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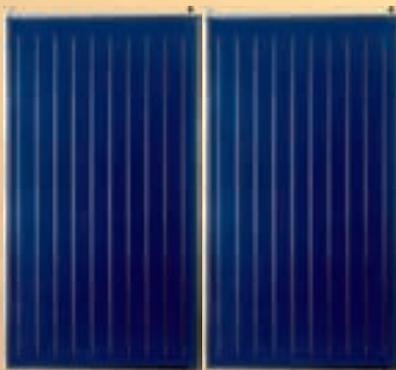
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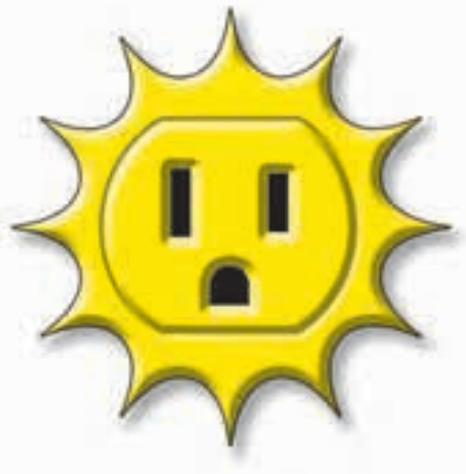
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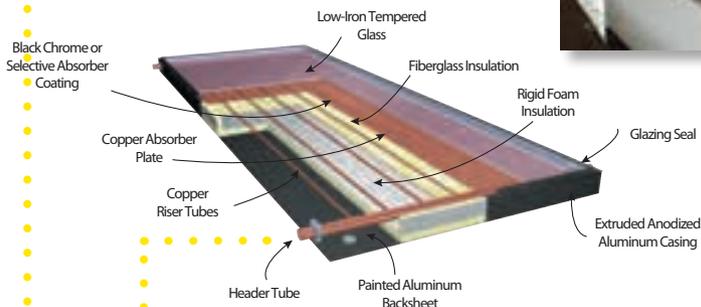
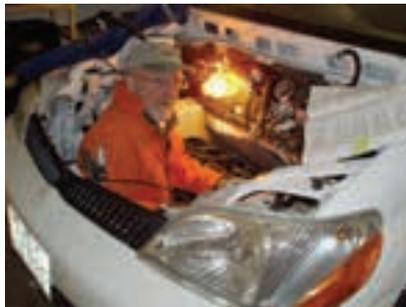
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from us to you

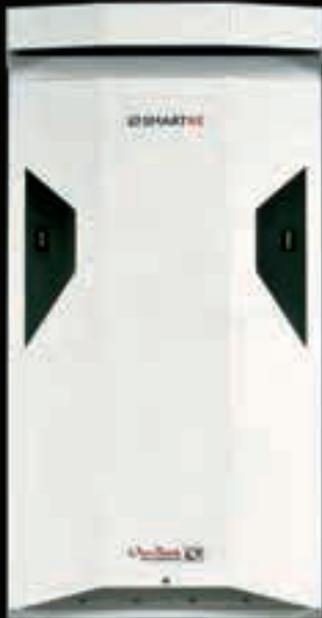
Growth & Development

Over the past 22 years, the cross section of *Home Power* readers has expanded from resourceful off-gridders seeking hard-to-find information to mainstream home and small business owners wanting to become educated consumers of on-grid technology or even seek work in the RE industry. The number of readers has been steadily increasing, into what seems now like a tidal wave of individuals seeking technically focused, expert information on how to design, install, and live with RE systems, and improve efficiency through conservation, technology, and eco-savvy construction.

I have also witnessed this transition as an educator with Solar Energy International (SEI). Years ago, SEI courses were not always full and were mostly attended by DIYers and college students looking for hands-on RE experience. Now, classes are generally filled months in advance and the majority of SEI students are destined for (or already working in) the RE industry. These students do not have the luxury of increasing their RE knowledge gradually, but need detailed RE expertise—and they want it fast. And that's where *Home Power* comes in, providing students and graduates alike with a constant stream of new information on developing RE technologies. Among other newsstand titles, *Home Power's* level of technical focus remains unique—serving the nitty-gritty details to existing and future RE professionals and end users, to keep them on the cutting edge of this rapidly changing industry.

Sometimes I find myself missing those “old days,” when only a handful of us RE geeks discussed the technical details of this PV installation or that wind generator. But I remind myself that this new movement is a fantastic testament to the burgeoning RE industry, one that for decades we have been hoping for. This “renewable energy stuff” is finally catching on, which means there's still hope for a sustainable future after all.

—Justine Sanchez,
for the *Home Power* crew



SmartRE



FLEXpower ONE



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Think About It...

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—Confucius



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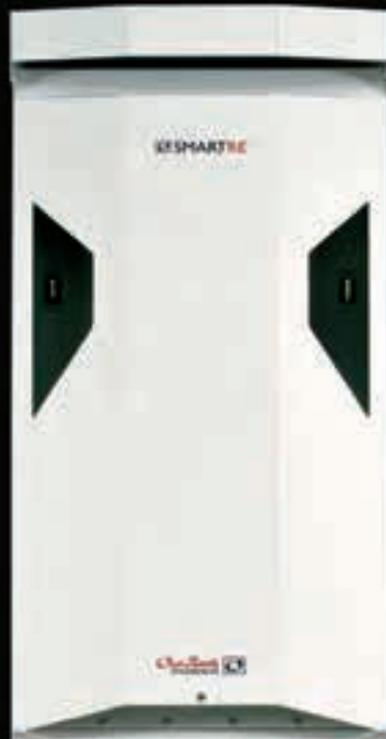
Utilizing the compact design of the FLEXware 250 enclosure, the fully pre-wired FLEXpower ONE system is designed for a quick and easy installation, saving both time and money. Using the new FLEXware 250 mounting plate the FLEXpower ONE system includes a single inverter, two FLEXware 250 enclosures, a single FLEXmax charge controller, a MATE, and a HUB4 in a small footprint. The FLEXpower ONE system also includes the inverter and PV array breakers, PV ground fault protection, an Input-Output-Bypass breaker assembly and either a US type GFCI (Type B) or a EU (Type F) AC outlet with one AC load breaker. The included hanging bracket makes the FLEXpower One easy to install and hides all of the mounting hardware for a cleaner, more professional installation.

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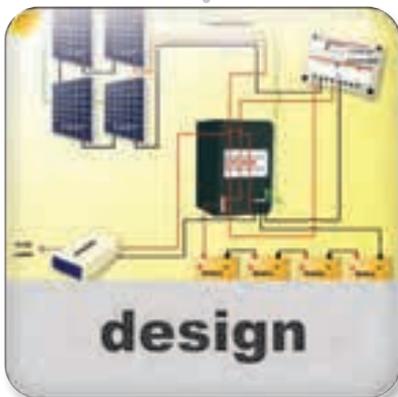
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Cutting Back (with the Joneses)

Last April, Julie Erickson opened what she thought was her family's electricity bill from Connexus Energy. Instead, she found a statement—an energy report card—that compared her home's energy use with that of 100 neighbors in similarly sized homes. Much to her surprise, her family scored poorly in terms of energy conservation, having used more energy than the majority of their neighbors over the past year.

"We thought we were pretty energy-conscious, yet we were on the higher end of consumption among our neighbors. It was a real wake-up call," says Erickson.

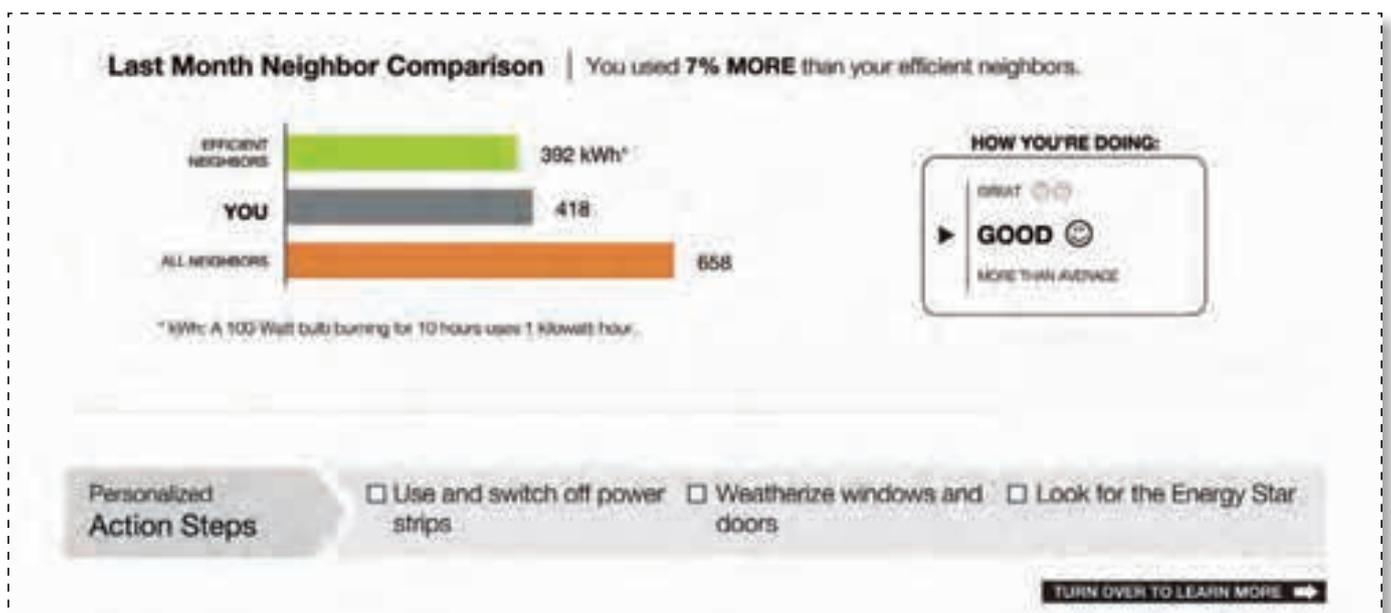
"It's a much more intelligent use of data, yet so incredibly simple...That information alone is resulting in energy savings."

Erickson is one of 40,000 customers randomly selected to receive a customized home energy report as part of a one-year pilot program sponsored by Connexus Energy, in conjunction with the Minnesota Department of Energy Security.

The program—created by Positive Energy, a Virginia-based software company that specializes in energy-efficiency solutions for utilities—takes a "Keeping up with the Joneses" approach to energy conservation, comparing neighbors with neighbors and bringing social motivators into play. The premise is based upon studies conducted by Robert Cialdini, a social psychologist at Arizona State University, whose research indicates that comparing people with their peers is one of the most effective motivators for changing behavior.

Connexus Energy, an electricity cooperative serving portions of the Minneapolis-Saint Paul metro region, is among the first utility companies in the nation to put this nontraditional approach into practice. The Sacramento Municipal Utility District led the way, conducting the first large-scale trial of the program in 2007.

So far, the results have been impressive, with participants saving an average of 2% to 3% more energy than other customers. As a result of Sacramento's initial success, more than 17 other major utilities nationwide are scheduled to implement similar programs in the next year.



Courtesy: Positive Energy

“Our goal for the next 12 months is to save enough energy to completely power 50,000 homes, and over the next five years, to take that number up to 500,000—by simply providing better information and helping people make small and easy adjustments to their daily habits,” says Alex Laskey, cofounder of Positive Energy.

Connexus is currently running several energy-efficiency pilot programs to determine which ones will prove most effective in meeting state-mandated conservation targets that require utilities to cut their customers’ consumption by 1.5% annually beginning in 2010. The home energy report program is among the most promising, according to Bob Saylor, manager of conservation and improvement for the utility.

“I remember looking at the graph and thinking, ‘Our neighbors are down here, and we’re up here. We need to do better.’”

Since the program rollout in February 2009, Connexus customers who received the reports have reduced their energy use by 2% more than those who did not. Saylor says no other program, aside from promoting the use of compact fluorescent bulbs, has proven as successful in reducing energy use or as cost-effective. The program, he says, costs only \$10 per customer annually, or roughly 5 cents for every kWh saved, compared to \$1 for every kWh saved from rebates for energy-efficient appliances.

“It’s a much more intelligent use of data, yet so incredibly simple. All we’re doing is sending out a piece of paper showing people how much energy they use compared to their neighbors and customizing the energy-efficiency tips to be more relevant to each household,” Saylor says. “That information alone is resulting in energy savings.”

Only halfway through its first trial year, a third-party assessment of customer feedback is underway. Barring any major hiccups, the utility intends to expand the program to its entire customer base in the next few years.

“We’re banking on customers wanting to one-up each other,” Saylor says. “It’s the American way, and it just might be the key to reducing our nation’s energy use.”

Erickson and her family are proof positive that a little healthy competition can work wonders.

“I remember looking at the graph and thinking, ‘Our neighbors are down here, and we’re up here. We need to do better,’” Erickson says. “It definitely got the point across and goes to show that peer pressure can still get to you at any age.”

Since receiving their first “report card” in the mail, the Erickson household has made some big changes. In addition to switching to compact fluorescent lightbulbs and using power strips to minimize phantom loads, the family installed a geothermal system to cut back on heating and cooling energy use.

A Positive Energy Report Card

Unlike Web-based home energy reporting services that rely on customers logging in to monitor their home energy consumption, Positive Energy’s reports are distributed through the mail in partnership with the utility.

Usage data is supplied by the utility to Positive Energy’s software, which tailors the conservation tips in each household report based on information distilled from public records and third-party marketing research. It also takes into account other factors, such as whether the customer rents or owns the home, or whether the house is heated by natural gas or electricity.

The reports—which arrive in the same kind of envelope that the utility uses for its official bills and notices—are mailed separately from the bill because studies show that mailers that arrive in the same envelope as bills are usually discarded without being read.

The reports show how much energy the average home in the neighborhood uses and how much energy is used by the most-efficient homes in the area. If a customer uses less electricity than their neighbors, they are praised with a row of smiley faces. If they use more, they receive no smiley faces. (Frowns were used initially in a similar program in Sacramento to indicate “below average” performance, but Positive Energy stopped using them after customers became upset.)

Customized Web-based interfaces round out the program, allowing customers to post feedback and learn about energy-saving solutions through the utility’s Web site.



They’ve also been working as a family, Erickson says, to practice energy-efficient behaviors. “Now, instead of leaving their computers on all the time, our daughters put them to sleep or shut them down, and my husband has become absolutely obsessed with unplugging the coffee pot and any other appliance that has a digital clock running all the time,” she says.

With all these changes in place, it’s no wonder that Erickson is anxiously awaiting her family’s next report card from Connexus. “We’re hoping,” she says, “for a smiley face or two.”

—Kelly Davidson

The View & The Vision: DENMARK 2005

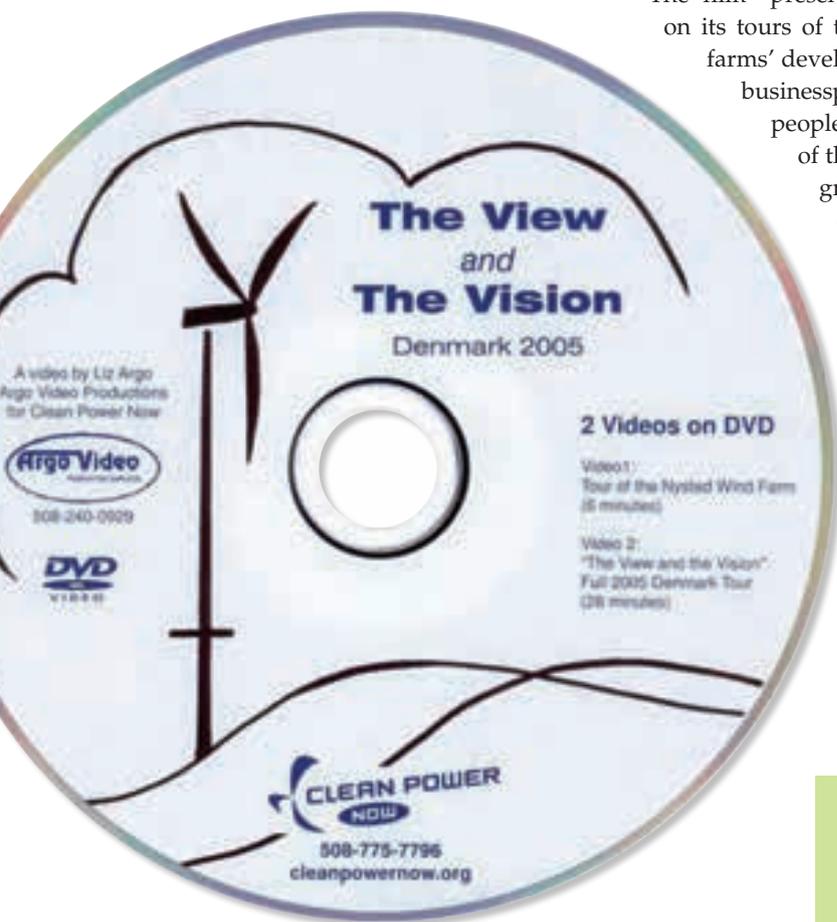
On Cape Cod, Massachusetts, the biggest energy story for nearly a decade has been the Cape Wind Project, the proposed offshore wind farm in Nantucket Sound (www.capewind.org). A number of groups and prominent figures have fought the project for years, saying that the installation would hurt wildlife, fishing, and tourism; spoil the beauty of Nantucket Sound; and interfere with airplane and marine radar.

Objections to the project inspired an enterprising group of Cape Cod residents to travel to Denmark to observe comparable offshore wind farms in Nysted and Blavand. Clean Power Now, a local nonprofit organization in Cape Cod, and Argo Video Productions spearheaded the trip and a film—*The View and The Vision: Denmark 2005*—that documents the group's journey and details how wind farms quite similar to Cape Wind's proposed project actually play out over time.

The film—presented in six- and 28-minute versions—follows the group on its tours of the wind farms and examines the issues surrounding the farms' development through a series of interviews with local residents, businesspeople, and government officials. As the film reveals, the people of Nysted and Blavand had reservations similar to those of the Cape Cod residents, but their objections turned out to be groundless. Over time, the wind farms have become sources of pride for the communities.

A DVD of the film, which has been shown at eco-film festivals nationwide, is available for free from Clean Power Now (508-775-7796; www.cleanpowernow.org).

—Ian Woofenden



Cape Cod Wind Update

Energy Management Inc., the company behind the Cape Wind Project, is nearly through all the legal hoops and is likely to begin installing the wind farm in the coming year. With a peak capacity of 420 megawatts, 130 turbines will supply electricity for 120,000 homes.



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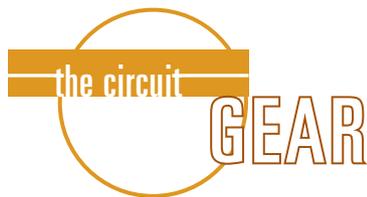
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Tigo Energy PV Module Maximizer & Maximizer Management Unit

Tigo Energy (www.tigoenergy.com), based in Los Gatos, California, is among a new wave of distributed maximum power point tracking (MPPT) PV system architecture providers and is set to release its Module Maximizer (retail: \$56 for each PV module) this fall, with UL listing pending. Installing a unit on a module optimizes the peak power performance of that module, and can help reduce losses due to partial array shading and module performance differences. The Maximizer allows modules of differing types and set at different orientations to feed the same grid-tied string inverter—without compromising system performance. Optionally, PV modules can be individually monitored with the Maximizer Management Unit (retail: about \$1,000). Tigo Energy's Web-based system monitoring allows installers and end users to access system performance from any Internet-connected computer. The MMU comes with a five-year Internet data-hosting contract (for an additional \$350 after a free six-month trial period).

Both the Module Maximizers and MMU can be installed on new or existing systems. Systems with existing inverters call for a series-string configuration using the MM-ES Maximizer. New systems will have the option of using a parallel configuration with the MM-EP, where the module maximizers create both a positive and negative array bus. For maintenance or emergency situations, the parallel configuration allows each module to be electrically shut down by either a safety button on the MMU or remotely over the Internet, reducing the danger of exposure from several hundred volts DC down to the open-circuit voltage of one module. Inverter manufacturer Kaco New Energy has collaborated with Tigo Energy to offer an inverter designed to optimize the benefits of the MM-EP, basically removing the MPPT hardware from the inverter and allowing the maximizers to perform this function instead. According to the manufacturer, the decreased cost of the inverter can offset much of the cost of adding Maximizers to the PV modules.

—Justine Sanchez



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KD205GX-LP \$603.00 \$2.94/watt
KD180GX-LP \$529.00 \$2.94/watt
KC135GX-LP \$397.00 \$2.94/watt
KC85T \$389.00 \$4.58/watt

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Sharp

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ND-224UC1 \$715.00 \$3.19/watt
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STP270-24/Vb1 \$807.00 \$2.99/watt
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Sanyo

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Our Price: \$935.00 \$4.35/watt

*Pallet pricing

Products



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M190-72-240-S11

Our Price : \$ 192.00



Outback Flexmax 80

Charge Controller

Our Price : \$ 580.00



Morningstar SunSaver

SS-MPPT-15L Charge Controller

Our Price : \$239.00



Southwest Windpower

Air-X Land 12V Wind Turbine

Our Price : \$699.00



SMA SB 7000US

7000W inverter

Our Price : \$4,108.00



Xantrex XW6048-120/240-60

Hybrid Inverter Charger

Our Price : \$ 3,488.00

Batteries

Deka/MK Battery 8G8DLTP-DEKA Gel
Surrette S-530 Deep Cycle Battery
Concorde Battery PVX-2580L
Trojan Battery T105

VOLTS/Ah	OUR PRICE
12V 225Ah	\$559.00
6V 400Ah	\$372.00
12V 255Ah	\$862.00
6V 225Ah	\$160.00

Charge controllers

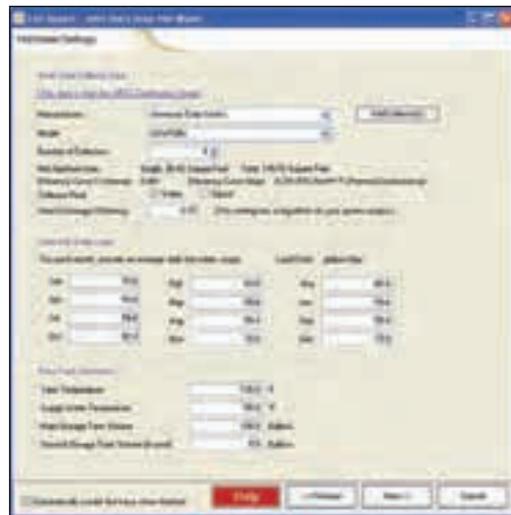
Xantrex XW Solar Charge Controller
Xantrex C35 Charge Controller
Apollo T80 Charge Controller
Blue Sky Energy Solar Boost 6024HDL w/Display
Morningstar TriStar TS-60 Charge Controller

AMPS	OUR PRICE
-	\$557.00
35A	\$104.00
80A	\$657.00
60A	\$583.00
60A	\$202.00

Pathfinder SHW Upgrade

The Solar Pathfinder (www.solarpathfinder.com), long an industry favorite as a solar site analysis tool, just got more useful for solar water heating designers and installers who want to estimate a system's performance at a particular site. The company's new software—a thermal module plug-in—interfaces seamlessly into the Pathfinder Assistant 4 software, providing information on more than 200 solar hot water collectors from the Solar Rating & Certification Corporation's OG-100 Standard catalog. Selecting a collector from the list automatically gives the collector's specifications, and aperture area, Y-intercept, and slope are integrated into the program. Data can also be entered manually for unlisted collectors. Entering other information, such as tank volume, azimuth, tilt angle, and tank and supply water temperature, allows the Assistant to calculate a performance estimate for the proposed system. The thermal module retails for \$49—and is in addition to the base Assistant program (\$149).

—Chuck Marken

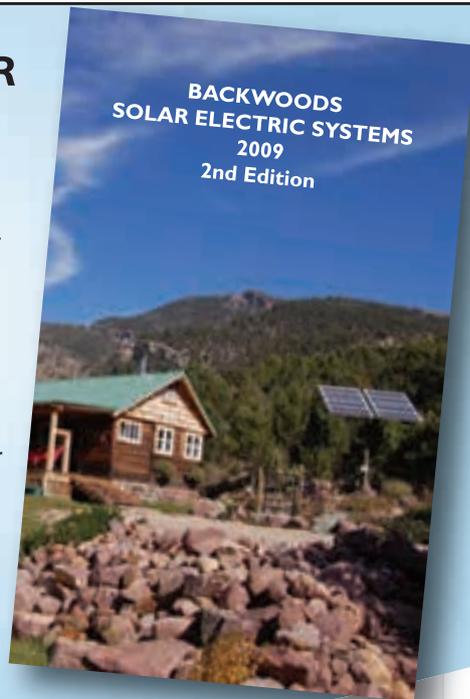


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EnerWorks HX & Insulated Line-Set

EnerWorks (www.enerworks.com), a Canadian solar water heating manufacturer, has added two options to its product lineup: a new double-wall heat exchanger for its Energy Station and a new flexible bundled line-set. The double-wall heat exchanger has been developed to comply with the regulations of some jurisdictions in United States and Canada. For areas where this is not a regulatory requirement, EnerWorks offers its standard single-wall heat exchanger. The company also offers small-diameter insulated tubing, with a temperature sensor and sensor wiring, for connections between SHW collectors and the pump station. The 50-foot and 75-foot sets come with “quick” connects on both ends to cut installation time.



Courtesy www.enerworks.com (2)



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Energizing Education

With back-to-school time upon us, *Home Power* applauds a few initiatives that are empowering the next generation with a positive RE outlook.

Solar Schoolhouse

www.solarschoolhouse.org

Started in 2000 by the Rarus Institute, a California-based nonprofit research organization, the Solar Schoolhouse (SSH) is spearheading renewable education for educators. The organization hosts one-day workshops where teachers can learn to build solar-powered fountains, set up a solar derby with miniature solar-electric cars, and design model homes using passive solar strategies and solar-electric principles.

In SSH's one-day Solar Primer workshops, teachers learn basic solar concepts by building miniature power stations and wiring PV modules—projects that can be easily replicated in most classrooms. In the five-day Summer Institute training session, participants learn how to integrate solar concepts into their curricula and tackle hands-on projects like building solar cookers and solar fountains. Educators have come from as far as Israel to take part in the program at Walker Creek Ranch in Petaluma, California.

SSH's signature workshops are an extension of the organization's DVD and books. The *Your Solar Home* series and *Teaching Solar* lessons include easy-to-follow instructions for activities ranging from building a pizza-box solar oven to organizing a "Solar Olympics."

SSH also has partnered with Solar Energy International and SMA America to present PV design and installation workshops at environmental outdoor schools throughout California. During this weeklong, on-site program, participants install a grid-tied solar-electric system at the host school.

The KidWind Project

www.kidwind.org

Michael Arquin didn't need a weatherman to know which way the wind was blowing. After teaching sixth-grade science in California, Arquin grew dissatisfied with the cost and quality of teaching materials for energy education. So, in 2004, after studying on a fellowship at Tufts University's Wright Center for Science Education, Arquin struck out on his own.

KidWind began as a Web site offering free lesson plans and other wind energy project ideas for educators. Then, in the fall of 2004, from Arquin's basement office and with a \$1,000 startup investment, KidWind started developing

and selling wind energy kits online. Now based in Saint Paul, Minnesota, Arquin has added other RE kits, and uses the revenue to support community outreach programs and workshops for elementary and secondary education teachers. Budget-strapped educators also can apply to win kits through a giveaway program. Beyond the classroom, KidWind offers educational tools and materials for science fairs, hobbyists, and professionals.

Wisconsin K-12 Energy Education Program (KEEP)

www.uwsp.edu/cnr/wcee/keep/

Wisconsin's state motto is "Forward," and nothing more aptly describes the future-looking vision of "America's Dairyland" than its K-12 Energy Education Program (KEEP), funded by Focus on Energy, a public-private partnership supplying energy information and services to utility customers throughout the state.

KEEP's primary initiative is the Focus on Energy Schools Program, which sponsors development courses for educators, opportunities for faculty to network with energy professionals, and student activities that allow kids to get their hands dirty and minds working. The program also facilitates energy audits for schools and helps them secure the funding to implement energy improvements and upgrades. In its 14 years, KEEP has reached thousands of teachers and more than 200,000 students.

Among the program's most successful and imitated activities is the annual Solar Olympics, where students from across the state compete in contests ranging from the best solar cooker to solar Q&A. The program's annual Energy Bookmark Contest combines art and energy: fifth through seventh graders design bookmarks that exemplify an energy theme, like that of the 2009 contest—"Energy Superheroes: The Quest for an Energy-Efficient Planet." Other competitions, including an international electric vehicle race and student builders of the year, target construction and technology students.

—Kelly Davidson

The nonprofit Redwood Alliance is providing free two-year subscriptions to *Home Power* magazine specifically for K-12 school libraries. School librarians can apply at www.hpmag.org.



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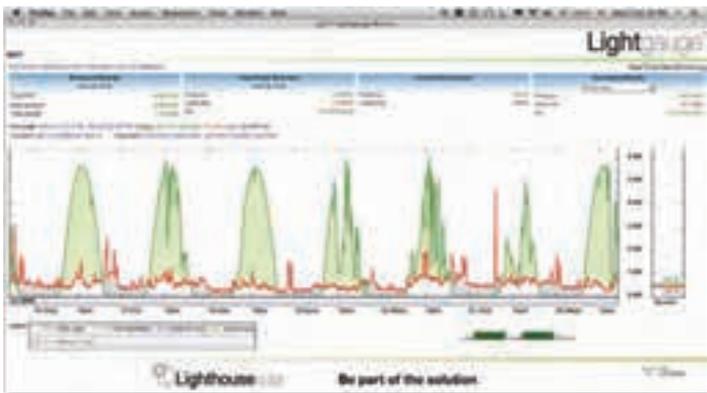
CONERGY

Net-Zero Energy Home ...with Data Monitoring

When architect Michael Kracauer decided to design his carbon-neutral home, he knew it would include renewable energy. What he didn't anticipate was what the PV system would reveal about his electricity use.

Kracauer's PV installation also included Lightgauge, a real-time data monitoring system based on eGauge—one of several online data monitoring solutions that give real-time visibility into renewable energy system performance. Attached to the utility service entrance into the home and the inverter output (or other devices being monitored), Lightgauge measures electrical flow through household and system wiring via current transformers. The software simultaneously monitors the PV system's production and the home's electric consumption and presents the information through a user-friendly computer interface.

“By making the electricity consumed in your home or business visible in real-time, the abstract understanding of electrical usage becomes tangible—and manageable.”



Courtesy Lighthouse Solar

The data monitoring system takes readings every second to log real-time performance data, with a capacity of up to 30 years' worth of information. Users access the information via the Web or a local area network. The Web page displays real-time PV system performance, the home's actual consumption, total PV-generated energy, kWh purchased from the grid, pounds of carbon dioxide offset, and carbon-savings equivalencies presented in "miles not driven" and "trees planted."

For Kracauer, the data monitoring system went beyond interesting—it also resulted in some lifestyle changes. "I was shocked by the load the electric dryer put on the system and the heat it added to the home," he explains. "So I bought a clothesline to use instead—my solar-powered clothes dryer."



Courtesy Lighthouse Solar

This kind of reaction is exactly why data monitoring systems are gaining popularity with end users and installers alike, and why Lighthouse Solar now includes them with all the systems the company installs. Scott Franklin, president of Lighthouse Solar, explains, "By making the electricity consumed in your home or business visible in real-time, the abstract understanding of electrical usage becomes tangible—and manageable."

—Topher Donahue

PROJECT: Kracauer residence

System: Residential grid-direct PV

Installer: Lighthouse Solar, www.lighthousesolar.com

Date commissioned: September 2008

Location: Boulder, Colorado, 40.02°N

Solar resource: 5.5 average daily sun-hours

Array size: 7.2 kW STC

Average annual production: 10,434 kWh AC

Average annual utility bill offset: 100%

EQUIPMENT SPECIFICATIONS

Modules: 36 Sanyo HIP-200BA3, 200 W STC

Inverter: Sunny Boy 7000

Array installation: Flush roof-mounted with UniRac SolarMount Standard Rail mounts to S5! clips to a standing seam metal roof oriented at 171° (west of south) at a 30° tilt

Web Extra: For more information on online system performance monitoring, see our article on "Monitoring Grid-Tied PV Systems" at www.homepower.com/webextras



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Shown with inverter (sold separately) and optional remote, DC breakers, and backplate.

