Screen Televisions
Medical Equipment
Audio Equipment
Laser Printers
Pure Sine Wave
Modified Sine Wave
• Run sensitive electronics that won't run with modified sine wave inverters.
• Certain appliances will run quieter, faster, cooler or with less electrical noise.
• Wagan Tech Pure Sine Inverters range from 180–5000 Watts.
• Compatible with off-grid solar power systems.
• Remote Control and USB power available on many models.
• Wagan Tech inverters are always 24 hour rated.
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KEEPING TABS ON YOUR PV SYSTEM

by Michael Brown

Until recently, consumers had few choices to help them keep tabs on their grid-tied PV systems. Most PV monitoring products were inverter-specific data loggers, which uploaded data to the manufacturer's Web portal. Homeowners had access to raw data—inverter energy production, simple alerts, and approximations of the CO_2 saved—but little more.

Now, monitoring products are providing deeper insight into PV performance and beyond—including whole-house energy management via energy generation and consumption monitoring. Newer monitoring systems can tell you how much money is saved on electric bills; report on whole building, branch circuit, and individual loads; and illustrate the effects of energy conservation steps taken.

The value of solar energy and energy conservation is best shown if their daily effects can be readily monitored. According to a February 2009 study by the Electric Power Research Institute, residential electricity usage feedback tools—such as monitoring devices—are effective at encouraging conservation. The study showed that using monitoring systems resulted in up to an 18% reduction in energy use, and that more direct, detailed information leads to higher levels of conservation. Being able to examine data can yield enough savings for the monitoring equipment to pay for itself—and more—over the life of the home.

"The future of residential PV in the United States is dramatically improving—playing a bigger role in the energy mix," says James Bickford of Tigo Energy, manufacturer of the Module Maximizer and its monitoring software. "The monitoring component will be a critical piece, allowing for control and management of distributed power sources and integration with the utilities."

There are many inverter and whole-house monitoring devices on the market—this article discusses hardware and software solutions that support monitoring of solar generation for residential systems.

The Pitfalls of Data Communication

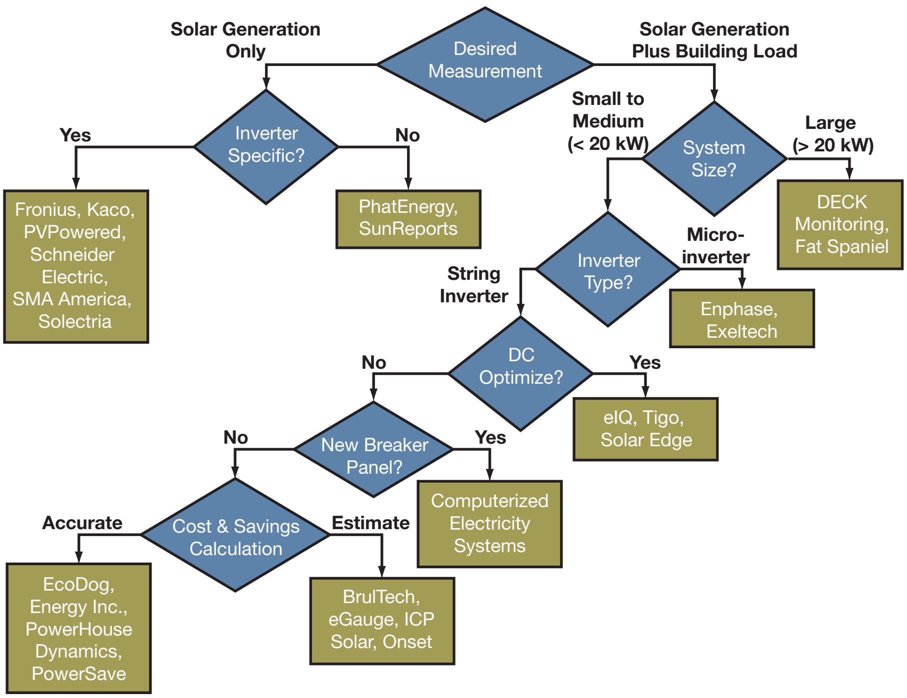
A big part of monitoring is getting the data where it needs to go. We can break data transfer into two parts of the communications process: from the solar equipment to the data logger, and from the data logger to the Internet.

A cable is the simplest means of getting the data from the solar equipment to the data logger—but running cables can be difficult or impossible due to the paths across land, in trenches, through walls, and in attics. This has driven the industry to introduce radio technologies such as wireless computer networking (WiFi); power line communications (PLC), which modulate data over AC lines; and radio technologies such as ZigBee, a wireless home area networks (WHAN) standard. These technologies have their own issues with distance, obstructions, and interference.

Moving the data from the logger to the Internet normally involves connecting with the homeowner's always-on Internet service, which is typically cable modem, DSL, or fiber optic network. Cat5 cables or WiFi are common but also share the above issues. Cellular routers allow for an upload strategy that's independent of the homeowner's service, but they can pose a significant one-time cost of about $200, as well as ongoing monthly data service fees. The cellular industry has recently recognized the need for residential data service and more affordable service plans are available, from $10 to $40 a month.

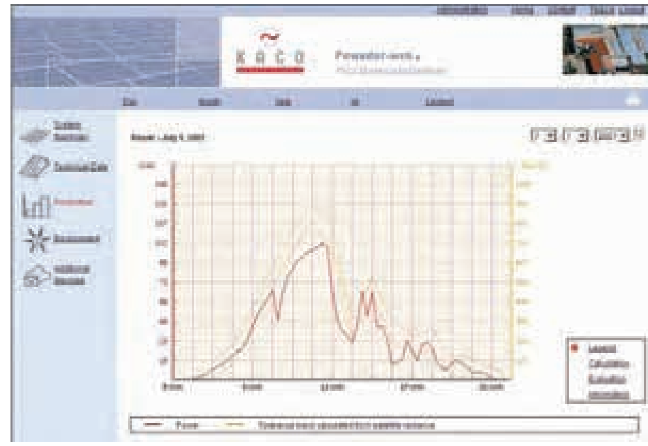
Careful review of the data communications requirements of the products, and assessing your situation, should lead to successful monitoring. Most products offer several options, so you'll need to research which data communication solution is best for your needs.

Choosing a Monitoring System

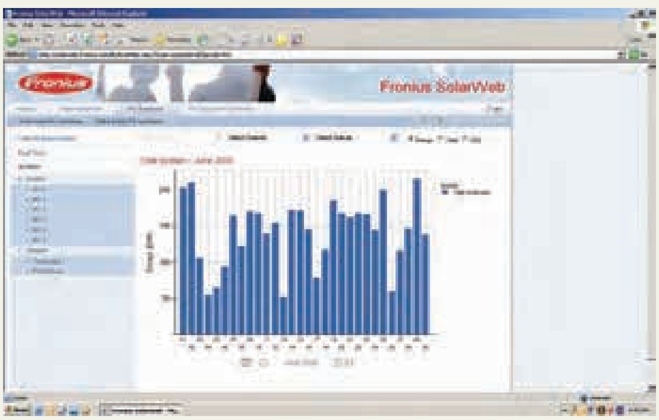


Inverter-Tied Monitoring

Manufacturers of residential-sized inverters provide proprietary, basic monitoring equipment. There is little compatibility *between* different manufacturers' systems, but there is movement to standardize cables, wireless communications, and data protocols. Most inverter-paired monitoring systems offer data loggers that upload to the manufacturer's Web site, and some offer wireless displays that communicate over radio, such as Bluetooth. With wireless options, carefully evaluate the distances and obstacles to ensure a strong signal. Manufacturers' data monitoring systems include:



Kaco's watchDOG card's Ethernet port provides system data monitoring. This data drives both the blueplanet Web portal and the customizable inSIGHT wireless Internet, which displays system data via an RSS data feed—an online format used for delivering regularly updated content. Their proLOG device adds PC monitoring of multiple inverters, along with alarms and weather station sensors.



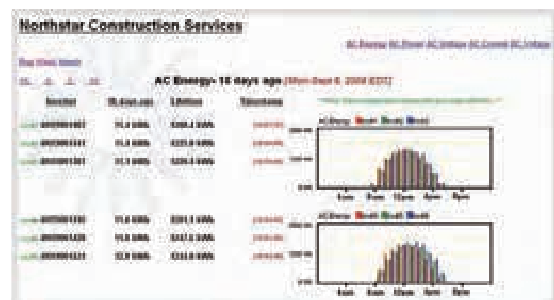
Fronius offers local PC data logging, analysis, and display; a weather station with multiple environmental sensors; and a wireless Personal Display. Data can be uploaded to their Solar.web site through a communications card and Data Logger Web device, which can be integrated with the Crestron home automation system. The wireless Personal Display uses a rechargable battery that must be recharged and replaced periodically, or plugged into an AC outlet (becoming a small phantom load).

PVPowered's PVM1010 module collects and uploads data to its www.mypvpower.com Web portal. Some inverter-independent monitoring systems, such as DECK monitoring, can connect to the PVM1010, and read the production and status data produced by the inverter. "The PVM1010 provides remote visibility to stakeholders in a system, enabling inverter system reports on system health, assisting the installer and manufacturer to provide a higher level of support," says Erick Petersen, vice president of sales and marketing at PVPowered.

Schneider Electric's RS-232 port provides for direct connection to a PC, and there are several third-party applications to collect and display the information. They also offer the GT Solar Inverter Monitor, which is wired to the inverter and is basically a remote version of the inverter faceplate meter. Slightly enhanced, it can show combined and separate information for up to five inverters. Their wireless gateway display can feed their Yahoo! widget via Ethernet or WiFi, but there is no Internet access to inverter data. Third party apps give you access to the raw data. I have a Schneider system and have built my own open-source solar monitoring application for it (mike-land.com/Solar_Power/solar_power.html).

Schneider Electric's wireless gateway display.

The SolrenView gateway routes inverter data to the company's Web site.



Solectria offers sophisticated monitoring options, with subarray monitoring, revenue-grade (+/-0.2% or 0.5% accuracy, depending on the meter) power readings, and delivery of data to state agencies for monthly rebate-check calculation. Inverters are wired to the gateway, which uploads data to the SolrenView Web site. Building energy consumption monitoring and weather stations are optional add-ons.

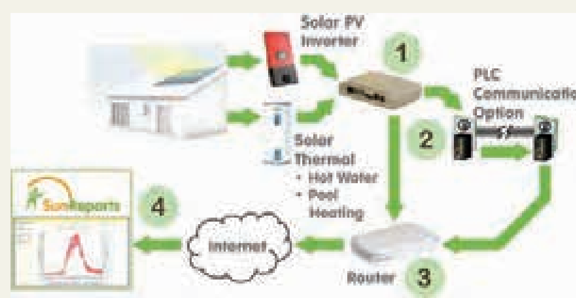
Inverter-Tied Monitoring

Company	Product Name	Consumption Tracking	Modbus Devices	Weather Station
Fronius • www.fronius.com	Personal Display, Solar.Web	N	N	Y
Kaco • www.kaco-newenergy.com	blueplanet (inverter); inSIGHT, proLOG, watchDOG (monitoring)	N	N	Y
PHAT Energy • www.phatenergy.com	PHATlogger	N	N	Y, with Heliodyne
PVPowered • www.pvpowered.com	PVM1010, mypvpower.com	N	Y	Y
Schneider Electric • www.schneider-electric.com	GT Solar Inverter Monitor, Gateway	N	N	Y
SMA America • www.sma-america.com	Sunny Web Box, Sunny Beam	N	N	Y
Solectria • www.solren.com	SolrenView, Gateway	Y	Y	Y
SunReports www.sunreports.com	Apollo1	N	Y, SHW, heat pumps, wind	N

SMA America's Sunny WebBox collects and uploads data to the Sunny Portal Web site through a wired piggyback card installed in each inverter. Weather station sensors can be added to the Sunny WebBox. The company has recently re-engineered and reintroduced the Sunny Beam wireless device, switching from cordless-phone radio technology to a Bluetooth card in each inverter to improve the integrity of the signal. But I have found distance limitations on the signal strength when walls or ceilings are between the inverter and the Sunny Beam. An integrated solar cell can keep the monitor's battery charged.

The Sunny Beam Bluetooth-connected wireless display.

SunReports is unique in this list, as it is an independent company, but it collects solar production data through a direct connection to SMA America, Kaco, Fronius, or PVPowered inverters. This avoids the hassle of installing alternating current transformers (CTs) into the breaker panel as required by most inverter-independent monitoring products (see "Inverter Independent Monitor" section). Its product can also monitor solar hot water systems. Data is collected by the Apollo1 unit and sent via Ethernet to the customer's router. It can compare actual power generation against PVWatts or other software energy predictions.



