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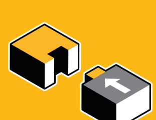

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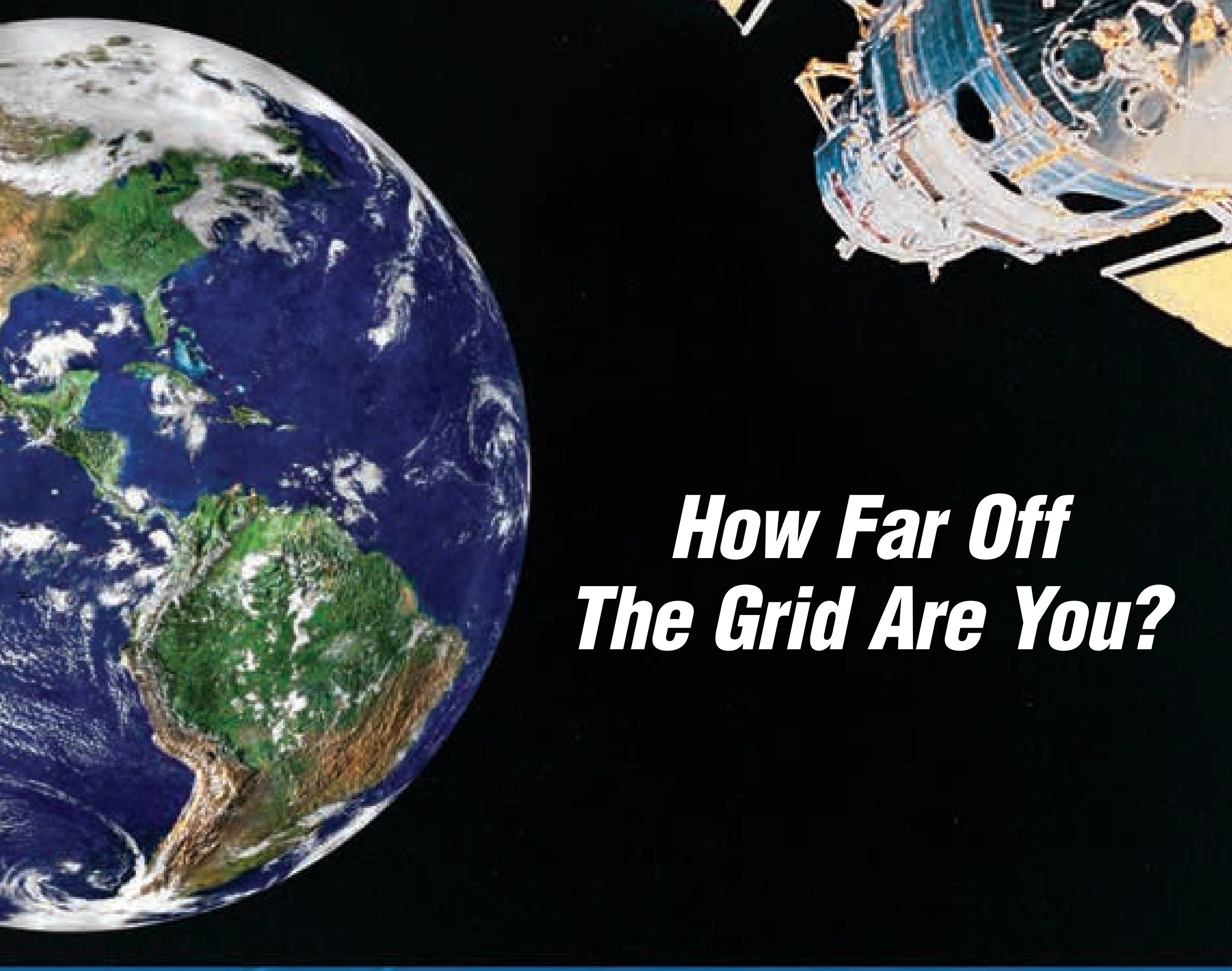