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The new MMP is an inclusive, easy-to-install panel designed to work with one Magnum MS-AE, MS, RD or other non-Magnum inverter/charger.

Features:

- **Small footprint:** only 12.5" wide x 18" tall x 8" deep
- **Money-saving design:** not only is the MMP less expensive, but it is pre-wired for fast installation, saving labor costs
- **Easy access:** front-mounted breakers and remote (optional)
- **Choices:** can be wired for 120 VAC or 120/240 VAC output
- **Inclusive:** works with non-Magnum inverter/chargers (stand-alone parts included)
- **Listed:** ETL listed to UL1741 and CSA C22.2 107-01

Includes:

- One DC breaker – 175A or 250A
- One AC bypass breaker – 30A dual pole or 60A single pole
- One AC input breaker – 30A dual pole or 60A single pole
- 500A/50mv DC shunt
- DC buss bars for battery positive and negative
- Din rail for optional DC mini breakers – will hold up to six breakers

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Justine Sanchez

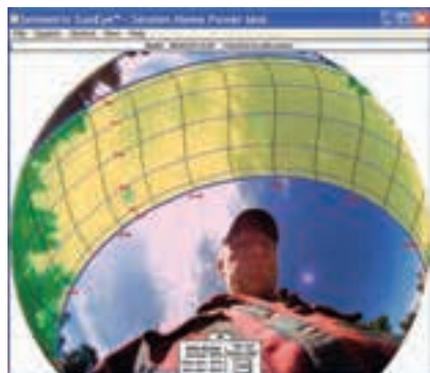
The first step in PV system design is to conduct a solar site analysis to determine if your site is a good candidate for a solar array. Typically, designers strive for placing systems in a wide-open, shade-free solar window from 9 a.m. to 3 p.m. But even the best plans go awry: A neighbor puts on a two-story addition, small trees grow into big trees...and shade happens.

Shading is a more prevalent occurrence in grid-tied PV systems, for two main reasons. First, the majority of these systems are located in urban and residential settings, where there are lots of nearby obstructions, such as trees, power poles, and other buildings. Second, because these systems are generally offsetting utility electricity usage—not acting as the sole power source—shading effects are less noticeable. If your system isn't producing optimally, your only indication

Once you've entered the remaining system parameters, such as array size and orientation, PVWatts generates estimated production figures that incorporate the shade factor.

would be a slightly higher electricity bill. In an off-grid system, shading's impact is more immediately noticed and tangible—if the PV system's production cannot adequately charge the batteries, the inverter may shut down due to low battery voltage and/or the generator may come on more frequently.

Strategies for dealing with shade depend on the *amount* of shade. For example, if the site is shaded for several peak sun-hours and the shade is unavoidable, then a solar array may not be an appropriate power source for the location (see "Solar Site Assessment" in *HP130*).



Solar access values can be used to adjust system output expectations.

But what about other situations, such as a site that gets only minimal shading, say for an hour during the prime solar window? The first and simplest step is to use the "shade factor" feature of a solar site assessment tool to estimate the system's performance. For example, if the Solmetric SunEye tool reports an annual solar access value of 81%, you can include this value in the PVWatts system derate factor to estimate annual system output. Multiply the default derate—0.77—by the tool's solar access value to get an adjusted derate factor. Once you've entered the remaining system parameters, such as array size and orientation, PVWatts generates estimated production figures that incorporate the shade factor. Then you can either live with it, or increase the array size to make up the difference, but only if additional modules are unshaded.

Another possibility for dealing with partial shading is to consider a system that uses distributed MPPT system architecture, such as the Enphase Energy microinverter approach (see *HP129*), Tigo Energy's Module Maximizer (see page 16), or National Semiconductor's SolarMagic Power Optimizer. Installed on each module, these products can help keep shaded modules from compromising the rest of the array's power output. Some of these products can have additional benefits as well, such as allowing systems to use different-sized modules, or modules or strings in different orientations within the same array, without compromising system efficiency. Some have individual module monitoring options to help pinpoint underperforming modules.

These new products are a hot topic in the solar industry, especially when discussing increased system costs versus benefits and long-term reliability, yet some PV professionals are already singing their praises, especially in terms of mitigating the effects of shading.

While partial shading is not an ideal situation for any PV array, solar site assessment tools used to calculate realistic system output expectations, along with some new PV technology, are helping address shading issues.

—Justine Sanchez

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LAMINATE HEAT ISSUE

I enjoyed your article reviewing thin-film and crystalline solar-electric technologies in *HP127*. However, a major consideration that may result in a net energy loss was overlooked. [Here in south Florida,] the dramatic increase in grid-tied customers with air-conditioning has changed our thinking. In most cases, air-conditioning represents 60 to 75% of the home's annual energy consumption. It takes about 1,250 watts of PV to offset just 1 hour of a high SEER, 12,000 Btu (1 ton) air conditioner's operation. Most homes have a 2- or 3-ton unit, cycling most of the day.

A roof with an array of modules, plus a ventilated air space underneath the array, realizes as much as an 80% reduction in required air-conditioning compared to a roof without an array of solar-electric modules. The "heat-shield" results in a significant "negawatt" gain on a daily basis, in addition to the electricity production. Thin-film arrays laminated to a roof surface essentially create a black solar-absorbing roof, potentially requiring more air-conditioning power than can be produced by the array. This is especially true for concrete and asphalt roofs that tend to retain the heat gain.

Bob Williams, Sea Air Land Technologies • Marathon, Florida

FINDING TRUE SOUTH

Your recent article on finding south ("Finding True South," *HP131*) overcomplicates the issue. Most media in most locales publish the hour and minute of sunrise and sunset. Subtract the former from the latter, divide by two, and add the result to the former to find the hour and minute of local high noon.

Select the appropriate corner of your house (any vertical object that will cast a shadow at the location of interest) and, precisely at the hour and minute of high noon, mark a convenient spot up the shadow line from a comparable point on the shadow line at the bottom end. Voila—you have the line of true north.

But if perchance you are sun-starved in Seattle, near or north of 66.5° latitude in the northern hemisphere around December 21, or have a burning desire to determine true north in the middle of the night, you may have to do it the hard way.

Robert R. Bullard, P. E. • New Smyrna Beach, Florida

OFF-GRID TRACKING

Justine Sanchez did a nice job with the tracking article in *HP131* ("Tracked PV Array Systems & Performance"), but left out one of the key reasons for off-grid tracking. If you live in the Southwest and want to avoid running a generator, a tracker is one way to accomplish this. Last winter, we had seven days that the sun came out between 8:30 a.m. and 10:30 a.m.—which gave us enough energy to charge our batteries. There were several late afternoons that provided good sun for a few hours, at a time when a fixed array would not reap the energy.

In summer, we run a small split-type air conditioner unit in the evenings. Our tracked array points at the sun until 7 p.m.—just when we need it to. Living off-grid is a challenge. But once you track the sun, there is no going back.

Dave Angelini • Mariposa, California

NO CAPACITY CAP ON TAX CREDIT

In the *HP131* article on the economics of renewable energy ("Money Matters: Does an RE System Make Economic Sense?"), I read, "For systems under 10 kW, the federal government offers a 30% tax credit to homeowners and businesses, with no cap." I believe that the 10 kW limit mentioned here is incorrect. There is no cap on PV system size. For reference, see Section 25D in Title 26 of the U.S Internal Revenue Code: "Residential energy efficient property."

Chris Carbonella, Whidbey Sun & Wind • Coupeville, Washington

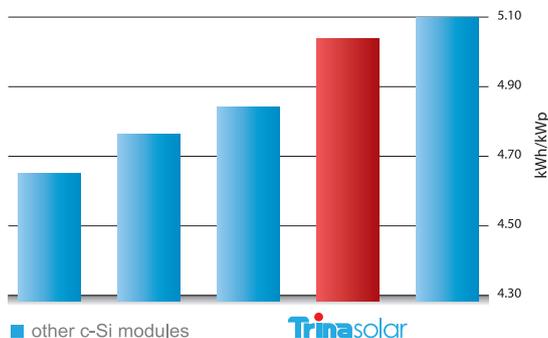
Thanks for that clarification, Chris. To read the full text of that section, visit the Database of State Incentives for Renewables & Efficiency at www.dsireusa.org/documents/Incentives/US37Fa.htm.



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SOLAR BOAT

My friend and I built a solar-powered pontoon boat at our college in southwest Florida. All materials and cash were donated. We raised all the money, and of course, put all the pieces together.

Our boat is a 2003 Crest pontoon boat (22 feet long; 8 1/2 feet wide) that is now powered by a solar-electric array. Although we haven't had a chance to test its limits yet, from early runs, we feel confident we can get 6 to 8 hours of run time using nothing but solar-generated electricity.

The array canopy stands 7 feet above the deck of the boat and is 10 feet long by 8 feet wide, with six BP Solar 175-watt modules. OutBack Power Systems' MPPT controller controls charging to our five 12-volt, 105 amp-hour AGM batteries.



Courtesy Matt Coalson

A Whisper XT outboard brushless motor propels the boat, using neodymium boron iron magnets, which produce more power than standard magnets, and at a higher rate of efficiency.

Now that we've built our boat, we're showing it off. We were in the Fourth of July parade with our boat in Naples, and when school starts this fall, we'll be demonstrating the technology to kindergarten through twelfth-grade students.

Matt Coalson • Naples, Florida

NOT-SO-SMART RFI

In the "Making the Connection" sidebar of the "smart grid" article in *HP132*, Mark Hazen describes BPL (broadband-over-power lines), which is also referred to as PCL (power line communication), in this way: "This technology rides over the power grid without polluting the air with radio frequency interference."

This is exactly what the BPL manufacturers, some utilities, and the Federal Communications Commission would want you to believe. Nothing could be further from the truth. Widespread interference is one of the well-documented problems that continue to plague this technology. There has been interference to police, fire, amateur radio, and other services. It can and does interfere with very low-output wireless radio devices used in homes and businesses. Unfortunately, our government touted this technology as a silver bullet without understanding or listening to good science and research.

The G2 or G3 technologies are much better suited to provide the needed communications required for the "Smart Grid." More can be learned about this at www.arrl.org/tis/info/HTML/plc.

Steven B. Handy •
Kekaha, Kauai, Hawaii

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Ask the EXPERTS!

Battery Woes

I have three parallel strings, each consisting of two Trojan T-105 batteries, in an off-grid, DC-only application (see *HP75*, page 21). The battery bank has never been discharged more than 100 Ah, and is usually fully charged the next day. Although the batteries once went 10 weeks without having water added, the electrolyte was *never* below the top of the plates. However, recently the electrolyte level in the middle pair of batteries was below the top of the plates after being topped off only two weeks before. The level in the other two pairs of batteries had only dropped a very small amount. What accounted for the large drop (about 750 ml each) in the middle pair?

John Surber • via e-mail

The middle pair of batteries is sick, very sick. As lead-acid batteries age, their internal resistance grows because of plate sulfation. This process progresses at a different rate in each 2-volt cell. The more series strings that are paralleled, the more difficult it is to evenly charge each cell throughout the pack.

With so many paralleled cells (six in each string), cell sulfation can occur (often in the middle of the pack), while adequate charge is maintained on other portions. In this circumstance, I suspect that the middle string of the battery bank experienced one or more of three effects:

- The middle pair has cells that are significantly sulfated, so as the pack charged they gassed considerably more than the remaining two battery pairs.
- The interconnects became corroded, leading to further unequal charge rates. (It could even have been the series interconnects.)
- The outer two pairs are sulfated only slightly less than the inner pair, creating resistance in their charge rate that further exacerbates the high rate of resistance—causing heat buildup and gassing of the inner pair. As the bank experiences greater resistance in each of the pairs, all of the cells experience the downward spiral of increasing sulfation and resistance, with the worst effects in the poorest cells of the bank.

Finally, if the pack truly never cycles below 85% state of charge, the pack may actually need *more* exercise. Lead-acid batteries don't like to be discharged fully and then only partially recharged, and they also do not like to be floated at a full state of charge without a regular discharge of 20% to 30%. A smaller pack may be exercised better and perform better, while eliminating some of the interconnects that limit the ability to create an even charge throughout the bank.



Courtesy John Surber

Regardless of the original cause of losing equal charging among the three pairs, the middle pair is clearly resisting charge, gassing rapidly, and wasting charge current while it boils off electrolyte. These 6-volt batteries are compromising the remaining T-105s and are best removed from the bank. When this is done, the remaining T-105s should be discharged and charged to see if they have any useful capacity remaining.

During charging, dying batteries will show rapid voltage rise; while under discharge, they'll show rapid voltage decrease. If this is the case, the remaining T-105s may be dying as well and the entire bank may need replacement. If, however, the remaining two or four T-105s charge and discharge slowly, they can be used until their capacity becomes inadequate. Adding new batteries to these old T-105s is a waste of funds and should be avoided. Use the remaining capacity for now, and replace the entire pack when the old batteries are no longer useful.

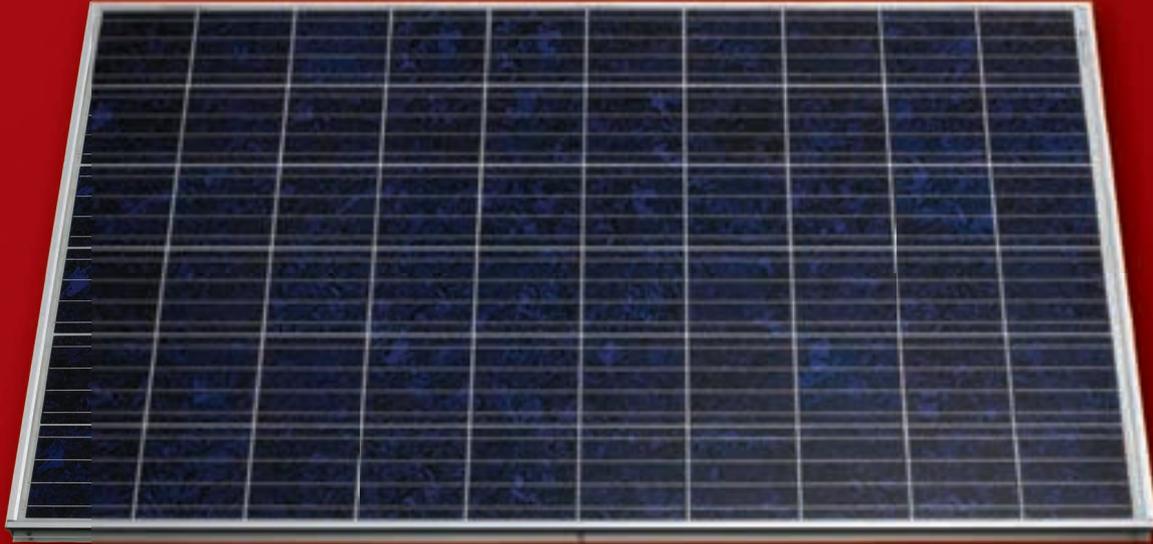
A lingering issue is how to avoid repeating this problem. The main concern is that multiple series strings of batteries put in parallel lead to uneven charge rates between series strings. To avoid this, first try to limit parallel strings by using larger 6-volt batteries (such as L-16s) or large 2-volt cells. Having fewer external series and parallel connections can help equal charging between battery cells. Also, cabling running to and from the battery bank charging/discharging sources should be located at electrically opposite corners of the battery bank for a more equal charge and discharge across the battery bank.

Next, regular, equalizing charges to the entire pack will aid in getting a complete charge to each cell. Finally, rotating batteries within the pack can more evenly distribute the charge between cells and also provides the opportunity to clean interconnects of corrosion and make sure connections are tight. If you think it sounds like getting the longest life from batteries is more work, you have it right.

Christopher LaForge • Great Northern Solar, Port Wing, Wisconsin

“The more series strings that are paralleled, the more difficult it is to evenly charge each cell throughout the pack.”

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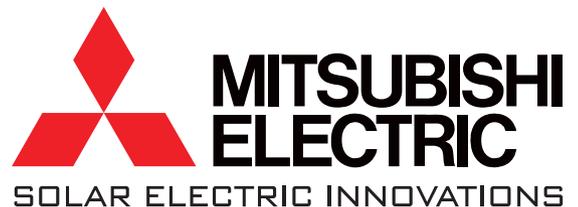
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Solar Heating for a Hot Tub

I have a 250-gallon electrically heated hot tub and want to know if there is a less costly way to heat that water. I also have a home office on my nearby back porch and wonder if the hot tub system could also provide space heating for the office in winter.

James Ball • Stamford, Connecticut

See the photo (this page, at right) of a drainback system installed on a 500-gallon hot tub. This simple system doesn't require any tub modification. The hot tub drain is connected to the pump inlet with a washing machine hose to supply the relatively cold water at the bottom of the tub to the collectors. The hose has a quick disconnect so it can be easily uncoupled for freeze protection. The hot return line is insulated and flows into the top of the tub.

When the pump shuts off (at night or during cloudy weather), air enters the return pipe and all the water drains out of the collectors and back into the hot tub. The March pump used requires the top of the collectors to be within 15 feet above the water level in the tub. The system also could be powered by a higher-head DC hot water circulator pump (harder to find) or an AC-powered high-head pump with a differential control. AC-powered high-head pumps are available in heads up to 32 feet.

The cost of this system was minimal (about \$550) because the owners had purchased a couple of used collectors. Other components included a PV module, pump, a little piping and insulation, and a switch to turn off the pump when the tub gets



Courtesy, Mary McArthur, New Mexico Solar Energy Association

too hot. A new collector and concealed plumbing would cost more—perhaps about \$1,500—to heat a 250-gallon tub. The system could be integrated into a space-heating assist, but the ease of the retrofit would depend on the existing heating system. If the water in the hot tub is maintained at a pH of 7 or above (to protect copper tubing), the system could be easily configured to use a fan-coil unit for heat delivery, which includes a fan and copper tube finned heat exchanger (radiator) to distribute the heat. Myson and McQuay are common trade names of fan-coils.

Chuck Marken • Solar Thermal Editor

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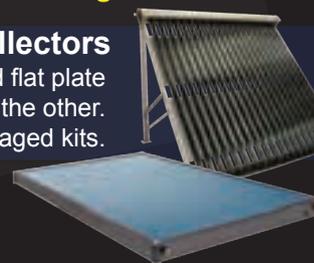
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Chuck Marken

Which Solar Collector?

I am planning to install a solar water heater soon. Reading *Home Power* articles has me wondering which type I should buy. I live in Ohio near the Pennsylvania border, about an hour due east of Cleveland. Peak sun-hours average about 3.8 hours a day here. What's your recommendation?

Frank Carradine • Fowler, Ohio

In a climate like Ohio's, you can expect that a selective surface flat-plate collector and evacuated-tube collector of equal size will produce about the same amount of domestic hot water year-round. But under

more ideal solar conditions, a flat-plate collector will outproduce the evacuated-tube collector most of the year, except during the winter.

Be aware that snow and frost can cause performance drops in evacuated tube collectors. The super-insulation of the vacuum in an evacuated tube collector can prevent snow from melting off the tubes. The sun can penetrate the snow to heat the absorber, but the superior insulation in some tube designs prevents the heat from melting the snow off the glass. There is no independent test data on how much this affects evacuated-tube collectors in different climates but it does mitigate—and can eliminate—the performance advantage of evacuated tubes in areas with large snow loads.

Note the photo (at left) of my home after a snow. The long collector on the left is double-glazed—the industry standard for air collectors in the early 1980s. Toward the back on the right is a smaller, more recently installed collector that's single-glazed and has a selective-surface absorber—the industry standard today. You can see that the snow is already sliding off the collector on the right, while the snow remains on the better-insulated, double-glazed collector on the left. I would imagine the phenomena would be more pronounced with a tube collector since their insulation is superior to double-glazing.

If frost and snow are an issue, which I believe they are in Ohio, I would choose a flat-plate collector. If winter snow or frost isn't a big issue, I would pick whatever collector has the lower cost (making sure to compare collectors of the same size)—unless you have an aesthetic preference.

Chuck Marken • Solar Thermal Editor

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PV Cost

Scientific American's March 2009 issue contains a survey of the status of alternative types of electricity generation. The author estimates the cost of solar electricity at between 46.9 and 70.5 cents per kilowatt-hour (kWh). This seems quite high to me. I have been subscribing to *Home Power* for many years and would be interested to learn your present estimate.

Carroll Swain • via e-mail

The per-kWh cost of PV electricity is calculated by dividing the cost of the complete solar-electric system by the system's energy output over its lifetime. So the cost will vary depending on system size, type, and location. Other expenses include design and installation, maintenance, and financing.

Total system energy output is measured by multiplying the rated power of the modules by the peak sun-hours for the location, and by applying an efficiency factor based on the type of system (batteryless or battery-based). Multiplying this by the PV system's estimated life span (in years) will give the system's estimated total lifetime output.

The calculations in the table are based on a 20-year system life span (which is conservative; other methods for estimating total PV system output use 30 years) and do not adjust for any incentives available. If both of these factors were incorporated, the estimated per-kWh cost would be reduced accordingly. (Also note that the 2 kW system example includes battery backup, which lowers system efficiency and yields a higher per-kWh rate compared to a 2 kW

Typical PV System Cost Per kWh

Grid-Tied System	Cost Per kWh	
	Sunny Climate	Cloudy Climate
2 kW with battery backup	\$0.36	\$0.80
50 kW batteryless	0.26	0.57
500 kW batteryless	0.20	0.45

*Source: www.solarbuzz.com (July 2009 estimates)

batteryless system.) Utility-scale systems produce electricity even more cheaply—a 12.6 MW solar-electric power plant in sun-drenched Nevada produces solar electricity at only 7.5 cents per kWh.

Compare these prices with retail grid electricity. Southern California Edison's prices range from about 10 to 37 cents per kWh depending on the amount used by customers. Peak electricity in California can cost as much as 42 cents to commercial users. Hawaiians pay more than 21 cents per kWh for residential use; commercial customers are charged almost 20 cents per kWh. Hence, in many situations, PV systems today already produce electricity cheaper than the grid. And barring battery or inverter replacement, a solar-electric system is a fixed, up-front investment, while most analysts expect utility electricity prices to continue to rise.

John Perlin • Author, *From Space to Earth: The Story of Solar Electricity*

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Metal Conduit Required?

I want to install a code-compliant, off-grid PV system for backup. My question concerns running conduit through a cinder-block wall. From my reading of the 2008 *National Electrical Code*, metal—not plastic—conduit should be used, although that section of the code is vague. My electrician friends think using PVC conduit should be OK and the building commissioners don't care as long as the PV modules are not mounted on the house or grid-tied.

How do most installers run conduit from one box to another box through cinder block? I am using metal boxes on each side of the wall and want to use 1-inch conduit. The cinder block is approximately 7 1/2 inches thick. I could use standard nipples through the block, but the stock lengths don't accommodate this well. I also thought of using fittings and flexible EMT inside the block to bridge between the two metal boxes. I can cut the EMT to size, but if I use fittings I would have to drill a 2-inch-diameter hole through each side of the cinder block.

Rick Phillips • via e-mail

The wording in Section 690.31(E) of the 2008 *NEC* is indeed vague and contained a typographical error. Code expert John Wiles believes that *all* PV source and output circuit wiring (both for off-grid and utility-interactive systems) should be contained in a metal raceway if run inside a building.

I think you could simply cut your EMT to size and attach your male adapters with locknuts and bushings entering each box. Flexible

EMT would work too, but you shouldn't need a 2-inch hole all the way through the cinder-block wall to accommodate 1-inch EMT. I would think a 1 1/4-inch hole would work. Making a slightly larger opening on each side of the wall would allow you to slide the outer part of the male adapters into the wall for a flush mount.

Justine Sanchez • Technical Editor, *Home Power* magazine

Power Factor Energy Savers?

I've seen a lot of devices advertised to shave your utility bills by correcting the power factor in your appliances. Do power-factor correction capacitors actually save homeowners kilowatt-hours and dollars?

James LaChance • Memphis, Tennessee

For years, numerous companies sold "magic boxes" that plug into the wall and promise to save electricity. In earlier decades, these devices were pure hoaxes. But in recent years, the rip-off artists have devised a better scam—claiming that they use phase shift (PF correction). Both "technologies" primarily perform one task—extracting money from customers' wallets.

A bad power factor occurs when feedback from the windings of electric motors causes a timing shift between AC voltage and amperage waveforms. A bad power factor just makes your kWh meter vibrate a bit as it spins, so it doesn't add any energy to the total amount—the meter is designed to ignore it. It does waste some

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It was a scam when it was a magical power-saving box, and it's still a scam, even if these companies claim that the technology is based on PFC phase shifting. The only truth is that your energy savings remain imaginary, while the profits flowing into the scam companies are real!

Bill Beaty • www.amasci.com

Judging Transportation

I will buy a new vehicle in the next year, and I'm trying to sort through the hype. Can you give me some guidance on how to evaluate passenger cars for their environmental impact? I know that some hybrids are more fuel-efficient than others. And I know that some diesels get very high fuel economy. Then there are electric vehicles. What criteria should be used to make an intelligent environmental transportation decision? Fuel economy? Cost? Carbon footprint? I hope you can give me a sensible approach to this decision.

James Randelli • Charlotte, North Carolina

If you rack up lots of miles each year, then fuel efficiency should be a high priority. In this case, your best option would be a pure electric vehicle (if its range can meet your needs), but none are currently available from major manufacturers. Next best would be a plug-



Courtesy: ShakataGaNai

This Toyota Prius was converted to a plug-in hybrid electric vehicle by www.CalCars.org.

in hybrid electric vehicle (PHEV), which makes a very significant difference in fuel consumption by shifting part of your driving to a different energy source: electricity. If you have a clean electricity source, such as solar, wind, or hydro, that's even better from an environmental standpoint. PHEVs are expected to hit the mainstream market in the near future. After that, a regular hybrid, which gets all of its energy from gasoline, since the gas engine charges the



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batteries, is a good choice. The hybrid takes advantage of the higher efficiency of the electric motor to improve fuel economy. If there is a comparable gas-engine version of the same vehicle, you can compare how much the mileage increases with the hybrid system. Beware, though: A so-called "mild hybrid" doesn't do much more than paste a green label on a standard vehicle.

Another avenue for more eco-friendly transportation would be to buy a diesel vehicle with the intention of operating it on biodiesel or straight/waste veggie oil (SVO/WVO). This requires a little more commitment on your part. For SVO operation, you need to install a special kit in the vehicle. For biodiesel, you need to locate a source of fuel or make your own. Both SVO and biodiesel face some regulatory hurdles, so you should check out the situation in your area before committing to this option. Caution is in order, though: Because of California's clean air regulations, most of the diesel passenger cars being imported to the United States do not achieve the good fuel economy of similar, but older models.

If you drive infrequently, other considerations will carry some weight. I would select a few high-fuel-efficiency vehicles that interest you, then check the manufacturers' Web sites to see what they say about clean manufacturing processes and manufacturing for recyclability. If the vehicle is being built in a new factory, it will almost certainly be built with cleaner processes, and the factory itself will be more efficient in its use of energy. In addition, there are new types of paint that are less toxic, and manufacturers are starting to build with more materials that can be recycled at the end of the vehicle's useful life.

From an emissions standpoint, a pure EV powered by RE produced at your home base, or an SVO vehicle would be cleanest. A plug-in hybrid would be a close second if your battery pack alone can get you most places you need to go. Conventional hybrids and biodiesel-fueled vehicles would be next. They both cover a broad range of emissions, depending on how much of the load is carried by the clean portions of the systems (batteries in the hybrid, bio in the biodiesel).

In all cases, the vehicle you choose should be small and, if non-electric, have a small engine. The bigger the vehicle, the more fuel it will consume. Small engines are "good enough" and appropriate for anyone serious about fuel economy.

Other options include a neighborhood electric vehicle (NEV), electric scooter, or bicycle, saving the car only for trips that really require it. Maybe joining a car-sharing service would meet some of your needs.

You're right: there are a lot of variables, and there is no one best answer for everyone. The good news is there are several options for creative solutions tailored to your needs.

Shari Prange • Transportation Editor

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THE SWITCH

FROM URBAN TO RURAL

by Kelly Davidson



Courtesy: Francie Von Mertens

Homeowners Chris Anderson and Anna Von Mertens (pictured above, with daughter Hayden) made a successful transition from city life to solar living in their off-grid home.

When California-based Borrego Solar Systems decided to open a regional office in New England, Chris Anderson, the company's chief technology officer, jumped at the chance to work in the new office. After more than a decade living in the San Francisco Bay Area, he and his wife, Anna Von Mertens, were ready for a change. The couple had wanted to move back east to be closer to family, and the new office location in Lowell, Massachusetts, was just across the state line from Hillsborough County, New Hampshire, Anna's hometown and where her parents lived.

Years of close-quartered urban abodes had left the couple longing to spread out and build a home that fit their needs and ideals. Not surprisingly, their vision included solar-electric and solar hot water systems. And while living off the grid may not have been on their minds when they went house-hunting, being gifted with 14 acres within a 108-acre parcel that Anna's mother had purchased to save from development changed their plans.

A conservation easement acquired by Anna's mother limited construction on the acreage to a maximum of two homes, protecting all the farmland and forestland from additional development for perpetuity—even under new ownership.

Even with the small-town conveniences of Peterborough, New Hampshire, only miles away, Chris admits that the idea of moving off the grid was somewhat intimidating. Although he was confident that the solar-electric and solar thermal systems could be sized appropriately to meet their needs, the transition from city life to country living was a concern.

The neo-traditional farmhouse's sunroom provides a warm transition from the outdoors.



Courtesy: Chris Anderson

"We were coming from the city, where we had amenities at our fingertips," says Chris, "and now we were trying to figure out what it was going to take to live off the grid. We had to learn the ins and outs of septic systems, evaluate the benefits of well water versus town water, and figure out how to get Internet and phone service."

With power lines a third of a mile from the property, connecting to the grid was an option. And while they liked the idea of feeding excess generation from their solar-electric system back to the grid and capitalizing on the state's net-metering rules, they didn't feel comfortable with the idea of running power lines through the adjacent wetlands. The cost of grid connection—close to \$50,000, including wetlands mitigation and utility work—seemed wasteful as well. Instead, the couple chose to put that money toward outfitting their home for off-grid living.

Chris and Anna enlisted longtime friend and architect Peter Larsen, of San Francisco, to design the home. The couple, who lived in an industrial loft space in Berkeley at the time, had a tall order. They wanted a home that fit the rural site and respected the local vernacular, yet had open, easily configurable spaces. Since they were planning to start a family, they also wanted room to grow—three bedrooms to accommodate a family of four comfortably. The design needed to be reasonably achievable for novice builders as well, since Chris and Anna planned to do much of the work themselves. Plus, the building design also needed to integrate the home's solar energy systems gracefully.

The design premise included a roof-mounted photovoltaic system with a battery bank; a solar hot water (SHW) system for domestic water heating and in-floor radiant heating; and a backup pellet-fueled boiler and propane generator. A large south-facing roof sloped to optimize production from the PV modules and SHW collectors, plus enough utility storage space for all of the requisite RE equipment, were among the key design requirements.

Building the Vision

Determined to have the exterior of the new structure fit in, the couple studied the design of the area's original farmhouses and colonial homes. Together with Peter, they explored various ways to combine the modern and colonial influences, from the basic building shape and roof profiles to fine-scale details and finishes.

Courtesy Chris Anderson



Large, south-facing windows admit solar gain, while the thermal mass in the concrete floors absorbs, stores, and reradiates the solar resource for wintertime heating.

Months of collaboration gave way to a simple design with a two-and-a-half-car garage and a main house, joined by a mudroom and vestibule, and topped by gabled roofs. Though the expansive use of windows on the south side and a standing-seam metal roof may not strictly adhere to the local aesthetic, the profile takes its cues from the area's colonial farmhouses. The exterior appears traditional, with rot-resistant cedar shingles left unfinished to weather naturally.

Inside, the layout and materials are modern. The 1,525-square-foot first floor hosts a great room and kitchen to the south, with a den, half bathroom, mudroom, and laundry room, while the second floor is divided into three bedrooms and two bathrooms, with an additional studio space for Anna, who works from home as a textile artist.

The home's layout was designed for energy efficiency and passive solar gain. Primary living spaces, like the living room and dining area, are laid out along the south side, maximizing

Energy-efficient appliances and cabinets made from locally milled lumber lend to the sustainable design of the kitchen.