Data Path to Internet	Accurate Financial Tracking	PC Display	Wireless Display	Web Site Display	iPhone App	Home Automation	Cost
Cat5 inverter to Data Logger Web, Cat5 to router	N	Y	Y	Y	N	Y	$300–800
Cat5 cable from watchDog to router	N	Y	Y	Y	N	N	watchDog $495; blueplanet from $2,150; inSIGHT from $195; proLOG from $975
WiFi to router	N	N	N	Y	Soon	N	$400–600
Cat5 cable from PVM1010 to router	N	N	N	mypvpower Web site	N	Y	$399
Cat5 or WiFi from Gateway to router	N	3rd Party	Y	Yahoo! widget	N	N	GT Solar Inverter Monitor $300; Gateway $650
Piggyback card RS-485 to Web Box, Cat5 to router	N	Y	Y	Y	N	N	$300–600
RS-485 from inverter to Gateway, Cat5 to router	N	N	N	Y	N	N	From $450
Wired to source, Cat5 &/or PLC Apollo1 to router	N	N	N	Y	N	N	$799

Inverter-Independent Monitoring

Several monitoring solutions are inverter-independent. The basic technology is to use CTs in the homeowner's circuit breaker panel to obtain data. One pair of CTs (for 240 V utility service) monitors the conductors from the inverter to a double-pole breaker to keep track of the home's PV generation. Another pair reads the conductors from the utility meter to the main breaker to track net building load—the amount of energy that comes from the utility. More CTs can be used to monitor individual 120 V branch circuits for appliances or other loads, or in pairs for 240 V branch circuits, such as for air conditioners. With an array of CTs installed in the circuit breaker panel, the raw data can reflect a home's full energy profile.

While this level of monitoring is powerful, installing CTs into a breaker panel presents some issues. First is jurisdiction approval and adherence to *National Electrical Code* standards. One issue is tapping into a branch circuit breaker—this enables the device to measure voltage and calculate power. Since this creates a small branch circuit inside the breaker panel, *NEC* Section 210.19 can apply. Some authorities also insist that the complete assembly of breaker panel and monitoring unit be UL-listed—an impossibility. UL Standard 1244 and 916 govern electrical monitoring devices, and vendors can choose to test and certify against one or both of these. Some permitting offices may be unfamiliar with this technology, so you may have to educate the staff on UL listing and *NEC* requirements that apply.

The second issue is physical space. CTs and the other equipment take up room in the typically already-crowded breaker panel. Locating additional equipment may necessitate mounting a suitable enclosure to the side of the breaker panel.

The third issue is data communication. Most CT-based systems transmit their data using PLC over the home's power lines to a data logger. Signal integrity can be compromised by branch circuit length and "noisy" devices near the logger, such as computers, home electronics, or motorized appliances such as refrigerators, blenders, and air conditioning compressors—anything that causes radio frequency interference (RFI). Despite the challenges, most CT-based systems have few problems.

Independent Options

Given the many options, how can you determine the best choice for your system? One differentiating factor is the device's ability to either estimate the savings and costs of PV generation and building consumption, or to accurately calculate it given the homeowner's utility rate schedule. Estimation based on a single approximate energy cost per kWh offers only a rough view of system performance, while accurate calculations allow the homeowner to do real analysis of generation and conservation effects on their actual utility charges.

Inverter-Independent Monitoring

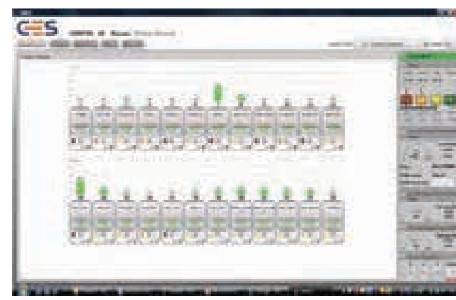
Company	Product	Consumption Tracking	Thermal Tracking	In Breaker Panel	Inverter-Direct	Modbus Devices
Also Energy • www.alsoenergy.com	PowerTrack, PowerLobby	Y, Net & branch circuit	Y	Y	SMA, Modbus	Y
BrulTech • www.etherbee.com	ECM-1240	Y, Net & branch circuit	N	Y	N	N
Computerized Electricity Systems • www.c-e-systems.com	Smart Distribution Panel	Y, Net & branch circuit	N	Replaces panel	N	N
DECK Monitoring • www.deckmonitoring.com	Residential Core Package	Y, Net & branch circuit	Y	Y	SMA, PVPowered	Y
EcoDog Inc. • www.ecodoginc.com	FIDO	Y, 16 branch circuits, max. 64 boxes × 16 CTs	Y	Y	N	N
eGauge • www.egauge.net	eGauge	Y (1), Net (2) & up to 9 branch circuits	N	Y	N	N
Energy Inc. • www.theenergydetective.com	TED 5000	Y	N	Y	N	N
Fat Spaniel • www.fatspaniel.com	Solar Splash	Y	Y	Y	Y	Y
ICP Solar • www.icpsolar.com	GreenMeter	Y, 4 AC circuits	N	Y	N	N
Onset • www.onsetcomp.com	HOBO	Y	Y	Y	N	N
PowerHouse Dynamics • www.powerhousedynamics.com	eMonitor	Y, Net & 100 branch circuits; plus appliance transmitters	Y	Y	N	N
PowerSave • www.currentcost.net	ENVI	Y, Net & 9 branch circuits, plus appliance transmitters	N	Y	N	N

Also Energy's PowerTrack device monitors solar-electric generation; whole-house and branch-circuit demand; and solar thermal systems; with accurate energy cost calculations (see "Independent Options" sidebar). It offers three models of weather station and can connect to SMA America inverters and any Modbus RS-485-compatible inverter (see below) and meter. The PowerLobby device is an option for performance display on a kiosk.

Modbus is an industrial-control data protocol that has been adopted by many commercial solar-monitoring devices, such as AC meters, weather stations, inverters (for status codes and power readings), and DC string current monitoring devices. RS-485 is a serial cable wire similar to the common RS-232 computer standard, but allows for up to 32 devices on a cable up to 4,000 feet long.

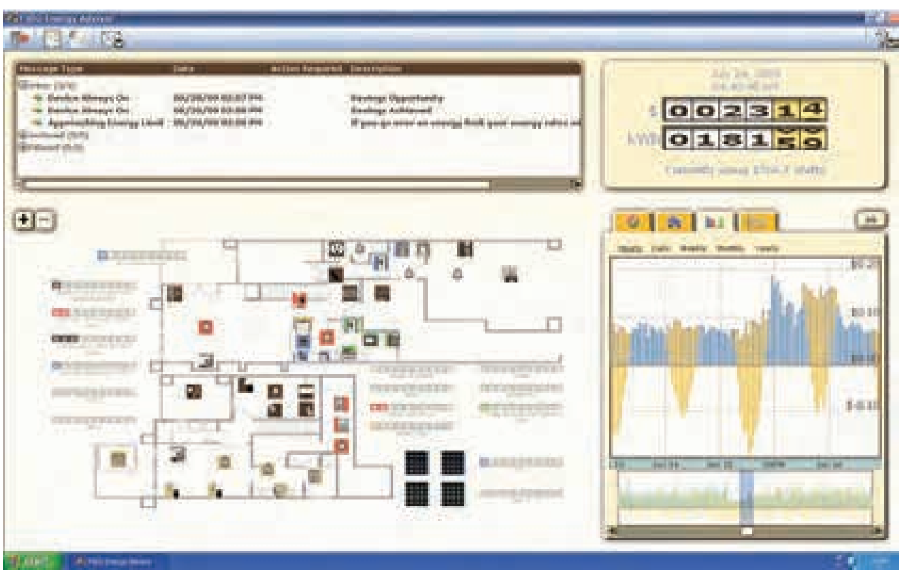
Brultech Research's ECM-1240 collects and displays solar-electric generation values, and whole-house and branch-circuit demand numbers for net-usage reporting. It offers several communication options using the EngineP software to connect to a local PC, Web site, and Google's PowerMeter.

Computerized Electricity Systems (CES) is unique in the market—its Smart Distribution Panel is an entire circuit breaker panel with built-in monitoring and automated switching/load balancing of 24 branch circuits. In addition to solar-electric system monitoring, it can integrate with wind and engine generators, smart meters, and smart appliances. CES offers a wireless display and a number of communication options to upload data to the Web site. The device also can communicate with home automation systems via its ZigBee interface.



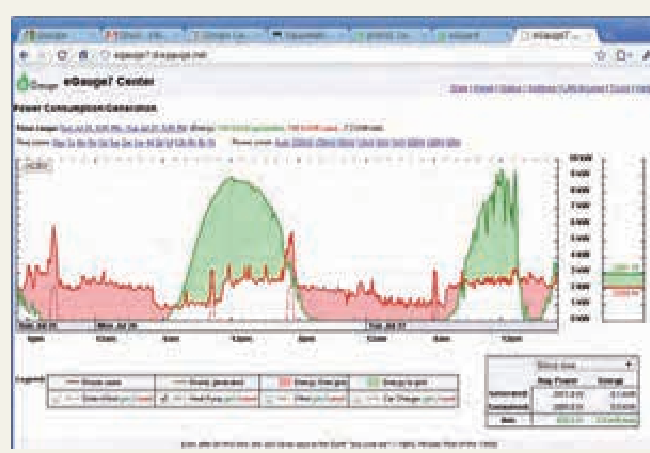
Weather Station	Data Path	Accurate Financial Tracking	PC Display	Wireless Display	Web Site Display	iPhone App	Home Auto-mation	Cost
Y	Cat5 to router	Y	N	N	Y	N	N	$300–2,000
N	RS-232 or ZigBee–Gateway to PC or Cat5 adaptors to router	N	Y	N	Y & Google PowerMeter	N	Y	
N	Cat5, WiFi, ZigBee, PLC, GPRS options	Y	N	Y	Y	N	Y	$1,500–3,000
Y	Cat5 to router	Y	Y	N	Y	N	N	$700–2,000
N	PLC, serial/USB port to PC	Y	Y	N	N	N	N	$1,000–1,700
N	PLC to HomePlug gateway	N	N	N, Archos tablet	Y, & Google PowerMeter	N	N	$550–950
N	PLC to Gateway, Cat5 to router	Y	Y	Y	Y	Y	Y	$200–400
Y	Cat5 to router, cell modem, satellite	Y	N	N	Y	3rd Party	Y	Installer sets price
Y	Cat5 to router	N	N	Y	Y	N	N	$499.95; weather sensors approx. $100 ea.
Y	Wired sensors to U30, Cat5 to router, WiFi or cellular	N	Y	N	Y	N	Y	Starting at $675
N	WiFi to router	Y	N	N	Y	Y	Y	Starting at $689
N	Wireless to Web Bridge, USB to PC, Cat5 to router	Y	Y	Y	Google PowerMeter	N	N	$129–200

DECK MONITORING'S Residential Core Package is at the high end of residential monitoring. It offers revenue-grade meters, with PV generation, and whole-house and branch-circuit demand monitoring. It also directly connects to SMA America and PVPowered inverters, and any on-site Modbus devices. Accurate energy calculations, weather station sensors, and a Web interface round out the monitoring needs of large residential systems (20 kW and up).



ECODOG'S FIDO system monitors energy generation and a nearly unlimited number of branch circuits for room-by-room monitoring of a building's energy consumption. Data is collected via PLC and displayed only on a local PC. The system generates recommendations for energy savings based on consumption patterns.

EGAUGE offers a low-cost solution for PV generation monitoring, with net and branch-circuit demand monitoring on up to 12 input channels. Data is sent over PLC to the homeowner's router. The company is working on a half-height enclosure for easier installation in the breaker panel. The device has a built-in Web server for local access, which displays the same highly detailed charts as the eGauge Web site to track energy generation and consumption. It also syncs with the Google PowerMeter Web site.



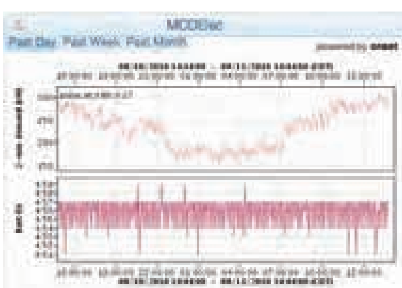
The Energy Detective reports real-time energy use.