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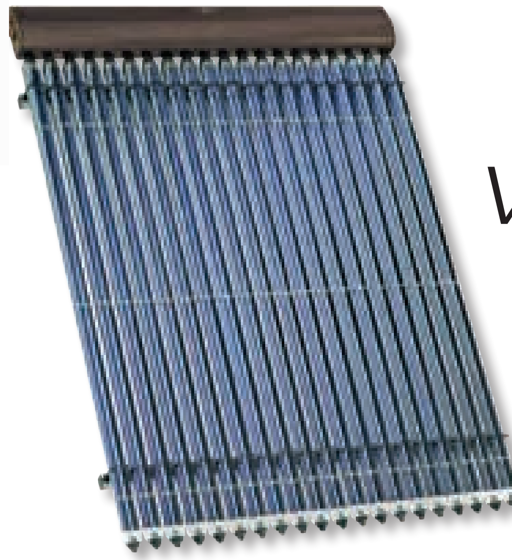
August & September 2009



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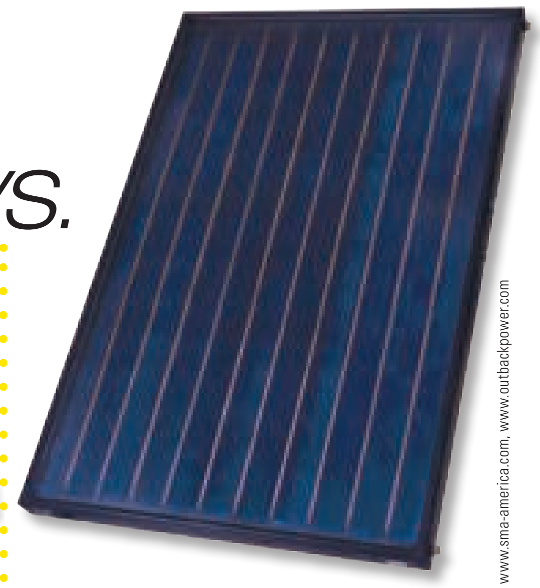

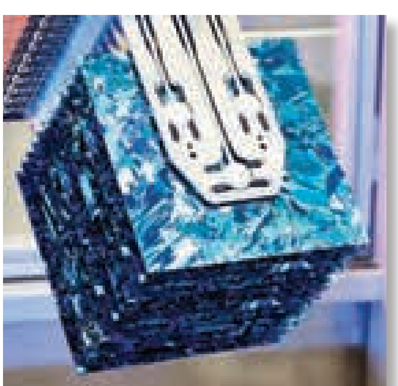

Clockwise from bottom left, courtesy: www.outbackpower.com , www.recgroup.com , www.elsterelectricity.com, www.viessmann.us, www.synergysolar.com, Shawn Schreiner, www.sma-america.com, www.outbackpower.com

On the Cover

Scott Crawford and Newt Loken of Solar Assist install Apricus evacuated-tube thermal collectors on a mixed-use building in Eugene, Oregon.

Photo by Shawn Schreiner

Regulars

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Renewable Electricity Literacy

As energy prices rise and environmental awareness and concerns increase, interest in renewable energy (RE) systems is growing rapidly. Media coverage is at an all-time high, but RE literacy isn't necessarily keeping pace with the interest and reporting. Not everyone reading or reporting on the technologies understands the basic concepts and terminology, which makes confusion more likely.

If you only have time to understand one energy concept, make it **kilowatt-hours.** This is a fundamental measure of energy, commonly applied to electricity, but also useful as a more general measure. Utilities sell us kilowatt-hours, and RE system owners "sell" renewable kilowatt-hours back to the utilities or put them into their battery banks. A *kilowatt* is a completely different animal—it's the *rate* of energy generation, use, or transfer (also called "power"). A kilowatt is like miles per hour (a rate), while a kilowatt-hour is like miles (a quantity).

When it comes to solar energy, understanding daily **peak sun-hours** is critical to good system design and performance projections. This is not something you observe, but a measured value of how much solar energy your site gets over the course of the year, accounting for weather, but not for shading. In North America, average daily peak sun-hours vary from about 2.4 to 6.6, with most sites falling in the 3 to 5 peak sun-hours range. You can find sun-hours data at http://rredc.nrel.gov/solar/pubs/redbook, as well as in print sources.