Courtesy Chris Anderson



AC-COUPLED SYSTEMS

Most renewable energy systems are DC-coupled, which means power sources, such as a PV array, wind generator, and battery bank, are joined together on the DC side of the system. An inverter is used to convert DC to AC power for any AC loads present.

AC coupling joins the various power sources on the AC side. With a PV system, this technique requires using more than one inverter since DC sources of power are still present and each power source must be converted to AC before they are joined.

The Anderson-Von Mertens off-grid system consists of a PV array that feeds through an SMA America Sunny Boy string inverter. The output of the Sunny Boy inverter is then routed to the AC load center—just as in a batteryless, grid-tied system. This system also uses two SMA Sunny Island inverters to convert 48 VDC from batteries into 120/240 VAC power that also feeds the AC load center.

With this AC coupling setup, the Sunny Island inverters provide AC voltage to the AC load center, effectively “tricking” the Sunny Boy inverter into thinking grid power is available and enabling it to send out power from the array. This power can then be used for powering AC loads that are running and/or be pulled back through the Sunny Island inverters to charge the batteries.

The last power source in the system is the Kohler generator that exports power to both AC inputs of the Sunny Island inverters for battery charging when the PV array isn't producing sufficient power. It also sends power to the AC load center.

Finally, a manual transfer switch allows the AC load center to be fed by the Sunny Boy and the Sunny Island inverters or the backup generator if the Sunny Island inverters fail.

A primary advantage of using an AC-coupled setup in an off-grid system is that high-voltage DC strings of modules can be used, reducing wire-size requirements and, therefore, array wiring costs. Plus, through the use of a string inverter, AC-coupled systems offer improved system efficiency since the array is not directly tied to the battery bank.

—Justine Sanchez

natural light in the most occupied portions of the house. In the winter, large south-facing windows capture solar heat until the late afternoon. On the north side, where the building will lose the most heat and needs protection from winter storms, windows are fewer and smaller. Secondary spaces, such as the closets, mudroom, half bathroom, and laundry room, are also clustered to the north.

On the first level, a concrete floor made with slag (an industrial by-product that replaces some of the portland cement) provides thermal mass for the radiant heating system and passive solar gain, minimizing backup heating needs in the colder seasons. High-density spray-foam insulation fills the wall cavity (2-by-6-inch studs on 16-inch centers), creating an insulating air seal for the entire home. An additional layer of 1-inch rigid foam board

(continued on page 44)

Courtesy: Chris Anderson



The 6.8 kW array was oversized to accommodate future loads. The array strings were configured to minimize the impact of early morning shading from the chimney.

PV SYSTEM SPECS

Overview

System type: Off-grid solar-electric

Location: Peterborough, New Hampshire

Solar resource: 4.6 average daily peak sun-hours

Record Low Temperature: -23°F

Average High Temperature: 79°F

Average monthly production: ~ 600 AC kWh

Percentage of required energy produced by the system: 95%; generator used 8 to 10 hrs. per week during the winter

Equipment

Modules: 42 modules: 27 Sharp 160, 160 W STC, 22.8 Vmp, 7.02 Imp, 28.4 Voc, 7.82 Isc; 15 Sharp 167, 167 W STC, 22.8 Vmp, 7.33 Imp, 28.9 Voc, 8.16 Isc

Array: Three 14-module series strings, 6,825 W STC total, 319.2 Vmp, 21.4 Imp, 400 Voc, 23.8 Isc

Array combiner box: Three strings run into fused DC disconnect, paralleled in wiring gutter before inverter

Array installation: Unirac SolarMount Light Rail, installed on south-facing roof (15° east of south), 45° tilt

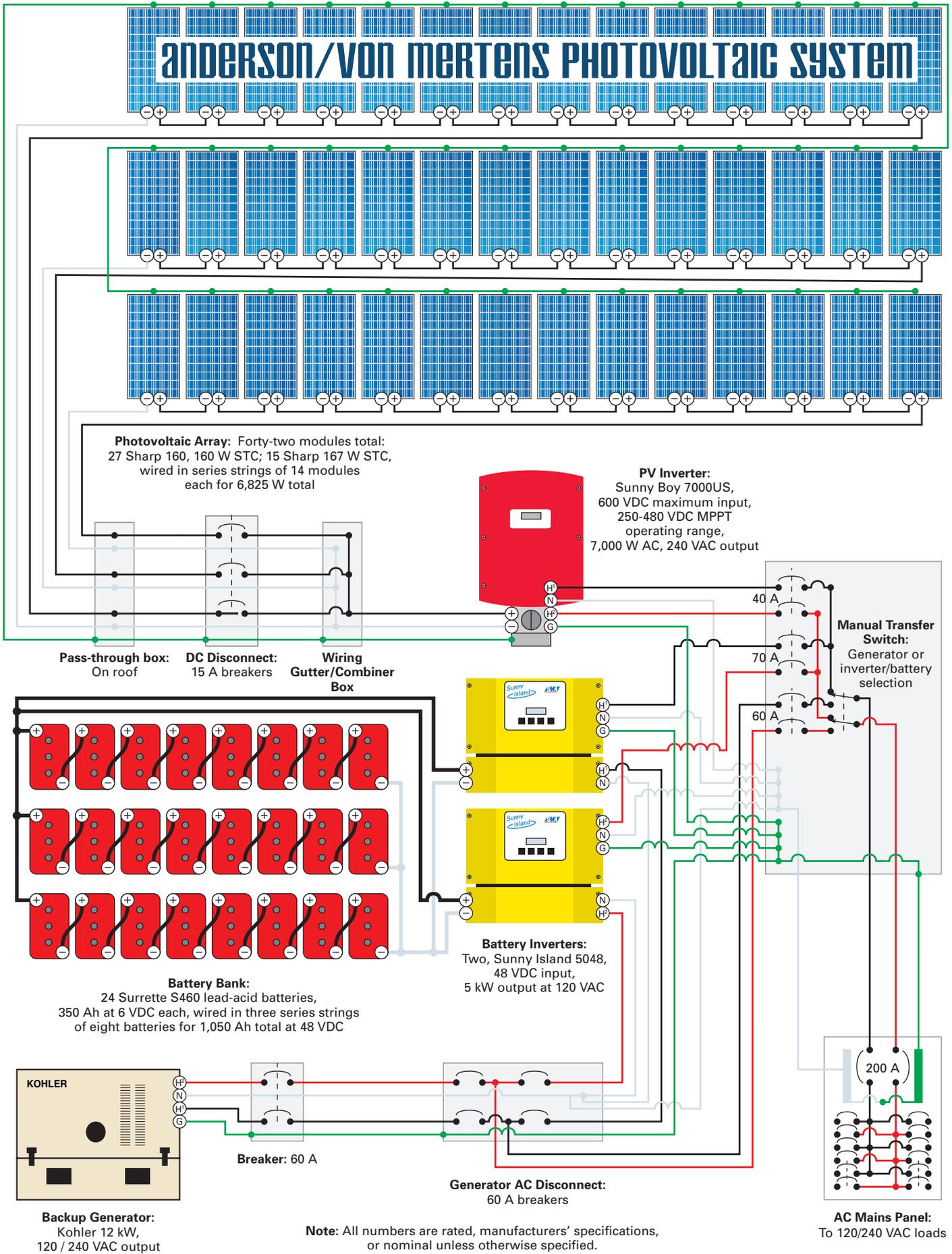
Inverter: SMA America, Sunny Boy 7,000US, 600 VDC maximum input, 250–480 VDC MPPT operating range, 7,000 W AC, 240 VAC output

Charge controller/battery inverter: Two, SMA America Sunny Island 5048

System performance metering: Sunny Web Box

Backup generator: Kohler 12 kW residential model

Batteries: 24 Surrette S460, 1,050 Ah at 48 VDC



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



Courtesy Chris Anderson

Seven Heliodyne Gobi flat-plate collectors provide domestic hot water and hydronic space heating.

insulation was attached to the exterior framing under the wood shingles, reducing thermal bridges at each stud, resulting in R-24 in the walls. Additionally, wood-to-wood junctions in the framing were caulked to reduce air infiltration.

To insulate the basement floor and walls, 2 1/4-inch thick rigid foam board (R-10) was mechanically fastened to the exterior of the moisture-sealed foundation walls and 2 inches of CFC-free rigid foam board was placed on grade prior to pouring the basement floor. In addition, foam was applied to the junction between the sills and sill-plates and to the entire rim/band perimeter in the basement to reduce infiltration. Eleven inches of blown-in cellulose insulation in the attic (R-40), and triple-glazed windows and insulated doors complete the high-performance building envelope.

Siting for Solar

An early challenge was siting the proposed 2,900-square-foot house on the 14-acre parcel, which is bound and fragmented by colonial-era stone walls common throughout New England. The way in which the stone walls cut across the most viable site—a hilltop clearing—made a true-south orientation impossible. So the broad side of the house was angled to magnetic south—15° east of true south—only slightly reducing the solar exposure.

The designs for the energy systems evolved over several months alongside the architectural plans. Ultimately, the parameters set forth by the structure—siting, roof angle, roof space, and equipment storage—dictated what was possible for system size and equipment selection. The final architectural plans called for a roof angle of 45° for year-round RE system production and roughly 1,000 square feet of south-facing roof space to mount PV modules and SHW collectors.

Sizing the Solar-Electric System

Designing the PV system began with a comprehensive load analysis, including the electricity needed for the well pump, refrigeration, water filtration system, and the computer controls and circulating pumps for the heating system.

“Calculating loads is where being the homeowner and system designer is a real advantage. No information gets lost in the exchange,” Chris says. “Because I was closer to the information and I understood our daily use and lifestyle, I knew where we could trim down, and I was able to make realistic choices.”

Among those choices was the decision to put in a propane range and clothes dryer, instead of electric models that can tip the energy scales with even occasional use. As a concession, however, Chris and Anna vowed to line-dry their clothes as much as possible and use the propane dryer sparingly.

Based on a load estimate of 17 kWh per day (including future demands—i.e. children), Chris determined that a 6.8 kW system would slightly exceed their needs,

allowing about 3 daily kWh of wiggle room.

Then the work was to maximize the PV system size in the allotted space. Chris ended up pairing 15 new 167 W Sharp modules with 27 used 160 W Sharp modules that he purchased from a system owner who had the other half of their roof-mounted modules stolen. Although the plug-and-play connectors had been cut in the theft attempt, Chris was able to make them work with some jumpers he made. He also ended up modifying the frames of the old modules to make them compatible with the new modules’ rail-mounting clips.

Although the inverter manufacturer does not recommend mixing and matching different module sizes, these modules had almost identical voltage ratings, so the losses were minimal and justified the money saved by purchasing the used modules. Ultimately, the pairing of new and used modules—wired in three 14-module series strings (fourteen 167 W modules, fourteen 160 W modules, and the last string comprised of thirteen 160 W plus one 167 W module)—worked well on the roof.

An architectural engineer and a licensed electrician, Chris has a technical background that trumps the average homeowner. Even still, he faced a slight learning curve when it came to working with the additional equipment that goes into

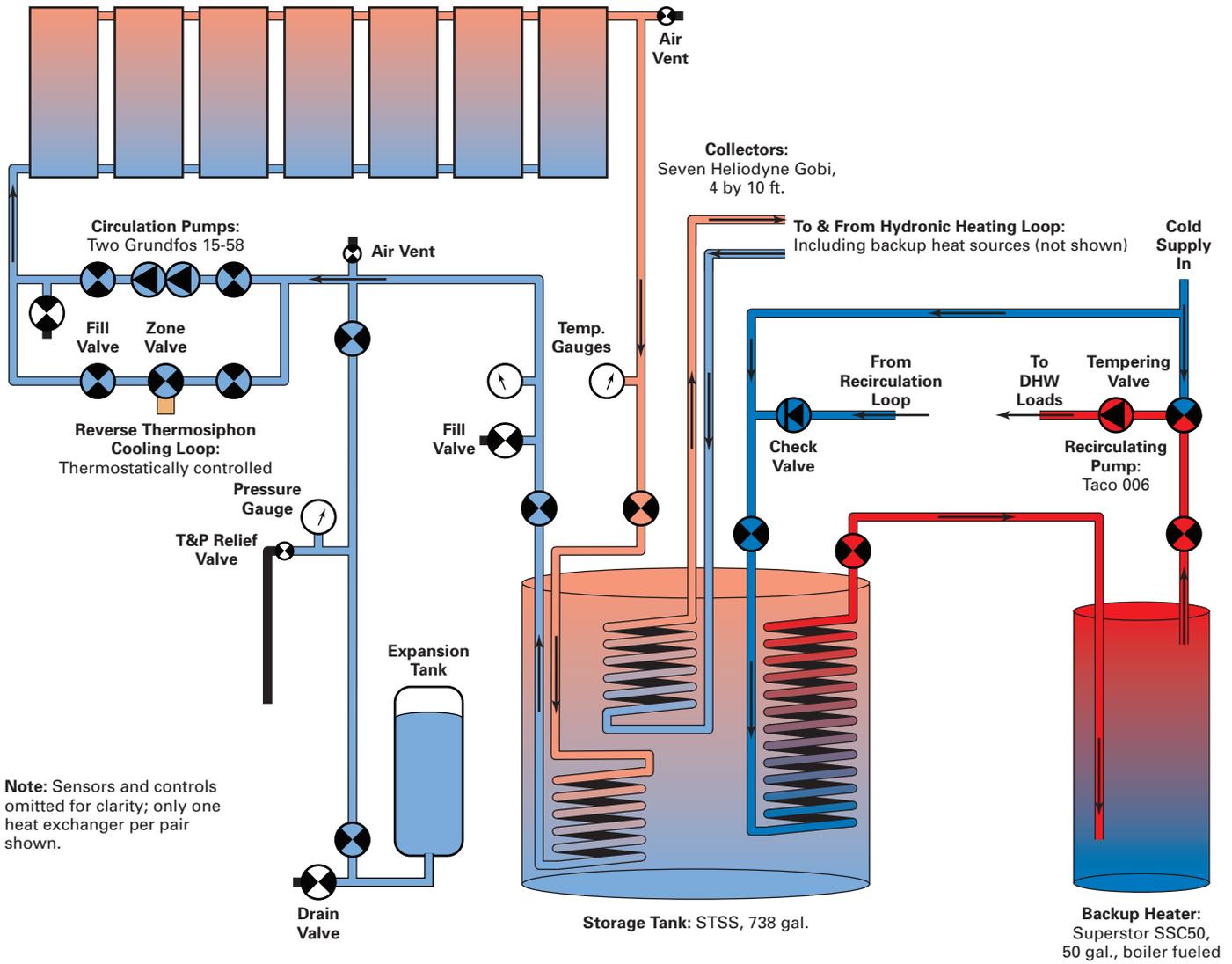
(continued on page 46)



The main 738-gallon storage tank’s heat exchangers serve the solar input and DHW and hydronic output loops.

Courtesy Chris Anderson

ANDERSON/VON MERTENS SOLAR THERMAL SYSTEM



Note: Sensors and controls omitted for clarity; only one heat exchanger per pair shown.

SOLAR THERMAL SYSTEM SPECS

Overview

System type: Closed-loop antifreeze system with heat exchanger

Percentage of hot water and heat produced annually: Est. 50%

Equipment

Collectors: 7, Heliodyne, Gobi 410, 4 x 10 ft.

Collector installation: Roof-mounted parallel to roof plane at 15° east of south

Heat-transfer fluid: Dowfrost HD

Circulation pump: 2 Grundfos SuperBrute 15-58 (in series)

Pump controller: PLC (controlling all mechanical systems) by Optimal Energy Solutions LLC

Storage

Main tank: STSS Co Inc., 738 gal.

Heat exchangers: STSS Inc.; two parallel 120 ft. copper coils in lower part of tank (solar collectors to storage); two parallel 90 ft. copper coils in upper part of tank (storage to radiant heating); plus 180 ft. copper coil to heat/preheat DHW

Backup DHW: Heat Transfer Products Inc. SuperStor 50 gal., heated by Harman PB105 pellet boiler

SUSTAINABLE FEATURES

- **Conservation easement (protects open land from development)**
- **Orientation & window placement maximizes natural daylighting & solar heat gain**
- **PV-generated electricity**
- **Solar-heated water for domestic water & in-floor radiant heating**
- **Wood-pellet-fueled backup boiler**
- **Hot water recirculation system**
- **Heavily insulated: spray-foam insulation; triple-glazed windows**
- **Slag used in concrete to replace a portion of the portland cement**
- **Native & low-water landscaping; pervious paving**
- **Finish lumber milled from trees felled on site (flooring, siding, cabinetry)**
- **Aluminum-clad & FSC-certified wood windows**
- **Naturally weathering exterior wood finishes (no refinishing/repainting)**
- **Metal roof (long life span, low maintenance)**
- **Durable, low-maintenance concrete floors**
- **Zero VOC paint**
- **Compact fluorescent lighting**
- **Energy-efficient appliances**

an off-grid PV system. “At Borrego, we specialize in grid-tied PV systems, so it was challenging for me to shift my mind-set, and think in terms of battery banks, chargers, and backup generators,” he says.

The array feeds an SMA America Sunny Boy inverter that is AC-coupled to two SMA Sunny Island inverters wired to the battery bank in the basement. At a depth of discharge of 80%, 24 deep-cycle Surrrette S460 batteries provide 840 amp-hours—up to two and a half days of energy with normal usage (about 17 kWh per day) or longer with conservative usage (13 to 14 kWh per day). The Sunny Island inverter system also controls a Kohler 12 kW propane generator to automatically charge the batteries as necessary—usually twice per week in winter and a few times per month the rest of the year, depending on weather patterns. The inverter will also start the generator periodically to equalize the batteries. The two Sunny Island inverters allow 240 VAC input/output to be used for balanced generator battery charging—and will be useful for powering a future workshop and a 240 VAC well pump.

Tackling the Solar Thermal System

For the solar thermal system, Chris turned to Henry Spindler of Optimal Energy Solutions in Keene, New Hampshire. Seven Heliodyne 4-by-10-foot collectors in a closed-loop antifreeze system with a heat exchanger heat water for a 738-

gallon storage tank with two output heat exchangers each for the domestic hot water and radiant floor systems.

The domestic hot water system uses a 50-gallon Superstor pressurized tank that is heated through heat exchangers in the larger tanks. A Harman pellet boiler provides backup heating for the radiant floor system and the DHW. The 50-gallon DHW tank is piped to the boiler as a separate zone. This is a typical setup with hydronic heating systems, where the boiler provides heating for the DHW tank through a heat exchanger.

The radiant floor system was designed for minimal power usage, with zone valves to allow individual thermostat control in seven zones of the home. The pellet boiler acts as a backup to the solar thermal system, also providing heat to a 1,200-gallon storage tank. (Additionally, the wood heater in the living room provides supplemental space heating, typically in the shoulder seasons when it is more practical to put another log on the fire than start up the boiler.)

The solar thermal system uses three strategies to prevent overheating in the summer months due to seasonal load imbalances. The control system energizes a zone valve that allows the system to thermosiphon at night until a selected temperature is reached, effectively limiting tank temperature through passive night radiation. Should the tank temperature still be too hot, the controls then circulate water to the larger 1,200-gallon boiler storage tank. In the event that both tanks reach the selected high temperature, the collector loop is energized at night to circulate fluid through the system and dissipate heat through night radiation.

Low-flow faucets and showerheads help conserve water throughout the home. A water recirculation system sends sink and shower water back to the tank—instead of down the drain—until it warms up.

Off-Grid Payoff

Currently, the AC-coupled PV system generates an average of 12.5 kWh per day. This is well below the designed 20 kWh per day that the system should be able to produce, due to the system being oversized for future needs. When energy production exceeds household consumption (frequent especially in the summer months), the Sunny Island sends a signal to the Sunny Boy inverter to put out less energy to prevent overcharging the batteries. This is the case with any stand-alone PV system that does not use diversion loads. If excess power is available but there is nowhere to send it, available power must be tapered down to avoid overcharging the batteries. When the future loads are added, the system will be able to more fully utilize the existing PV array, and the average daily kWh production will be higher.

The solar thermal system provides all of the DHW and any required heat for the home through early fall. In the dead of winter, the thermal energy generated from the collectors is enough to bring water in the 738-gallon storage tank up to about 92°F—an ample temperature to provide baseline heating through the radiant floor system. For heating performance, Chris says, the system must circulate water that’s at least 10°F warmer than the desired air temperature. Since the DHW generally requires a temperature of 115°F, the backup boiler is usually required in the late fall, winter, and early spring.

Courtesy Chris Anderson



Off-grid homeowners Anna and Chris.

Chris estimates that they're saving approximately \$1,700 per year in avoided heating fuel costs—assuming \$2,400 fuel costs for fuel oil compared to their actual cost of \$700 for pellets. Their solar thermal investment will continue to pay off as heating oil prices rise.

Chris and Anna say that the shift to off-grid living with renewable technologies has been fairly seamless. The real challenges of off-grid living were less tangible—adapting to the seclusion of their new surroundings, for instance, while raising their daughter Hayden, who was born a month after their home's completion.

“Not having neighbors was a big change. There's no running next door to borrow a cup of sugar. Our only neighbors are the few houses we can see far across the valley,” Anna says.

That may soon change. Friends from Berkeley, who also plan to start a family, purchased the adjacent 14-acre lot from Anna's mother and are starting construction on the second home allowed under the conservation easement. The plan is to connect the two homes' solar-electric systems, using underground conduit Chris already put in place, and someday add a wind turbine between the two properties for additional RE generation.

Access

Associate editor Kelly Davidson (kelly.davidson@homepower.com) and her niece are doing their part to keep New Jersey's beaches clean by picking up trash on their walks. Even 4-year-old Ava Jade knows that trash on the beach spoils the fun for everyone.

Optimal Energy Solutions LLC • 603-354-7919 • SHW design
Peter Larsen • 415-335-0857 • Architect

PV & Solar Thermal System Components:

- Grundfos • www.grundfos.com • Circulation pump
- Harman • www.harmanstoves.com • Pellet boiler
- Heat Transfer Products Inc. • www.htproducts.com • DHW storage tank
- Heliodyne • www.heliodyne.com • SHW collectors
- Sharp Solar • www.solar.sharppusa.com • PV modules
- SMA America • www.sma-america.com • Inverters
- STSS • www.stsscointc.com • SHW storage tank & heat exchangers
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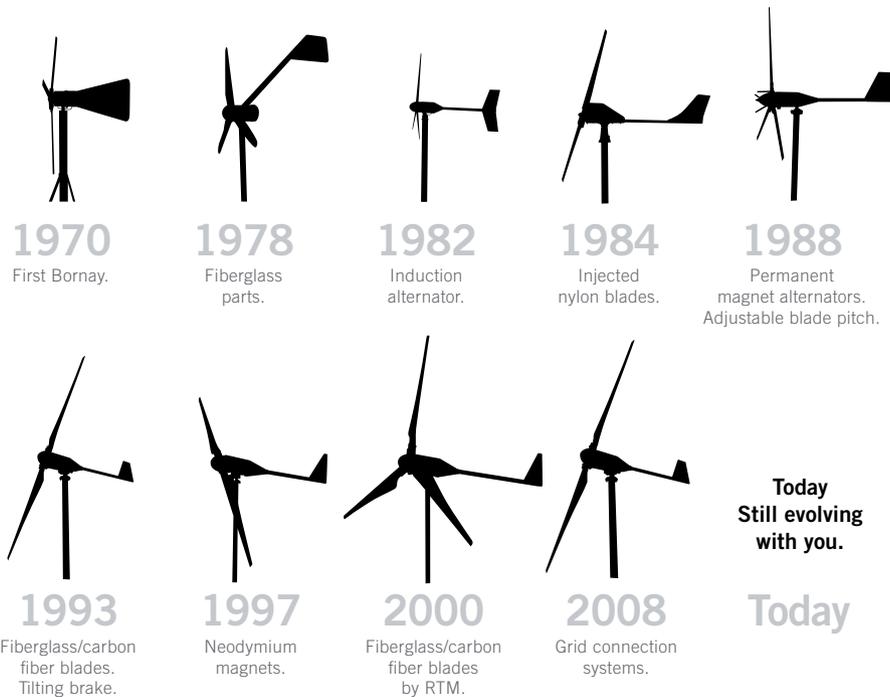


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SEEKING PEAK PERFORMANCE



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This Bainbridge Island, Washington, home maximizes PV coverage of south-facing roof area. To avoid shading and simplify the layout and rack system, chimney and other roof penetrations are concentrated on the north roof.

Lowering the Cost of Grid-Tied PV Systems

by Brian Mehalic

Solar-electric systems are becoming more common on homes, businesses, and as large generating facilities. This is partially due to increased incentives and rebates available, which help reduce system costs. However, while it may not be an apples-to-apples comparison, the fact remains that PV-generated electricity can be 1.5 to 4 times the cost of the typical, fossil-fuel-dominated utility blend.

The price per kilowatt-hour (kWh) for a PV system is calculated by dividing the system cost by its estimated lifetime energy production. One way to reduce the cost per kWh is to maximize the energy the system produces. Of course, the benefits of PV-generated electricity go far beyond the system's

initial cost: Each clean kWh produced by a PV system can displace a kWh that would be produced by conventional (polluting) energy sources. So wringing as much production as possible from your PV system makes good sense financially *and* environmentally.

PV modules typically have warranties of 20 years or more, and expected operational lives of more than 30 years. Over this time, a small amount of lost energy each day can add up to significant losses. Poor installation practices can result in increased maintenance, added downtime, and even greater losses. Fortunately, there are opportunities to optimize performance throughout the design and installation process—and lower the cost per kWh.

Site Analysis

A thorough analysis of the proposed site and the associated electrical load is one of the first steps in system design. Poor decisions or miscalculations during these early stages can dramatically affect system performance. In many cases, system size is influenced mainly by budget and space constraints, with load requirements usually a lesser factor.

Squeezing in modules to increase array size can sometimes result in diminishing returns. For instance, at a partly shaded site, adding an additional module to a string may be more trouble than it's worth. If even one module ends up with more shading than the others in the string, the whole string's production can be reduced. Additionally, if an array is shaded above a certain percentage, some rebate programs reduce the amount reimbursed. Bypass diodes inside modules, specifying microinverters, and careful siting can help mitigate shading, but adding modules solely to increase system size beyond the shade-free maximum must be carefully considered to ensure that it is not done at too high of a cost per kWh.

A shade-free south-facing roof, in great condition, with a good pitch for the latitude and lots of space, is an installer's dream. More typical, however, are roof penetrations (such as chimneys and vents) that obstruct and eat up potential space, trees that will eventually shade the site, and future buildings that may get placed on the empty lot next door. Some of these issues can be predicted by using one of the popular site analysis and shading tools available (see "Solar Site Assessment" in *HP130* for details). Addressing others requires foresight and planning: Who will trim the trees? Will new construction nearby be tall enough to cause shading? Will the roof last the life of the array?

Even a small amount of shading can have a significant effect on array production.



Courtesy www.habittek.com

Courtesy Brian Mehalic



While perfect solar orientation may maximize production, other costs (labor, racks, wind loading, and aesthetics) may outweigh the benefits.

In most cases, the greatest amount of annual energy production requires the array to face true south and be tilted at an angle equal to the local latitude. This can often be accomplished with pole- or ground-mounted arrays. Roof-mounted systems are less flexible—typically the angle and orientation of the array will be that of the roof.

An array facing within 45° of true south and tilted to within 20° of the latitude will usually produce 85% or more of that of a perfectly oriented array. A program such as PVWatts (see *Access*) can be used to estimate array production based on the proposed installation. Calculating the output of the proposed array and dividing this result by the output for an array set at an ideal angle and orientation will determine what percentage of the ideal output the actual installation will generate (see "Shade-Free Solutions" in *HP132*).

Site variables may also have an impact on available rebates. Larger installations typically receive production-based incentives (PBIs), which are also becoming more common in residential programs. Under these incentive programs, payments are made over time to system owners based on the energy produced. Lost production equals a lower PBI payment. Other incentive programs pay rebates

Solar site assessment tools can help you select a shade-free location.

Courtesy Ben Root





www.KelvinHughesProductions.com

Roof standoff height—the space between the back of the module and the roof—affects air circulation, and thus cell temperature and performance.

based on the system’s rated size. Rebates can be reduced if the array orientation deviates too far from true south, the tilt angle is too flat or steep, or if shading affects the array. The double whammy of lost production and lost incentives can dramatically increase the cost per kWh. (For more information on the impacts of angle and orientation, see “Optimizing a PV Array” in *HP130*.)

Load Analysis

Off-grid and other battery-based PV systems may be the only source of electricity—or supply critical backup power—and proper design requires a detailed accounting of each electrical load to be powered. Load analysis tends to be more straightforward with grid-tied systems. For existing utility customers, one or more years of billing history is usually available, showing kWh consumed and total cost by month. Projecting the electricity consumption of new occupancy can be more challenging, and may require a thorough analysis of the appliances and other loads, along with an examination of

Realistic Expectations

The nameplate power rating of a PV module is determined under standard test conditions (STC): insolation of 1,000 watts per square meter and a 25°C (77°F) cell temperature. Unfortunately, these conditions are not typical of real-world situations. For instance, on sunny days the actual temperature of a cell in a module can be 25°C to 40°C above the ambient temperature, raising the operating temperature well above that at which the module was tested for rating purposes.

As the temperature of a PV cell increases, voltage decreases—this is known as the temperature coefficient. Module *current* (Isc) actually increases as the temperature rises, but not as fast as the voltage decreases, which means that a module’s output will normally be less than its rated power. The overall effect of temperature may be published as the coefficient of maximum power (Pmax or Pmp) of the module. For example:

- **Module rating, STC =** 180 W
- **Temperature coefficient, Voc =** -0.346%/°C
- **Temperature coefficient, Isc =** +0.057%/°C
- **Temperature coefficient, Pmax =** -0.478%/°C

In this case, for each degree Celsius that the cell temperature rises above 25°C, the module output (Pmax) will decrease by almost half a percent. A cell temperature of 45°C (113°F—not an uncommon operating condition) would mean a 9.6% loss of power:

(Cell temperature – STC temperature) x temperature coefficient
Pmax = Adjusted power at operating temperature

$(45^{\circ}\text{C} - 25^{\circ}\text{C}) \times -0.478\% / ^{\circ}\text{C} = -9.56\%$

$180 \text{ W} \times -0.0956 = -17.2 \text{ W}$

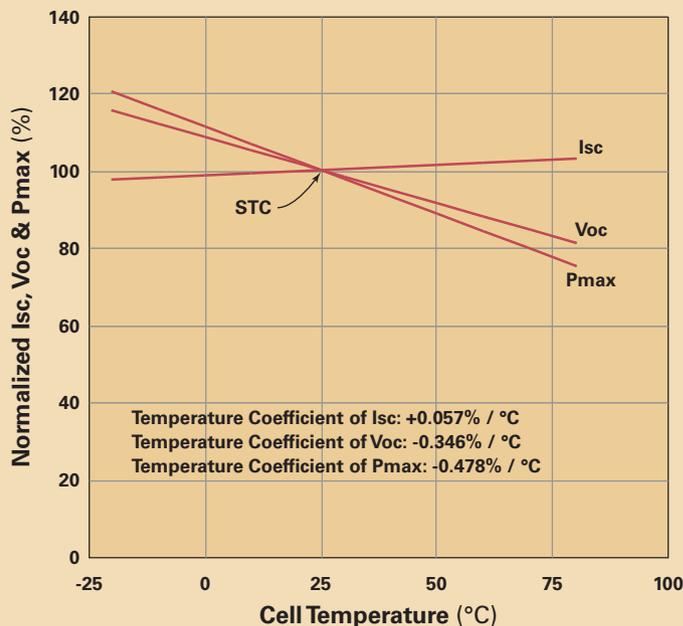
$180 \text{ W} - 17.2 \text{ W} = 162.8 \text{ W at } 45^{\circ}\text{C cell temperature}$

In cold, sunny conditions with cell temperatures *below* 25°C, power increases proportionally. However, “less than labeled” output is normally the case with PV modules. For more realistic ratings, the www.gosolarcalifornia.org Web site lists module PTC ratings. Based on different test conditions—a 20°C ambient (rather than cell) temperature—PTC ratings typically run 10% to 20% less than the STC ratings for the same module.

Leaving an air space between the roof surface and mounted modules allows for airflow to keep operating temperatures as low as possible. Four inches of space is the minimum, though sometimes aesthetics trumps performance. Adding a space between rows of modules can have a similar effect (and also allow easier access).