ENERGY INC. offers The Energy Detective (TED) 5000 that can monitor solar or wind generation, and whole-house or branch-circuit consumption. It can handle accurate utility energy calculations, displayed on a small wireless device, a local PC, the TED Web site, or the Google PowerMeter Web site. Several iPhone apps are available from third-party developers to sync with TED, allowing homeowners to keep tabs on their home from their phone.

FAT SPANIEL offers solar monitoring for small home systems to multi-megawatt systems. For the residential market, its Solar Splash offers inverter-direct connections to most inverters on the market, revenue-grade power meters for generation and consumption, weather stations, accurate energy calculations, and a custom iPhone app. The company recently exited the monitoring hardware market and has built a network of compatible hardware suppliers across the industry.

ICP Solar's wall-mounted energy logger and display.

ICP SOLAR'S GreenMeter offers monitoring on up to four DC and four AC circuits, handling multiple solar and wind, inverter, and branch circuits. It offers a weather station and a wall-mounted LCD display. The meter can also keep track of battery state of charge, such as amp-hours and amp-hours remaining. It also calculates greenhouse gas savings, cost savings, and revenue generation.

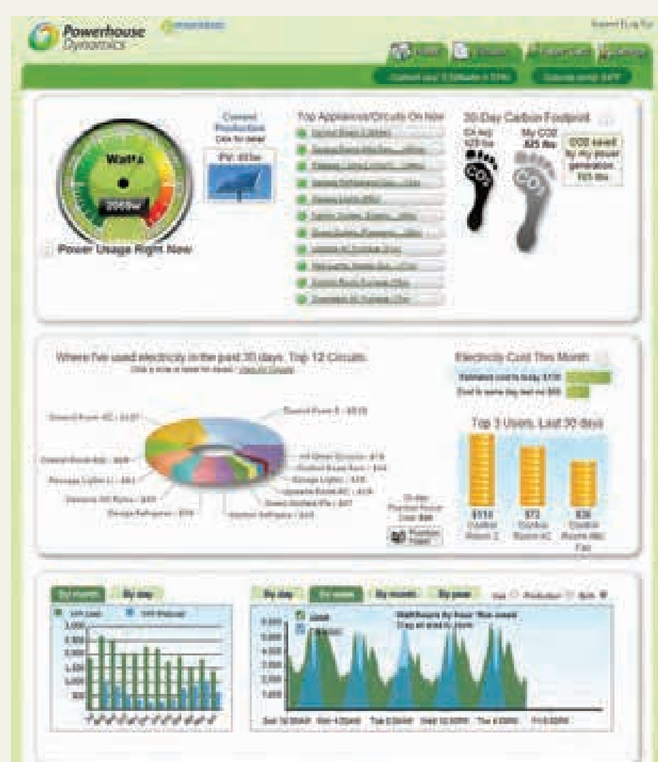


ONSET'S HOBO solar monitoring system is part of its overall data logging and monitoring product line. The U30 system can measure any number of DC or AC conductors for PV generation, as well as building net and branch circuits. A wide variety of weather station sensors can be added to the system. Data can be viewed on a local PC or the HOBOlink Web site.

PowerSave's monitor offers a graphical user interface.

POWERSAVE'S ENVI system measures up to nine solar, net demand, and branch circuits, along with optional appliance monitors. The system comes with a wireless display and feeds local PCs and the Google PowerMeter. Several third-party applications have been written to leverage the data collected by the ENVI—some are free, some are not.

POWERHOUSE DYNAMICS' eMonitor system measures solar generation, net building energy use, and up to 100 branch circuits. It can integrate with thermostats and other home automation systems. It offers a Web site and an iPhone app, with consumption alerts and recommendations.



Module-Level Monitoring

PV systems can suffer from a range of energy-limiting problems, like module mismatch, partial shading, complex layouts, and subarrays on different roof planes. To address these issues, single-module AC and DC maximization technologies have been developed. Module-level monitoring is a beneficial side effect, and customers have taken a more active interest in their systems due to the level of information available.

Microinverters mimic the function of a string inverter, but for individual modules. Mounted on the racking system or the back of each module, a microinverter takes DC power from its partner module and produces AC power at its individual maximum power point (MPP), squeezing the most out of each module and, therefore, the maximum power out of the whole system. Microinverters allow more freedom of design since modules can be placed on different roof surfaces and angles, without degrading the overall power generation. Since there is intelligence built into each microinverter, the separate data can be collected and sent to a data logger. Data is normally transported from the microinverters to a logger via a PLC, removing the need for a separate data cable.

DC maximizers adjust the DC voltage and current for some or all of the modules in a string to generate more DC power than would have otherwise been available. With a standard string inverter, underperforming modules drag down the whole system's power production. DC maximizing allows for more freedom of design, since a roof with partial shading risk can have more modules installed than otherwise—partially shaded modules won't sabotage the whole system. Since it's difficult to transmit data over DC wiring, most DC maximizers use either a separate data wire or wireless communication with the data logger.

With both single-module technologies, data is uploaded through a gateway and the homeowner's Internet connection to the manufacturer's Web servers displaying a visual representation of system performance. These Web sites display individual module performance, with the module's graphic representation laid out in the same pattern as the physical modules. The module displays normally show a numerical and color indication of power—brighter colors indicate more power generation. Users can trigger a time-lapse display or move a slider back and forth, showing dawn-to-dusk performance. The color cue can help detect an underperforming module or string, which could be due to shading, soiling, module mismatch, blown fuses, or broken wires. The installer can troubleshoot the system, armed with a great deal of information about the system's issues.

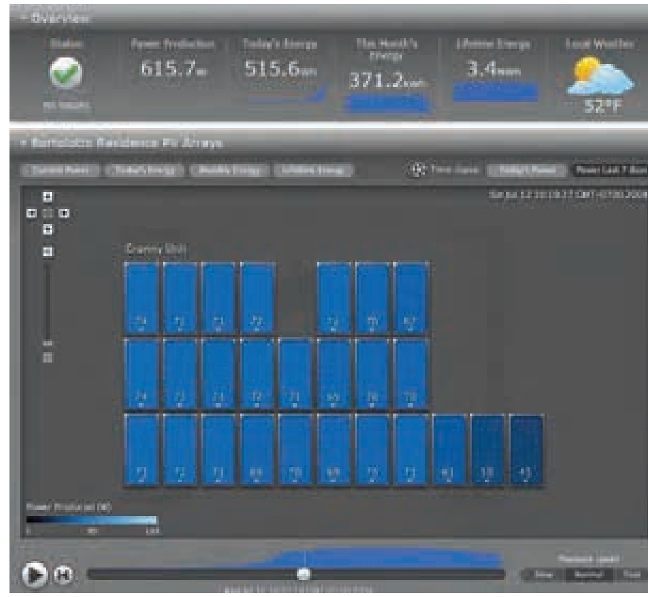
At this point, quantifying the actual *additional* power generated is difficult, since module-level monitoring is only available with microinverters and maximizers installed—you cannot see what the individual modules are producing without the distributed MPPT equipment. However, the non-quantifiable aspect of these systems—the benefits of module-level monitoring—should be taken into account in the overall decision process. Module-level equipment and monitoring systems include:

EIQ offers the Parallux DC vBoost 250 and 350 W converters, which can be installed on one or more PV modules in the system, as long as the power does not exceed the limit of the vBoost. For example, two 125 W modules could be connected to the vBoost 250, but monitoring would be for the pair, not for individual modules. The eIQ uses a parallel wiring architecture to generate constant voltage coming into the inverter, maximizing the inverter's MPPT system. The Monitoring System's Communications Module reads the module-level power information from each vBoost DC converter over the DC power line, avoiding an additional data cable or wireless radio system. It uploads to the manufacturer's Web site or can be downloaded for analysis on a local PC, and offers financial reporting and fault-detection alerts.

Module-Level Monitoring

Company	Product Name	Consumption Tracking	Technology	PV Tracking	Inverter Direct	Modbus
eIQ • www.eiqenergy.com	Parallux Monitoring System	N	DC maximizer	Y	N	N
Enphase • www.enphaseenergy.com	Envoy	N	AC microinverter	Y	N	N
Exeltech • www.exeltech.com	PVAC Module, HelioSentry	N	AC module	Y	N	N
Solar Edge • www.solaredge.com	PowerBox	N	DC maximizer & matching inverter	Y	Y	N
Tigo • www.tigoenergy.com	Module Maximizer	N	DC maximizer	Y	SMA	Y

Enphase's Envoy device collects monitoring data from each microinverter over the AC power lines. The Envoy uploads to the Enlighten Web site where homeowners can view real-time or time-lapse historical data for each module. Alerts are sent if modules are not performing adequately compared to their neighbors. Enphase also has a "smart thermostat" called Environ which allows Enphase system owners to control their heating and cooling systems with an advanced thermostat.



Exeltech's AC module integrates an AC microinverter in the junction box on the back of each module. This saves the additional cable and installation time at the site, and lowers cost due to the high level of integration possible at the factory. The modules transmit data over the AC power lines to the HelioSentry device, which logs and uploads solar power generation and building load information to a local PC or for remote viewing with additional software.

The SolarEdge PowerBox and inverter.

SolarEdge installs a PowerBox on each module, or includes it in the junction box, for controlling the DC voltage. The matching SolarEdge inverter is tuned to work best at a single DC voltage. Controlling both the generation and conversion of DC power can lead to production improvements of up to 25% compared to central inverter systems without distributed MPPT. The software automatically detects problems, issues status reports, alerts via e-mail, and provides recommendations and suggests solutions.

Weather Station	Data Path to Internet	Accurate Financial Tracking	PC Display	Wireless Display	Web Site Display	iPhone App	Home Automation	Cost
Y	Cat5, WiFi, satellite	Y	N	N	Y	N	N	Distributors set price
N	PLC to Envoy, Cat5 to router	N	N	N	Y	Y	N	Included; $365 for Envoy; plus $9/microinverter for 5 years of service
Y	WiFi to router	N	Y	Y	N	N	N	$750
N	PLC to inverter, Cat5 to router	N	N	N	Y	Y	N	TBD
Y	ZigBee to MMU, Cat5 to router	N	N	N	Y	N	N	$200 for 5 years; $625 for MMU, plus $350 for 5 years of service

Module-Level Monitoring, Continued

Tigo Energy offers Module Maximizers, which attach to the frame corner on the back of each module. The Maximizer Management Unit (MMU) communicates bidirectionally with the Maximizers over a wireless network, adjusting DC variables to maximize the system's power. The MMU uploads data to the Tigo Web site via an Ethernet connection, with WiFi coming soon. Homeowners can review module-level DC power details. The MMU can be wired to SMA America, Fronius, and Kaco inverters to reflect the inverter's actual AC output power readings. Alerts are generated based on expected performance value setpoints.

Other Monitoring Solutions

Solar installation companies are realizing the value of including or adding a monitoring system to their customers' projects. Monitoring adds significant value to help the customer understand whole-house energy management, and assists service departments in diagnosing any issues. A few of the larger installation companies' offerings are listed below:

Akeena uses Fat Spaniel's residential system (described above). **Lighthouse Solar** includes eGauge's system as its Lightgauge monitoring system. **PHAT Energy's** PHATLogger is an open hardware, software, and data platform that the company uses for its solar installations. It also plans to provide the device to the monitoring market by the end of 2010. Currently, the device can collect data from SMA America and Solectria inverters. Data is uploaded via a WiFi connection to the customer's router. PHAT Energy plans to have an iPhone application by the end of 2010. **REC Solar** currently includes The Energy Detective's solar generation and building load-monitoring solution with each residential system. If the customer chooses to use Tigo's module maximizing system, then a Tigo monitoring system is installed instead. **SolarCity**'s in-house SolarGuard system has a Web site and iPhone application for users, and is actively monitored for any underperformance. **SunPower**'s in-house Monitoring System has a wireless in-home display, Web interface, and iPhone application.

Google PowerMeter makes a consumer's energy consumption data transparent and readily accessible from any Web connection. The goals? Heighten energy awareness and get consumers to take ownership of and reduce their energy usage. The PowerMeter allows users to track their energy use over time—by the day, week, or month—in a graphical format and to investigate phantom (always-on) loads, which are reflected by darker, shaded portions in the graphs. Consumers can also set their energy savings goals with the Budget Tracker and share their consumption (and reduction) information with family and friends. So far, availability is limited to certain partnering utilities and companies in the United States—SDG&E (San Diego), JEA (Florida), Current Cost, eGauge, and Energy Inc.