Looking at the wind resource, the most important concept to understand is **average wind speed.** While utility wind farmers use more sophisticated measurements, simple average wind speed is enough to make realistic design choices for small-scale sites. Home-scale wind sites fall in the 7 to 14 mph average wind speed range, with most below 12 mph average. This is *not* an instantaneous speed, nor is it a rough guesstimate or observation. Without it, you can only guess about how much energy you might get from a wind generator.

Hydro-electric system production is based on two factors. One is **head**, the vertical distance between where you take the water out of the stream and the turbine. The other is **flow**, commonly measured in gallons per minute. These are equal factors in the hydropower equation, so doubling or halving either will double or halve production. You need either significant head or flow (or both!) to make a significant amount of hydro-electricity.

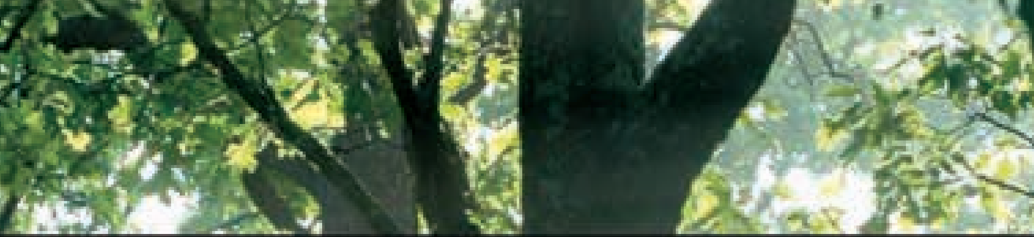
These basic terms will get you started on understanding renewable energy concepts. Reading *Home Power* will take you further—we've been speaking the lingo and walking the talk for 22 years. Understanding and using the terms of the trade clearly and carefully will help you have reasonable expectations, and then reach them!

—Ian Woofenden, for the *Home Power* crew

Think About It...

"If you look at the science about what is happening on Earth and aren't pessimistic, you don't understand data. But if you meet the people who are working to restore this Earth… and you aren't optimistic, you haven't got a pulse."

—Paul Hawken



NEW GROWTH, MORE OPPORTUNITIES

SmartRE

The revolutionary Smart Renewable Energy solution from OutBack Power, bringing you simplified grid-tie solar with back-up power for residential and small commercial applications.

Designed with an emphasis on ease of installation, the SmartRE solution installs and operates similarly to a regular grid-tie solar inverter but with the unique additional benefit of providing UPS quality battery back-up during utility outages. An integrated ultra-fast AC transfer switch guarantees that even sensitive back-up loads, like computers, never know when a utility outage occurs. Matching outdoor/rainproof power electronics and battery enclosures constructed of aluminum make the SmartRE a versatile product that can be installed both indoors or outdoors. Available in power levels up to 6kW and capable of providing as much as 69 kWh of back-up power during outages, there is a SmartRE solution for your application.

FLEXpower ONE

The new pre-wired FLEXpower ONE system includes all the essential protective devices in the smallest possible space at the lowest installed cost.

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.

The OutBack Power FLEXpower ONE system is the only choice when you need a fully integrated, true-sinewave, reliable power system that saves both time and money while still looking great.

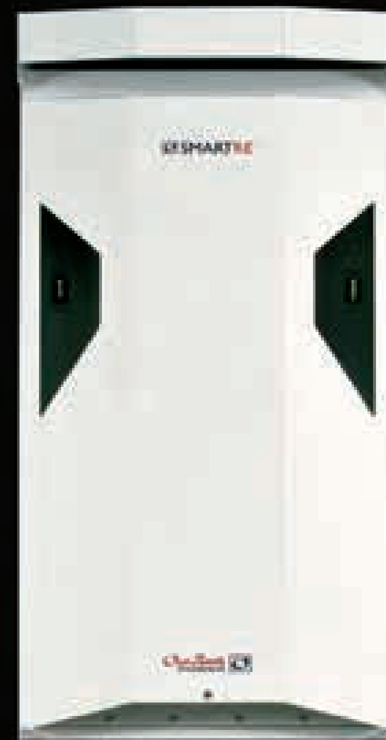
GTFX & GVFX LA Series

The new OutBack LA Series true sinewave grid interactive inverter/charger is designed for use in 60 Hz countries outside of the US and Canada that have utility grids with nominal AC voltages higher or lower than 120VAC.