Pole- and ground-mounted arrays typically operate at cooler temperatures compared to roof-mounted systems, and usually offer the ability to match the ideal angle and orientation. However, even though a few more kWh can be wrung from a ground- or pole-mounted system, increased rack and labor costs mean that the cost per kWh is likely to be higher than a roof-mounted system.

Example of the Temperature Dependence of Isc, Voc & Pmax



Time-of-Use Metering

Especially during the cooling season, the load on the electric grid varies greatly at different times of the day. Peaks coincide with people getting ready for or coming home from work, and with the hottest part of the day, when the most air conditioners are running full-blast.

Utilities need to be able to safely meet the peak demand, and they accomplish this through a combination of “peaker” generating facilities and energy purchase contracts. But peak energy is the most expensive for the utility to maintain since these power plants have to be ready to supply energy only during peak usage times, and sit idle other times.

To encourage decreased use during peak periods, time-of-use (TOU) rate plans charge more for electricity when there is more demand and less when demand is reduced. Lower-than-normal rates in off-peak times compensate for the increased on-peak rates, potentially reducing electric bills and reducing the amount of peak capacity the utility must have available.

The details for TOU rate plans—including whether or not net-metered PV systems can take advantage of them—can vary considerably and can be complicated to decipher. But often, a PV system’s highest production—during the peak sun-hours between 9 a.m. and 3 p.m.—also coincides with the highest peak grid usage. If excess PV energy is credited in dollars at the higher on-peak rates, then the credit can be used to purchase lower-priced, off-peak kWh at night, when the PV system is offline. This can tremendously lower the system’s cost per kWh.

Another possible TOU scenario is when excess energy can only be used as a credit during the period in which it was generated. This is the most difficult situation to assess, and requires careful analysis of system production and load by period, as well as how annual surplus is accounted for.

For customers who already have TOU metering and are adding a PV system, detailed billing history will usually break down total consumption into on- and off-peak periods. Customers with higher on-peak usage are most likely to benefit from the combination of PV and TOU. This includes home offices, commercial and industrial facilities, and households with large daytime loads.



Inverter manufacturers offer online tools to make sure series strings of modules are optimally matched to an inverter, maximizing system performance.

utility bills from the previous residence, past tenants, and/or similar homes. The more data the better—if possible, view several years’ worth to take into account occasional aberrations, such as a holiday when lots of guests increased the load.

A thorough profile is necessary because of the various utility accounting methods for grid-connected PV systems, particularly with surplus generation. The most progressive programs use feed-in tariffs (a type of production-based incentive), which pay premium prices for RE-generated electricity. But most utility customers have only net metering—a kWh-for-kWh exchange. Net metering values PV energy at the retail price but usually does not pay for production beyond what the customer uses. Any excess production is usually carried over between billing cycles and for up to a year. After that it is lost—given away to the utility. In some states, the utility pays for excess generation at “avoided cost,” closer to the wholesale price per kWh.

Any time PV production is undervalued in this manner, the effective cost per kWh of the system increases. In contrast, many utilities have tiered rate plans, where the cost per kWh for utility electricity increases as more energy is used, especially during the hot summer months. During these times, increased PV output, whether by design or by the simple fact that there is more sun, increases the average value of each kWh generated by the system. In this scenario, a smaller system may have a lower price per kWh because a larger percentage of the energy generated will be credited at a higher rate—effectively “shaving” the most expensive kWh purchased during the year. Time-of-use rate plans further complicate the analysis (see “Time-of-Use Metering” sidebar). Coordinating between monthly consumption patterns, expected system output, and the ins and outs of specific utility requirements and programs can be daunting—just remember PV energy is pricey, so there’s no reason to give it away.

Selecting Equipment to Maximize Performance

The list of available PV modules, inverters, and other equipment literally grows by the day. Ten-year inverter and 25-year module warranties are the industry norm, with some exceptions. Competing claims of performance and efficiency are complicated by standardized ratings that don’t duplicate realistic operating conditions (see “Realistic Expectations” sidebar). Cost, usually expressed in dollars per watt when pricing modules or inverters, always plays a role, along with availability and familiarity—look for the good deal, but in all cases, choose equipment that has a good reputation in the field.



Courtesy Brian Methalic

Mounting thermally sensitive fuses or breakers on hot roofs or in other sunny locations can cause nuisance-tripping, increasing downtime and reducing the system's lifetime energy production.

Module Considerations. One of the biggest differences between modules is power tolerance, which is the expected variation from a module's rated output. For example, a 200-watt module with a tolerance of +/-7% could actually produce from 186 to 214 W. Many modules are in the +/-3 to +/-5% range; some have a wider range, as high as +/-10%. Others guarantee a positive power tolerance, stating that the module will produce *at least* its rated power.

The wider the power tolerance in the module, the more likely it is that the PV array will have modules with different operating characteristics. For instance, the 200 W module mentioned previously has a power tolerance spanning nearly 30 W. Individual modules in this array are likely to operate at

significantly different maximum power points. Because they are often wired together to an inverter capable of tracking only one maximum power point, the lower-output modules will tend to "pull down" the ones with higher outputs. When wired in series, the current of the string will be closer to the current of the lowest-rated module. When wired in parallel, the voltage of the strings will tend to be the average of the strings' combined voltages. Since most grid-tied systems have source circuits wired in series and parallel, this results in lost power and means that a +/- power tolerance is usually only a minus. To combat this issue, modules with a narrow (or positive only) power tolerance can be used. Or consider using microinverters, where each module is paired with its own inverter or with inverters that can track more than one MPPT.

Matching the number and model of a PV module to an inverter requires careful consideration of local temperature extremes and the overall size and wiring configuration of the array (see "String Theory: PV Array Voltage Calculations" in *HP125*). Coupling an inverter to an array that barely meets the inverter's DC input voltage will result in disappointing performance: In addition to the decrease in voltage due to temperature, modules will also lose some power output over time due to dust, degradation, corrosion, and increased connection resistance. Though it may take several years, these combined factors can result in a low-enough voltage to shut down the inverter. (See the "Grid-Tied Inverter Buyer's Guide" in this issue for more information.)

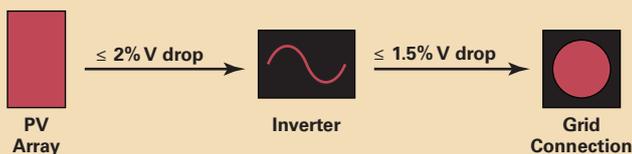
Installation Considerations. Regardless of how well a system is designed, improper installation can result in poor performance. PV systems should operate for decades, and the materials and methods to install them should be selected accordingly. Wire, conduit, and associated hardware typically make up a small percentage of PV system cost—skimping on them may result in decreased output and, therefore, a higher cost per kWh.

Loose connections are a common and potentially serious installation issue. They lead to increased voltage drop, lost output, and added maintenance costs. At worst, the increased resistance leads to heat buildup and fire. Troubleshooting

Voltage Drop

Even though it's not a calculation required by the *NEC*, ignoring voltage drop—caused by a conductor's internal resistance as current flows through it—can result in sizable energy losses as well as increase the possibility of the array output falling below the inverter's minimum DC input voltage.

Good system design limits total voltage drop on DC circuits to 2% or less. Voltage drop between the inverter and its connection with the grid should usually be 1.5% or less to ensure that the inverter has enough voltage to push back the AC voltage from the grid. Voltage drop on this circuit will result in the inverter "seeing" a voltage above that measured at the point of connection; if this is too high, it can exceed the AC operating voltage window of the inverter, causing it to go offline. (See "Back Page Basics" in this issue and "Voltage Drop after *NEC* Requirements" in *HP80*.) Numerous voltage-drop calculators, such as those on inverter manufacturer Web sites, are available—though it is always wise to double-check results.



Roof overhangs can provide some shade, but the inverter may still be subject to direct sunlight and elevated operating temperatures at different times. A shading analysis tool can also be used to determine inverter placement.

Courtesy Brian Methalic



loose or sporadic connections can be time-consuming and frustrating, so minimize their likelihood from the start: All connections in the system should be tightened to the specifications of the device, and should be appropriate for the size and type of wire, as well as for the location. Torque wrenches are fairly common (torque screwdrivers much less so), but specs for tightening screw terminals are provided for components and should be followed.

But They're Supposed To Be in the Sun

Both PV modules and inverters operate more efficiently at cooler temperatures. While most grid-tied inverters are designed for outside installation and housed in outdoor-rated enclosures, they should not be mounted in direct sunlight, as this will cause them to operate less efficiently. In addition to the lost output, inverter life is likely to be shortened. While the expectations built into most PV financial modeling programs include inverter replacement, "burning" through several expensive inverters will dramatically increase the system's cost per kWh. The LCD display in most inverters also can be rendered useless after too much sun exposure.

Placing overcurrent protection devices in excessively hot and sunny locations can also lead to unexpected downtime and the loss of energy production. Fuses and breakers are thermal devices—they rely on the heat generated by current running through them to "trip" and disconnect, protecting the wiring from overcurrent conditions. When operating in high ambient temperatures, the ratings of fuses and breakers are effectively lowered, meaning that they may "nuisance trip" even when carrying less current than they are rated for.

Until the fuse is replaced or the breaker reset, the output of the PV source circuit or array connected to that overcurrent device will be lost. Because grid-tied systems operate "silently," the building will still have power even if the inverter is offline—lost production may not be noticed until the next electricity bill reports higher-than-normal usage. Keeping combiner boxes off hot roofs and out of direct sunlight and wiring roof-mounted arrays with home runs from each source circuit back to an inverter mounted in a shaded location (build an awning if necessary) can be good strategies to ensure that the system stays online.

Access

Brian Mehalic (brian@solarenergy.org) is a NABCEP-certified PV installer, with experience designing, installing, and servicing PV, thermal, wind, and water-pumping systems. He is currently an instructor for Solar Energy International and works on curriculum development for SEI's PV program from his home in Prescott, Arizona.

Further Reading:

- "Solar Survey," by Justine Sanchez, *HP130*
 - "Optimizing a PV Array" by David Del Vecchio, *HP130*
 - "String Theory: PV Array Voltage Calculations," by Ryan Mayfield, *HP125*
 - "Voltage Drop after NEC Requirements," by John Wiles, *HP80*
- Consumer Energy Center Equipment Ratings •
www.gosolarcalifornia.org/equipment
 PVWatts • www.nrel.gov/rredc/pvwatts



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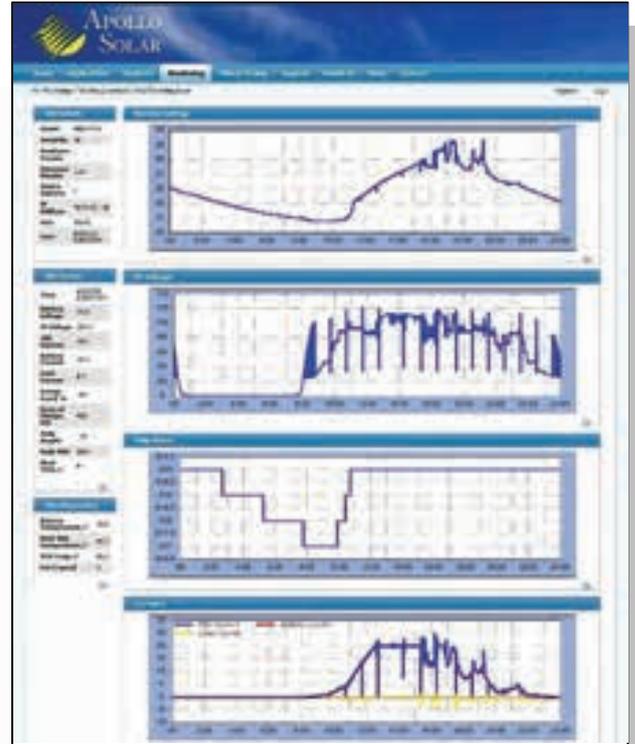
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GRID-TIED INVERTER buyer's guide



Shawn Schreiner

by Ryan Mayfield

In the past decade, manufacturers have made advancements in their grid-tied (GT, a.k.a. utility-interactive or grid-direct) inverters that have helped the PV industry flourish. The ability for PV arrays to operate at elevated DC voltages, and for inverters to accurately operate at the array's maximum power point to produce maximum power and simultaneously safely interact with the utility grid, are two examples of the technologies used in modern GT inverters.

Traditional high-DC voltage GT inverters are commonly referred to as "string" inverters because multiple modules wired into a series "string" are needed to meet the inverter's operating voltage specifications. This article focuses mainly on available residential grid-tied string inverters that are UL-listed for use in the United States. Additionally, information on microinverters is included in the text and specifications table.

The Specs

The specifications table shows grid-tied inverters available for the residential market. Technical data listed for each inverter has either been supplied directly by the inverter manufacturers or taken from inverter specification sheets and owner's manuals. Each specification and its relevance to system design and inverter selection is discussed below.

DC Input Variables

Maximum Recommended PV Input Power—The recommended or maximum input power values for the inverter. This typically exceeds the AC output power rating by 5 to 40%, as STC power is rarely achieved due to inverter inefficiencies, module operating temperatures, and wire loss. If the array is located in a cool climate, where power losses due to temperature are minimal, then sizing a system at this spec may yield an array that is slightly oversized. This can cause power clipping, where some of the available input power is not processed into output.

Maximum Open-Circuit Voltage—All inverters have a limited amount of voltage they can accept. This number is dictated by the manufacturer's design and choice of components. The maximum voltage for residential inverters is limited to 600 VDC. For equipment exceeding this voltage, the NEC has increased requirements.

The PV array's maximum open-circuit voltage (Voc) must always be less than the inverter's limit. Since an array's voltage is directly affected by temperature, the design voltage calculations must reflect this relationship (see "PV Buyer's Guide" in *HP128*; "String Theory" in *HP125*, and "Code Calculations" in *HP129* for more information). Dividing the inverter's maximum Voc by the module's temperature-

String Inverters vs. Microinverters

Unlike a string inverter, which is connected to a string of many modules, a microinverter is paired with each module.

Microinverters have certain advantages compared to traditional string inverters. Their use eliminates the need for string-sizing calculations. Plus, because each module-inverter pair is wired in parallel to the other module-inverter pairs, modules with lower power outputs do not drag down higher-producing pairs, and energy loss due to partial array shading is reduced. Finally, instead of working with high-voltage DC, installers need only work with conventional AC electricity.

However, not all installations are compatible with a microinverter system. Microinverters have a narrow voltage window that works only with some PV modules. Also, in a situation where there is minimal shading, a traditional string inverter may prove to be a more economical choice.

Some installers are embracing the new release of the Enphase microinverters, while others are holding a wait-and-see approach. Other microinverters are likely to follow and we may also see some true AC modules, where the unit includes an inverter attached and prewired to the module.

Microinverters are still considered utility-interactive inverters in the eyes of the *National Electrical Code (NEC)*, so make sure you and the authority having jurisdiction (AHJ, or electrical inspector) are in agreement about installation requirements—specially with regard to disconnects. For additional information on the installation of a microinverter system, see “PV Micromanaging” (HP129).



Courtesy www.enphaseenergy.com

Enphase M series microinverters help mitigate partial array shading issues and allow for standard AC wiring on the roof.

adjusted Voc will yield the maximum number of PV modules that can be placed in series for your site.

Many inverter manufacturers have online string-sizing calculators to figure how many modules of a particular model can be used in series with the inverter. The recommended module configurations listed in these programs consider the maximum Voc and the minimum operating voltage, as well as the PV start voltage (see below), so that designers can easily determine the appropriate number of modules in series.

PV Start Voltage—This is the minimum PV array voltage the inverter needs to put out energy. Array voltage typically approaches Voc as the morning sun first hits the modules, making the startup voltage easy to achieve. But if the fewest possible number of modules were used in the series string, and module temperatures are high, it is possible for the inverter to shut down because of reduced voltage. The array’s voltage would not be high enough to run the inverter, and the inverter would not turn on again until the array cooled considerably.



Courtesy www.fronius-usa.com

The Fronius IG Plus series inverter has an integrated fused combiner box and DC disconnect. Also, its AC output is field-adjustable for 208, 240, or 277 VAC for either residential or commercial applications.



Courtesy www.motech.com.tw

The Motech PVMate inverter has an integrated fused combiner box and DC disconnect. Its AC output is also field-adjustable to 208 or 240 VAC.

Courtesy www.power-one.com



Power-One/Magnetek PVI series inverters have two MPPT input circuits and an integrated DC disconnect. AC output is field-adjustable to 208, 240, and 277 VAC.

Kaco xi 02 series inverters have integrated DC and AC disconnects, and AC output is field-adjustable to 208 or 240 VAC.



Courtesy www.kaco-newenergy.com

Coupled with module voltage degradation over time, PV start voltage becomes more difficult to achieve as the array ages. That's why system integrators aim for the middle-to-high end of the recommended number of series modules. For example, if a manufacturer's string-sizing program calculates that the inverter will work with eight to 12 modules in series, it is prudent to specify 10 to 12 modules in each series string.

Maximum Power Point Tracking (MPPT) Voltage Range—Most grid-tied inverters include MPPT circuits, enabling them to harvest the maximum amount of power

from the PV array. MPPT must operate within a range of voltages—the MPPT window.

The upper end of the MPPT window will always be less than the maximum open-circuit voltage. The lower end of the MPPT window is usually of greater concern. If array voltage drops to the minimum MPPT value, the inverter's ability to harvest the maximum amount of power will be compromised. Again, this problem can be avoided by choosing a string of modules with the number of modules in series at the middle to higher end of the recommended range.

Maximum Input Current—This is the DC current the inverter can accept. Some inverter manufacturers will specify the maximum short-circuit current allowed from the array, while others will list the maximum operating current. This value should always be reviewed during design. But so long as the array operates within the correct voltage window and less than the maximum power input value, the current maximum will almost always be within specification. In addition, the inverter will also limit input current by keeping the output current at the required level to protect itself.

Number of String Inputs—This value tells us the number of input terminal pairs. Most inverters can accommodate more than one series string of modules, allowing installers to parallel strings of modules in the inverter itself. If bringing separate individual series strings from the array to the inverter is inconvenient (say if the distance from the array to the inverter is far and, perhaps, for troubleshooting purposes, isolating strings closer to the array is desired), another option is to parallel strings in an external combiner box.

Courtesy www.sma-america.com



The SMA America Sunny Boy US series inverter has an integrated fused combiner box and DC disconnect. AC output is also field-adjustable to 208 or 240 VAC, and some models also adjust to 277 VAC.

Courtesy www.pvpowered.com



PV Powered PVP series inverters have integrated DC and AC disconnects that meet the UL 98 standard, which means they are considered to be “enclosed and dead-front switches” helpful for installation and inspection.

Xantrex GT inverters have integrated DC and AC disconnects, and AC output is field-adjustable to 208 or 240 VAC.



Courtesy www.xantrex.com

Number of Independent MPPT Circuits—Currently, only Aurora inverters have multiple MPPT circuits within a single inverter. This feature allows arrays with differing configurations and/or different orientations and tilts to be connected to the same inverter without maximum power point tracking losses. Differing arrays will have different maximum power points. Some inverters without multiple MPPT circuits (such as SMA America’s) require keeping all module strings identical so that the inverter can find and track the maximum power point of the PV system. Other inverter companies (like Fronius) claim their inverters can accommodate differing strings with one MPPT circuit and suffer only minimal (1%) MPPT losses. Regardless, the best practice is to keep all the strings at the same orientation on a single MPPT circuit.

AC Variables

CEC Rated Power Output—The maximum output watts from the inverter. This spec can vary depending on environmental factors, such as inverter operating temperature.

The Consumer Energy Center (CEC), which administers California’s PV rebate market, has established a testing protocol to compare inverters’ rated power output, efficiency, and night tare losses on an equal basis. The CEC requires that all inverters sold within their rebate program list the inverter’s maximum continuous power output at an ambient temperature of 40°C (104°F). This number can help determine the inverter’s ability to produce continuous power at elevated temperatures. Many manufacturers include this information on their spec sheets.

Solectria Renewables PVI 1800 and 2500 series inverters come prewired with DC and AC cabling, and can be integrated with DC and AC disconnect assembly options. The AC output is field-adjustable to 208 and 240 VAC.



Courtesy www.safen.com

(continued on page 64)

Batteryless Grid-Tied Inverter Specifications

Manufacturer	Model	Max. Recommended PV Input Power (kW)	Max. Voc	PV Start Voltage	MPPT Voltage Range	Max. Input Current (A)	# of String Inputs	# of Indep. MPPT Circuits	CEC Rated Power (kW)	Nominal Output Voltage
Enphase Energy www.enphaseenergy.com	M175-24-240-S	0.21	54	25	25-40	8.0	—	1	0.175	240
	M190-72-240-S	0.23	54	22	22-40	10.0	—	1	0.190	240
	M200-32-240-S	0.24	80	44	44-65	5.0	—	1	0.200	240
Fronius www.fronius.com	IG 2000	2.5	500	150	150-450	13.6	3	1	2.0	240
	IG 3000	3.3	500	150	150-450	18.0	3	1	2.7	240
	IG Plus 3.0	3.45	600	245	230-500	14.0	6	1	3.0	208; 240; 277
	IG Plus 3.8	4.4	600	245	230-500	17.8	6	1	3.8	208; 240; 277
	IG 4000	5.0	500	150	150-450	26.1	3	1	4.0	240
	IG Plus 5.0	5.75	600	245	230-500	23.4	6	1	5.0	208; 240; 277
	IG 5100	6.3	500	150	150-450	33.2	3	1	5.1	240
	IG Plus 6.0	6.9	600	245	230-500	28.1	6	1	6.0	208; 240; 277
	IG Plus 7.5	8.6	600	245	230-500	35.1	6	1	7.5	208; 240; 277
	IG Plus 10.0	11.5	600	245	230-500	46.7	6	1	10.0	208; 240; 277
	IG Plus 11.4	13.1	600	245	230-500	53.3	6	1	11.4	208; 240; 277
IG Plus 11.4-3	13.1	600	245	230-500	53.3	6	1	11.4	208; 240	
Kaco Solar www.kacosolar.com	1501xi	1.8	400	125	125-300	15.0	2	1	1.5	240
	1502xi	2.0	500	125	125-400	13.0	2	1	1.5	208; 240
	2502xi	3.0	550	200	200-450	13.0	2	1	2.5	208; 240
	2901xi	3.8	400	125	125-300	33.0	2	1	2.9	240
	3601xi	4.8	400	125	125-300	48.0	3	1	3.6	240
Motech www.motech.com.tw	PVMate 2900U	3.6	600	235	200-550	16.0	3	1	2.7; 2.9	208; 240
	PVMate 3900U	4.9	600	235	200-550	20.0	4	1	3.4; 3.9	208; 240
	PVMate 4900U	6.2	600	235	200-550	25.0	4	1	4.3; 4.9	208; 240
	PVMate 5300U	6.7	600	235	200-550	25.0	4	1	4.6; 5.3	208; 240
Power-One/Magnetek www.power-one.com	PVI-3.0-OUTD/-S	3.5	600	200	90-580	10.0	2	2	3.0	208; 240; 277
	PVI-3.6-OUTD/-S	4.2	600	200	90-580	16.0	2	2	3.6	208; 240; 277
	PVI-4.2-OUTD/-S	4.82	600	200	90-580	16.0	2	2	4.2	208; 240; 277
	PVI-5000-OUTD-US	5.3	600	200	90-580	18.0	2	2	5.0	208; 240; 277
	PVI-6000-OUTD-US	6.4	600	200	90-580	18.0	2	2	6.0	208; 240; 277

Max. Output Current (A)	Peak Efficiency	CEC Weighted Efficiency	CEC Night Tare Loss (W)	Cooling Method	Integrated AC/DC Disconnects	Integrated Fused Combiner	Max. AC OCPD Rating (A)	DC/AC Terminal Range (AWG)	NEMA Encl. Rating	Weight (Lbs.)	Warranty (Standard/Extended)
0.8	95.0%	94.5%	0.58	Passive	—	—	15	—	6	4	15
0.8	95.5%	95.0%	0.03	Passive	—	—	15	—	6	4	15
0.8	95.3%	95.0%	0.48	Passive	—	—	15	—	6	4	15
8.4	95.2%	93.5%	0.91	Fan	DC/AC	No	20	8-12; 6-12	3R	26	10
11.3	95.2%	94.0%	0.91	Fan	DC/AC	No	20	8-12; 6-12	3R	26	10
14.4; 12.5; 10.8	96.2%	95.0%; 95.5%; 95.5%	0.62; 0.83; 1.10	Fan	DC	Yes	20; 20; 15	6-14; 4-14	3R	31	10
18.3; 15.8; 13.7	96.2%	95.0%; 95.5%; 95.5%	0.62; 0.83; 1.10	Fan	DC	Yes	25; 20; 20	6-14; 4-14	3R	31	10
16.7	95.2%	94.0%	0.90	Fan	DC/AC	No	30	6-10	3R	42	10
24.0; 20.8; 18.1	96.2%	95.5%; 95.5%; 96.0%	0.71; 0.76; 1.02	Fan	DC	Yes	30; 30; 25	6-14; 4-14	3R	57	10
21.3	95.2%	94.5%	0.91	Fan	DC/AC	No	30	6-10	3R	42	10
28.8; 25.0; 21.7	96.2%	95.5%; 96.0%; 96.0%	0.71; 0.76; 1.02	Fan	DC	Yes	40; 35; 30	6-14; 4-14	3R	57	10
36.1; 31.3; 27.1	96.2%	95.0%; 95.5%; 96.0%	0.71; 0.76; 1.02	Fan	DC	Yes	45; 40; 35	6-14; 4-14	3R	57	10
48.1; 41.7; 36.1	96.2%	95.0%; 95.5%; 96.0%	0.64; 0.85; 1.13	Fan	DC	Yes	60; 60; 45	6-14; 4-14	3R	82	10
54.8; 47.5; 41.2	96.2%	95.5%; 96.0%; 96.0%	0.64; 0.85; 1.13	Fan	DC	Yes	70; 60; 60	6-14; 4-14	3R	82	10
31.6; 27.4	96.2%	95.0%; 95.5%	0.90; 1.00	Fan	DC	Yes	40; 35	6-14; 4-14	3R	82	10
15.0	95.0%	94.0%	2.63	Passive	—	No	15	6-12	3R	31	10
8.0	95.5%; 95.9%	95.0%; 95.5%	0.3	Passive	DC/AC	No	15	6-12	3R	41	10
12.5	95.6%; 95.9%	95.0%; 95.5%	0.3	Passive	DC/AC	No	20	6-12	3R	52	10
20.0	95.0%	94.0%	2.77	Passive	—	No	20	6-12	3R	52	10
30.0	95.0%	93.5%	3.11	Passive	—	No	30	6-12	3R	66	10
13.0	96.4%; 96.7%	95.5%; 96.0%	10.6; 10.3	Passive	DC	Yes	20	6-12	3R	51	10
16.3	96.5%; 96.7%	95.5%; 96.0%	12.0; 11.0	Passive/ Fan	DC	Yes	25	6-12	3R	51	10
20.7	96.4%; 96.7%	96.0%; 96.0%	14.0; 14.0	Passive/ Fan	DC	Yes	30	6-12	3R	62	10
22.1	96.3%; 96.6%	95.5%; 96.0%	14.0; 14.0	Passive/ Fan	DC	Yes	30	6-12	3R	62	10
14.5; 14.5; 12.0	96.8%	96.0%	0.1; 0.1; 0.2	Passive	DC	No	20; 20; 15	6-20	4X	46	5; 10(CA)/10
17.2; 17.2; 16.0	96.8%	96.0%	0.1; 0.2; 0.2	Passive	DC	No	25; 25; 15	6-20	4X	46	5; 10(CA)/10
20.0; 20.0; 20.0	96.8%	96.0%	0.1; 0.2; 0.2	Passive	DC	No	25; 25; 25	6-20	4X	46	5; 10(CA)/10
24.0; 20.0; 18.0	97.0%	96.0%; 96.5%; 96.5%	0.18; 0.24; 0.32	Passive	DC	No	40	4-10	4X	66	5; 10(CA)/10
29.0; 25.0; 21.6	97.0%	96.0%; 96.5%; 96.5%	0.18; 0.24; 0.32	Passive	DC	No	40	4-8	4X	66	5; 10(CA)/10

Batteryless Grid-Tied Inverter Specifications, cont.

Manufacturer	Model	Max. Recommended PV Input Power (kW)	Max. Voc	PV Start Voltage	MPPT Voltage Range	Max. Input Current (A)	# of String Inputs	# of Indep. MPPT Circuits	CEC Rated Power (kW)	Nominal Output Voltage
PV Powered www.pvpowered.com	PVP1100EVR	1.4	500	130	115-450	10.0	3	1	1.1	120
	PVP1100	1.4	500	165	150-450	10.0	3	1	1.1	120
	PVP2000EVR	2.5	500	130	115-450	18.0	3	1	2.0	240
	PVP2000	2.5	500	165	150-450	18.0	3	1	2.0	240
	PVP2500	3.13	500	155	140-450	20.0	3	1	2.5	240
	PVP3000	3.75	500	185	170-450	18.0	3	1	3.0	240
	PVP3500	4.38	500	215	200-450	18.0	3	1	3.5	240
	PVP4800	6.0	500	215	200-450	26.0	3	1	4.8	240
	PVP5200	6.5	500	255	240-450	25.0	3	1	5.2	240
SMA America www.sma-america.com	SB 700U	0.875	250	150	125-200	7.0	2	1	0.7	120
		0.750	200	125	100-160	7.0	2	1	0.6	120
		0.575	150	95	77-120	7.0	2	1	0.46	120
	SB 3000US	3.75	500	228	180-400; 200-400	17.0	2 ¹	1	3.0	208; 240
	SB 4000US	5.0	600	285	220-480; 250-480	18.0	2 ¹	1	3.5; 4.0	208; 240
	SB 5000US	6.25	600	300	250-480	21.0	3 ¹	1	5.0	208; 240; 277
	SB 6000US	7.5	600	300	250-480	25.0	3 ¹	1	6.0	208; 240; 277
	SB 7000US	8.75	600	300	250-480	30.0	3 ¹	1	7.0	208; 240; 277
Solectria Renewables www.solren.com	PVI 1800	2.2	400	150	125-350	11.0	1	1	1.8	208; 240
	PVI 2500	3.2	400	150	125-350	15.0	1	1	2.5	208; 240
	PVI 3000	3.6	600	235	200-550	16.0	3	1	2.7; 2.9	208; 240
	PVI 4000	4.9	600	235	200-550	20.0	4	1	3.4; 3.9	208; 240
	PVI 5000	6.2	600	235	200-550	25.0	4	1	4.3; 4.9	208; 240
	PVI 5300	6.7	600	235	200-550	25.0	4	1	4.6; 5.3	208; 240
Xantrex www.xantrex.com	GT2.8	3.1	600	160	195-550	14.9, 15.4	2	1	2.7; 2.8	208; 240
	GT3.3N	3.5	600	160	200-550	16.5, 17.5	2	1	3.1; 3.3	208; 240
	GT3.8	3.6; 4.2	600	160	195-550	19.5, 20.8	2	1	3.5; 3.8	208; 240
	GT4.0N	4.2	600	190	235-550	17.0, 18.0	2	1	3.8; 4.0	208; 240
	GT5.0	4.8; 5.4	600	190	235-550	20.0, 22.0	3	1	4.5; 5.0	208; 240

1. Optional SMA America disconnect includes four fused series string inputs. 2. Solectria Renewables offers integrated power panels with DC or AC disconnects.

Nominal Output Voltage—The nominal utility voltage the inverter can be connected to. Residences usually have 120 or 240 VAC utility service. Some inverters can be field-configured to other voltages, such as 208 and 277 VAC, which are usually at commercial sites. This flexibility is handy for installers working in both of these PV markets, as they do not have to

worry about accidentally ordering or bringing a residential inverter to a commercial job or vice versa.

Maximum Output Current—GT inverters are current-limited on the output side, meaning that they are unable to produce current levels above their rating. This spec determines overcurrent protection and is used to calculate conductor size.