Access

Michael Brown (mwbrown42@gmail.com) worked in software architecture, development, and support at IBM for 22 years. He joined REC Solar Inc. shortly after having the company install a solar-electric system at his house, and is in the process of converting a Porsche 914 to full electric drive (porsche914e.blogspot.com).

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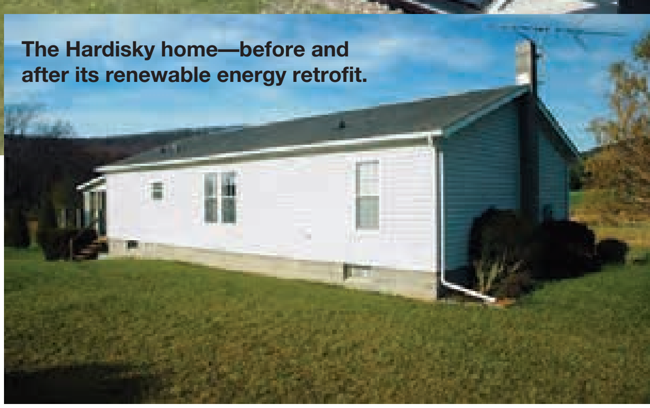


The Hardisky home—before and after its renewable energy retrofit.

Project Name: Hardisky Green Energy Home Retrofit

Designer & Installer: K.C. Larson Inc. of Williamsport, Pennsylvania

Location: Loganton, Pennsylvania—41° N latitude

Date Commissioned: April 19, 2010

Solar Resource: 4.2 average daily sun-hours

Average Annual Utility Electricity Offset (PV & SHW Systems): 17,500 kWh

with Kelly Davidson
photos by Tom Hardisky

A net-zero-energy home is an ambitious goal for a newcomer to renewable energy, but that didn't stop Tom Hardisky. Last spring, after years of exploring various options, the wildlife biologist retrofitted his 1991 ranch home in Pennsylvania with solar-electric, solar hot water, and heat pump systems that should offset 100% of his household energy needs. *Home Power* spoke to Tom about his project, motivations, and lessons learned, as well as the process of selecting a system designer and the challenges of navigating all of the available incentives.

Home Power: What sparked your interest in renewable energy?

Tom Hardisky: When I was in grade school some 30 years ago, my science teacher broke the disturbing news: We will someday run out of fossil fuel. She said that our generation was charged with finding a lasting energy solution without further tapping into our dwindling energy resources. I realized then that by being dependent on a nonrenewable energy supply, we were moving down a disastrous path.

HP: So, after all those years, what motivated you to move forward with this project now?

Tom: The time was right as far as incentives. In addition, electricity rate caps began expiring at the beginning of 2010 for Pennsylvania electric utility companies. My electric company, Pennsylvania Power and Light, is gradually increasing electric rates. For average PP&L customers, that translates into an increase of approximately 30% in 2010. I anticipate never-ending rate increases—I thought there would be no better time to do this.

The major financial incentive for my retrofit was the Pennsylvania Sunshine Program rebate, which provided 35%

The generation from 40 solar-electric modules offsets the home's electricity use, while eight solar hot water collectors supply the home's hot water and some supplemental space heating.

of the cost of my PV system. The only stipulation is that it could not exceed 10 kW. The combined effect of PV, solar hot water, and heat pump financial incentives actually broadened my vision. I ended up maximizing PV module coverage on my roof *and* investing in solar hot water and heat pump systems.

Income from solar RE credits (SRECs) was an important incentive as well. I have a five-year contract with Sol Systems LLC that pays me $280 per solar-produced megawatt-hour.

In addition, the heat pump qualified for a $400 rebate through my local electric company's E-power Program. And, when I file federal income taxes next year, I will be able to take advantage of an available tax credit. An after-rebate 30% federal tax credit will be an important source of investment return.

HP: What made you decide to go for net-zero energy for your home?

Tom: I'm a conservationist by nature and profession, so an energy-independent home was logical and always my dream. I wanted an RE system that would meet all of my energy needs, including home heating, hot water, and electricity. I thought maybe I could set an example for other homeowners and help us move toward that lasting renewable solution proposed by my grade-school teacher.

HP: Once you got serious about the idea, what steps did you take?

Tom: When a PV installation short course was offered by the Honesdale, Pennsylvania-based Sustainable Energy Education Development Support, I jumped at the opportunity to learn more—and possibly complete most of the installation myself. The real value in taking the course was a good education in solar energy system basics—terminology, components, and designs. By the end of the three-day workshop, I realized that having basic plumbing and home wiring skills was not enough for me to take on such a project. This was no weekend project. If I wanted a well-designed, high-quality RE system, I needed professional help.

HP: How did you choose a system designer to work with?

Tom: At a local Go Green Expo, I spoke to several RE installers. Most installers were very new to the business. Their level of experience seemed to be reflected in the quality of their expo displays and their answers to basic questions, such as, "What renewable energy system options are available?" I found that the most knowledgeable professionals had well-organized, attractive exhibits with informative literature. Designers who placed most of their emphasis on educating me rather than selling their products and services were the type of people I wanted to do business with. Installers who provided free site visits and solar analyses were on my preferred list.

PV System

Forty Schüco 210-watt modules were installed on Schüco ezRails, which were attached to the standing seam roof's metal pans using nonpenetrating S-5! clamps. The air gap provided by the racking system helps air flow between the modules and metal roof, keeping the modules cooler and improving the system's overall efficiency. The four strings of 10 modules are wired to two Fronius 4,000 W inverters (20 modules per inverter), which are located next to the main service panel in the basement. In the first three months of operation, the system has produced 3,615 kWh, slightly exceeding PVWatts' estimate of 3,430 kWh.

PV Tech Specs

Overview

System type: 8.4 kW batteryless grid-tied PV

Location: Loganton, Pennsylvania; 41°N latitude

Date commissioned: April 2010

Solar resource: 4.2 average daily sun-hours

Annual production estimate: 9,750 kWh

Utility electricity offset to date: 100% (before a new heat pump system)

Equipment

Modules: 40 Schüco, SMAU-1 210 modules, 210 W STC, 26.3 Vmp, 7.98 Imp, 33.7 Voc, 8.35 Isc

Array: Four 10-module series strings, 8,400 W STC total (263 Vmp; each string: 7.98 Imp, 337 Voc, 8.35 Isc)

Array combiner box: 6- by 6-inch box

Array DC disconnect: 30 A Square D-3 pole disconnect, HU361

Array installation: Schüco ezRail and S-5! seam clamps; azimuth 220° (approximately SW), tilt 15°

Inverters: Two Fronius IG 4000, 500 VDC maximum input, 150–450 VDC MPPT operating range, 4,000 W AC, 240 VAC output

System performance metering: Two kWh production meters

Two Fronius grid-tied inverters make up the balance of the home's photovoltaic system.

HP: Why did you decide to work with the designer you ultimately selected?

Tom: Because of the questions *they* asked *me*. The best question they asked was, "What are your energy and overall project objectives?" The K.C. Larson staff also answered all of my technical questions, and they were very receptive to allowing me to reduce costs by completing some project tasks on my own.

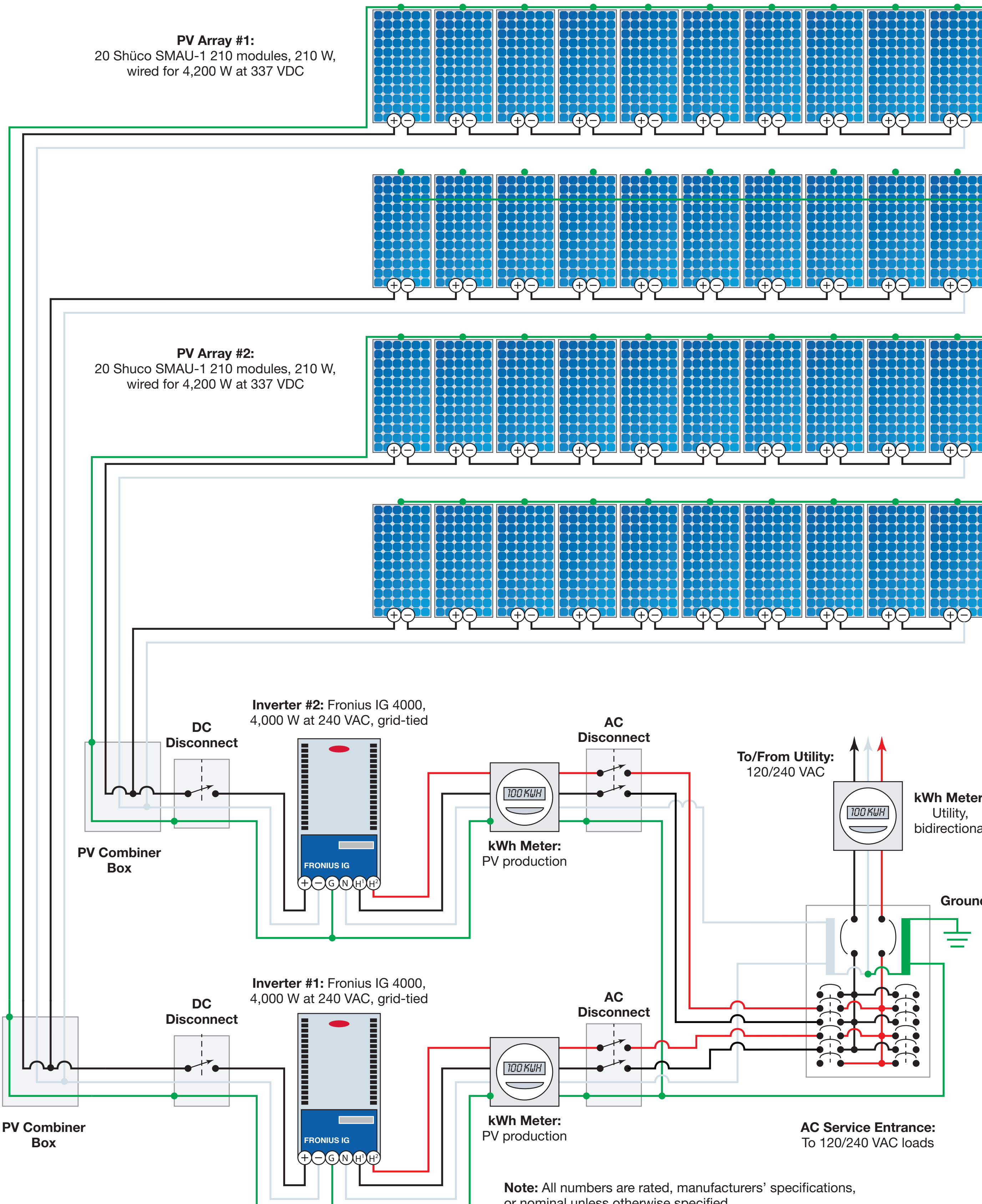
HP: What modifications did you make to your home prior to installation?

Tom: My existing asphalt shingle roof was 18 years old but in good repair. However, the installers asked me to consider having a standing-seam metal roof installed because it would last the life of the PV system. They also asked me to specify a light color to decrease heat buildup during the summer months.

Prior to the roof installation, I relocated the plumbing roof vent pipes and exhaust ducts from the south side of the roof to the north side. That left the entire south-facing roof free of obstacles, maximizing roof space for the PV array.

The installer also recommended that I replace my 18-year-old electric water heater, so I installed a new, more efficient, 50-gallon water heater to minimize the chance of future problems. I also sealed air leaks. I installed new basement windows with a much higher R-value, insulated the attic with fiberglass blanket insulation, and caulked and added 2-inch foam insulation along the perimeter of the basement to decrease heat loss and air infiltration.

Hardisky Grid-Tied PV System



Note: All numbers are rated, manufacturers' specifications, or nominal unless otherwise specified.

Solar Thermal System & Space Heating System

The SHW and space heating system consists of eight collectors heating two 120-gallon tanks for heat storage that supplement the winter space-heating load. The heat is delivered to the home through a ceiling-mounted fan coil unit in the basement. In operation, the hot water is pumped from the solar storage tanks through the coils in the fan coil unit, and the fan distributes heat to the basement—with the goal of heating the basement to 75° F-plus during the daylight hours. Natural convection carries the heat upstairs.

To control the seasonal overproduction during the summer, this system has isolation valves that allow five collectors to be covered and one storage tank to be taken out of production in the summer when the heat isn't needed, leaving three collectors uncovered and a single tank supply in operation for the SHW load. By isolating the one tank in this system, the SHW has a quicker recovery at the expense of less heat storage for extended periods of cloudy weather or extra-large loads. However, three collectors can more than adequately heat a 120-gallon tank in the summer.