The LA series has been developed for areas that frequently experience high or low voltage conditions such as surges, spikes or brownouts, the LA Series grid reconnect timers have also been shortened to improve system performance. Incorporating a DC to AC sinewave inverter, battery charger and AC transfer the GTFX and GVFX LA Series Inverter/Chargers give you the ability to sell solar, wind or hydro power back to the utility grid while providing back-up power in the event of a utility outage. Our built in transfer switch automatically disconnects your loads from the utility grid and powers them from the inverter in the event of an outage, allowing you to continue using your solar and battery back-up power, unlike traditional battery-less grid-tie systems.

OutBack POWER

www.outbackpower.com



SmartRE

FLEXpower ONE
Pre-wired System

GTFX & GVFX LA Series

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PV Recycling

Responding to criticism about potential toxic waste generated during the manufacture of PV modules, the U.S. solar industry is taking steps to stay as clean and green as possible, launching initiatives aimed at ensuring manufacturer responsibility throughout the supply chain.

Over the past year, the industry has come under attack from national news outlets—the *Los Angeles Times* and *The Washington Post*, among others. A report released earlier this year by the Silicon Valley Toxics Coalition (SVTC) fueled the fire. Known for advocating safety and manufacturer responsibility in the high-tech industries, the SVTC takes particular offense with the low wages and lax environmental policies in countries where some PV modules are manufactured—namely China, where there have been reports of PV manufacturing facilities illegally dumping chemical by-products of silicon production.

For now, a number of U.S. manufacturers with European operations are finding the support and resources they need through PV Cycle, a voluntary take-back and recycling program for end-of-life modules in Europe.

On the disposal side, the SVTC urges the solar industry to address potential risks immediately, or warns that we'll risk repeating the mistakes made by the microelectronics industry, which waited decades before putting recycling programs in place and also generates millions of tons of toxic "e-waste" annually in the United States. The report draws parallels between the two industries, asserting that silicon-based PV production involves many of the same materials used in microelectronics production and therefore presents many of the same hazards.

The solar industry, as the report acknowledges, still has a window of opportunity to avert the problem. Because PV modules can last more than 30 years and the U.S. solar industry is still relatively young, having experienced its most substantial growth over the last decade, the volume of waste generated by retired modules each year is low. By about 2020, however, the systems of recent years may be ready to face disposal.

Several companies are already bracing for the future by developing recycling plans and programs. SolarWorld has established a new recycling facility in Germany. There, retired modules are dismantled piece by piece, and the materials, including silicon wafers, are recovered for recycling or reuse

Courtesy www.solarworld-usa.com

in new PV modules. The company plans to open a domestic facility down the line, but for now, retired modules are shipped by container from its U.S. headquarters in Oregon to Germany.

First Solar Inc., an Arizona-based manufacturer of thin-film PV laminates, assumes all costs associated with collecting and recycling its retired modules. The company not only has recycling operations at each of its manufacturing facilities in the United States and abroad, but also set up an independent trust to support recycling and disposing of its modules—even if the company should cease to exist.

Though the SVTC report raised questions about the darker side of the PV industry, some good has come from the bad publicity. Its message of cradle-to-cradle product stewardship and life-cycle thinking is widely supported within the industry and has prompted an industry-wide discussion about waste- disposal practices.

Leading the conversation is the Solar Energy Industries Association (SEIA), a national trade organization based in Washington, D.C. In March, the SEIA board established a committee to address the environmental, health, and safety implications of solar products. The committee—comprised of representatives from PV manufacturers, including First Solar, SolarWorld, SunPower, SunTech, and Sharp—is charged with developing the first large-scale recycling initiative in the United States.