Max. Output Current (A)	Peak Efficiency	CEC Weighted Efficiency	CEC Night Tare Loss (W)	Cooling Method	Integrated AC/DC Disconnects	Integrated Fused Combiner	Max. AC OCPD Rating (A)	DC/AC Terminal Range (AWG)	NEMA Encl. Rating	Weight (Lbs.)	Warranty (Standard/Extended)
10.0	92.5%	90.5%	3.60	Passive	DC/AC	No	15	6-18	3R	55	10
10.0	93.3%	91.5%	3.60	Passive	DC/AC	No	15	6-18	3R	55	10
9.0	93.5%	92.0%	3.60	Passive	DC/AC	No	20	6-18	3R	65	10
9.0	93.9%	92.5%	3.60	Passive	DC/AC	No	20	6-18	3R	65	10
11.0	95.8%	94.5%	3.90	Passive	DC/AC	No	20	6-18	3R	70	10
13.0	94.3%	93.5%	3.63	Passive	DC/AC	No	20	6-18	3R	80	10
15.0	96.7%	95.5%	3.86	Passive	DC/AC	No	30	6-18	3R	85	10
21.0	97.2%	96.0%	4.10	Passive	DC/AC	No	30	6-18	3R	135	10
23.0	97.0%	96.0%	4.00	Passive	DC/AC	No	30	6-18	3R	135	10
7.0	93.6%	91.5%	0.04	Passive	—	No	15	6-10; 6-14	3X	51	10/20
6.0	93.3%	91.5%	0.04	Passive	—	No	15	6-10; 6-14	3X	51	10/20
4.0	92.4%	91.5%	0.04	Passive	—	No	15	6-10; 6-14	3X	51	10/20
15.0; 12.5	96.5%	95.0%; 95.5%	0.08; 0.07	Passive/ Fan	DC	Yes	30	6-10	3R	84	10/20
17.0; 16.6	96.8%	95.5%; 96.0%	0.14; 0.17	Passive/ Fan	DC	Yes	30	6-10	3R	84	10/20
24.0; 20.8; 18.0	96.8%	95.5%	0.46; 0.72; 1.41	Passive/ Fan	DC	Yes	50	6-10	3R	141	10/20
29.0; 25.0; 21.6	97.0%	95.5%; 95.5%; 96.0%	0.46; 0.72; 1.41	Passive/ Fan	DC	Yes	50	6-10	3R	141	10/20
34.0; 29.0; 25.3	97.1%	95.5%; 96.0%; 96.0%	0.46; 0.72; 1.41	Passive/ Fan	DC	Yes	50	6-10	3R	141	10/20
10.0; 8.7	94.5%	92.5%	0.26; 0.14	Passive	N/A ²	No	15	10	4	34	5/10 & 15
12.0; 10.2	94.8%	92.0%; 93.0%	0.10; 0.32	Passive/ Fan	N/A ²	No	15	10	4	35	5/10 & 15
13.0	96.4%; 96.7%	95.5%; 96.0%	0.50; 0.50	Passive	DC	Yes	20	6-12	3R	47	10/15
16.3	96.5%; 96.7%	95.5%; 96.0%	0.50; 0.50	Passive	DC	Yes	25	6-12	3R	48	10/15
20.7	96.4%; 96.7%	96.0%; 96.0%	0.50; 0.50	Passive/ Fan	DC	Yes	30	6-12	3R	58	10/15
22.1	96.3%; 96.6%	95.5%; 96.0%	0.50; 0.50	Passive/ Fan	DC	Yes	30	6-12	3R	60	10/15
13.0; 11.7	94.6%; 95.0%	93.5%; 94.0%	1.00	Passive	DC/AC	No	15	6-14	3R	49	10
14.9; 13.8	95.6%; 95.9%	95.0%; 95.5%	1.24; 1.52	Passive	DC/AC	No	20	6-14	3R	49	10
16.8; 15.8	95.6%; 95.9%	95.0%	1.00	Passive	DC/AC	No	25; 20	6-14	3R	58	10
18.3; 16.7	95.7%; 96.0%	95.0%; 95.5%	1.00	Passive	DC/AC	No	25	6-14	3R	58	10
22.0; 21.0	95.5%; 95.9%	95.0%; 95.5%	1.00	Passive	DC/AC	No	30	6-14	3R	58	10

Performance

Peak Efficiency—The efficiency under optimum conditions; *not* the inverter’s average efficiency.

CEC Weighted Efficiency—A more helpful efficiency value, derived from testing inverters at various DC voltage inputs. If the manufacturer doesn’t publish this data, it is

available on the Go Solar Web site (see Access). The CEC’s test has become a de facto specification for all U.S. inverter manufacturers. The efficiencies recorded at each power and voltage level are weighted for the portion of time the inverter is run under each condition, then averaged for a more accurate overall operating efficiency.

CEC Night Tare Loss—The power losses incurred when the inverter is on, but not producing energy. This is the phantom load of the inverter. The higher the value, the more energy that will be consumed overnight, when the array is not producing power. If the manufacturer doesn't list this information, it is available on the CEC Web site.

Mechanical

Cooling Method—As with all electronics, inverters work best at moderate temperatures. It is best to mount the inverter out of direct sunlight and allow good airflow around the unit, but every inverter will use either active (fans) or passive cooling.

Active cooling can quickly move air across the inverter when cooling is required, but having moving parts increases the risk of failure. Plus, the fan consumes additional energy.

Passive or convective cooling uses heat sinks—metal fins that help draw heat away from the electronics. This eliminates moving parts, but adds to the weight of the inverter. It also may limit inverter placement, since sufficient airflow is imperative with convective cooling.

Integrated AC/DC Disconnects—Some inverters include AC and DC disconnects (and some combine them into a single switch), creating a simpler installation and giving service personnel an easy disconnect location. Many of these included disconnect boxes also act as the DC combiner with fusing (see next spec). Some inverters can be detached from their disconnect enclosures without dismantling the disconnect box, for easier and safer inverter servicing. Even with integrated disconnects, a local AHJ may still require including external disconnects, depending on the location of the inverter and service entrance equipment.

Integrated Fused Combiner—This feature eliminates the need for an upstream combiner box with fusing. Individual string fusing may not be required for systems containing three or fewer series strings (see "PV Combiner Box Buyer's Guide" in *HP132*). Even if fusing is not required, isolating one string from another can help in troubleshooting and servicing the system. In some scenarios, using an integrated combiner in the inverter will be convenient and less expensive (less to be purchased). If the arrays are far from the inverter, then a combiner box closer to the array may be convenient.

Maximum AC Overcurrent Protection Device (OCPD) Rating—Typically, a dedicated breaker in the AC main load center connects a residential inverter to the utility service. The current rating of this OCPD is specified by the inverter manufacturer.

An undersized breaker can cause "nuisance tripping," turning off the inverter even though the array is producing power. An oversized breaker may not properly protect the inverter or wiring in the case of a malfunction.

DC/AC Terminal Conductor Range—Large-enough terminals are crucial for accommodating the large wires used to limit voltage drop for longer wire runs. If the terminal size is not large enough, using smaller wire pigtailed spliced to the larger wire inside the inverter housing (if there is room) or in an external junction box may be necessary.

NEMA Enclosure Ratings—The National Electrical Manufacturers Association develops electrical industry

standards and ratings for electrical enclosures. Some PV inverters are rated Type 1, which indicates that the inverters must be installed in an indoor environment. Ratings of 3R and 3X indicate that the unit is weather-resistant and can be mounted outside in a vertical position. (Most grid-tied inverters carry a 3R rating.) A 4 or 4X rating indicates that the enclosure is watertight and that the inverter can be mounted in a sloped or horizontal position. Boxes with a NEMA 6 rating can handle being submerged for a limited duration and at a certain maximum depth.

Weight—Needed to determine the ease of lifting the inverter into place for installation. For inverter spacing, also check manufacturer's specifications for the unit's dimensions.

Warranty—Before you buy, evaluate the warranty terms for each inverter considered. Typically, inverter manufacturers offer full warranties for their products for five to 10 years. Extended warranties can sometimes be purchased as well.

Depending on the situation and the particular manufacturer's in-house warranty process, it may be possible to receive an advanced replacement for failed units, reducing the time that your system is down. Some manufacturers also pay the service technician for dealing with warranty claims.

Additional Information

Manufacturer spec sheets may not always include all the information needed to plan the installation, so check the installation manual for additional information. Some inverters require a neutral connection to monitor the AC voltage and frequency per Underwriters Laboratories Standard 1741; others do not. You will also need to verify the mechanical data, including the mounting method and hardware needed for mounting.

After the installation, if you want to keep tabs on your inverter and system's function, one option (not listed on the table) is computer or Web-based monitoring. A variety of system monitoring solutions are available, from simple on-board displays to full online power/energy monitoring and weather-station-type displays. For an overview, see "Monitoring Grid-Tied PV Systems" in *HP132*.

Access

Ryan Mayfield (ryan@renewableassociates.com) has a degree in environmental engineering from Humboldt State University and lives in Corvallis, Oregon. He teaches PV classes at Lane Community College and Solar Energy International, and is a principal at Renewable Energy Associates, a PV system design and training firm. He holds an Oregon renewable energy technician license.

California Energy Commission • www.gosolarcalifornia.org • Listing of California eligible RE equipment, including the state's additional inverter specifications



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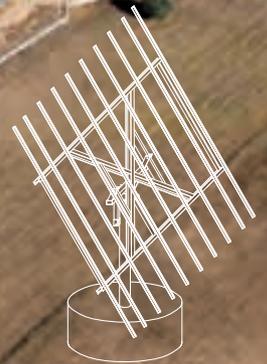
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Solar Collectors

...Behind the Glass

by Chuck Marken

Solar collectors are the engines that drive all solar energy heating systems. If variety is the spice of life, then the full lineup of solar thermal collectors is a flavorful dish indeed. Although solar heating collectors have settled upon a few basic designs, they are still manufactured in an array of configurations. We'll look at the different classifications and types of collectors, and briefly examine the construction differences, which can affect system performance. For in-depth coverage of Solar Rating and Certification Corporation (SRCC) certified collectors, see the 2008 buyer's guide in *HP123*.

Solar collectors are classified by the temperatures that can be produced under normal amounts of solar radiation. The collector's end-use application can be determined by the temperature classification. Low-temperature collectors (which typically produce temperatures lower than 110°F) are used for applications such as swimming pool heating. Medium-temperature collectors (up to 200°F) are used for space heating and heating domestic hot water. High-temperature concentrators (greater than 250°F) track the sun and are capable of producing the high temperatures required to drive Stirling-cycle heat engines and steam turbines. Let's start low and work our way up.

Low-Temp Collectors

First in the collector lineup are unglazed collectors, which include swimming pool collectors—the most popular solar thermal system in the United States. The collectors are simple and inexpensive, and the systems follow suit.

Early pool collectors were made from copper tubing and plates—essentially the absorber of a classic flat-plate collector with larger header tubes to accommodate the flow rates associated with swimming pool pumps. But copper swimming pool collectors gave up the market long ago to black plastic polymer collectors, especially polypropylene, a relatively high-temperature plastic. With no insulation or other



Courtesy www.solarexpert.com

Simple unglazed solar pool collectors offer great energy savings over conventionally heated pools and spas.

Cutaway of a polypropylene solar pool heating collector.

protection from the weather, these systems are only for seasonal use in most climates. Solar pool heating systems have such a high benefit-to-cost ratio that they are routinely excluded from incentives for solar energy heating equipment.



Chuck Marken



Courtesy Brian Melholic



Flat-plate collectors are most commonly used to supply hot water for domestic and space heating uses.

Medium-Temp Collectors

For all but the mildest climates, two main types of medium-temperature collectors are available: **flat-plate** and **evacuated-tube**. Flat-plate collectors have a history going back at least 100 years; evacuated tubes have been available for about three decades. Flat-plate collectors are less expensive per square foot of collector—and this has made market penetration tough for evacuated-tube collectors, except in colder, cloudier climates where tube collectors may outperform flat plates. The cost difference between the collectors fluctuates with the price of copper, a primary material used in most flat-plate collectors. Both tubes and plates are used in applications such as domestic hot water systems, space heating, and indoor pool heating. To be eligible for the federal government's residential solar investment tax credits, collectors must be certified by the SRCC. Commercial and industrial scale projects don't require the certification to be eligible for the 30% credit.

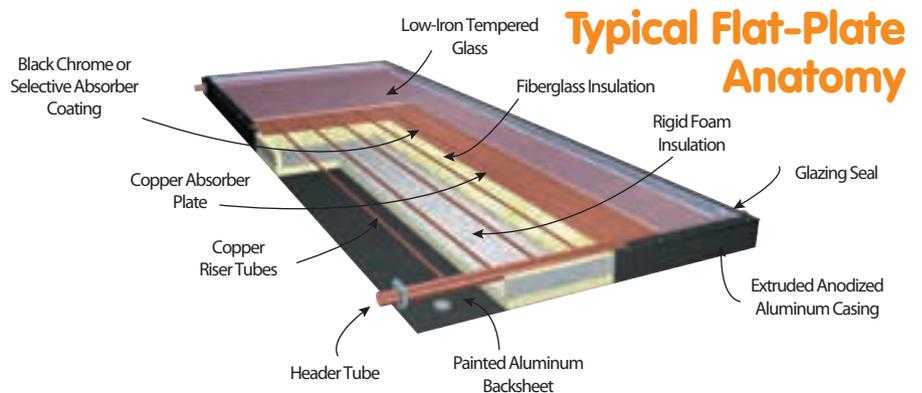
Flat-Plate Collectors

Flat-plate collectors are named after their flat absorber plate. These collectors are made with a metal enclosure (usually aluminum) and high-temperature insulation, and usually are covered with a sheet of low-iron tempered glass. Low-iron glass is important in collector design because, compared to typical window glass, it passes about 7% more light to the absorber inside the collector. The tempering of the glass makes it tough enough to withstand all but the largest hailstones.

Absorbers can be configured in a couple of ways. One design—a grid—uses multiple small riser tubes spaced a few inches apart. Each riser is brazed to the headers—the horizontal tubes that allow collectors to be connected together quickly. The entire tube assembly is then bonded to the absorber plate. Multiple riser tubes allow even flow through the collector with minimal restrictions.

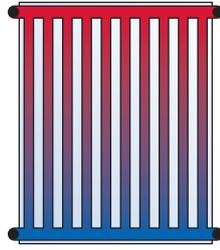
Another design uses a single tube to bend back and forth in a serpentine pattern between two headers, a strategy for antifreeze-based systems. A downside to this design is that, in a drainback system, the single, bent riser tube can retain water and possibly freeze.

Besides differences in absorber configuration, collectors may locate headers inside or outside of the frame. Collectors with internal headers are designed to be connected together. With two inlets and two outlets, connections between collectors can be accomplished with minimal materials and labor. A classic internal-header collector has headers that are

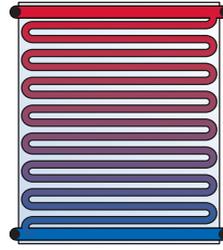


Courtesy www.sunearthinc.com

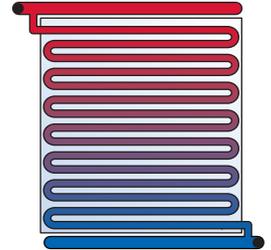
Flat-Plate Configurations



Grid-Style Absorber with Internal Headers



Serpentine-Style Absorber with Internal Headers



Serpentine-Style Absorber with External Headers

large enough not to impede the flow when a row of eight to 10 collectors are installed in parallel.

External header collectors have a single inlet and outlet, and a simple serpentine bend tube. External header collectors require extra materials and labor in parallel-collector configurations.

An option to the external header is connecting multiple collectors in series. A series connection requires that each collector's outlet is connected to the next collector's inlet. Each collector in series is hotter than the preceding one and the system experiences more heat loss. While an appreciable drop

in production doesn't occur with just a couple of collectors in series—the more that are connected, the worse the heat loss becomes.

Regardless of the design, the riser tubes through which the collector-loop fluid flows must be soldered, brazed, or welded to the absorber plate, or bonded to the absorber plate with a high-temperature, thermally conductive adhesive. Bonding of the plate to the tubes is critical to the collector's performance—a poor bond can cut the collector's heat production by 50% or more.

Integrated Collector/Storage Units



The oldest design for a medium-temperature collector is the batch water heater. At its simplest, it is an insulated box with a black-painted tank inside and a glass cover that faces the sun. The use of batch heaters in mild climates transcends more than a century of fairly wide popularity. In places where freezing temperatures are common, batch heaters can be used seasonally, and bypassed and drained when winter weather comes.

Progressive-tube batch water heaters are a more recent development. Instead of a single, large tank, the water is contained in several 4-inch-diameter tubes. The tubes are piped in series, with the cold water entering at the bottom of the collector and the hot exiting at the top. The progressive-tube design allows the water to stratify more, limiting the mixing of the incoming cold water with the exiting hot water. Both the tank-type and progressive-tube batch heaters are classified as integrated collector/storage (ICS) units.

Flat-plate and twin-tube evacuated collectors that are designed with the tank attached are also classified as ICS units. These designs depend upon thermosyphoning, where hotter liquids "rise" and colder "fall" as long as the storage tank is higher

than the collector. ICS units are completely passive and don't depend on any moving parts or electricity to operate, though some contain electric water-heating elements for backup.

The flat-plate ICS designs use a classic flat-plate collector. The hot exit pipe of the collector is piped to the top port of the storage tank. The cold (or bottom) port of the storage tank is piped to the cold inlet at the bottom of the collector. As long as the sun is shining, water circulates through the collector and tank.

The twin-tube evacuated tube design is similar, although these heaters are only for use with unpressurized water systems. The inner tube of the twin tube is painted black and acts as an absorber. Each tube is "plugged in" at the bottom of a special stainless steel tank with gasketed ports the same diameter of the twin tube, one port for each tube. When the tank is filled with water, the inner tube is also filled with water. When the sun heats the inner tube through the black-painted absorber, the water moves by thermosyphon into the tank. The evacuated tube ICS has a freeze-tolerance advantage over the flat-plate thermosyphon unit due to the high insulation value of the vacuum.

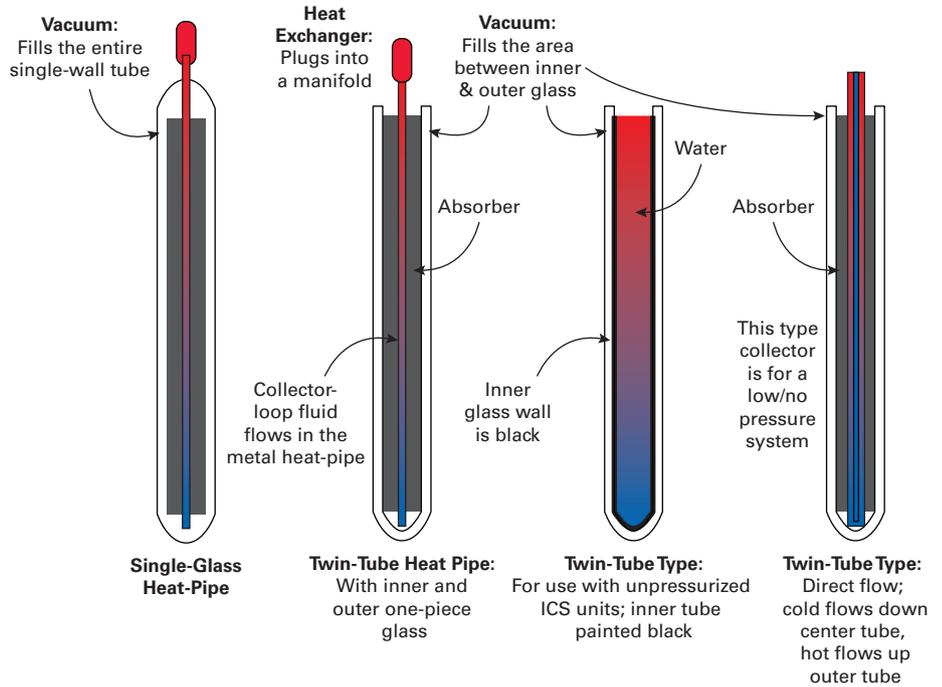
Evacuated-Tube Collectors

Evacuated-tube collectors depend on vacuum technology for superior heat retention—a vacuum is an excellent thermal insulator. Even a relatively small space filled with a vacuum provides much better insulation than the foam, fiberglass, and glass cover of a flat-plate collector. With superior heat retention, evacuated tubes are often preferred in colder climates and cloudy regions where flat-plate collectors have lower performance.

Many early evacuated tubes had design flaws that caused the loss of the vacuum after only a few years. When the vacuum is gone, the heat retention advantage is also eliminated. But the past problems with vacuum loss have been addressed, and vacuum tube collectors are enjoying a renaissance throughout many countries in the world. Because of their popularity in China and Europe, the tubes have an increasing share of the world market in SHW collectors.

Tubes can be configured differently for various applications. The largest difference is where the all-important vacuum is contained.

In a **single-glass** tube, the vacuum fills the entire space inside the glass tube. These were the first type of evacuated-tube collectors manufactured, and experienced problems with the vacuum escaping at the top of the tube, where the glass was sealed to the absorber tubing. These early collectors also were made of inferior glass that was very fragile, and many fell victim to hailstones. Today, all the tubes are made with



more-durable borosilicate glass or soda-lime glass. Older designs with single-glass tubes have a copper waterway bonded to a flat copper absorber inside the tube. The collector-loop fluid enters the tube at the top and exits at the bottom. Another direct-flow design locates both the supply and return tubing at the top of the tube. However, this design—where the collector loop fluid directly flows through the tube—has fallen out of favor because trapped fluid limits the tubes to an antifreeze system. Plus, broken tubes are not easily replaced.

The most popular evacuated-tube design incorporates a heat exchanger in each tube. In these designs, the heat exchanger consists of a single tube—a “heat pipe”—bonded to the absorber plate. The solar radiation heats the tube absorber, which heats the heat pipe, boiling and vaporizing the fluid (typically alcohol or purified water with special additives) inside it. At the top of the tube, a heat exchanger transfers the heat from the vapor to a manifold, through which collector-loop fluid circulates. The heat-pipe design allows each evacuated tube to be a separate collector and makes the entire system modular. This is popular with some installers since the collector can be assembled on the roof. Plus, since there is a “dry” connection between the absorber and the header, installation is much easier than with direct-flow collectors. Individual tubes can also be exchanged without draining the entire system of its fluid. Finally, should one tube break, there is little impact on the complete system.

Twin-tube collectors are built similarly to the popular vacuum bottles that keep drinks warm or cold. Two separate tubes, one inner and one outer, contain a vacuum between them. Most twin tubes use the heat-pipe design described above, but can be used in direct-flow and integrated collector/storage units (see “Integrated Collector/Storage Systems” sidebar, previous page). The heat-pipe design in a twin-tube collector is the same as in a single-glass collector and they enjoy the same benefit of superior insulation.

Absorber Coatings

Flat-black paint was used on all solar collectors up to the late 1970s. Although this coating has high absorption (about 95% of solar radiation), it also has high emissivity (also about 95%), resulting in efficiency losses.

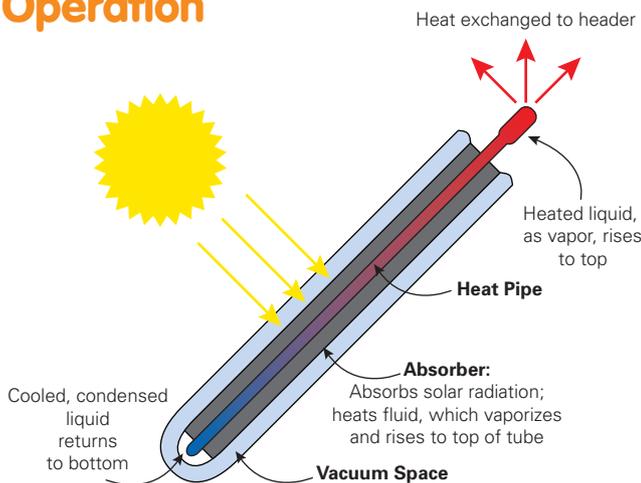
A significant improvement in collector performance came from the advent of selective-surface coatings, which absorb about as much radiation as flat-black paint but emit only 10% to 20%. This amounts to a gain of a few percentage points in collector performance. A selective coating is a complex and expensive process compared to simply painting an absorber—but it is worthwhile in many cases, such as installations in colder climates. Some selective-surface coatings are called black chrome, black crystal, and sputtered aluminum.



Courtesy www.thermomax.com

A modern evacuated-tube collector, showing the heat exchanger at the top of the tube and its connection to the manifold.

Evacuated Tube Operation



Air Collectors

Least known in the medium-temperature category, air collectors are used for space heating. They are similar to liquid flat-plate collectors and are difficult to differentiate from a distance. The only differences from SHW collectors is that air collectors don't have any tubing bonded to the absorber plate and use round ducts on the back, instead of tubing on the side, as the collectors' inlets and outlets.

Air from any room or building is ducted to the collector, where it passes over its aluminum absorber, gaining 30°F to 60°F depending on the room air temperature and amount of sunshine available. Then the heated air is circulated back into the room/building. The collectors can use passive air

circulation but most often include a blower to force circulation and increase efficiency. The efficiency of air collectors is about 10% lower than liquid collectors due to the lower density and heat-carrying capacity of air.

Air collectors can also be configured as transpired air collectors, which have thousands of tiny holes in the absorber. Heat is transferred from the absorber to the air as it moves from one side of the absorber sheet to the other.

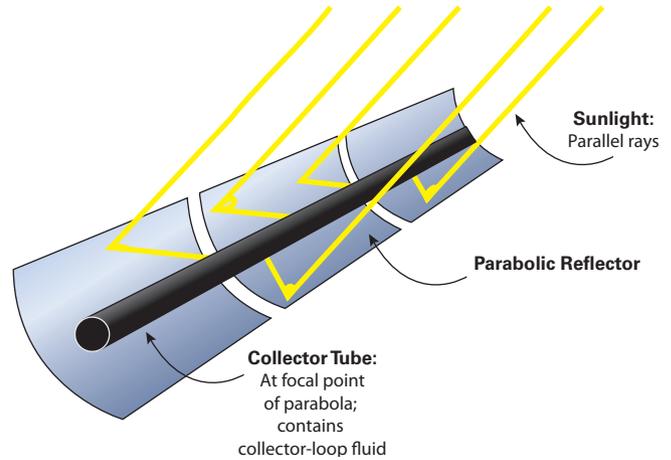
High-Temperature Concentrating Collectors

Solar concentrators are capable of making high-pressure steam (400°F to 750°F) and have limited residential applications. With few exceptions, the niche for concentrators is utility-scale electrical generation. Concentrators compete economically with hydro, wind, biomass, and photovoltaics.

Concentrators must track the sun throughout the day to maximize their potential. The concentration of the sun's rays requires direct-beam solar radiation (primarily desert sun) and this need is a limiting factor in their deployment.

Concentrators come in two types: line-focus and point-focus collectors. A parabolic trough reflector is the collection part of a line-focus collector. A black target tube runs the length of the trough and is mounted at the focal point of the mirrored, curved surface. The trough reflects about 90% to 95% of the direct-beam radiation onto the target tube, heating the circulating collector-loop fluid within it. Typical systems run synthetic oil through the target tubes and exchange the heat to a water loop, creating steam to drive a turbine that generates electricity.

Parabolic Trough Reflector



Courtesy Greg Kolb, Sandia National Laboratories



A large array of parabolic trough concentrating collectors at Kramer Junction, California.

Point-focus collectors typically resemble satellite dishes. Instead of focusing on a tube, the collectors focus on a point. The dishes that collect the solar radiation are also parabolic mirrors, only round. These systems are used to heat buildings and make hot water in desert climates, although the market is limited. The piping to and from the collector is usually underground. In freezing climates, antifreeze is used as the collector fluid. The dishes are also used as the heat source for a Stirling engine. A single, large mirror or several smaller mirrors focus the solar radiation on the cylinder of a Stirling-cycle heat engine, which is coupled to a generator to make a stand-alone electric power plant. The units have been built in 5 to 30 kW capacities.

A central receiver system is another type of point-focus collector. It consists of a receiver tower surrounded by large mirrors called heliostats. The heliostats are computer-controlled and track the sun in concert to reflect the solar radiation onto the receiver. The collector-loop fluid is piped to a heat exchanger and steam is used to drive a turbine to produce electricity. These large point-focus collectors can concentrate enough solar energy on the receiver to create temperatures in the thousands of degrees. Few large central receivers are in operation—they are still considered to be in the research-and-development phase. They also have high initial costs and other issues surrounding the high temperatures they produce. The only application for central receivers is the utility-scale generation of electricity.

What's Best for You?

The classification of the collectors by their effective end-use temperatures is a helpful method of differentiation. The residential uses of solar heating collectors eliminate high-temperature collectors for consideration by most people.

Medium-temperature collectors apply to residential applications, and can effectively heat domestic water and assist in space heating throughout most of North America. Commercial or industrial applications not requiring high temperatures are also good candidates for medium-temperature collectors. ICS units are popular in many southern states with mild climates. Flat plates are the choice throughout most of the United States for heating water, but evacuated tubes have become popular in some northern climates.

Point focus parabolic dish with Stirling engine at Plataforma Solar de Almeria in Spain. Note the parabolic troughs in the background, turned out of the sun to stop heat production.



Courtesy: Schlaich Bergermann und Partner



Courtesy: Thomas Mancini, Sandia National Laboratories

Low-temperature collectors are used almost exclusively for heating pools and hot tubs, with the season dictated by the local climate. They can also be used for heating domestic water in very mild climates, but these systems are rare and have questionable performance in medium to cold climates in the winter.

The SRCC publishes catalogs of the collectors and systems certified under their program, which is recognized in many federal, state, local, and utility incentive programs for solar thermal systems. The catalogs are updated a few times per year and are available at www.solar-rating.org.

Access

Solar thermal editor **Chuck Marken** (chuck.marken@homepower.com) is a New Mexico licensed plumber, electrician, and heating and air conditioning contractor. He has been installing and servicing solar thermal systems since 1979. Chuck is an instructor for Solar Energy International and teaches solar workshops throughout the United States.



A Stirling engine driven by heat from focused mirrors can produce up to 30 kW of electricity.

An advertisement for U.S. Battery Solar Deep Cycle Batteries. The background is green with a grid pattern and a large image of the sun. The text reads: "SOLAR DEEP CYCLE BATTERIES" in large white and green letters. Below this, it says "For Reliable Energy Storage Always Demand U.S. Battery's Diamond Plate Technology® Batteries." There are five batteries shown in various colors (blue, white, red). At the bottom, it says "Our Battery line is an excellent energy storage source for most solar applications and our batteries will take the XTREME heavy day to day charge-discharge cycling." and "To See Our Entire Line Please Visit Our Web Site WWW.USBATTERY.COM". The U.S. Battery logo and the XTREME CAPACITY logo are also present.

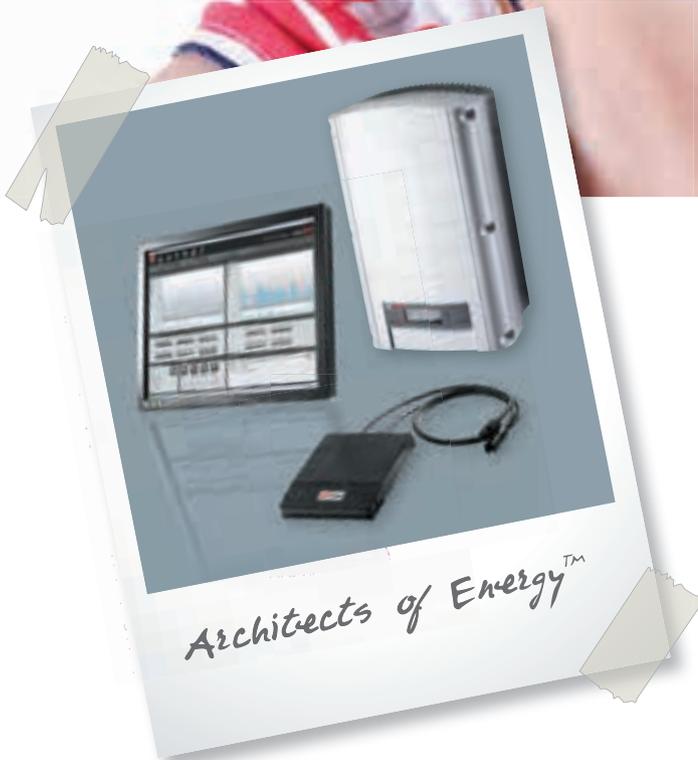
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APPROPRIATE TECHNOLOGY

for the Developing World

by Ian Woofenden



While it's easy to get focused on our energy and economic problems here in North America, the largest portion of the globe's population lives well below our standard of living and our standard of energy usage. Yet many aspire to our standard, so if you care about the environment, you should care about how people in "developing" areas change and develop in relation to energy. If they all follow our North American example, Earth is in big trouble.