SHW Tech Specs

Overview

System type: Closed-loop, antifreeze solar hot water

Annual production estimate: 26,597,631 Btu total

Average annual electricity offset: 7,795 kWh

Estimated percentage of hot water produced annually: 75%

Equipment

Collectors: 8, Schüco, Slim V

Collector installation: Ground mount on concrete pad, portrait-oriented Schüco exFlatroof TH angle and safety cross kit. Azimuth at 220°; tilt at 40°

Heat-transfer fluid: Propylene glycol

Pump controller: Schüco, Solar Pump Station, GL-30, #PS-1.3

Hydronic heater: Beacon/Morris, HB136A hydronic heater; 35,900 Btu with speed controller

Storage

Tanks: 2, Rheem, #120HE-1, 120 gal.

Heat exchanger: Exterior wraparound; vented for leak detection

Backup DHW: Whirlpool Energy Smart, 50 gal. electric water heater

Production

Summer mode: 3 collectors for 3 months: 3,449,673+/- Btu

Heating-season mode: 8 collectors for 9 months: 23,147,958+/- Btu

Average annual energy offset: 7,795 kWh

The balance of system components of the solar hot water system.

Since the system was installed, I've identified additional sources of heat loss as well—namely basement doors, the electric service entrance, and other unsealed foundation wall openings/cracks. I'm in the process of completing these improvements.

HP: Did you make lifestyle or energy use adjustments?

Tom: Although I made no major lifestyle changes, I am now much more conscious of my use of energy. Turning off unnecessary lighting was always a routine. However, soon after project completion, I found myself trying to figure out why my house used 6 to 8 kWh overnight—even when the heating or air conditioning was not running. I discovered that the outside security lighting was responsible for about 5 kWh each night.

My habits with respect to hot water usage have changed. During the warm months, I produce much more hot water than I can use. I used to wash my white clothes in warm water. Now, I always use hot water. When I need a bucket of water for cleaning or rinsing, I reach for the hot water faucet.

HP: What was the home's initial energy profile, and how did it change?

Tom: Prior to my solar system installation, I had an 18-year-old electric water heater, no central air-conditioning, and forced-air oil heat. Annual heating oil charges were about $880, and my annual electric bill exceeded $900. My annual electric consumption over the past two years averaged 5,344 kWh.

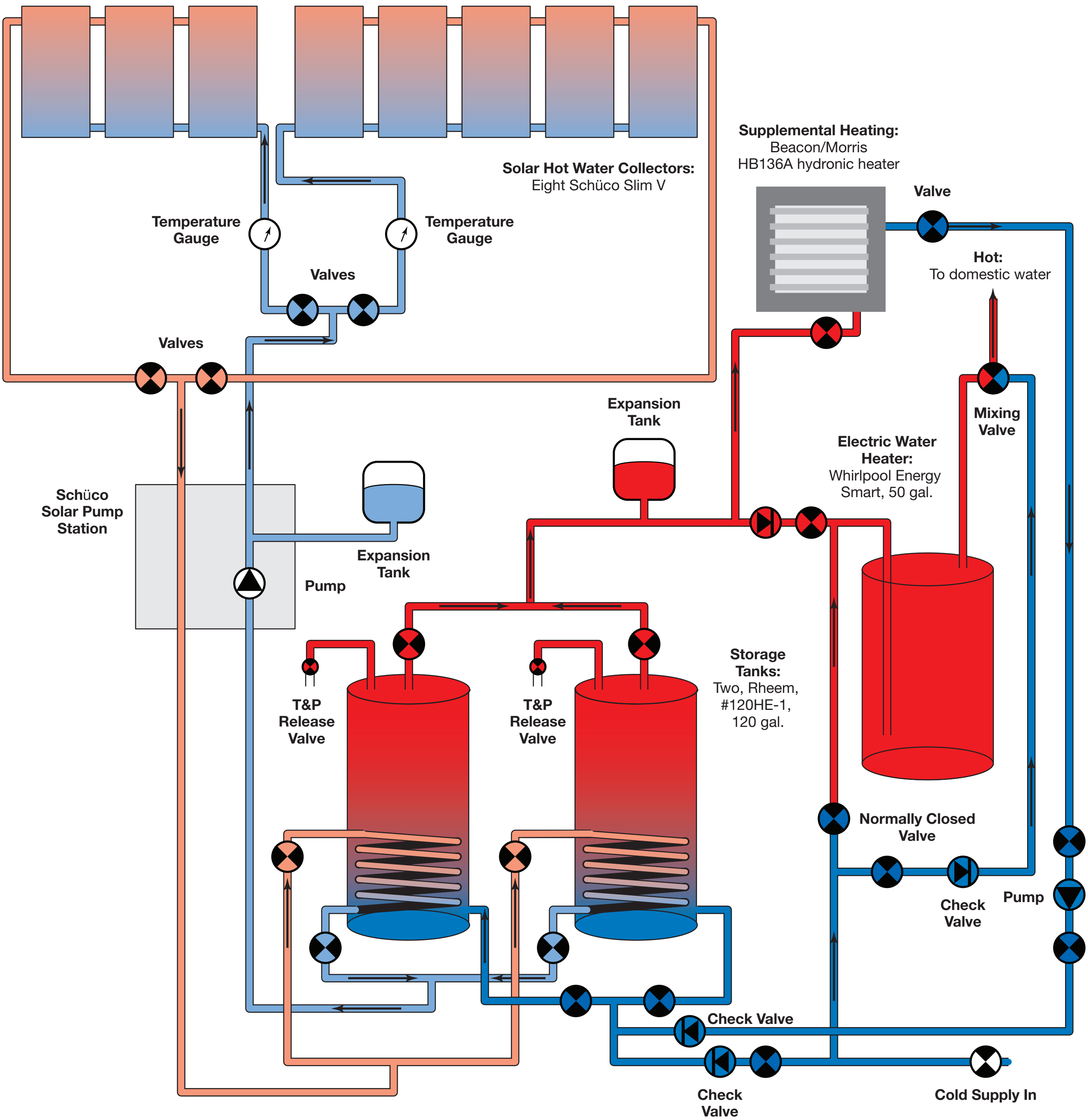
The new heat pump provides central air-conditioning that I did not have before, and I now have a much more efficient electric water heater and electric forced-air heat. Since I did away with the old furnace, I no longer need heating oil.

Overall, my electric consumption increased by 21% since system installation, primarily because of the new electric heat pump, but during the first three months of operation, I had a monthly electric bill of $8.45—the minimum base distribution charge from the electric company.

HP: Do the systems need maintenance?

Tom: Thus far, there has been minimal system maintenance. Because of excess hot water production, I cover five of the eight solar collectors and close down half of the solar

Hardisky Domestic SHW System



The solar fan-coil unit in the basement, which serves to supplement the home's space-heating system.

Right: A high-efficiency heat pump replaced the old furnace, providing space heating and cooling.

thermal system during the summer months. All eight panels will be in operation during the spring, fall, and winter. The maintenance work entails moving panel covers and closing a few ball valves. I'll periodically change filters in my air exchanger, and that's about it for the year.

HP: What did you learn from the installation process?

Tom: Never underestimate the effects of shading. During the design phase, the folks at K.C. Larson asked me to take my chimney down to the roofline since I had removed the fuel-oil-fired furnace. Although I did not need the existing chimney, I balked. The slight shading that my chimney temporarily casts on my PV modules in the morning seemed insignificant. However, as the sun path changed, I noticed some solar energy loss. Considering the cumulative impact of this partial shading, I decided to lower my chimney to eliminate any shading issues but still leave Saint Nicholas with suitable access.

HP: Your goal is to produce more energy than you use. Do you think you'll be able to achieve your net-zero target?

Tom: Energy use during the winter months will greatly influence my net-zero status.

The PVWatts calculator estimates my PV system's annual production at 9,750 kWh. If my energy consumption does not increase by more than 82% of last year (5,344 kWh), I should reach net zero.

With my solar hot water system and more efficient home heating and cooling, I am confident that my systems will produce more energy than I use annually.

With the combined output of the solar hot water and PV systems, the Hardisky home should be able to reach its annual net-zero energy goals.

Q&A

K.C. Larson's Keevin Larson discusses the energy systems for Tom's net-zero home.

HP: Tom did not set out initially to design a net-zero home, so how did the project evolve to that level?

Keevin: The possibility of a net-zero status arose during the final design of the solar thermal system, but after the PV system design was complete. The roof was to be completely covered with PV modules and all of the available ground space was slated for the thermal collectors. After Tom approved the solar thermal and heat pump designs, it was then I knew the home could be very close to net-zero.

HP: How do all of the systems work together to achieve the net-zero goal?

Keevin: The air-to-air heat pump system puts out twice as much heat energy as the electricity put into it. Since the PV system generates electricity, it helps offset the heat pump's use during the air-conditioning mode. The heat pump system also contains a backup electric resistance heating element, which is energized if the heat pump cannot provide the needed home-heating capacity. This is when the space-heating mode of the solar thermal system can help supplement the home's space-heating needs. The less the heating element is energized, the more savings.

HP: What process did you use to design the solar hot water system?

Keevin: We installed a similar but smaller system in early 2009 for another client. This system had five thermal collectors and two 105-gallon solar storage tanks. This system proved the concept of heating the basement mass during the daytime, allowing the heat to radiate up to the first floor during the day and into the evening hours. But that other project's basement has much more heat loss than Tom's basement, so this system will retain a warm temperature within the confines of the basement for a much longer period of time. In other words, fewer Btu of heat are required due to less heat loss and outside infiltration.

HP: How does the SHW hydronic design optimize efficiency?

Keevin: If the basement temperature is 60°F or above and the temperature in the solar storage tank is at least 75°F, the hydronic heater can still heat the basement with solar. The heater can be advantageous due to the quick delivery of the heat—it raises the space temperature instantly, and this heated air rises up to the first floor.

HP: What savings does the heat-pump system offer over the old oil-fueled furnace?

Keevin: Tom's furnace used, on average, 355 gallons of No. 2 fuel oil each year. At an average of about $2.25 per gallon, a furnace with 80% efficiency would cost $20.39 per 1 million Btu. If utility electricity cost $0.11 per kWh, the cost to run his heat pump would be about $16.12 per 1 million Btu—a 21% savings.

When the weather gets really cold, below the 35ºF effective capability of the heat pump, the backup electric resistance heat will kick in. This, by definition, has a lower coefficient of performance, and uses more energy. Since it's electric, the PV system will offset at least a portion of that. But considering completed and future weatherization upgrades, the comparative amount of heating the home will require is still unknown.

Home Heating & Cooling with a Heat Pump

The home's oil-fired hot air furnace was removed and replaced with a new energy efficient heat pump that was connected to the existing ductwork. The ductwork was modified to better balance the system operation. The PV system will offset the electricity required to operate the heat pump. During the heating season, the solar thermal system helps supplement the heat pump to decrease the heating cycles and electricity used, sending solar-heated water to a hydronic heating unit located in the basement.

Access

Tom Hardisky (disky@tds.net) lives on a 13-acre farm in rural Pennsylvania. He is a wildlife research biologist for the Pennsylvania Game Commission. He has bachelor's degrees in biology and wildlife science, as well as a master's degree in wildlife ecology.

K.C. Larson • www.kclarson.com

Pennsylvania Sunshine Program • www.depweb.state.pa.us • State incentives

Sol Systems • www.solsystemscompany.com • RECs

System Component Manufacturers:

Schüco USA • www.schueco.com • PV modules, SHW collectors
Fronius • www.fronius.com • Inverters
Goodman • www.goodmanmfg.com • Heat pump
Rheem • www.rheem.com • Storage tanks


Trojan
2 VOLT
L16RE-2V
RENEWABLE ENERGY
Trojan
DEEP-CYCLE
GEL
Trojan
27-AGM
CYCLING AGM
12 VOLT
Pb

Taking Your Home's Energy Temperature

Courtesy Fred Rogers

by Fred Rogers

"I've worked on insulating my home and conserving energy.
How can I tell if my work has reduced my household energy consumption?"

Homes of all ages can benefit from higher levels of insulation, higher-performance windows, and weather stripping—but measuring the actual benefits can be difficult because fuel costs and the weather vary from year to year. This article describes one way to answer the effectiveness question, by using information available to most homeowners at no cost.