Find out what all the buzz is about. Download *Toward a Just and Sustainable Solar Energy Industry* at the Web site for the Silicon Valley Toxics Coalition. www.etoxics.org.

"Our goal is to stay ahead of the curve. We're in a favorable position in that we're still a very young industry and we have some time, but it's important that we take a leadership role now so we can deal with any current issues and have the best practices in place when the time comes," says Monique Hanis, SEIA spokesperson.

For now, a number of U.S. manufacturers with European operations are finding the support and resources they need through PV Cycle, a voluntary take-back and recycling program for end-of-life modules in Europe.

"What everyone must realize is that virtually every product is made with chemicals, and that the solar industry is a community of professionals who genuinely care about environmental impact and producing a green product. That's why we all got into this business in the first place," says Lisa Kruger, First Solar's vice president of sustainable development.

"Rest assured," Kruger adds, "that the entire industry is committed to doing what it takes to create a climate change solution for today that does not impose a waste management issue of tomorrow."

—Kelly Davidson

Capitol Carbon Cleanup

For all its talk of harnessing the power of the wind, capturing the sun, and using water to meet our nation's energy needs, one fossil-fuel dinosaur sits just steps from Congress: the Capitol Power Plant.

The plant is the primary source of air pollution in the District of Columbia, but that is about to change. In an effort to clean up Congress's image and the District's air quality, House Speaker Nancy Pelosi and Senate Majority Leader Harry Reid have announced that the plant will no longer burn coal to heat the Capitol's many buildings and water supply, but will start using natural gas, a cleaner-burning fuel. Although change won't come cheap—the switch will cost $7 million, according to Stephen Ayers, the acting architect of the Capitol—it does signal a growing governmental consciousness to address global warming issues here at home.

Renewable Lawns

Buying that new mower next season might just come with a double dose of incentive: one for your pocketbook and one for the environment. If Vermont Senators Patrick Leahy and Bernie Sanders and Vermont Representative Peter Welch can pass their latest bill, consumers will get a 25% tax credit (up to $1,000) when they purchase cleaner-fueled lawn, garden, and forestry power equipment.

Products that will quality for the 25% tax credit include those that are powered by a motor drawing current from solar, electricity, or rechargeable or replacement batteries; have a hybrid-electric drivetrain and/or cutting system powered by a generator or electrical storage device combined with a small engine; or are powered by renewable power sources and regulated by the Environmental Protection Agency. The goal of the bill is to reduce dependence on foreign oil, while cultivating an incentive for consumers to buy clean, renewably powered equipment for their businesses and homes.

Lone Star State Landfill Goes Solar

What can you do with a full landfill? After decades of taking the community's refuse, the 680-acre Tessman Road Landfill in San Antonio, Texas, is putting part of its site to use to make energy. A flexible photovoltaic cover has transformed 5.6 acres of the landfill's south-facing slope into a solar farm. Republic Services Inc., the Arizona-based company that owns the landfill, worked with United Solar Ovonic of Michigan to develop the first-of-its-kind solar-electric landfill cap—more than 1,000 Uni-Solar flexible solar strips adhered to the synthetic geomembrane liner used to cover and close the landfill when it reaches capacity.

The new solar-electric cover complements the landfill's biogas-to-energy system, which has been in operation since 2002. Republic and CPS Energy, the local utility, will study and document the results of this solar demonstration project to determine the feasibility of using the solar-electric cover on other landfills.

With more than 300 days of sunshine in San Antonio per year, Republic estimates that the energy produced by the PV and biogas systems will create enough energy to power 5,500 area homes. The company's research suggests that as many as 2,350 acres of its 213 landfills nationwide could be fitted with solar-electric covers, generating enough solar energy to power up to 47,000 homes.

Several landfills nationwide are equipped with solar-electric systems, with countless others slated for future installations. Tessman is the only one currently utilizing the Uni-Solar flexible landfill cap.