If you care about people and want to become involved in spreading renewable energy, the developing world is ripe for your efforts. With a modest amount of money, time, and effort, you can have a big impact on families and communities. And if a good job is done, the systems will be an example for others in the community and beyond.

This article looks at specific technologies that you might consider working with in the developing world, and explores their appropriateness and cost, as well as design and implementation issues. Susan Kinne of Grupo Fenix, an organization that implements appropriate technologies in Nicaragua, says that developing-world communities have a chance to avoid some of the poor development choices we in the "prematurely developed" world have made. Properly executed, technology in the developing world can provide sustainability, a higher quality of life, and renewable energy for all.

Energy Use in the Developing World

The Alliance for Rural Electrification reports that roughly 2.4 billion people rely on burning biomass—wood, agricultural residues, and dung—for cooking and heating. About 1.6 billion have no access to electricity. Of the homes not connected to the grid, about 10% use car batteries for electrical energy storage, according to a report published by the World Bank.

Current mainstream energy technologies in the developing world tend to mirror what we see in North America:

- Electrical grids powered by coal, oil, gas, nuclear, hydro, and diesel
- Propane for cooking, space heating, and water heating
- Diesel- and gasoline-fueled transportation

Top to Bottom:

Putting up a PV system for home lighting and communications in Ecuador.
A rooftop PV system in Sierra Leone provides power for lighting an educational facility.
A PV-powered health clinic in Burma.
Piping for a solar-powered water pumping system in Benin.

Courtesy www.sunepi.org (4)

All of these technologies have social, environmental, and economic costs. Besides increasing air pollution and having serious environmental impacts for extraction and transportation, fossil-fuel-based electricity—when available—is often unreliable and expensive enough that poorer people cannot hook up to the grid.

Propane, diesel, and gasoline are also expensive, and often require transportation from rural areas to towns to refill portable bottles or fuel tanks. In one rural Costa Rican town I work in, buying fuel means a one- to three-hour trip by bus, horse, car, or motorcycle.

Energy sources tend to be less clean and less safe than what we are used to in the “developed” world because standards of living and environmental quality are lower, and corners get cut in the design and operation of energy plants. And because family income is much lower, these fuels tend to be relatively expensive—sometimes prohibitively—for people in the developing world. In Namibia, for example, consumers pay \$0.83 per liter (\$3.13 per gallon) for diesel fuel. While this doesn’t sound like much, put this in context with the country’s average annual income of about US\$4,200 in 2008. In comparison, U.S. consumers paid an average of \$2.46 per gallon for diesel fuel (July 2009) and had an average income almost 10 times greater than that of a Namibian.

Wood and other biomass, which are typically used for cooking and heating, come at less out-of-pocket expense in most cases, but at greater time and health costs. People (most often women and children) may spend many hours every day gathering wood, sometimes from a great distance. Increasing populations have put increased pressure on wood resources, resulting in localized deforestation. In some areas, the nearest fuelwood can be a five-mile trek (or more), according to the Food and Agriculture Organization of the United Nations. As regions become deforested, women and children are forced to walk longer distances to find firewood, leaving less time for other pursuits—like learning to read, helping with the home, and livelihoods.

The indoor air pollution from burning biomass in open fires and unvented, inefficient stoves causes major health problems. In a 2008 study published in the *BMC International Health & Human Rights* journal, which focused on the health effects of burning biomass fuels, rural women “reported two to three times more respiratory disease in their children and themselves” compared to those with urban-traditional and middle-class backgrounds.

Appropriate Technology

So what can renewable energy offer people in the developing world? A lot! In fact, much more for much less than it can for those of us with “developed” energy appetites. A very modest investment in renewable technology infrastructure can mean dramatic changes in comfort, health, education, income, and safety.

The primary renewable technologies used in the developing world are solar cooking; solar water heating and purification; solar, wind, and hydro electricity; and methane biodigesters.

Solar cooking is one of the simplest and most cost-effective RE technologies. With adequate sunshine, a solar cooker can offset the use of electricity, gas, or wood for cooking, saving families money, time, and effort spent gathering, and reducing the pressure on natural resources.



Courtesy www.sunepi.org (2)



Courtesy www.solarenergy.org



Courtesy www.sunepi.org



Courtesy www.solarenergy.org

Top to Bottom:
 Putting up solar-powered lighting at a medical training facility in Burma.
 PV electricity powers a medical center in Rwanda.
 School-children work on PV-powered computers in Pinar del Rio, Cuba.
 Mounting an array for a medical center in Rwanda.
 Rumalda, of the Solar Women of Totogalpa, prepares to bake a cake
 in a solar oven in Sabana Grande, Nicaragua.

WHAT'S DEVELOPMENT?

While there is much debate about the terminology and what constitutes a “developing” country, it is generally agreed that the economies of countries are categorized by statistical indices, such as per capita income, literacy, life expectancy, and so forth. The International Monetary Fund’s April 2009 *World Economic Outlook* report classifies about 150 out of the world’s almost 200 countries as “emerging and developing economies.”

The United Nations Statistics Division notes that “the designations ‘developed’ and ‘developing’ are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process.”

Often, “undeveloped” countries are *more* developed in the things that make higher-quality lives—more time for connecting with family, community, and friends, and a stronger connection with nature. While we in “developed” countries have an image of our life as better, we actually spend much of our working lives dreaming of the leisure, connection, and lack of focus on superficial things that many people in the developing world already have.

There’s a popular tale that involves a North American businessman giving advice to a Mexican fisherman. The businessman notes that the fisherman goes out in his boat for only half the day, catches the fish he needs, and spends the rest of his day with his family. He suggests that the Mexican invest in more boats, hire other fishermen, catch a lot of fish, and become “successful,” so that in 20 years, he will have the leisure time to go out in his boat for just the morning and spend the rest of the day with his family.

A solar cooker is an insulated box with a glass top and one or more reflectors to concentrate sunlight through the glass. Even home-built versions can attain temperatures of 300°F. A wide variety of foods can be conveniently and safely cooked, including beans, rice, vegetables, tubers, and whole roasts of meat.

Because it is not a fast cooking method in most cases, solar cooking requires some advance planning and some patience—two things that people in “developed” countries may be short on, but people in the developing world come by more naturally. By preparing the evening meal right after lunch and putting it in the solar oven, the meal can be ready to go when dinnertime rolls around.

A high-performance solar cooker can be built or bought for a few hundred dollars. Simpler manufactured cookers can be purchased for less than \$100, or constructed for far less in materials cost.

Solar Water Heating. Just as it can heat a solar cooker, sunshine can heat water for dish and hand washing, bathing, and cooking. If freezing is not a concern, solar hot water systems can be as simple as a black plastic bag, a coil of black pipe, or even a black-painted barrel.

Low-pressure passive solar water heaters—with no pumps or controls—are well suited for the developing world. These “batch collectors”—where a quantity of water is contained in a collector vessel and heated without cycling between a tank and the collector—are effective and practical.

Solar water heating is not common in the developing world for a couple of reasons. Many such places are located in warmer climates, where hot water is less desired: People have lived for centuries in these locales without hot water, so culturally it is not the norm. In one location, a group I was leading installed a solar water heater for a shower. Later, we were told by one of the locals that they wait until the evening to shower—when the stored water is at its coolest.

Left to right: A thermosyphon solar hot water system in Costa Rica.

A simple batch water heater in Costa Rica.

Installing a 200 W low-head hydro turbine in Mae Klang Luang village, Chiang Mai province, Thailand.

PV-powered water pumping in Pakistan.



Courtesy www.solarenergy.org [2]



Courtesy www.sunepi.org



With all renewable energy technologies in the developing world, being aware of the actual *need* is important. Solar hot water may be most applicable in health clinics, schools, and daycare centers where there is a need to cleanse instruments or dishes. In areas where cold temperatures prevail, including mountainous regions and northern climes, solar heating systems can also be important for heating bathing water.

Solar water purification can help provide safe drinking water to the estimated 1.3 billion people worldwide who suffer with contaminated water supplies, which lead to the deaths of 2 million children each year.

Two solar technologies can help. One is solar distillation, which uses a box, pit, or cone-shaped plastic structure that allows water to condense on a piece of glass or plastic and run into a collection container. The condensed water is pure and safe to drink. Unfortunately, except for very large units, most solar stills only produce modest quantities of distilled water.

Solar pasteurization is a more practical alternative for purifying larger volumes of water. Tests have shown that bringing water to 149°F inactivates all pathogenic microbes, and solar cookers can easily achieve this. To provide temperature monitoring to assure water is adequately heated, Solar Cookers International has developed a low-tech thermometer for use with water heating in solar cookers. Placed in the water to be pasteurized, a tube, which contains soybean wax that melts at 158°F, shows when the water has achieved the appropriate temperature.

Solar Electricity. In many undeveloped areas, people rely on candles or kerosene for lighting, or disposable batteries and car batteries powering DC

lights. In some cases, a rag wick stuffed into a jar of kerosene serves as illumination. A small solar-electric system with electric lighting can provide much more and better-quality light, and eliminates the ongoing costs of buying candles or fuel.

Early adopters of PV technologies tend to be community organizations such as schools, clinics, and community centers—but individuals soon see that the technology will also work in their homes. Though simple lighting systems are common, the applications for solar-electric technology don't end there, but include water pumping, refrigeration, and electricity for appliances and tools.

Developing world solar-electric systems often take the form of a single PV module, a controller with built-in metering, a deep-cycle battery, wiring, and disconnects. Most system parts are durable and long-lasting if installed well. The battery will need to be replaced perhaps every five years, depending on the original quality and how well it is cared for.

Because most developing world PV systems are off-grid, users must be educated about the limits of the systems. Some method of monitoring the battery state of charge is crucial. Sometimes this can be as simple as a red-yellow-green light system in the charge controller, which warns users when the battery is low. State of charge may also be displayed graphically or numerically, either with a "fuel gauge" or a percentage. It is common to include a low-voltage disconnect in the controller, which automatically shuts off electrical output until battery state of charge returns to an acceptable level.

The downside to solar electricity is its relatively high up-front cost, which can range from \$200 to \$600 for a rudimentary system to power a few lights. Financing or subsidization from nonprofit organizations, community groups, or individuals is often necessary.

Right: Wind energy powers a school and community center on a remote Nicaraguan island.

Below: Fabricating PV racks for off-grid schools in Sierra Leone.



Courtesy www.solarenergy.org

Below: A 1 kW hydro system in E Wi Jo village, Tak Province, Thailand, powers lights for 40 huts and the school.

Courtesy www.palangthai.org



Courtesy www.sunepi.org





Courtesy www.sunepi.org



Courtesy www.palangthai.org (2)



Courtesy www.solarenergy.org (2)

Hydro-Electricity. Where available, hydro-electricity can offer a cost-effective and reliable source of electricity. Applications range from very small homebrew systems to power a few lights to larger, “village power” systems.

These systems include some form of intake in the stream to get a portion of the water into a pipe or flume. The water runs downhill to a turbine, which consists of a runner that is turned by the water to spin an alternator. Small systems are typically battery-based but can be batteryless for specific applications.

Costs for a very small system might be \$1,000 or less, if labor is cheap and homebrew equipment is used. A village power system might cost \$25,000 and up, depending on the size of the system. This might sound like a lot, but for the energy delivered, hydro systems tend to be the most cost-effective. Fund-raising for village power systems can take many forms, including by charitable organizations and individuals, with some buy-in by the recipients.

The biggest drawback of hydro systems is that the resource is relatively rare. Often the falling water is not located near where the electricity is needed. And if it’s a long distance, pipe and wire costs can be high.

Wind Electricity. Of the three renewable electricity technologies, wind electricity is the most difficult to tap effectively over the long haul. A turbine’s constant exposure to the weather coupled with its difficult job of capturing the resource make many small wind installations unreliable at best. Plus, few sites have a wind resource worth tapping that is easy to access cheaply.

Wind-electric systems consist of a wind generator, a tall tower to get it up above all obstructions, transmission wires down the tower and to the controller, a battery bank, possibly an inverter, and standard distribution hardware.

Village-sized wind systems can cost from \$10,000 on up, but grants and private donations can cover equipment and installation costs. As with other electrical systems, the recipients often contribute labor, food, lodging, transportation, and building materials.

If the people involved are willing to perform regular maintenance, be prepared for failure and repair, and understand that this is challenging technology, tapping the wind can be rewarding.

Methane Biodigesters. Although less common, producing methane gas with a biodigester is one of the simplest and most economical technologies used in the developing world. Only solar cooking is easier and cheaper to implement. For about \$200, a methane biodigester can be built that will produce cooking gas for a family of five to seven people from the manure of two or three cows or pigs.

These systems use a long, large, doubled plastic tube as the digester—where microbial breakdown of the manure takes place. An entry pipe to add the manure-and-water slurry lies at one end. A pipe at the other end allows the digested slurry to exit after several weeks in the tube. A small tube exiting the top of the large tube vents the accumulated methane gas through a simple pressure-relief valve to the cooking stove.

Top to Bottom:

A PV system in Burma.

Hauling a 3.2 kW hydro turbine to power a school, community center, and church in Huai Kra Thing village, Tak Province, Thailand.

Milling grain with hydro power in Mbinga, Tanzania.

A methane cookstove and a biodigester in Costa Rica.



Courtesy www.sunepi.org

A doctor poses in front of the 10 kW PV array at a health center in Burundi.

Besides making cooking gas, methane systems transform a potential pollutant that can end up in streams and rivers into a more benign fertilizer. The digesters require protection from the elements and from sharp-toothed animals, but are otherwise sturdy and long-lasting. They offset the use of electricity, propane, and wood for cooking, and can be used at any hour of day or night—an advantage compared to solar cookers.

One installation I was involved with in Costa Rica was especially successful. Don Mario had enough pigs to supply gas for both his and his daughter and son-in-law's home. On a recent visit, Mario showed off the system by cranking up the gas flame—it almost scorched the metal roof of the family's kitchen. The gringo visitors teased him that he could fry eggs on his roof.

Access

Ian Woofenden (ian.woofenden@homepower.com) coordinates and teaches RE workshops in Costa Rica for Solar Energy International, and also consults and volunteers on other RE projects in the developing world.

Palang Thai • www.palangthai.org

Solar Energy International • www.solarenergy.org

Sun Energy Power International • www.sunepi.org

Further Reading:

"Clean Water from the Sun," Laurie Stone, *HP62*

"Cooking Under the Sun," Rose Woofenden, *HP107*

"Low-Head Microhydro: Thai Style," Chris Greacen, *HP124*

"RE Independence in Nicaragua," Andreas Karelis, *HP123*

"Solar Cooking in Kenya," Barbara Knudson & Mark Aalfs, *HP66*

"Solar Electricity for the Developing World," Walt Ratterman, *HP119*

"Turning Waste Into Fuel: Methane Biodigester Basics," Ilan Adler, *HP116*



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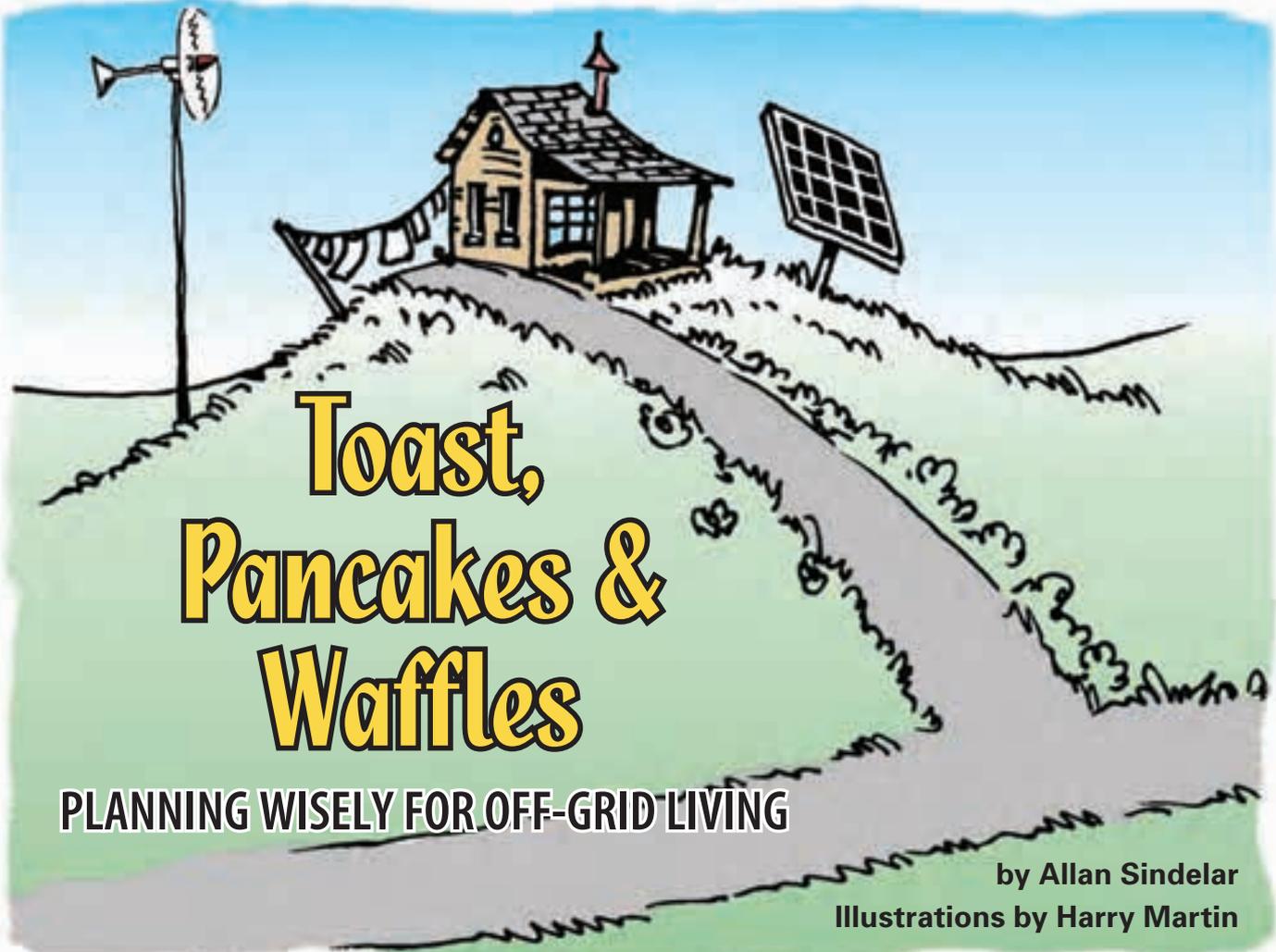
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PLANNING WISELY FOR OFF-GRID LIVING

by Allan Sindelar

Illustrations by Harry Martin

Living well on a small and finite amount of electricity is not mysterious or difficult. It starts with careful adherence to three basic principles:

1. Shift inappropriate loads to other forms of energy.
2. Reduce waste through efficiency, and increase conservation.
3. Use energy in proportion to the amount available.

The average home here in New Mexico uses 600 kWh of electricity per month, or about 20 kWh per day. This works out to a bill of about \$50 per month, plus base charges. By comparison, a 1 kW PV array in a modern off-grid power system produces about 5 kWh per day in summer and a bit less than 4 kWh per day in winter. This is less than 25% of the amount of electricity used by the typical home. Yet for plenty of off-grid homes in New Mexico, a 1 kW system yields more than adequate power to run all of the lights, appliances, and electronics that make a comfortable life.



All forms of energy are not created equal. Electricity is a specialized, high-quality form that is not suited to all applications, but great for some: lights, electronics, and motors, plus a few other specialized uses.

A load analysis—a systematic and methodical listing of everything you expect to power in your home—has always been an essential part of off-grid power system design. For each load, the expected power consumption and hours of use are listed. (For information on completing a load analysis, see the “Assessing Loads” sidebar.) There are no one-size-fits-all solutions—each off-grid system is uniquely designed to its site, loads, budget, and the personal wishes of its owners.

Shifting Loads

All forms of energy are not created equal. Electricity is a specialized, high-quality form that is not suited to all applications but great for some: lights, electronics, and motors, plus a few other specialized uses. By matching the best form of energy to its appropriate use, electricity consumption can be greatly reduced while enhancing comfort and convenience.

Five common uses of electricity in conventional on-grid homes won't typically show up in an off-grid home. Each consumes too much energy to be appropriate when the supply is limited by typical PV system costs. All five of these use electricity in ways best served by other forms of energy.

Space Heating. Electricity may be used to run thermostats, pumps, and boiler controls, but in an off-grid system it is not usually turned into actual heat. The sun's heat is best used directly. Build or retrofit your home to hold in as much heat as possible by maximally insulating the structure's walls, ceilings, and/or attic spaces, and floor. Seal gaps and cracks well. If you're building a new home, incorporate passive solar strategies by using properly sized south glazing and plenty of thermal mass. If you have or are planning in-floor radiant heat, active solar thermal collectors (“solar heat”) can be installed to decrease or avoid boiler use. Otherwise (or in addition), plan to use wood or propane heaters to provide space heating.

Water Heating. Use the sun directly to heat your water with a solar hot water system and use a high-efficiency propane water heater as backup.

Tankless gas water heaters are an option for some homes. However, in areas where hard water predominates, the cost and hassle of the increased maintenance and repairs due to scaling buildup tend to offset potential energy savings. Tankless water heaters use multiple small tubes to heat water quickly. The minerals build up in the small passages, decreasing the unit's efficiency.

Assessing Loads

A load analysis is a listing of everything you expect to power in your off-grid home with the power consumption and hours in use summed and averaged to estimate normal daily energy consumption. For most off-grid homeowners, a load analysis should reflect winter living habits, when consumption is greatest.

It's a rigorous and time-consuming process, but necessary. For system designers, it serves four purposes:

1. Lists and quantifies actual loads, so the system can be sized to meet the home's needs.
2. Helps identify ways to use less energy to achieve the same result, which can reduce system size and cost.
3. Helps identify overlooked or inappropriate loads, potential problems, and special cases, so that alternative ways of achieving the desired results, while using less electrical energy, can be suggested.
4. Serves as a document of record. That is, if a system proves insufficient in the future, a record was kept of how much energy use was expected. Actual consumption can then be reevaluated, and loads reduced or the system expanded.

For the client, a fifth benefit arises that is really the most important of all: a valuable self-education process. Most of us who have lived with utility power have taken it for granted: We use it as needed and pay the bill each month. We have had little reason to know how the energy is used: how much and for what. The load analysis process is an excellent consciousness-raising activity. By understanding how and where you're using solar electricity, you are far more likely to be satisfied with your power system—and its limits and blessings—over the many decades you will own it.

Many PV system installers or dealers offer forms to help the load analysis process. For more information, read “Getting Started with Renewable Energy: Professional Load Analysis and Site Survey,” available from *Home Power* Web Extras at www.homepower.com/webextras. Once you have an understanding of how to perform a load analysis, you can use an inexpensive measurement device, such as the Kill A Watt meter, which allows you to plug in any AC device and measure its power and energy consumption.



Cooking. Plan to use a gas range and oven, not an electric one. But beware: Many gas ovens use electric “glow-bars” that can draw up to 500 W continuously when the oven is on.

Also consider a solar oven, if your lifestyle allows. Many of the common-sense solutions to living well when you’re off the grid are simply reapplying lost wisdom from days before electricity was taken for granted. For instance, a summer kitchen, often located outdoors in a screened porch on the north side of the home, allows for preparing summertime meals without overheating the home.

Clothes Drying. In most parts of the country, a solar clothes dryer (also known as a clothesline) or an indoor drying rack can be used year-round. To back up these strategies, however, your standard clothes dryer should use gas, not electricity, for heat.

Air-Conditioning. Space cooling is usually only needed during summer months—when more PV power is often available—but conventional whole-house air conditioning is still too large of a load. Good passive design—like having adequate overhangs to shade windows, having trees and shrubs shade

Many of the common-sense solutions to living well when you’re off the grid are simply reapplying lost wisdom from days before electricity was taken for granted.

the house, and using good ventilation strategies—can often eliminate the need for any mechanical cooling. Otherwise, fans and evaporative cooling (“swamp coolers”) work well in arid climates. Ultra-efficient DC evaporative coolers are available that work very well.

Improve Efficiency

Efficiency is always the first step in reducing consumption. Efficiency expert Amory Lovins of the Rocky Mountain Institute calls this “negawatts”—energy not consumed is energy that does not need to be produced. A good guideline is that for every dollar spent on upgrading efficiency, about \$3 to \$5 can be saved on PV system costs. Here are some good ways to start reducing waste through greater efficiency:

Lighting. Compact fluorescent lightbulbs (CFLs) use one-third the energy of incandescent bulbs to generate the same amount of usable light. Modern CFLs have eliminated the flicker and harsh colors reminiscent of fluorescent lighting of years past, and will fit in most lamps.

LED technology also has rapidly advanced in recent years, and “bulbs” are now available, generally through online sources, to fit most lighting needs. LEDs typically use approximately 5% to 15% of the energy of an equivalent incandescent bulb, but are significantly more expensive than CFLs.

Consider task lighting rather than area lighting—focus light where it is needed, rather than lighting an entire room. Use multiple lights in different locations, switched separately. Being off-grid doesn’t limit you to boring lighting. Plan your lighting to meet building code and functional needs with maximum efficiency. Then add decorative lighting wherever you wish—just control it separately, and use it with discretion and only when you have the energy reserves to afford it.

Refrigeration. A refrigerator is one of the biggest electrical loads in an efficient home and is often the single largest daily user of electricity in an off-grid home. Older conventional refrigerators consume two to five times as much electricity as the most energy-efficient new models.

Mainstream brands—like Amana, Maytag, and Kenmore—have become quite efficient in recent years and are affordable. However, the specific model must be carefully chosen, using Energy Star guidelines (see Access). The most efficient full-size modern units only use a bit more than 1 kWh per day,



which will be reported on the yellow Energy Star tag—for instance, “This model uses 392 kWh/year.”

Super-efficient refrigerators that sip even less energy are available, such as the Sun Frost or SunDanzer brands. But their designs are not quite as convenient as modern mainstream fridges, and they can be more expensive. However, in some cases, the difference in price can make up for the extra PV modules needed to power a mainstream fridge.

If you want a full-size freezer, plan to locate it in an unheated outbuilding or portal, shaded from direct sun and preferably placed in a relatively cool space. In a cold climate, a freezer located outdoors will use very little electricity in the winter. Again, choose the most efficient modern model available. Chest freezers use less electricity than upright models because they do not lose as much cool air when the door is opened. Also consider past approaches to keeping food: Home-canned preserves and vegetables can be a satisfying means of storing food without a freezer.

Clothes Washing. Front-loading clothes washers use far less electricity, water, and water-heating energy than conventional top loaders, and there are now many efficient models to choose from. But make sure to buy one from a store with a forgiving return policy: Some modern sine wave inverters are not compatible with high-efficiency, electronically controlled washers.

Computer. A laptop uses less energy than a desktop model, as it's designed to run on stored battery power. But desktop models with LCD monitors are getting more efficient all the time. An inkjet printer uses less energy than a laser printer. Plug peripherals into plug strips so you can easily turn them off when they're not in use.

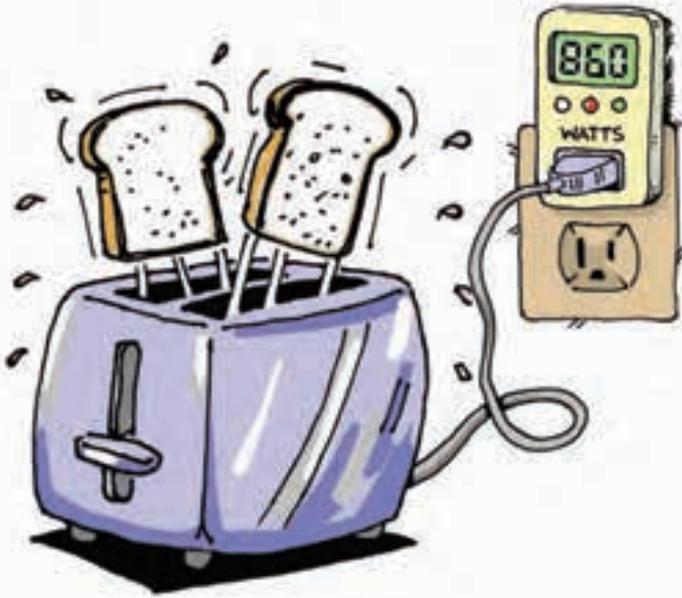
Heating. If you plan to have central heat with full thermostat control, it must be hydronic—meaning hot liquid.

Efficiency is always the first step in reducing consumption...for every dollar spent on upgrading efficiency, about \$3 to \$5 can be saved on PV system costs.

Either in-floor, baseboard, or wall-panel radiant is fine. A conventional hydronic system uses a substantial amount of electricity: Although manufacturers of radiant boilers and heating systems have put great effort into maximizing thermal efficiency, they've put less into electrical efficiency. For a home that is served by conventional utility power, the relatively low electrical demand of a conventional hydronic heating system is acceptable. In an off-grid home, however, a conventional hydronic installation will often lead to disappointing results. When a standard boiler system is installed in an independently powered home, the electrical demand of the heating system alone can exceed the daily output of the renewable power system.

Cost-effective modifications for controlling and distributing hydronic heat are available that use a fraction of the electricity of a conventional system. Larger-diameter tubing and multiple parallel loops allow smaller pumps to be used. A master thermostat that shuts off all power when





Toast, waffles, or pancakes:
Off-grid living means not that we go without the energy that we need, but that we live more in tune with the natural rhythms around us.

the call for heat is satisfied reduces the phantom load. Since off-grid homes use batteries, smaller DC primary and zone pumps may be substituted for the single large AC pump and zone valves. A knowledgeable hydronic engineer who is familiar with low-head DC circulators—plumbed typically in a primary/secondary loop configuration—may be able to design an ultra-efficient system for your off-grid home.

Otherwise, gas space heaters or a wood heater are good heat sources, especially in a thermally efficient home. Pellet and corn heaters can be used off-grid, but their fans, feed screws, and electrical controls are in continuous duty during winter and can be significant loads. Interest in geothermal heat pumps is growing, but they are typically impractical for an off-grid home, since, like an air conditioner, the compressor requires a lot of energy. Total electrical consumption for these geothermal systems ranges from about 10 to 30 kWh per day depending on the climate, season, and home construction and size.

Phantom loads are any devices that consume small amounts of power continuously, even when they're supposedly turned off. To point out their significance, phantom loads account for about 6% of the entire residential electricity consumption in the United States. Any appliances that include a remote control or have an internal power supply are probably phantom loads: stereos, TVs, DVD players, most computers and peripherals, and the AC adapters ("wall cubes") used with many small appliances.

The only way to eliminate a phantom load is to physically or electrically unplug the device from its outlet. These loads can be plugged into a power strip, which is turned off when not in use. When building or remodeling, add switches to conveniently control outlets intended for known phantom loads, such as audio/video equipment. A tip: Battery-powered clocks work just as well as the plug-in kind.

Off-Grid Design & Discretionary Loads

Off-grid home power systems are usually based on winter needs, since winter loads are typically greatest. Shorter, colder days mean more indoor activities and increased use of lights,

and most homes will have added heating loads. Shorter days also mean less solar energy collected. A well-designed home power system in a sunny climate will typically meet 80% to 90% of the home's winter base electrical load, usually with an engine generator making up the rest.

Note that just adding 10% to 20% more PV power capacity won't eliminate the need for occasional backup charging. Predictions of monthly solar irradiance are based on historical averages, and weather patterns never play by the rules of system design. Sometimes, weeks of bright winter sun—and full batteries—will prevail; other times, occasional long cloudy periods will necessitate running a generator to keep batteries charged. Plus, occasional equalizing (a controlled overcharge) of a battery bank is needed. A power system will need a substantially oversized array and battery bank to eliminate all generator charging, and most budgets don't allow this. Typically, the goal is to balance minimal generator charging, which will usually occur in winter, with a PV system that is sufficient to meet the majority of winter energy needs.

A PV system that is sufficient during most of the winter will provide an excess of charging power the rest of the year, when days are longer and loads are typically fewer. Herein lies a wonderful paradox of off-grid living: After going to the effort to live within the bounds of the system's reduced output in winter, you may have more energy available than you can use in other seasons.