Our Energy Retrofit

My wife Penny and I live in a small house in Reno, Nevada. Our 1952 home was built with minimal insulation—as we discovered when we started renovations in 1995. There was no insulation in the wall cavities, and only about 1 inch of deteriorated fiberglass batts in the attic.

Over the past 15 years, we added layers of R-21 fiberglass batts in the attic; they now total about 9 inches in depth. We inserted R-21 fiberglass batts into the previously empty outer wall cavities, with $^3/_8$-inch rigid-foam insulation (R-2) over the fiberglass batts and the wall studs to reduce thermal bridging. As of this time, we have insulated about one-third of the perimeter wall area.

Layering batts of new insulation over older insulation is an easy way to improve a home's energy efficiency.

Courtesy Fred Rogers

We also replaced the old steel-frame, single-pane windows and the old doors with double-pane vinyl units (U-value approximately 0.5). About 70% of the window replacement took place in 1995, before this study began, and the remaining 30% in 2002.

Our winter solar exposure is very poor, so our focus has been on incremental, yearly do-it-yourself insulation projects. For us, January is "attic insulation month."

The Approach

Most homeowners can measure the amount of energy used for home heating in the winter months. We can also factor in colder or warmer weather conditions by using appropriate temperature data. We can then calculate our winter heating energy use using a "weather factor" with one caveat: the "human factor"—individual consumption patterns that may be uncontrollable. For example, you may not be able to take into account unusual adjustments to your home thermostat—like if a guest stays for a lengthy visit or if someone gets sick. We have a programmable thermostat and we don't override its settings often. So, in our case, it's typically weather that drives heating fuel consumption.

Measuring Home Heating Energy

Electricity, natural gas, and oil are commonly used in home heating; you can determine your energy consumption for whichever of these fuels you use. The consumption of electrical energy, whether generated by your own renewable energy system or the local power company, is measured in kilowatt-hours (kWh). Natural gas is typically measured in "therms," the energy content of the gas consumed. If you buy these fuels from a utility, you'll find monthly consumption numbers reported on your bills. Fuel-oil consumption is measured in gallons. Oil consumption from a tank can be read using a dipstick, but the stick needs to be calibrated for the specific tank.

In any case, you want to measure your actual energy consumption, not use a dollar energy cost that's subject to the ups and downs of market forces.

Adding It Up

An insulation's R-value indicates how well it resists heat flow. Generally, the higher the R-value, the better the insulation is at doing its job. But how and where insulation is installed also affects its performance. Insulation that is compressed too tightly into a space will not give its full R-value. And a ceiling or wall's total R-value will usually be lower than the R-value of the insulation, mainly due to thermal bridging (increased conduction) that occurs through studs or joists because of their lower thermal resistance. Oak Ridge National Laboratory offers a whole-wall R-value calculator at www.ornl.gov/sci/roofs+walls/AWT/InteractiveCalculators/rvalueinfo.htm.

—Claire Anderson

Taking Temperatures

When you're measuring temperature, give some forethought to where the sensors and thermometers are located.

According to NOAA guidelines (www.nws.noaa.gov/om/coop/standard.htm), surface air temperature measurements for meteorological purposes are taken at 5 feet above the ground. This height is representative of people's living and working proximities.

Because the goal is to measure the temperature of free-flowing air, it is necessary to ensure that the thermometer or sensor is reading the heat flux to or from the air—and not other sources, like direct sunlight. A sensor mounted on the wall of a building will measure some useless combination of the surrounding air and the building material's temperatures.

A small, louvered box painted with bright white paint may serve the do-it-yourselfer about as well as commercially available aspirated sun shields. NOAA's guidelines also call for the sensor to be no closer to an obstruction than four times the height of the obstruction, and to be at least 100 feet from any paved or concrete surface.

In addition to old-fashioned thermometers, electronic sensors are available, some with wireless communication between the outdoor sensor and an indoor display.

—Fred Rogers

Insulation upgrades included rigid foam-board (at left) over R-21 fiberglass batts (on right).

Courtesy Fred Rogers

Insulation Zones

The U.S. Department of Energy provides minimum recommended R-values for homes based on climate, heating source, and the space needing insulation, such as attics, basements, or walls (see map below right). Consider exceeding these levels (superinsulating) for maximum energy efficiency. You'll need to compare the life-cycle savings to your initial insulation budget to figure out the best return for your investment.

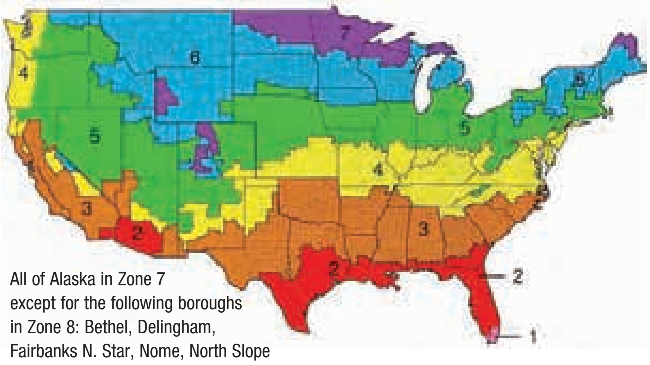
If you have a limited budget for insulation, experts recommend insulating your attic or ceiling first. Compared to floors and walls, attics are a major contributor to a home's heat gain and loss, and bundling up an attic can shave up to 30% from your energy usage. Besides having a large surface area for heat transfer, attics commonly have other conduits for air infiltration, such as light fixtures, plumbing and electrical chases, chimneys, exhaust fans, and ducts. Together, these can account for more heat transfer than the *entire* flat surface of your attic (see the "Don't Forget Ducts" sidebar).

Next, insulate walls and floors. In new homes, adequately insulating walls is a no-brainer. In older homes, however, it may be an expensive and difficult task. Get an estimate first, and then do the math to see how long it will take to recoup your investment at a 16% to 20% savings on your heating and cooling. Insulating crawl spaces and underneath floors can save 5% to 15% on heating energy, and is usually an easier job.

—Claire Anderson

Insulation Recommendations for New Wood-Framed Houses

Zone	Heating System	Attic	Cathedral Ceiling	Wall: Cavity	Wall: Insulation Sheathing	Floor
1	All types	R-30–R-49	R-22–R-38	R-13–R-15	None	R-13
2	Gas, oil, heat pump	R-30–R-60	R-22–R-38	R-13–R-15	None	R-13
	Electric furnace	R-30–R-60	R-22–R-38	R-13–R-15	None	R-19–R-25
3	Gas, oil, heat pump	R-30–R-60	R-22–R-38	R-13–R-15	None	R-25
	Electric furnace	R-30–R-60	R-22–R-38	R-13–R-15	R-2.5–R-5	R-25
4	Gas, oil, heat pump	R-38–R-60	R-30–R-38	R-13–R-15	R-2.5–R-6	R-25–R-30
	Electric furnace	R-38–R-60	R-30–R-38	R-13–R-15	R-5–R-6	R-25–R-30
5	Gas, oil, heat pump	R-38–R-60	R-30–R-38	R-13–R-15	R-2.5–R-6	R-25–R-30
	Electric furnace	R-38–R-60	R-30–R-60	R-13–R-21	R-5–R-6	R-25–R-30
6	All types	R-49–R-60	R-30–R-60	R-13–R-21	R-5–R-6	R-25–R-30
7	All types	R-49–R-60	R-30–R-60	R-13–R-21	R-5–R-6	R-25–R-30
8	All types	R-49–R-60	R-30–R-60	R-13–R-21	R-5–R-6	R-25–R-30



All of Alaska in Zone 7 except for the following boroughs in Zone 8: Bethel, Delingham, Fairbanks N. Star, Nome, North Slope Northwest ArticDeling, Southeast Fairbanks, Wade Hampton, Yukon-Koyukuk

Recommendations for Existing Wood-Framed Houses

Zone	Add Insulation to Attic: Uninsulated Attic	Add Insulation to Attic: Existing 3–4 In. of Insulation	Wall: Uninsulated Wood-Frame	Wall: Insulated Wood-Frame	Floor
1	R-30–R-49	R-25–R-30	Fill with blow-in	None extra	R-13
2	R-30–R-60	R-25–R-38	Fill with blow-in	None extra	R-13–R-19
3	R-30–R-60	R-25–R-38	Fill with blow-in, add R-5 wall sheathing under new siding	None extra	R-19–R-25
4	R-38–R-60	R-38	Fill with blow-in, add R-5 wall sheathing under new siding	Add R-5 wall sheathing under new siding	R-25–R-30
5	R-49–R-60	R-38–R-49	Fill with blow-in, add R-5–R-6 wall sheathing under new siding	Add R-5 wall sheathing under new siding	R-25–R-30
6	R-49–R-60	R-38–R-49	Fill with blow-in, add R-5–R-6 wall sheathing under new siding	Add R-5 wall sheathing under new siding	R-25–R-30
7	R-49–R-60	R-38–R-49	Fill with blow-in, add R-5–R-6 wall sheathing under new siding	Add R-5 wall sheathing under new siding	R-25–R-30
8	R-49–R-60	R-38–R-49	Fill with blow-in, add R-5–R-6 wall sheathing under new siding	Add R-5 wall sheathing under new siding	R-25–R-30

Map and data courtesy U.S. DOE

During the main heating months of November through February (2005–2006 and 2009–2010), we used 80 to 136 therms of natural gas per month. (During that same period, the cost per therm varied from $0.98 to $1.22, which demonstrates why you cannot base your energy use calculations on billing dollar amounts.)

The Weather Factor

Reno, Nevada, is a high-desert environment subject to moderately cold winters. Our average temperatures for November, December, January, and February are 40.9, 33.6, 33.6, and 38.5°F respectively. But these are averages derived over decades; what we wanted was the monthly average for specific months—say December of 2008 and 2009—since we wanted to be able to take colder or warmer months into account as we examined our energy use.

Heating and ventilating engineers often use "heating degree-days" (HDD) as an index of the amount of heat needed to maintain comfortable surroundings for people occupying homes or businesses. HDD are defined as 65°F minus the average temperature for one or more days. In Reno last December, with an average temperature of 26.9°F, our HDD total for the month was (65°F - 26.9°F) times 31 days, or about 1,181 HDD. (December 2008 was milder, with 952 HDD.)

Courtesy Fred Rogers

Having the wall open for insulating made it easier to replace the old single-pane windows with more energy-efficient ones.

Don't Forget Ducts

After ceilings, floors, and walls, ductwork can account for up to 15% of a home's winter heat loss, according to the U.S. Department of Energy. This network of tubes in a home's walls, floors, and ceilings distributes conditioned air to the rooms in your home. Most systems, unless they're relatively new, are uninsulated or not insulated properly. And uninsulated and leaky ducts translate into energy dollars down the drain.

Insulating and sealing ducts is especially important if they are located in unconditioned spaces. In the wintertime, ducts can leak heat, and in the summertime, they can draw in hot air, decreasing your central air-conditioning system's efficiency.

Minor duct repairs are easy to do yourself, but you may want to consult a pro to test, insulate, and seal ducts in unconditioned spaces. First look for sections that should be joined, but have separated, and then look for obvious holes. Seal your ducts with Underwriters Laboratories (UL) certified tape to ensure a long-lasting bond. Insulating ducts in a basement will make the basement colder in winter, so if both the ducts and the basement walls are uninsulated, consider insulating both. To help prevent condensation on cooling ducts, make sure there's a well-sealed vapor barrier on the outside of the insulation. In most areas, use duct wrap insulation of R-4 or R-6.

—Claire Anderson

Average temperature data for specific months in specific years is available for various cities through the National Oceanographic & Atmospheric Administration's (NOAA) Regional Climate Centers (see Access). If you live close enough to one of these cities, you can probably use NOAA's HDD data. However, you will need to judge whether or not the temperature variations at the official measurement site are similar to those at your house, since microclimate variations can be significant depending on heat-island effects (i.e., the prevalence of buildings and pavement); elevation differences; and proximity to water. It's important that the official site's temperature rises and falls roughly in proportion to what you observe at home, but absolute accuracy isn't necessary. You just want reliable and consistent HDD data to take into account warmer and cooler months as you examine your energy consumption.

If you can't find HDD data from an official site close enough to your home, you can probably find monthly average temperature data for a nearby site and calculate your own HDD numbers. You can also install your own thermometer and measure maximum, minimum, and average temperatures at your home (see "Taking Temperatures" sidebar). Automatic digital systems will record the data even if you're away, but the siting of the temperature sensor is somewhat critical.