SolaDeck Flashed Enclosures

This spring, RSTC Enterprises Inc released two additional models of its SolaDeck PV-roof enclosure, ETL listed to the Underwriters Laboratories' 1741 standard as combiner boxes. SolaDeck is a NEMA 3R seamless, powder-coated, weather-tight enclosure that flashes into the roof deck, eliminating the need for a separate roof flashing system. Its low profile (2.5 inches thick) allows for mounting under some PV arrays. With 3-inch or 6-inch fixed din rails, mounting fuse holders, terminal blocks, and power blocks is a snap. Basic units have the din rail, dual-space ground lug, three roof deck knockouts at 0.5, 0.75, and 1 inch, and five positions to enter or exit the box with conduit or strain fittings. SolaDeck systems are being used for wire transition pass-throughs as well as for combiner boxes.

—Justine Sanchez

Courtesy www.rstcenterprises.com (2)

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Kyocera 3.0 Kit

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ASG Power Kyocera 4.9 kW GT Kit

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Our Price: $21,855.00

Panels by the Pallet

Evergreen Solar

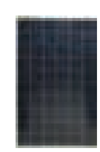
ES-A-205-f2ab**	$644.00	$2.99/watt
ES-190*	$610.00	$3.14/watt
ES-180*	$610.00	$3.14/watt

*Pallet pricing
**Blemished modules are only visualized blemished. The are fully warrantied, UL Listed, and generate normal rated power.

Kyocera

KD210GX-LP	$706.00	$3.11/watt
KD205GX-LP	$654.00	$3.06/watt
KD180GX-LP	$610.00	$3.06/watt
KC130TM	$519.00	$3.99/watt
KC85T	$389.00	$4.58/watt

*Pallet pricing



Sharp

ND-V230C1	$768.00	$3.34/watt
ND-224U1F	$732.00	$3.27/watt
ND-216U1F	$706.00	$3.27/watt
NT-175U1	$676.00	$3.18/watt

*Pallet pricing

Suntech Power

STP175S-24Ab-1 175W 24V Panels

Our Price: $549.00 $3.07/watt

*Pallet pricing

SolarWorld

SW175 175W 24V Panels

Our Price: $627.00 $3.58/watt

*Pallet pricing

Sanyo

HIP-215NKHA5, 215W 30V Panels

Our Price: $935.00 $4.35/watt

*Pallet pricing

Products

Enphase Micro-Inverter

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

Batteries	VOLTS/Ah	OUR PRICE
Deka/MK Battery 8G8DLTP-DEKA Gel	12V 225Ah	$559.00
Surrette S-530 Deep Cycle Battery	6V 400Ah	$372.00
Concorde Battery PVX-2580L	12V 255Ah	$862.00
Trojan Battery T105	6V 225Ah	$160.00

Charge controllers

Charge controllers	AMPS	OUR PRICE
Xantrex XW Solar Charge Controller	-	$557.00
Xantrex C35 Charge Controller	35A	$104.00
Apollo T80 Charge Controller	80A	$657.00
Blue Sky Energy Solar Boost 6024HDL w/Display	60A	$583.00
Morningstar TriStar TS-60 Charge Controller	60A	$202.00

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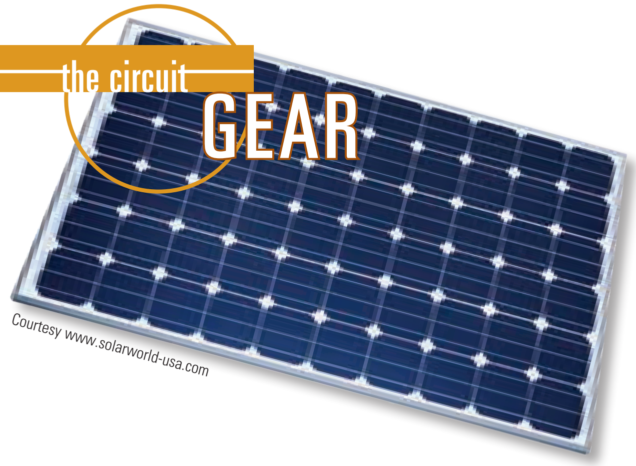
*Please note pricing and availability subject to change in this crazy market