This is part of the magic of off-grid living: The role of the PV array is to provide energy to fill the batteries. Once the batteries are full, the charge controller turns off the power from the array, as there's nowhere else for it to go. At this point, any energy not used is energy wasted. But as the investment in the power system has been made already and the sun's energy is free, it might as well be used.

A discretionary load is any power-using device that may be turned off or left unused when cloudy weather hits and/or the batteries are depleted. This is a normal and valuable aspect of the initial system design process. By identifying certain household loads as discretionary, the size and cost of the power system can be substantially reduced.

Common household loads identified as discretionary include toaster ovens, coffee makers, clothes dryers, and cordless phones. A microwave oven is a discretionary load, although most modern off-grid homes have one. It uses much less energy than a toaster oven, mainly because it runs for only a few minutes at a time. But because most microwaves have phantom-load clock-timers, they should be installed on a plug strip. When batteries have a low state of charge, use of these appliances should be curtailed.

Phantom loads like home audio/video equipment, chargers for cordless tools, and the like also may be considered discretionary: Put on a plug strip, they can be left on nine months of the year and turned off when not in use during the shorter days of winter. A modern large-screen TV and home theater system is discretionary if there's a smaller TV for use during winter. "Discretionary" also means that the appliance may be used during cloudy periods, but may mean using the generator a bit to supplement solar charging.

On a typical morning in my off-grid home, I will toast a bagel for breakfast. For me and for most people, toast is an important part of breakfast, a toaster is a basic tool of daily life, and toast is difficult to make any other way. And while a toaster draws a fair amount of power, its run time is just a few minutes.

During most of the year, I know that I can toast my bagel and do all of the other energy-using activities of daily life with the confidence that my batteries will be full by day's end—or, if that day is cloudy, within a day or two. In winter, though, I will check the weather report (and look out the window) in the morning, then check my system monitor to note how full the batteries are. On a typical winter morning when my batteries are at, say, 85% full, and I expect them to be at 100% by day's end, I enjoy my toasted bagel. If it looks bright and sunny outside, and I know I'll fill my batteries by 3 p.m., I may get out the electric waffle iron, knowing that the half-hour use of the electric iron will be easily handled by the day's solar input. But if it has been stormy for the

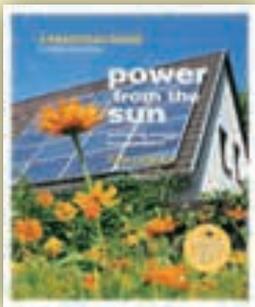
last three days, my system monitor shows the batteries to be about 60%, and it's still cloudy, I'll make pancakes on the gas stove.

Toast, waffles, or pancakes: Off-grid living means not that we go without the energy that we need, but that we live more in tune with the natural rhythms around us. Appreciating that our electricity comes from the sun, we let our habits be defined by the daily and seasonal cycles of the sun's patterns where we live. By paying attention to such natural cycles, we greatly reduce our dependence on a fossil-fueled backup generator. In my home, we raised our kids for seven years with no generator (and, yes, a larger-than-usual PV array and battery bank). While we never ran out of stored energy, the kids knew that a few times each winter we needed to go into "conservation mode," using fewer lights, keeping the computer off, and eating pancakes more than usual.

Access

Allan Sindelar (allan@positiveenergysolar.com) installed his first off-grid PV system in 1988, founded Positive Energy Inc. of Santa Fe in 1997, and has lived off-grid since 1999. He is a licensed commercial electrician and a NABCEP-certified PV installer.

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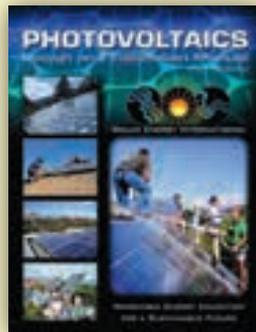
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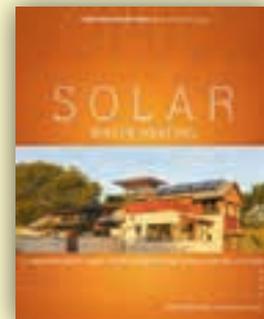
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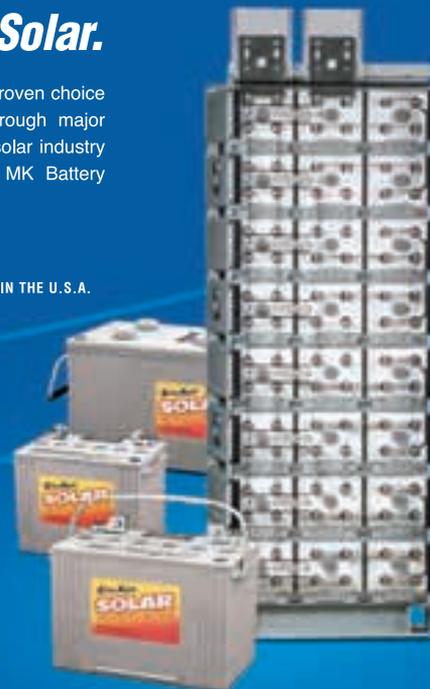
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THE ECHO GOES ELECTRIC

With lots of elbow grease and EV know-how, Randy Brooks transformed his Toyota Echo into a pollution-free family car.



Story & photos by Randy Brooks

For many years, I have been interested in electric vehicles and gasoline-to-electric conversions. In November 2007, I attended a weeklong electric vehicle (EV) conversion workshop, where the class converted two Volkswagen Rabbits. After this, I became even more determined to find a way to put this technology to work for my family.

Our initial goal was to use an EV to drive to town (2 miles), run errands, then return. Speed limits along the route are 25, 30, and 45 mph. Although Washington state limits neighborhood electric vehicles to 35 mph, we could probably have sneaked by with one. However, eventually we decided that we wanted a car with enough range and speed to travel to the nearest large town, 36 miles away, and be able to recharge before returning. Speed limits there and back are 60 mph.

We considered converting our Ford Escape hybrid to a plug-in hybrid electric vehicle (PHEV), but the conversion would not allow “electric only” driving for the short distance to town and back. As with the stock hybrid, the PHEV would require the internal combustion engine (ICE) to run until the catalytic converter was warmed up. In winter, this often requires the entire trip to town and back. Unlike Toyota Prius PHEV conversions, which can use electric propulsion for up

to 20 miles without starting the ICE, the Escape PHEV would require some use of fossil fuel for the short trip.

There are no production all-electric vehicles that would meet our needs and budget, so converting an ICE vehicle to electric drive was our only option. We decided to find a lightweight, relatively late-model car to convert—one with four doors and a more efficient standard transmission.

After considering several vehicles, we identified the Toyota Echo as the “donor” car. The Echo has the same body as the 2001 Prius—light and aerodynamic. A good donor vehicle weighs 2,000 to 2,500 pounds; the Echo’s curb weight is 2,055 pounds. In December 2007, we test-drove a 2002 Echo four-door sedan with a five-speed, manual transmission. It was a comfortable, quiet, peppy car, and we bought it on the spot.

I cleaned out the garage, built a new workbench, and put the Echo inside just as snow began to fall. Armed with the Echo’s official repair and electrical system manuals, I started planning my “winter project.”

One of the first things I did was sign up for the Seattle Electric Vehicle Association e-mail list, and sent an e-mail to the list with general plans, asking for suggestions. Overnight, I had replies to several of my questions. I found the Internet

Installing the Electric Motor

1



2



3



1. The author and his son Greg, pictured with the removed engine and transmission. 2. Removing the original power steering rack. 3. The AC motor with the clutch and flywheel assembly, bolted to the adapter plate. 4. The transmission, ready for installation. 5. The motor and transmission installed with the new motor adapter.

4



5



AC vs. DC Conversions

Most EV conversions use direct current (DC) motors. They are readily available, less expensive than alternating current (AC) motor conversions, and can offer excellent acceleration. But most DC motor conversions do not have regenerative braking, which makes the car feel more “normal.” Regenerative braking also can improve range (15 to 30%) and reduce brake wear by providing some compression-like braking. Acceleration in my AC-converted car is brisk enough, but certainly not as great as a DC conversion.

to be a terrific resource for researching EV questions and components, and I bought several components online, including the conversion kit.

In January 2008, my son Greg and I started the project by removing the ICE components and mapping out battery storage. While we waited for the conversion kit to be delivered, the deconstruction continued with removal of the power steering rack and the starter gear ring from the flywheel.

The kit arrived six months later—so much for the “winter project” idea—and we started assembling the EV components. Attaching the electric motor to the transmission and reinstalling it in the car just took a few hours, with help from friends, and we starting putting the car back together, installing a manual steering rack.

Installing Batteries: Trunk &

6



7



8



9



This page: 6. The foam-board battery mock-up. 7. The cut-out trunk floor, ready for the battery box. 8. The custom battery box, placed in the trunk. 9. The trunk batteries, strapped down, with acrylic plastic cover in place.

Opposite: 10. The backseat battery box in place. 11. Batteries wired and installed in the box. 12. The backseat battery installation, safely covered. 13. Seats installed and batteries covered.

In September, I started planning battery placement. I downloaded a spec sheet for the battery I had chosen and made a cardboard battery model to test mounting options. I printed a scale drawing of the battery on my computer, pasted it to architectural foam board, cut it out, and then glued it together. From that, I drew up plans for the battery boxes—one would go beneath the rear seats and one would go under the trunk.

Fourteen Odyssey 12-volt AGM batteries were delivered in October. Thirteen were to be used (156 V nominal), with one spare. A friend helped cut out the floor pan under the rear seat and trunk to prepare for the battery boxes. The locally made battery boxes arrived in December, fitting the holes we made in the floor pan with only a little trimming on the floor pan. The batteries fit into the boxes perfectly, leaving a little room for battery expansion as they warm under charge and discharge.

Once the batteries were installed and secure, I started working on the wiring, running cabling from the batteries to the components in the cab of the car, and installing the Link 10 battery monitor. Once that was complete, I secured

EV Conversion Costs

Item	Cost
Canadian EV conversion kit	\$10,800
2002 Toyota Echo	8,800
14 Odyssey PC1500/34M 12 V AGM batteries	3,500
Battery box (also includes decals & misc. supplies)	478
Manual steering rack	262
Repair & electrical system manual	223
Air shocks	90
Wheel alignment	60
Battery mats	50
Freon removal	37
Total	\$23,822

Rear Seat

10



11



12



13



Tools to Have on Hand

- Basic mechanic's tool set (metric & SAE)
- Floor jack & jack stands—get high-quality ones, your life depends on them
- Creeper—for easy access under the car
- Portable engine hoist (borrow or rent)
- Volt/ohm meter
- Wire and cable cutters & crimpers
- Manufacturer's shop & electrical manual for donor car (priceless!)
- Resealable plastic storage bags, notepaper & permanent-ink pens—for bagging small parts with a note describing where the parts go
- Camera for taking "before-and-after" photos of everything

EV Battery Banks

Choosing a battery type and size requires answering several questions:

- **What voltage does your motor and controller require for optimum operation?** The AC motor/controller we used operates between 144 and 336 volts. One conversion kit provider recommended a 144 V battery bank (twelve 12 V batteries in series), but another strongly recommended 156 V so the controller would not cut out when voltage sagged under load.
- **How much weight can the donor car carry?** Stay within the gross vehicle weight limit, including passengers and cargo. Exceeding the weight limit can damage the axle bearings.
- **What is the weight distribution fore and aft?** Heavily weighting a front-wheel-drive vehicle to the rear is probably not a good idea. Consider staying close to the stock vehicle weight distribution or about 50/50 fore and aft.
- **How much room do you have?** Many EV conversions have batteries mounted above the motor in the engine bay, obstructing the view of the motor and other drive components. For educational purposes, I wanted to be able to show off the electrical components, so I specified a smaller battery pack to meet the decreased space available and weight limits.
- **What range do you want between charges?** Although most people want as much range as possible, I purposefully sacrificed range to stay within the original gross weight and not have batteries in the engine bay. I also intend to upgrade to lithium ion batteries in the future, which will improve range.
- **How much battery maintenance are you willing to do?** Flooded lead-acid batteries are the least expensive type of battery but require vented battery boxes and regular maintenance, such as adding distilled water. Sealed lead-acid batteries do not require active venting or watering but require more careful charging to avoid loss of their irreplaceable electrolyte. They also need a battery management system (BMS) to ensure equal charging or regular checks of individual battery voltage to discover any state-of-charge imbalance between batteries. Nickel metal hydride or lithium ion batteries also generally require a BMS.
- **How much money do you want to spend initially and in the long run?** While lead-acid batteries may be cheaper initially, lithium ion may be cheaper over the long run because the battery bank will last longer.

Installing Charger & Controller

14



15



16



14. The Azure digital motor controller (DMOC) mounted. 15. The AC battery charger mounted in the trunk. 16. Programming the DMOC via a laptop.

the rear seat battery box top and reinstalled the rear floor carpet, seat belts, seat backs, and seat cushion.

At the end of January, I tested the Link 10 and set it for my battery's amp-hour capacity. I also tested the AC battery charger. With the new batteries at above 20% state of charge, the charger draws 3 to 9 amps AC.

Next, I installed the Azure digital motor controller (DMOC). In early February, I gave the car—still on jack stands—its first “test drive.” I switched the forward/reverse switch to forward, made sure the transmission was in neutral, and advanced the throttle. The motor turned! I put the car in first gear and slowly advanced the throttle again. The drive wheels turned in the right direction!

Greg and I took the car off the jack stands and checked the fender well height at the rear wheels. It was 1 inch lower than the stock height before the conversion. I added 12 psi to the rear tires (Air Lift recommends adding 2 psi per 100 pounds of added weight, and we have 650 pounds of batteries), which reached the maximum 44 psi recommended on the tire sidewall. I also added 15 psi to the air shocks I had installed and could feel and see the rear of the car rise.

Then, the moment of truth—we drove the car out of the garage, for the first time in more than a year. But when I tried to back up by switching the forward/reverse switch to reverse and applying the accelerator, the controller

cut out. The controller reset immediately when I released the throttle. I then switched to forward, and shifted the transmission to reverse, and the same thing happened. I suspected that the controller cutout was a max torque setting issue, which goes into error mode when the motor is starting to turn under load.

The next day, I took the car to town, avoiding the problem by driving the car using the clutch and first gear to start moving, and shifting up and down as needed. The EV drove just like an ICE car, with the regenerative braking acting like engine compression braking when downshifting. It was really nice to see the Link 10 meter voltage climb when decelerating, adding that energy back into the battery pack.

But there was still the issue of the controller cutout to solve. Canadian Electric Vehicles Ltd. e-mailed me instructions for using a laptop computer to capture motor controller data for Azure Dynamics to review. I set up the laptop in the car and recorded data with the car in first gear. As expected, the controller cut out. But this time, I had the data, which I e-mailed to Canadian EV. I received instructions back in just a few hours to change a setting in the controller. On another drive, we captured data on two high-speed controller cutouts, and sent that data to Canadian EV. In the meantime, I tried easing up on the throttle, which eliminated controller cutouts.

Details

17. The Link 10 volt/amp meter: the EV's "fuel gauge," mounted in the dash for easy viewing. 18. Air shock in stock coil spring and tubing to air valve through trunk floor. 19. The AC charging plug. 20. Cruising at 70 mph during the highway road test. 21. An under-the-hood look at the completed installation.



21



Main EV Components

Charger: Plugged into a 120 or 240 VAC household outlet, the charger converts alternating current to direct current to charge the EV batteries.

Batteries: Sealed or flooded, and in an array of possible chemistry types and voltages, the battery bank stores and provides the energy for the vehicle.

Controller: The brains of the propulsion system, the controller adjusts the amount of energy sent to the motor based on input from the throttle potbox.

Potbox: Converts the motion of the throttle pedal into an electrical signal for the controller.

Motor: The brawn of the EV, a DC or AC electric motor converts electrical energy into mechanical energy to move the vehicle.

Transmission: Mounted to the electric motor the same way it would mount to a gasoline engine, the gearbox transfers power and torque to the drive wheels.

Main Contactor: The EV's main on/off control, this relay is often controlled by a standard key switch.

Instrumentation: The right meters are crucial to keeping tabs on your EV's performance. Standard are a voltmeter, ammeter, and an amp-hour meter.

Emergency Disconnect: This emergency breaker/switch automatically disconnects the battery bank in the unlikely event of a short circuit. The switch can also be used to manually disconnect the battery bank.

DC/DC Converter: Converts EV battery pack voltage to standard 12 VDC to run common automotive electrical accessories like the windshield wipers and sound system.

I finally figured out that I'd been shifting up too quickly. Based on power curves I'd seen, the optimum motor speed is about 4,000 rpm. On another test drive, with a friend reading out motor rpm and amps from the PC display, I stayed in second gear until 45 mph (4,000 rpm), and stayed in third until 60 mph (4,000 rpm). The car cruised easily on a flat highway at 70 mph with no problem. There was throttle left, but I didn't try to go faster than that. The return route home from the highway includes a steep, 2-mile-long hill. I kept the car in second gear and came up the hill with no problem at 40 to 45 mph, the speed limit.

Later, I received more advice from Azure to change another setting. After making the change, I drove to town, ran errands, and came home without any controller cutouts. Success!

Once the car was road-worthy, I began monitoring mileage and charging kWh to calculate the car's energy use and cost. At our electricity rate of \$0.028 per kWh, it costs about 25 cents to charge the car—about 1 cent per mile. That's pretty good, even compared to the original Echo's 40 mpg. For comparison, at the current \$2 per gallon cost for gasoline, it would cost 5 cents per mile to run the ICE car. Last summer's gasoline price of \$4 per gallon would have cost me 10 cents per mile.

EV Conversion Tips & Tricks

- **Subscribe to an EV e-mail list and don't be afraid to post your general plans and ask for comments and suggestions.**
- **Keep the car in its original condition until the conversion kit is received.** That way, it's still functional while you wait—not just taking up space in your garage. Most importantly, you are more likely to remember how to put it back together.
- **Identify efficiency gains.** For instance, automatic transmissions are not as efficient as manual transmissions. Power steering is less efficient than manual steering mechanisms. Wherever you can reduce mechanical losses from motor-driven components, do so.
- **Use ceramic core heaters instead of fluid heaters.** Some tests show that fluid heaters take almost 10 minutes to warm up, whereas ceramic heaters get hot within seconds. A dual ceramic heater core is recommended for cold climates.
- **Make a battery master plan.** Batteries add significant weight to the vehicle, so try to distribute the weight evenly. Before my conversion, the front axle weighed in at 1,400 pounds and the rear axle weighed 980 pounds, for a total of 2,380 pounds. After the conversion, the front axle weighed 1,200 pounds and the rear axle weighed 1,520 pounds for a total of 2,720 pounds, still below the maximum gross vehicle weight (2,915 pounds) listed on the door post.
- **Decide how active you want to be in managing your batteries.** I decided to use sealed AGM batteries. Using a sealed battery means I won't have to be concerned about battery box ventilation, or have to water them. On the downside, a battery management system may be needed to ensure the batteries charge equally and do not charge too quickly, which can ruin them. If possible, use batteries all from the same production run, numbered sequentially, to ensure consistent performance.
- **Measure the height of the transmission relative to the chassis.** You'll need to duplicate this height with the electric motor installed to avoid binding the drive train.
- **Consider removing the starter gear ring from the flywheel, since this will slightly reduce air drag inside the bell housing.** Some people remove the entire flywheel, but I think it's best to keep it for smooth motor operation.
- **Remember: You're working with electricity!** Take precautions. While doing any wiring, turn off the main circuit breaker. A mistake here can result in injury, or harm components or tools.
- **Fool the stock gauges.** With no gas-tank sending unit, the gas gauge shows "empty", which is no problem, but the low-fuel light by the odometer flashed annoyingly. Checking the electrical shop manual, I found that a 50-ohm resistor wired to the gas-gauge sending unit would "spoo" the gauge to show half full, with no low-fuel light flashing.
- **Pay attention to the motor power curves.** The optimum motor rpm for mine is about 4,000. You'll need to tailor your driving accordingly for optimum performance.
- **Check with your insurance provider.** Our insurance company initially said they would not insure a conversion, but our track record with them over the last 40 years is excellent, so they agreed to insure our conversion for the car's book value, plus the value of the conversion. EV discussion groups can help you find an insurer if yours declines coverage.



On average, we use about 0.27 kWh per mile from the battery pack (0.3 kWh per mile from the outlet, due to charger inefficiency). The battery has a capacity of about 9.7 kWh (156 V nominal x 62 Ah). If I discharge to 20% state of charge (SOC), I'd use 7.7 kWh. At 0.27 kWh per mile, the car should be able to travel 28 miles. Although this won't get us to the nearest large town, it's an acceptable range. (Most Americans drive 30 miles or less daily.) If I abuse the batteries to 0% SOC, the car might be able to travel 35 miles. But so far, our longest drives have been about 22 miles with 40% SOC left, and this meets our needs very well.

In the five months since we put the car on the road, we've put more than 2,000 miles on it. We use it exclusively for local driving and don't cringe when we make multiple trips to town in a day, since the cost per mile is minimal and we're using clean, renewable, hydro grid power for our energy

source. We also have a 1.9 kW grid-tied PV system that typically produces more power each day than we use in the car. So you could say our car is solar-powered.

We've tweaked the DMOC settings a couple times to get optimum performance, and will install an electric air-conditioning compressor and electric cabin heat next. Overall, we are quite pleased with the car—you can tell by our "EV grin" every time we drive it!

Access

Randy Brooks (randy@brookssolar.com) and his wife Anne operate Brooks Solar, a renewable energy business in Chelan, Washington.

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Inverter Grounding

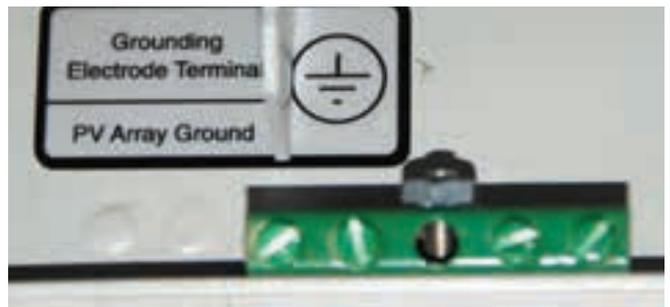
by John Wiles

Properly connecting a utility-interactive inverter is critical to the safe, long-term, and reliable operation of the entire renewable energy system. Correct grounding of the inverter will minimize the possibility of electrical shock and damage from surge currents. While complex, it is important to understand and apply the requirements of Section 690.47 of the *National Electrical Code (NEC)* to the inverter grounding connections.

Equipment-Grounding Conductors

In a typical small PV system (less than 20 kW), the inverter serves as a central point for grounding connections. The DC equipment-grounding conductor from the PV array and the DC disconnect are connected to the inverter. The AC inverter output circuit equipment-grounding conductor leading to the point of connection with the utility is also connected to the inverter. Under the 2005 *NEC*, the DC equipment-grounding conductors may be the only connection the module frames have to earth. If these grounding conductors are connected only to the inverter, then the inverter must be properly connected to ground (earth) for a safe installation. UL Standard 1741 requires equipment-grounding terminals for both the AC and DC circuits.

This inverter meets the minimum requirement of three grounding connection terminals.



Close-up of an inverter with a grounding bus bar and the required grounding electrode conductor (GEC) terminal marking.

Grounding-Electrode Terminal

Nearly all utility-interactive inverters include transformers, are connected to grounded PV arrays, and have an internal ground-fault indication/detection (GFID) system. This GFID system includes the internal bonding jumper between the DC grounded conductor and the grounding system. The presence of this DC bonding jumper requires, according to UL Standard 1741, that the inverter have a DC grounding electrode terminal.

With only one grounding terminal (PE), this inverter does not meet UL 1741 requirements.





Equipment grounding conductors are permanent leads coming out of the inverter.

These grounding connection requirements require that each inverter have a minimum of three terminals available. They will normally all be connected (bonded) together electrically in the inverter and they will be connected to the inverter chassis.

To ensure proper grounding of the entire PV system, it is necessary to connect all three of these terminals properly. Unfortunately, some manufacturers and their certification/listing agencies are allowing inverters to reach the market that do not have all three of these terminals. Because other countries do not ground PV systems like our Code requires, some inverters get certified/listed without a DC grounding-electrode terminal. The Europeans use the term “protective earth” (PE) terminal instead of “equipment grounding terminal.” Others have only one equipment-grounding terminal, not the required two, and may not even have a grounding-electrode conductor terminal.

Some inverters have an external grounding electrode terminal (see photo, above right) and the equipment-grounding conductors are permanent leads coming out of the inverter (pictured in the photo above).

When using one of these inverters with missing grounding terminals, it is acceptable to splice the AC and DC equipment-grounding conductors together and connect them to a single equipment-grounding terminal. However, the grounding-electrode conductor must be connected directly to the proper terminal and should not be spliced.



Close-up of an external grounding electrode terminal.

Grounding the Inverter

Section 690.47(C) of the *NEC*, which addresses the DC grounding electrode connection, contains significant changes between the 2005 and 2008 editions. As far as I can determine, either the requirements of this section in the 2005 *NEC* or the permissive requirements in the 2008 *NEC* may be applied to connect the grounding-electrode conductor when using either Code. A proposal has been submitted for the 2011 *NEC* that includes all three methods and will clarify what is acceptable. That proposal (below) may help interpret the requirements for 690.47(C) in the 2008 *NEC*. The first two methods in the proposal align with 690.47(C)(1) and 690.47(C)(2) in the 2005 *NEC*, while the third method coincides with 690.47(C) in the 2008 *NEC*.

690.47(C) Systems with Alternating and Direct Current Grounding Requirements. PV systems having direct current (DC) circuits and alternating current (AC) circuits with no direct connection between the DC grounded conductor and AC grounded conductor shall have a DC grounding system. The DC grounding system shall be bonded to the AC grounding system by one of the methods listed in (1), (2), or (3).

This section shall not apply to AC PV modules.

When using the methods of (2) or (3), a visual inspection shall be made to ensure that the existing AC grounding-electrode system meets the applicable requirements of Article 250, Part III.

FPN No. 1: ANSI/Underwriters Laboratories Standard 1741 for PV inverters and charge controllers requires that any inverter or charge controller that has a bonding jumper between the grounded DC conductor and the grounding system connection point have that point marked as a grounding-electrode conductor (GEC) connection point. In PV inverters, the terminals for the DC equipment-grounding conductors and the terminals for AC equipment-grounding conductors

are generally connected to or electrically in common with a grounding bus bar that has a marked DC GEC terminal (depicted in the photo on page 106, upper right).

FPN No.2: For utility-interactive systems, the existing premises grounding system serves as the AC grounding system.

(1) Separate DC Grounding Electrode System Bonded to the AC Grounding Electrode System. A separate DC grounding electrode or system shall be installed, and it shall be bonded directly to the AC grounding-electrode system. The size of any bonding jumper(s) between AC and DC systems shall be based on the larger size of the existing AC grounding-electrode conductor or the size of the DC grounding-electrode conductor specified by 250.166. The DC grounding-electrode system conductor(s) or the bonding jumpers to the AC grounding-electrode system shall not be used as a substitute for any required AC equipment-grounding conductors.

Exception: Where the existing AC grounding electrode is not readily accessible, the bonding conductor shall be permitted to be connected to the AC grounding-electrode conductor as close as possible to the AC grounding electrode with an irreversible splice.

(2) Common DC and AC Grounding Electrode. A DC grounding-electrode conductor of the size specified by 250.166 shall be run from the marked direct-current grounding electrode connection point to the AC grounding-electrode. This DC grounding-electrode conductor shall not be used as a substitute for any required AC equipment-grounding conductors.

Exception: Where the existing AC grounding electrode is not readily accessible, the DC grounding electrode conductor shall be permitted to be connected to the AC grounding-electrode conductor as close as possible to the AC grounding electrode with an irreversible splice.

(3) Combined DC Grounding-Electrode Conductor and AC Equipment-Grounding Conductor. An unspliced, or irreversibly spliced, combined grounding conductor shall be run from the marked DC grounding-electrode conductor connection point along with the AC circuit conductors to the grounding bus bar in the associated AC equipment. This combined grounding conductor shall be the larger of the size specified by 250.122 or 250.166 and shall be installed in accordance with 250.64(E).

While any of the three methods of making connections to the inverter grounding electrode terminal may be used, there are advantages and disadvantages to each.

Method 1—similar to 690.47(C)(1) in the 2005 NEC—has the advantage of routing surges picked up by the array more directly to earth than methods 2 or 3. However, since the bonding conductor between the new DC grounding electrode

must be bonded to the existing building's AC grounding electrode, the size, routing, and cost of that conductor needs to be considered.

Method 2—similar to 690.47(C)(2) in the 2005 NEC—uses fewer components than the other two methods and also routes surges to earth without getting near the AC service equipment.

Method 3—similar to 690.47(C) in the 2008 NEC—combines the inverter AC equipment-grounding conductor with the DC grounding-electrode terminal, saving wire. However, the requirement to bond the conductor at the entrance and exit of each metallic conduit and enclosure may become difficult with conductor sizes greater than about 6 AWG, especially since the conductor must remain unspliced or irreversibly spliced. Also, any surges picked up by the array will be routed directly to the service equipment and may be more likely to enter the building's wiring system than when grounding-electrode conductors are routed more directly to ground.

The complex and unclear section 690.47(D) in the 2008 NEC requires a direct connection between the array and earth, in addition to any required equipment-grounding conductors between the array and the rest of the system. This requirement applies to ground- and pole-mounted PV arrays and to arrays where the inverter is mounted on a different structure than the array. There is an exception for systems where the PV array and the inverter are mounted on the same structure, but exactly what is excepted—the grounding electrode conductor, the grounding electrode, or both—is not clear. It has been proposed that this lightning damage reduction requirement be deleted from the 2011 NEC as it is not directly related to safety.

Proper grounding connections at the inverter are critical to a safe and properly operating PV system. These connections may be the only connections that the entire system has to earth. All connections must be made, and that may prove difficult if manufacturers have not included the proper number of terminals.

Access

John Wiles (jwiles@nmsu.edu; 575-646-6105) works at the Institute for Energy and the Environment (IEE) at New Mexico State University. He 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





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A Magnum Energy installation in Oregon

Photo compliments of Lance Barker



A triple stack in Hawaii using the MidNite Nottagutter

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Getting FIT

The Ultimate RE Incentive

by Michael Welch

Fifteen years ago, *Home Power* first reported on rate-based incentives (RBIs), which offer a premium per-kWh price for grid-tied renewable electricity with the intent of giving RE technologies a boost. At that time, Germany had just introduced these incentives, showing strong support for a renewable energy future.

The crew at *Home Power* realized that RBIs could become the most successful method of giving RE the boost it needed to catch up with conventional electricity production technologies. Now, 15 years later, the success of Germany's incentive program is proven, with the country having greater than half of the entire world's installed PV capacity. But here in the United States, conventional energy industries prevailed, as their vast political influence limited RE incentives to the much-less-effective rebate programs.

New Game

But maybe that is changing. After a decade and a half of the RE industry's fast growth in Germany and other countries with similar government-sponsored incentives, the United States is finally inching toward embracing this incentive structure.

RBIs are more recently known here as feed-in tariffs (FITs), renewable tariffs, RE payments (REPs), and others. But no matter what you call them, the concept is the same: Laws and regulations require utilities to pay a premium price over a set period of time for the renewable energy produced, to cover system costs and offer an attractive profit to the system owner. These tariffs are structured similarly to how utilities buy and sell conventionally made energy. Thus the concept is familiar to utilities and their regulators, which may lead to somewhat easier acceptance.

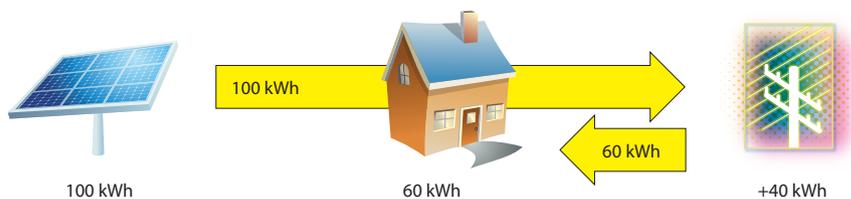
The major difference between FITs and conventional energy tariffs is that the intent goes beyond just supplying energy—the idea is to promote the use of renewable energy by richly rewarding system owners. Per-kWh payments for renewably produced electricity are set higher than

Net Metering



Under net metering, the homeowner uses renewable energy to offset domestic use. Any surplus RE that's produced is typically donated to the utility.