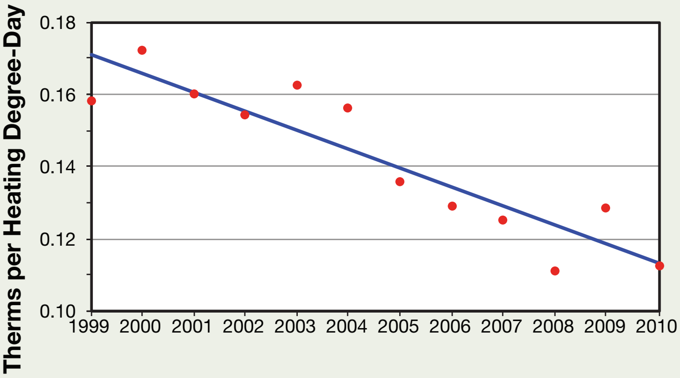
Using HDD allows comparing, for example, my energy use in December 2008 to that of December 2009—taking warmer or cooler weather conditions into account.

Insulation Comparison

Loose Fill	R-Value Per Inch*	R-Value Per Thickness*
Fiberglass	2.2–2.9	–
Rock wool	2.2–2.9	–
Cellulose	3.1–3.7	–
Batts		
Fiberglass	2.9–3.8	–
Wool	3.5	–
Cotton	3–3.7	–
Rigid Board		
EPS	3.9–4.2	–
XPS	5.0	–
Polyisocyanurate	5.6–7	–
Liquid Foam		
Cementitious foam	3.9	–
Polyurethane	5.6–6.2	–
Other		
Straw bale	1.5	–
Straw-clay	1.6	–
Rastra (8 in. thick block)	–	11.0
SIPs (3.5–9.38 in. thick)	–	14.0–37.0
ICFs (10 in. thick)	–	17.0–26.0

*All values are estimates; total R-value will vary depending on material and installation techniques.

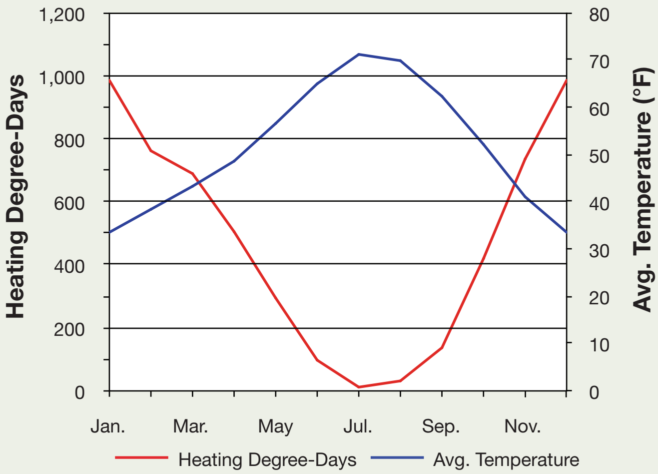
Results of Efficiency & Insulation Improvements



Our Reno Example

A Carrier 132,000 Btu, 80% efficient natural gas furnace replaced the original oil burner and it has heated our home since 1995. We have monthly data showing the amount of therms consumed since 1999. We concluded that National Weather Service monthly average temperature data from Reno International Airport (about 4 miles away) would serve our purpose as an index of major monthly temperature changes.

Reno Avg. Temperature & Heating Degree-Days*



*1971–2000

The "Results" graph shows the amount of natural gas used to heat our house, divided by the number of HDDs, averaged over our two coldest months, December and January. The downward trend reflects our year-after-year insulation and efficiency efforts, equaling about 40% over 12 years..

Of course, 12 years aren't needed for this kind of study. For example, if you're interested in examining your energy consumption before and after an insulation retrofit, collect your fuel-usage numbers for a couple years before and after the work, and then obtain or calculate HDD for the winter months for those years. Plot your data to see if there's a significant reduction following your insulation project, then you'll be able to clearly visualize the benefits of your work.

Access

C.F. (Fred) Rogers, Ph.D., is a retired atmospheric scientist. His current interests include looking for good science education materials for his grandchildren and composing a Web site honoring a pioneering cloud physicist.

HDD data for selected cities • www.cpc.noaa.gov/products/analysis_monitoring/cdus/degree_days

National Oceanic & Atmospheric Administration (NOAA) regional climate centers • www.ncdc.noaa.gov/oa/climate/regionalclimatecenters.html

Many thanks to Jim Ashby, Michelle Breckner, and Kelly Redmond at the Western Regional Climate Center for their help in accessing the wealth of temperature data on the WRCC web site. Thanks also to Adrienne Furman at Nevada Energy, who kindly helped me recover missing natural gas consumption data from the early years of this study.

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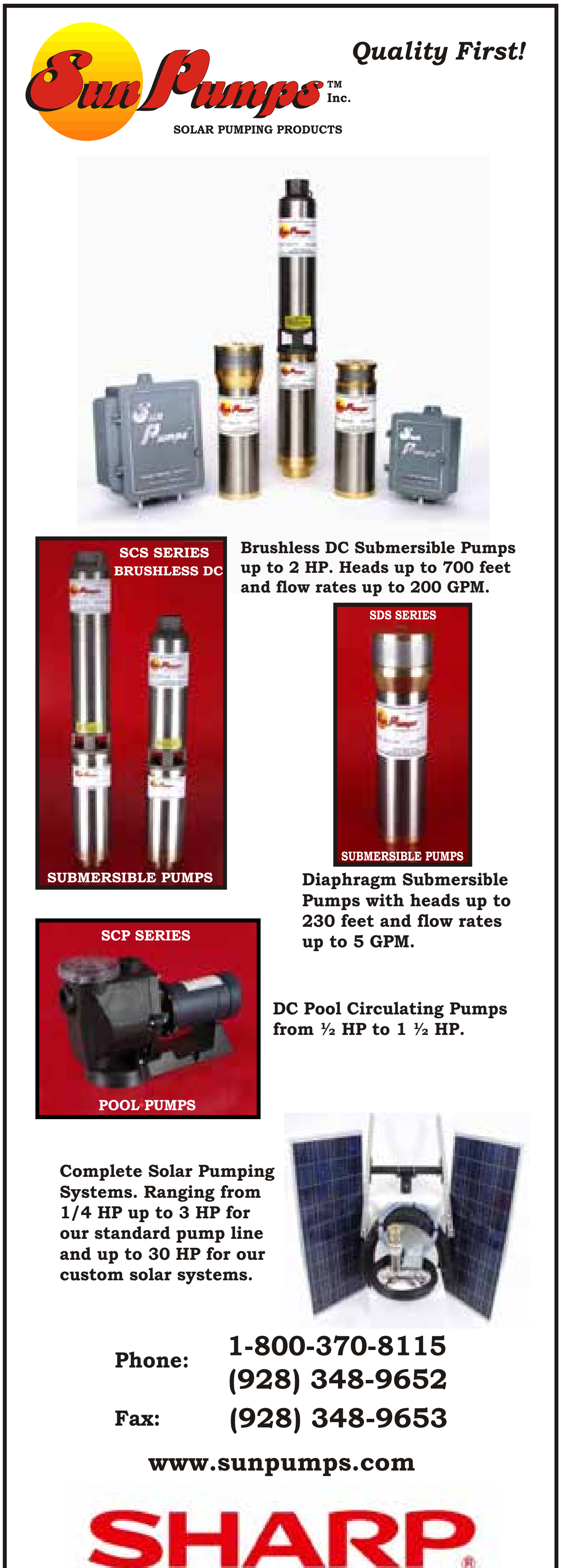
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code corner

Ungrounded PV Systems

by John Wiles

More than 100 years ago, the debate on grounded versus ungrounded electrical systems began. The United States went with grounded, while many other countries went with ungrounded. The PV codes in the United States are now allowing some equipment that is used in other parts of the world.

When we discuss grounded versus ungrounded electrical systems, we are addressing whether one of the current-carrying circuit conductors, like the AC neutral conductor, is grounded or not. Except for ungrounded, three-phase delta-connected transmission and distribution systems, most of our electrical systems in the United States have a grounded circuit conductor. In Europe and elsewhere, ungrounded electrical systems are common. In Germany, ungrounded three-phase AC power at 230 V comes directly into dwellings.

To some extent, most electrical systems in developed counties use a system of equipment-grounding conductors—called protective earth (PE) in Europe—to provide an outer layer of defense against electrical shock from exposed conductive surfaces that could become energized. As in the United States, double-insulated appliances and electrical tools can be found that do not require equipment-grounding systems.

History, equipment, training, and experiences on both sides of the issue show that both systems provide equal levels of safety. As the world grows smaller, IEC standards in Europe are being harmonized with the standards developed by Underwriters Laboratories (UL) here in the United States—and the codes are slowly adopting similar requirements and allowances.

Impact on PV System Design

Since 1984, when PV requirements first appeared in the *National Electrical Code,* PV systems installed in the United States have been required to have a grounded circuit conductor. PV systems with maximum system voltages of 50 V or below were not required to have a grounded circuit conductor. In the *2005 NEC*, Section 690.35 was added to permit the use of ungrounded PV arrays. Ungrounded PV arrays do not have a conductor directly connected to the grounding electrode system like grounded arrays do. The ungrounded systems will still be required to use equipment grounding conductors, though, to provide protection from shock. Typically, these ungrounded PV arrays will operate at 125 V and up, but no specific voltage range or limit is imposed. Of course, Section 690.7 restricts residential PV arrays to 600 V, either grounded or ungrounded.

In utility-interactive PV systems, the inverter is a switching device and filter, with other added control components. The switch reverses the polarity of the DC output from the PV array 120 times per second, generating a 60 Hz wave form that is shaped into a sine wave by the filter. In Europe, 100 switches per second are used to generate 50 Hz.

Because European PV arrays and electrical systems are ungrounded, their utility-interactive inverters are relatively simple compared to U.S. inverters. In the United States, with a grounded circuit conductor from the PV array and a grounded circuit conductor in the AC inverter output circuit, using a direct switching device is not possible—the switch would be shorted as it tried to reverse the polarity of the DC circuit into an AC signal. A transformer is

SMA Sunny Boy 9 kW transformerless inverter.

Microinverter & AC PV Module Details

NEC requirements for microinverters, combinations of microinverters attached to PV modules, and AC PV modules continue to pose some confusion to installers and inspectors alike.

Both microinverters and microinverters attached to PV modules in the field or in the factory that have any exposed DC single conductor cables are required to meet all of the *NEC's* DC wiring requirements. These may include Section 690.5 ground-fault detector requirements, DC and AC disconnect requirements (potentially handled by connectors listed as disconnects), and inverter DC grounding-electrode requirements.

True AC PV modules, as defined on Sections 690.2 and 690.6, have a module and inverter factory-assembled as one environmentally protected unit—there is no accessible DC wiring, so none of the *Code's* DC wiring requirements apply. A single equipment-grounding connection will usually be the only requirement to properly ground an AC PV module.

required in inverters used in the United States to isolate the grounded DC circuits from the grounded AC circuits. The transformer is usually heavy, costly, and bulky—decreasing efficiency and increasing the inverter's size and shipping costs.

With the advent of Section 690.35 of the 2005 *NEC*, ungrounded PV arrays can be installed in the United States, using transformerless inverters now listed to UL Standard 1741. Several inverters are on the market now. So what are these systems going to look like to PV installers and inspectors?

Ungrounded Perspective

Ungrounded PV systems are not significantly different from common grounded PV systems found in the United States: They will continue to have equipment-grounding conductors that will connect the module frames, racks, enclosures of combiners, disconnects, and inverters together and to ground (in Europe, called "earth").

According to *NEC* Section 690.35 (B), DC overcurrent protection (for three or more strings of modules) will be required in both of the ungrounded circuit conductors. PV string combiners will have overcurrent protection in both the positive and negative DC inputs from each string of modules.

The PV DC disconnect will be required in both of the ungrounded conductors (690.35(A)). With disconnects required in each ungrounded circuit conductor, external and internal disconnects will have a switch pole in each of the circuit conductors coming from the PV array.

Ampacity calculations will be the same for grounded and ungrounded systems, and the calculations for maximum system voltage will be the same. The white color code for a grounded conductor *will no longer be used*. It is logical that the color code of red for a positive conductor and black for a negative conductor be used, but there is no *Code* requirement that these colors be used. As before, the module interconnecting cable and other short runs of exposed, single conductor cables will usually have black insulation (for superior UV resistance) with colored markings used for identification.