Feed-In Tariff (FIT)



With a feed-in tariff, the homeowner sells all their renewably generated electricity to the utility at a premium price and buys all energy used at retail rates.

Adapted from "Feed-In Tariffs in America: Driving the Economy with Renewable Energy Policy that Works," by John Farrell & the New Rules Project

conventional market prices for fossil-fuel-based electricity, as an incentive to add renewable energy to the grid. Most utility tariffs are based on conventional fuel and power plant costs—in other words, what it takes to replace the energy without considering the higher purpose. But not RE FITs: They are based on the higher costs of RE because, again, the point is to encourage RE sources over the environmentally undesirable conventional sources.

With net metering, an RE system's output may cover household usage, then anything left over is often given away to the utility, or in some states purchased by the utility at wholesale rates. Net metering encourages limiting the system size to that which merely covers the household usage. But a FIT pays the system owner a premium price for all the system's energy production, thus encouraging as large a system as possible, which increases the amount of RE on the grid for others to use and furthering even more RE by decreasing system costs through ever-increasing economies of scale. Finally, FITs help RE cross socio-economic lines. More property owners could afford a system under FIT payment

schemes—whereas as things stand with current incentives, often only the well-off can afford systems.

In Florida, the Gainesville Regional Utilities made recent headlines by implementing a true FIT for PV systems. Other states and municipalities offer customers some type of performance-based incentive, but often those are different from FITs. For example, for system sizes smaller than 50 kW, California now offers an up-front single-rebate payment that is not based strictly on system size, but includes performance factors that affect output, such as geographic location, tilt, and shading. Or, system owners can choose a per-kWh payout over five years. The payout amount is close

to European payouts, but the five-year limit disqualifies it as a tariff. In California, larger systems must use the per-kWh payout, and soon all system sizes will be limited to that choice.

What It Takes

The key features of successfully implemented FITs have been:

- High-enough per-kWh payments to cover system costs, plus provide a reasonable profit to the system owner
- Long-enough terms to ensure confidence that system

How FITs Work

The point of FITs, as with other current incentives, is to increase the amount of RE in the electric-energy mix. Here in the United States, we have seen a slow but steady increase in the use of PV and wind energy. Compared to places that are using effective FIT incentives, however, U.S. RE growth has been sluggish.

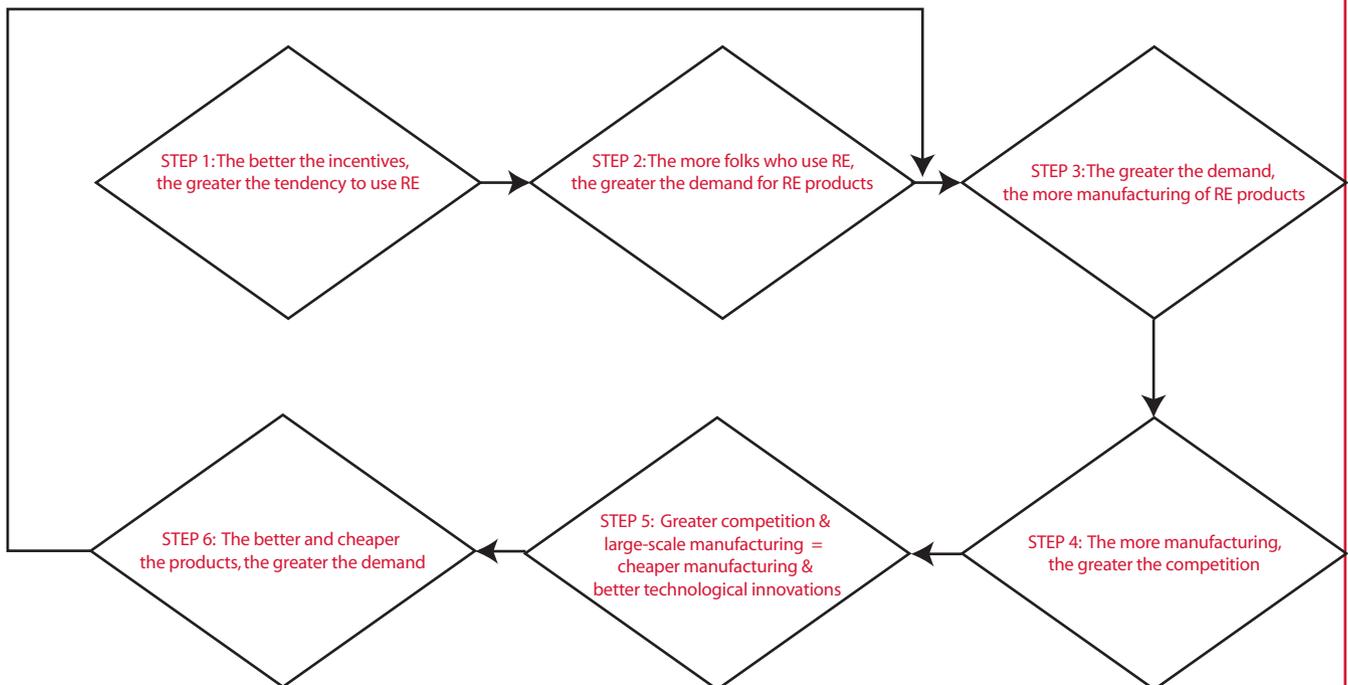
The cycle of incentives—and how it increases the use of RE—is depicted below. Note that Step 6 brings the cycle back to Step 2, to start over again with added strength. In addition to its initial input (Step 1), an ongoing, effectively large incentive compounds the ever-increasing nature of the cycle, adding even more growth to the use of RE. In the case of FITs that pay a premium price for RE-made electricity, there is nothing to stop the cycle.

European FITs had been paying the equivalent of about \$0.50 to \$1.00 per kWh for PV-made energy. About five years ago in

Germany, the amount paid for grid-tied solar-electric systems equaled about \$0.70 per kWh. The payment was guaranteed for 20 years, with the tariff for new systems decreasing 5% each year.

Assuming a 1 kW PV system, payments for energy production would total more than \$12,000 over the 20 years. At about \$10 per watt installed (in 2004), these systems were poised to make a profit immediately.

With these kinds of guaranteed payments, lenders are willing to make low-interest loans. Loan repayments are low enough to create a monthly profit for the system owner and, of course, soon lead to ownership of a system that will continue producing both energy and income for years to come. The German system makes homeowners equal participants in the renewable energy revolution—not a second thought or an add-on.



owners (and their financiers) will recoup the initial investment

- Not limited to any particular class of system installation (like residential vs. commercial) or size of project
- Payment amounts vary based on technology, system size, and application
- Simple to understand
- Periodic review of both success as an incentive and the amount of profit, so that payments and term lengths can be adjusted appropriately. Review also allows for addition of new technologies to the program, as appropriate.

The main components critical to the success of a FIT plan are a high-enough rate and a long-enough contract term. As proven by other marginally helpful incentives, payments or terms that are too low make it harder for a system owner to make an economic case for system purchase. For example, Washington state was first to pass a statewide FIT-like program. Unfortunately, both the rate and the term were low—the program seemed to be designed more to encourage the local economy rather than build an RE future. Starting at \$0.15 per kWh, the rate is adjustable up to a maximum of \$0.54 per kWh, but only if both the PV modules and inverter used are manufactured within the state. The maximum term length was nine years, which was not quite long enough for most owners to recoup their investment, and there was a \$2,000 cap on the annual payments that effectively limited the size of the eligible system. The program was altered this summer to extend payments until 2020, and the annual cap increased to \$5,000.

Some successful programs have fairly complex tariffs for RE projects, carefully constructed to account for a variety of circumstances. They often differentiate payment amount and term length by the project type (PV, wind, biomass, etc.) and the scale of the projects (home, business, or utility; plus sizing options within the categories). This makes a lot of sense because some RE technologies and scales of systems are easier and cheaper to implement than others or have higher output, so the tariffs and term lengths need to be adjusted accordingly.

Big Business Resists Getting FITs

Just as the United States would benefit from a national net metering law that would finally bring all utilities, whether private or public, under the same regulations, we would also greatly benefit from a national FIT law. Too many states and utilities have been dragging their feet when it comes to RE incentives. A national FIT would encourage more RE in general, help RE businesses that are having trouble during our current economic “downturn,” create U.S. jobs, and would significantly help the national effort to reduce climate-changing greenhouse gas emissions to the needed 90% below 1990 levels.

But establishing FITs is not going to be easy. Corporate influence is still a principal driving force behind our elected officials’ and bureaucrats’ decisions, and the fossil-fuel and nuclear industries work hard to keep their conventional

technologies on top. Just as corporations and their legislative puppets bent recent climate and energy legislation in the House to their wishes, they will be working hard to make FIT laws untenable or severely limited in scope.

“Greened” utilities claim to be environmentally responsible, but only as far as their own self-interests dictate. Already, they are claiming FITs are unfair to users without RE systems, since, under the FIT system, the increased cost for RE-generated electricity is spread out over all rate payers—not just RE system owners. They conveniently ignore the fact that their polluting, resource-hogging technologies have environmental and human health costs that go beyond the balance sheet.

Expect utilities to eventually capitulate and allow FITs, but they will seek limits—like requiring that they make money off the systems too, possibly by receiving the systems’ renewable energy credits (green tags, or RECs) instead of the system owners, or claiming others’ FIT-qualified systems as part of any required renewable energy portfolio standards. They will likely push for low caps to be placed on the number of systems, which they successfully have done with other incentives and even net metering.

Finally FIT

Our climate and renewable energy future are inextricably entwined, and both require leaving the greedy self-interests of conventional energy companies behind. We citizens need to tirelessly lobby to get first-rate FIT programs enacted, and the only way to do that is through participation in our government, no matter the difficulty. Let your legislators know that you want strong, effective FIT programs, and that you want fewer of your tax dollars to go toward supporting conventional technologies. For starters, the Alliance for Renewable Energy has a sign-on letter that can be sent to your representatives (see Access) to begin the citizen-lobbying process. Then don’t forget to tell your friends and neighbors about FITs via letters to the editor and even online social-networking sites like Facebook and Twitter.

Access

Author **Michael Welch** (michael.welch@homepower.com) dreams of a nuclear-free and fossil fuel-free future that will come quicker with the help of RBIs.

Alliance for Renewable Energy • www.allianceforrenewableenergy.org • Take action to promote FITs

Wind-Works • www.wind-works.org • Paul Gipe’s repository of articles and commentary on FITs

Further Info on FITs:

World Future Council • www.worldfuturecouncil.org/arguing_fits.html

FITs email listserver • http://uk.groups.yahoo.com/group/feed_in_tariffs/



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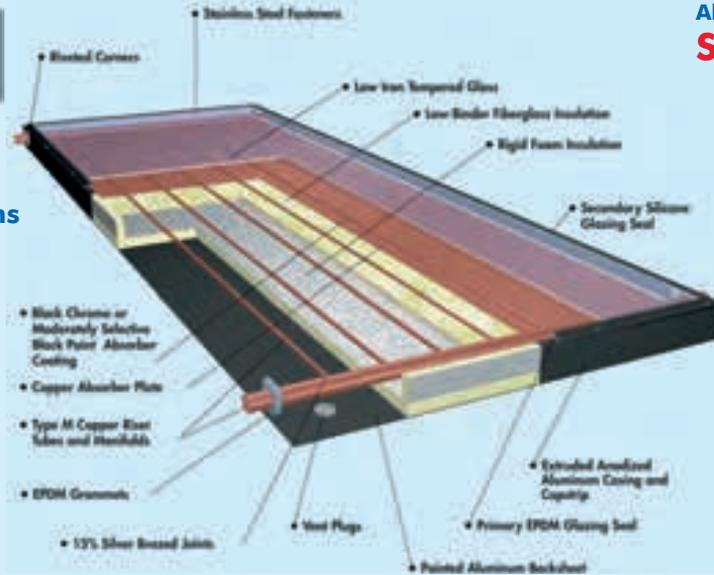
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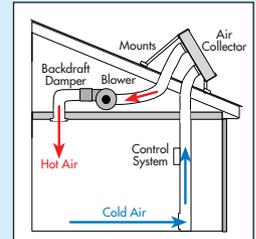
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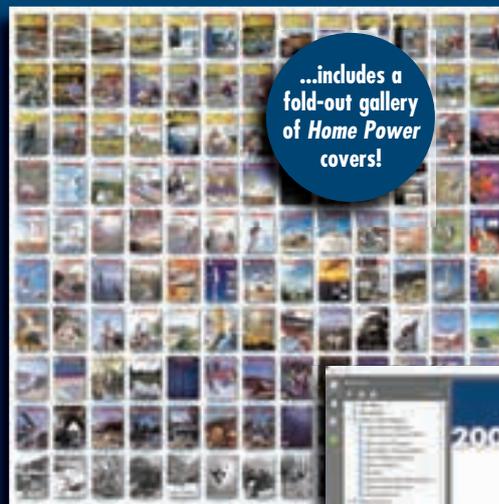
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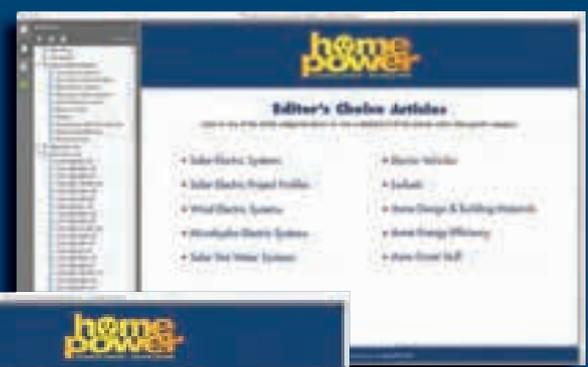
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A Shady Deal

by Kathleen Jarschke-Schultze



Continuing our effort to use fewer resources to heat and cool our 1960s-era home, my husband Bob-O and I decided to make a “Warm Window” shade for the large, 5- by 8-foot picture window in our living room. Although we upgraded it from a single to double-pane unit 19 years ago, it still was a significant source of heat gain and loss through the seasons.

It's Curtains for Me

For the last 13 years, this window has sported a paper honeycomb shade, which was fairly efficient at keeping the heat in during the winter and keeping the house cooler in the summer. Recently, though, one of the internal support cords broke. Those shades are very expensive, especially such a large one, so I tried every way I could to fix it, to no avail. Then Bob-O came across the Warm Window insulated shade system during an Internet search.

That sounded great, but here's the thing: You can't just buy one. You have to make it yourself. Several companies will sell you the components, but those components are also

expensive. I'm crafty, but sewing up some window shades was a daunting proposition for a non-seamstress like me. Thankfully, Warm Window promised a non-sewing work-around.

I had to think about constructing the insulated shades for a couple of days just to work up my courage. This was going to be an expensive commitment and I was still doubtful about my success in taking the non-sewing approach. I decided I would give it a go, as the broken shade was a daily hassle to carefully, but not completely, raise and lower. The site offered an assembly manual, which I printed. There were the instructions and a worksheet to work out exactly what and how much materials I would need for our big front window. I took the required measurements and then plugged them into the worksheet formulas.

Order Up

I needed to buy enough decorative fabric to cover the entire window, with a little extra on both sides. The next item I

needed was the Warm Window fabric, which consists of four layers of material: a lining of lightweight cotton cloth; thin polyester batting; a reflective polyethylene vapor barrier; and a reflective poly film with air-trapping fibers. This is all quilted together, with the seams running horizontally the length of the fabric in 3.5-inch-wide rows. It comes in 65-inch and 45-inch widths, so my huge window required piecing a length of each together.

Also needed are many little plastic rings (96, for my job), which act as guides for the large amount of cordage needed to thread the mechanism that raises and lowers the shade. Along the sides of the shade are 3-inch-long magnetic strips (one between each quilt line), to line up with the long magnetic tape you fasten along each side of the window. Oh yes, and a small metal pulley, a 1-foot-wide by 2-inch-thick board the width of the window, and enough eyebolts to place one every 12 inches along the board, above each line of little plastic rings for the draw cords. The last item I purchased was enough sticky-backed Velcro to span the top of the curtain on its top back edge, with its mating side spanning the fabric-covered board.

I drove the 50-plus miles to the fabric store—by myself—to choose the cover cloth. I could not let Bob-O pick the cover cloth. I may be paranoid here, but this man has no fashion sense—I even pick out all his clothes. What if he picked a plaid? Yikes! After all, we were going to be staring at the decision for years to come.

I had measured and calculated for a 65-inch-wide bolt of cloth, but the only acceptable pattern to my discerning eye, a brown background with green palm fronds, was on a 45-inch-wide bolt. I explained the problem to the salesperson, who pointed me to a conversion table for just that issue. I got the recommended length, plus another half yard just in case.

Construction Zone

The Warm Window cloth, metal pulley, nylon cord, and magnetic strips arrived shortly after ordering them. I started to lay out the cover cloth, which required emptying the living room to use the floor. I marked off the measured corners with masking tape, and then discovered I was short 30 inches of the cover material. It was another two weeks before I could get to town to get what I needed. Thankfully, the bolt had enough fabric, but not much more. The clerk gave me the rest of the bolt for half price. (I figure to make a matching couch bolster with the leftovers.)

Some stuff called Steam-a-Seam 2 was recommended for non-seamstress types. To use it, you need a steam iron, so I dug in my back closet and found mine gathering dust. A little gadget known as the Buttoneer was my next purchase. I would use this to attach all the itty-bitty plastic rings.

Now, I did my best to follow Warm Window's Six Simple Steps. I labored, hunkering down on my hands and knees, for two days. It started with cutting, pinning, and then steam-ironing seams shut. Then I had to place the little magnetic strips in the right sequence and all in the same direction on each side. Two panels of the cover cloth could not easily be joined with the Steam-a-Seam, so I ended up hand-sewing the entire length.

I will say here that nothing turned out or was as easy as it had been purported to be. The Steam-a-Seam was supposed

to provide a temporary bond between two pieces of fabric—and become permanent when you steam-ironed it. But with the fabric I used, there was no temporary bond, so I was forced to do all my ironing in the living room on my hands and knees, with a piece of cardboard under the material to prevent melting our rug. Once I steamed the seam, it did hold well, though. I had to practice several times to get the hang of the Buttoneer contraption to attach all my little plastic rings. But I was victorious there as well.

The small magnetic strips had little arrows on them so you could be sure to place them in the right direction. The whole drape was inside-out when I attached the magnetic strips. When I turned it right-side out, the strips were inside the overlap of the cover cloth on each side, and magnetically facing the right way. I was very pleased.

I covered the board with extra cloth using white glue brushed on and dried in the sun. Once the glue was dry, I attached the metal pulley on one side of the board, placing the eyebolts every 12 inches across the bottom of the board. I adhered the Velcro tape to the bottom front of the board, then stapled it down.

I attached the drape to the mounting board, mating the Velcro strips. I strung the nylon cord, starting at the bottom ring in each row, threading the cord up through each ring, then along the bottom of the board through each eyebolt, and finally through the pulley at the end. As I worked across the drape, each cord was successively longer and the cord bundle coming through the pulley was fatter. When I had finished threading, I pulled down each cord from the pulley until the tension was equal on each and tied them all into a knot near the pulley. Then I braided the dangling mass of cords into submission and order.

Curtain Call

Standing on a kitchen chair, I attached the anchor board to the wall above the window with deck screws. I wanted to surprise Bob-O with the finished Warm Window when he got home that day. I got my roll of sticky-backed magnetic tape and ran a strip down each side of the window to mate with the little strips in the shade. I was very careful to check the orientation of the magnetic attraction so they would mate and not repel each other.

It all worked. We have to carefully raise the shade and help it fold correctly as we raise it, but that will become easier as the material gets a memory and folds in the right places more easily. I'm glad I attempted the largest window first. Even though it was a more painful process, it will make the biggest difference in energy savings, keeping the house cooler in summer and warmer in winter. Making shades for the smaller-sized windows will be easier with my learned experience, but I won't be tackling those for a while. Now, the bigger question remains: Do you think I can make that couch bolster with a glue gun? *[Ed. Note: Yes, we do.]*

Access

Kathleen Jarschke-Schultze (kathleen.jarschke-schultze@homepower.com) is keeping her cool at her off-grid home in northernmost California.





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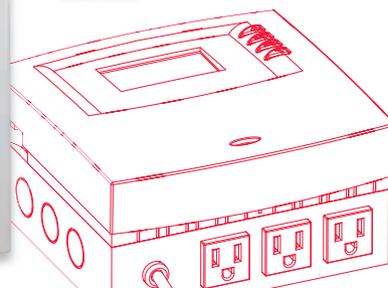
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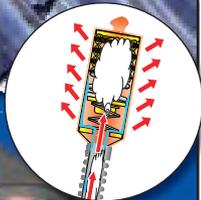


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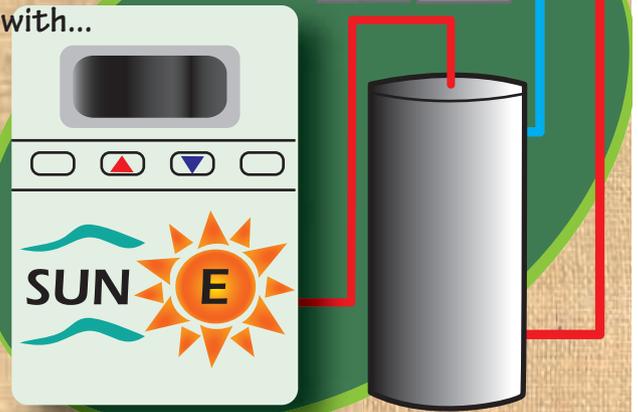
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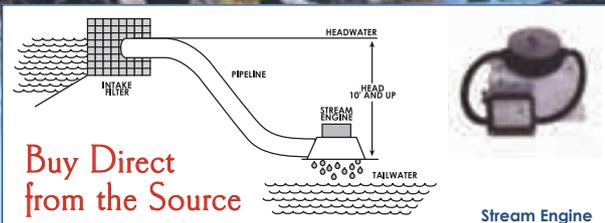
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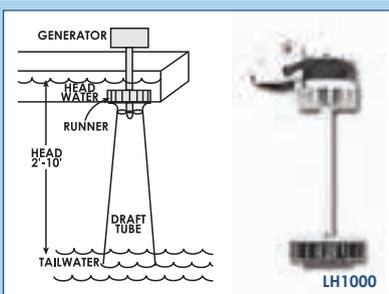
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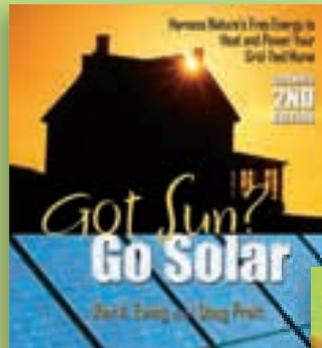


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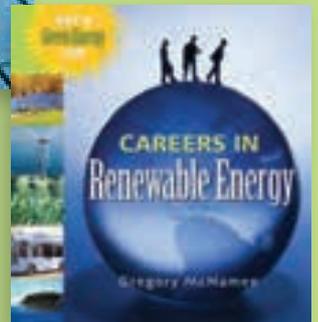
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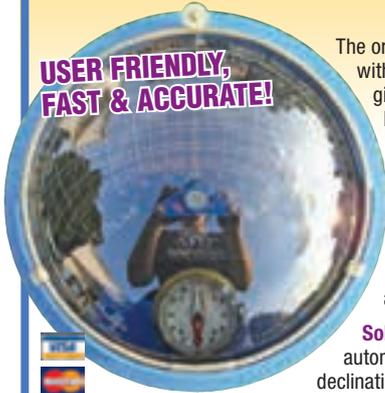
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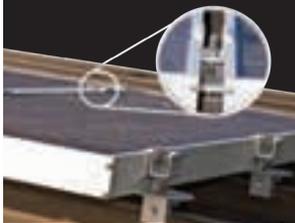
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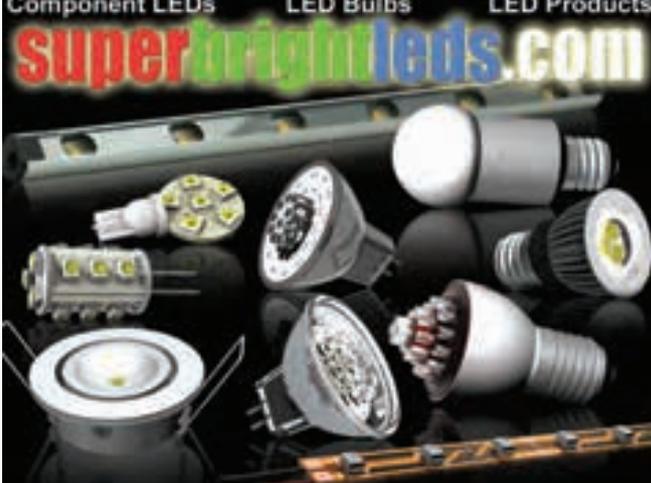
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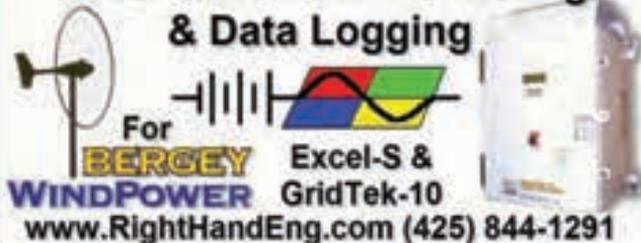


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Voltage Drop

Terms such as voltage loss, conductor heating loss, or line loss all generally refer to the phenomenon of voltage drop—the loss of voltage, and therefore energy, over wires due to wire’s resistance. This loss is a dissipation of heat from the wire.

The greater the length, the greater the resistance in the wire; the smaller the wire size (diameter), the greater the resistance. For renewable energy systems, losses of a few percent can add up to a significant energy loss over the system’s life. In addition, sizing the wiring so voltage stays within the inverter’s specified range is crucial.

Voltage drop is frequently expressed as a percentage of the nominal circuit voltage. For household circuits, nominal circuit voltage is 120 VAC. In renewable energy systems, it might be the nominal battery voltage of 12, 24, or 48 VDC, or the maximum power array voltage for a grid-tied PV system.

For reasonable operation efficiency, voltage drop from source to farthest outlet is suggested by the *National Electrical Code* to be less than 5%. But higher standards of 1% to 3% voltage drop are common in renewable energy systems, with the grid-tied inverter output circuit (inverter to main service panel) being limited to less than 1.5%.

Since a larger wire has less resistance to the flow of electricity, increasing size is usually the solution to maintaining acceptable efficiency over greater distance. But how do you know which wire size is appropriate?

Voltage (V), current (I), and resistance (R) are related according to Ohm’s Law:

$$V = I \times R$$

$$V_{\text{lost}} = I \times R \text{ (over distance)}$$

$$V_{\text{drop}} (\%) = V_{\text{lost}} \div V_{\text{nominal}}$$

For a household, a #12AWG wire might be specified for a 20 A circuit. If 12 A flow at 120 VAC and the outlet is 80 feet from the main panel, the voltage drop is as follows (note: don’t forget to multiply by 2 to account for round-trip distance and to divide by 1,000 to change the resistance figure to ohms per ft.):

$$V_{\text{lost}} = 12 \text{ A} \times 2 \times 80 \text{ ft.} \times 1.98 \text{ ohms per 1,000 ft.} \div 1,000 = 3.8 \text{ VAC}$$

$$V_{\text{drop}} (\%) = 3.8 \text{ V} \div 120 \text{ V} = 3.2\%$$

This is on the edge of the recommended range; upsizing the wire to #10 AWG would reduce voltage drop in the circuit to about 2%.

For a 48 V battery-based system where the PV modules (array Imp) might be sending as much as 30 A to the batteries located 100 feet away, the voltage drop in #4 AWG wire is determined:

Resistance in Uncoated Copper Stranded Wire

Wire Size (AWG)	Ohms per 1,000 ft.
12	1.980
10	1.240
8	0.778
6	0.491
4	0.308
3	0.245
2	0.194
1	0.154

Note: Resistance at 75°C (167°F) for uncoated copper wire

Source: NEC Table 8.

$$V_{\text{lost}} = 30 \text{ A} \times 2 \times 100 \text{ ft.} \times 0.308 \text{ ohms per 1,000 ft.} \div 1,000 = 1.85 \text{ VDC}$$

$$V_{\text{drop}} (\%) = 1.85 \text{ V} \div 48 \text{ V} = 3.9\%$$

Upsizing this to a #3 AWG would keep this circuit to a 3% voltage drop. Note: This calculation used the maximum power point current (Imp) of the modules. If the modules are spending most of their time sending only 20 A, then a #4 AWG wire would keep the losses at less than 3%.

For a batteryless system, the maximum power voltage of a series string might be 350 VDC*. If this string carries 16 A at peak power over 150 feet on #10 AWG wires:

$$V_{\text{lost}} = 16 \text{ A} \times 2 \times 150 \text{ ft.} \times 1.24 \text{ ohms per 1,000 ft.} \div 1,000 = 5.95 \text{ VDC}$$

$$V_{\text{drop}} (\%) = 5.95 \text{ V} \div 350 \text{ V} = 1.7\%$$

***Note: Because hotter temperatures will reduce array voltage, you may want to incorporate the module temperature coefficient of Vmp for the site’s average high temperature to calculate array voltage to be used in voltage-drop calculations.**

As illustrated, increasing wire size is one way to reduce voltage drop. Other options include increasing system voltage (for example, design battery-based systems for higher voltage, such as 48 V or higher using a step up/down charge controller), or reducing wire run length if possible. These are all potential ways to reduce voltage drop to help keep system efficiency within bounds.

—Erika Weliczko

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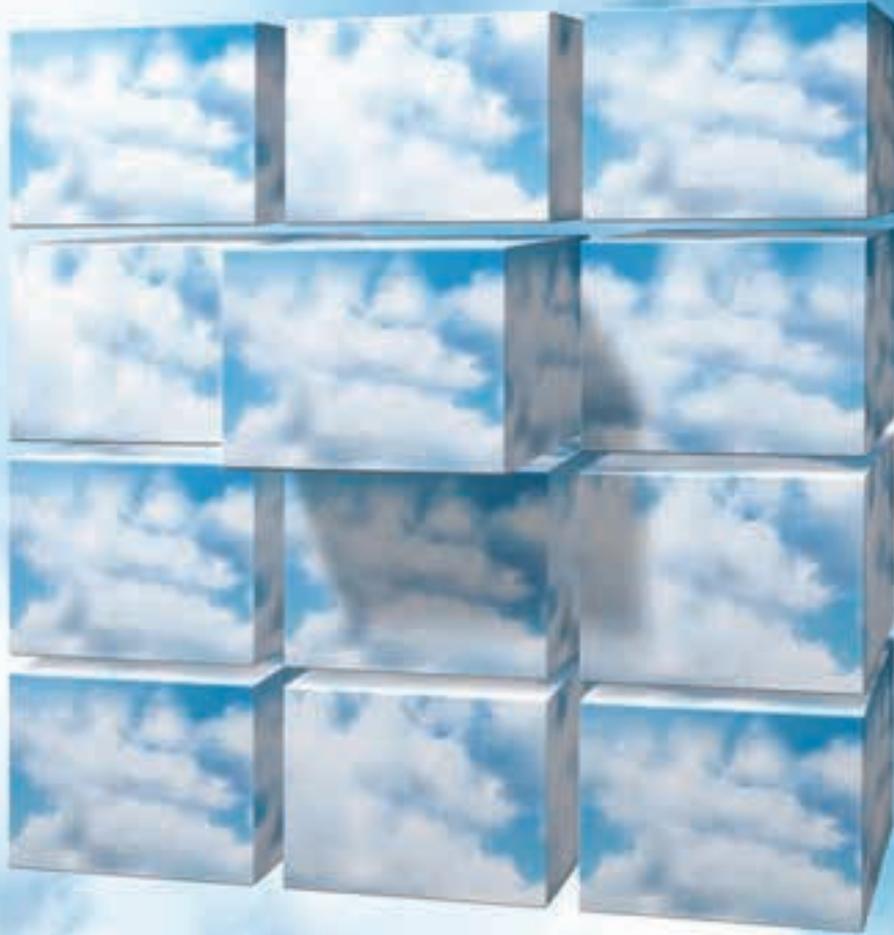
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