All exposed, single-conductor cables, including those attached directly to the module, must be the new PV Wire or PV Cable made and listed to UL Standard 4703 (690.35(D)(3)). The USE-2 conductors used in many applications for grounded PV arrays are not acceptable in these systems. Installers and inspectors should be aware that some of the European PV cables, PV wires, or other cables with similar names made for the European market (and even made to UL Standard 4703) may use fine-stranded, flexible conductors. Obtaining suitable lugs and terminals for use where these cables transition to a conduit wiring method may be difficult (see *NEC* 690. 31(F) and *Code Corner 104* for details).

The inverter must be listed and clearly marked for use with ungrounded PV arrays, and it must have an appropriate internal ground-fault detection and indication system (690.35(C)). That ground-fault circuit will not be required to interrupt the ground-fault current (as is required on grounded PV arrays) on an ungrounded system, since there will be no ground-fault currents. The inverter or charge controller will be required to shut down and indicate that a ground fault has occurred.

Access

John Wiles (jwiles@nmsu.edu; 575-646-6105) works at the Institute for Energy and the Environment at New Mexico State University. John provides engineering support to the PV industry and a focal point for PV system code issues.

Southwest Technology Development Institute • www.nmsu.edu/~tdi/Photovoltaics/Codes-Stds/Codes-Stds.html • PV systems inspector/installer checklist, previous "Perspectives on PV" and *Code Corner* articles, and *Photovoltaic Power Systems & the 2005 National Electrical Code: Suggested Practices*, by John Wiles

Learning to Jøtul

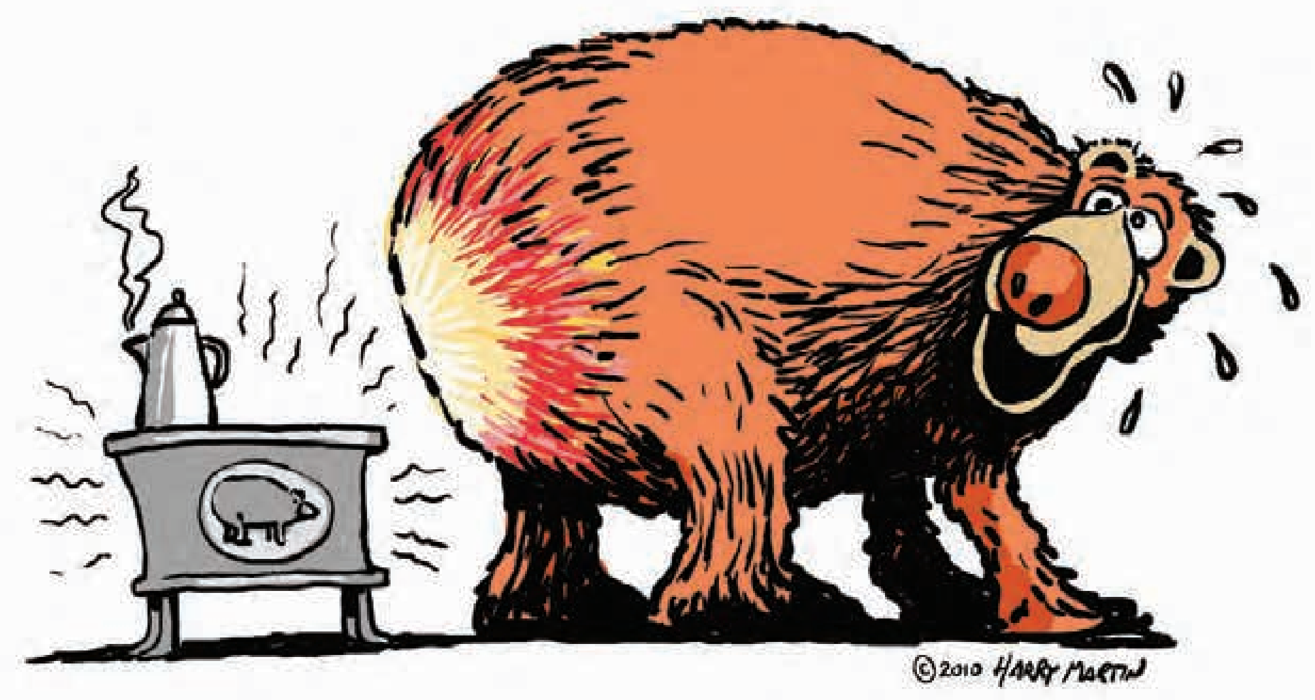
by Kathleen Jarschke-Schultze

Early last spring, my husband Bob-O and I ordered new parts for our 30-year-old wood heater. It was our only source of heat other than the solar gain that comes weakly through the south-facing windows.

After arduous searching, we thought we found a company that would provide new burn plates, which hang on the heater's inside walls and take the brunt of the heat. The old ones were cracked and warped so much they would hang only tenuously, falling off their perch when jostled by loading firewood. The heater has to be cool before the plates can be rehung, so they spent a good deal of the winter propped up against the inside of the heater.

After waiting six months for delivery and not having our phone calls or e-mails returned, we came to grips with the fact that instead of fixing our old one, we would be buying a new heater. But we really liked the old heater: After 20 winters, we were old friends and had no secrets or surprises between us. I could get a roaring fire going fairly quickly and keep the coals all night. My little heat-powered Eco Fan sitting on top of the stove would still be turning its blades, albeit slowly, in the morning. We called our friend, Bill Battagin of Feather River Solar and Stoveworks, and he recommended a Jøtul Black Bear, almost exactly the same size as our old heater.

Eg grev ned min eld—sent om kveld—naar dagen er slut gud gje min eld alder slokna ut.



While I loved the old Waterford, I have to admit that the Jøtul is much prettier. An image of a black bear is cast into the long sides. On the front, the Norwegian words cast into the iron roughly translate to "I built me a flame late one night. When day is done, God will my flame never die out." Heady stuff for a heater. I took it as artistic license.

Fire Tender

We loved the looks of the new heater, but were curious if it could hold a fire all night—an important feature for me, as I would be the one getting up in the night to stoke the stove. I prefer a full night's sleep, uninterrupted by chores. Our wood heater backs up into a brick fireplace, but has its own triple-wall chimney that follows the flue out the top. If the mass of the brick hearth cools, we lose a good deal of heat.

After one particularly cold autumn night, an apprentice for our business mentioned that he had lit the first fire of the season and wanted to know if we had. Bob-O admitted we had. "How long will it burn?" the apprentice asked.

"Oh, if it's up to Kathleen," Bob-O replied, "'til April."

I admit it—I'm a hothouse flower. I do not want to be cold in my own home. This inclination has selected me as the home fire-tender. I bring in the firewood (although Bob-O actually helps me a lot), I clean the ashes out, I start the fires, and I bring last night's coals back to life. Sometimes I chop kindling. With our old heater, having to use kindling to make the heater come alive in the morning was rare. I could stuff it full of wood at night, close all the drafts, and there would be good coals to work with in the morning. It would take some time and effort to get a fire crackling again, but I became very good at it.

Bill installed our Black Bear, instructing me to initially make four small fires—each just big enough to make the outside too hot to touch, with a cool-down period between each fire—to season the cast iron.

It took awhile to get used to the new heater. Jøtul has a non-catalytic, secondary combustion system—which always leaves a small draft in the heater—and burns the fuel differently than the old heater. We had to learn to let the fire die down a little before we stoked it. The Jøtul had the reputation of being a good coal-keeper. In fact, it is so amazing at keeping coals alive that we renamed it "Lazarus"—it brings the fire back from the dead every time.

Warm Winter Jøtuling

We entered this last winter wondering if we would like the Jøtul. I can safely say we love it. We burned the same amount of wood (three cords of seasoned hardwood), but I *felt* warmer. It was a long, cold spring, so it was hard to judge whether the Jøtul burned our wood more slowly than the old heater.

What I do know is that the Jøtul provides steady, continuous warmth. I chopped kindling maybe five times all winter and Bob-O the same. Some of those times were when we had been gone for days and would return to a frigid house. We always bring in kindling and wood right before we leave. Next to the hearth, I keep newspapers in my dad's old olive-curing crock. When we return home, everything we need is at the ready to get a good fire going and begin heating up the brick hearth. It takes a day and a half to warm the mass of brick.

Courtesy Bob-O Schultze

Until December 31, 2010, homeowners can get a 30% federal tax credit for purchasing and installing a wood heater with at least a 75% thermal rating.

When Bill installed our stovepipe years ago, he told us we would never be able to use the fireplace again. We did not mind in the least. Fireplaces are so inefficient, and I imagine them to be quite messy—even messier than having a wood stove in your living room. We've never regretted the decision to modify the fireplace flue.

I would not have thought there would be a lot of new technology in wood heating, but our Jøtul has proven me wrong. The difference between the old and the new was not the size or capacity, but the way it burns the wood so efficiently and provides the coals for the next day's fire. I should have realized the words on the front plaque were not just for decoration, but righteous bragging about a really good wood heater. "When day is done, God will my flame never die out."

Access

Kathleen Jarschke-Schultze (kathleen.jarschke-schultze@homepower.com) grew up in the Napa Valley amidst a large, raucous family who always saw life as an adventure to be experienced and enjoyed. Twenty-five years of living beyond power lines with her husband Bob-O has provided that adventure, tempered with growing knowledge, and fraught with humor.

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When Do You Need a Charge Controller?

Morningstar's TriStar MPPT charge controller (45 or 60 amp) is one option for a whole-house RE system.

Whenever you have a charging source (solar-electric system, or hydro, wind, or engine generator) connected to the batteries, controlling the rate of charge is vital.

Charge controllers protect RE system batteries by managing the amount of energy the battery receives. Overdischarging and undercharging can lead to decreased capacity, early failure, and replacement of an expensive component. Controllers adjust their behavior based on battery voltage. Besides managing the current to the batteries, some controllers can act as load controllers, disconnecting DC loads if battery voltage gets too low. For wind and hydro systems, with outputs that should not be turned off, some charge controllers can be used as diversion controllers, sending excess power to a DC heating element instead of overcharging the batteries.

For smaller systems—such as a battery-powered DC light charged by a single PV module—a basic shunt or series controller may be sufficient. Shunt controllers release excess energy as heat, while series devices act like on/off switches. When battery voltage drops below a preset level, the controller switches on the circuit that allows current to move to the batteries. Pulse-width-modulating (PWM) controllers use rapid electronic switching of input, regulating the energy flow by decreasing the amount of their "on" state as batteries become fully charged.

For residential systems, maximum power point tracking (MPPT) controllers allow the PV array to operate at optimal conditions for optimal production. MPPT controllers turn excess array voltage into usable current for battery charging, offering the most energy increase in cooler temperatures and times of lower battery charge—often the case for off-grid PV systems during the short days of winter.

Sizing a charge controller for a PV array depends on the controller type selected (MPPT vs. non-MPPT). Controllers should be sized by the operating voltage and the current of the charging source and, if it is also a load controller, of the load. To size a PWM, series, or shunt charge controller with load control, the array short-circuit current (Isc), nominal voltage, and the DC load current and voltage are used. For example, a system consisting of a single 80 W module (12 V nominal; Isc = 4.8 A) that charges a 12 V battery and operates a 60 W, 12 VDC light could safely use a 6 A (or higher), 12 V controller with a load control that disconnects the light when battery voltage is too low:

Charge controller: 4.8 A × 1 module in parallel × 1.25 (safety factor to account for high irradiance conditions) = 6 A

Load control: 60 W ÷ 12 V = 5 A

PWM, series, and shunt controllers are typically available in 12, 24, or 48 V nominal, with amperage capacity from 6 to 60 A.

MPPT charge controllers usually do not offer DC load control, since primary loads in residential systems are AC and controlled (and protected from under-voltage) by an inverter. Manufacturers provide maximum PV array voltage and wattage (STC) values on their specification sheets (or offer array string-sizing tools on their Web sites) for MPPT charge controller sizing. Let's say a 60 A MPPT controller's spec sheet shows a maximum array voltage of 150 VDC. The array power the controller can handle depends on the nominal battery bank voltage: at 12 V, the maximum array size the controller can deal with is 800 W; at 24 V, it's 1,600 W; at 48 V, it's 3,200 W. If the array's power capability is higher, look for a higher amperage charge controller, or split the array into subarrays and use multiple charge controllers. MPPT controllers are commonly available in 60 and 80 A.

While a charge controller can help protect batteries, thoughtful system design should account for proper battery sizing. If your loads consistently discharge your batteries, then revisiting the load analysis, battery capacity, and charging requirements might be in order.

—Erika Weliczko