Courtesy www.solarworld-usa.com

SolarWorld Releases High-Capacity Modules

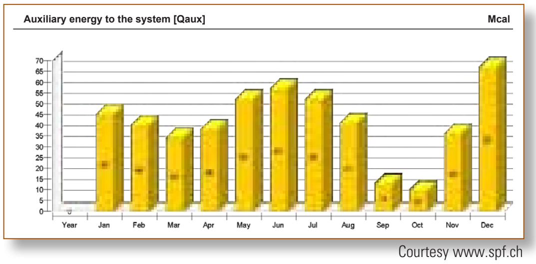
Solar World has released its SW220 and SW230 Mono series Sunmodule. These high-capacity 60-cell PV modules have a +/- 3% power tolerance, and come pre-wired with MC Type 4 locking connectors and three bypass diodes. While the standard Sunmodule has a white sheet and silver-colored aluminum frame, black frames and backsheet models are available as well. All Sunmodules come with a 25-year power warranty and can be returned to Solar World for recycling at the end of their life.

—Justine Sanchez

Solar Thermal System Design Software

Solar thermal system integrators and homeowners who want to design their own solar hot water system can now do so from the comfort of their laptops with SPF Solartechnik's latest software release—Polysun 4. This solar water and space heating simulation application now includes data for designers in the United States. The program incorporates SRCC collector data, irradiance levels, and weather data for hundreds of locations throughout North America. Input the type of system and the installation location, collector size, model, and tank size, along with other installation variables, and the program runs a simulation of performance and gives a detailed set of results. The simulation also produces easy-to-read graphs. The application tool comes in three levels—Polysun Light, Professional, and Designer, with the Light version priced at $159. www.velasolaris.com

—Chuck Marken



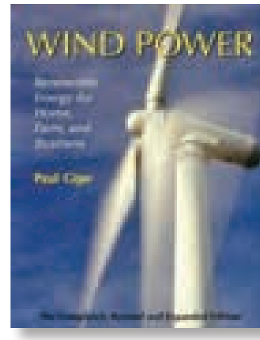
Courtesy www.spf.ch

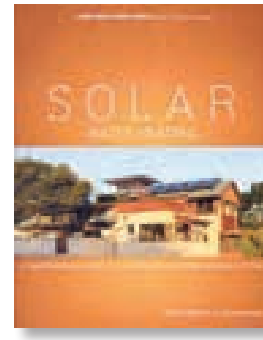
Summer Reading for Solar Enthusiasts

Take advantage of the summer rays with *The Solar Food Dryer* by Eben Fodor (New Society Publishers, 2005). With your own solar-powered food dryer, you can quickly and efficiently dry all your extra garden veggies, fruits, and herbs to keep their goodness all year long—with free sunshine! Step-by-step plans show you how to build a high-performance, low-cost solar food dryer from readily available materials. Plus: food-drying tips and recipes.

For an excellent primer on solar hot water systems, spend some time with *Solar Water Heating: A Comprehensive Guide to Solar Water and Space Heating Systems* (New Society, 2006) by Bob Ramlow, with Benjamin Nusz. While useful for any newcomer to SHW, this well-organized text is a particularly valuable resource for anyone living in a harsh climate, as it reflects Ramlow's 30-plus years installing SHW systems in Wisconsin.

For a classic introduction to small wind-electric systems, pick up *Wind Power: Renewable Energy for Home, Farm, and Business* by Paul Gipe (Chelsea Green, 2004). This book covers wind power basics, from estimating your wind resource and your annual energy output with a given system to issues related to siting, installation, and utility interconnection. Chapters devoted to the rotor, transmission, and tower leave you with a thorough understanding of the mechanics.





Buyer Beware

Readers have been asking us about the recent proliferation of renewable energy e-publications and videos available for sale on the 'Net. Although much of the general RE information is accurate, many of these books and videos purport to show you how to build "solar panels" and "windmills" to make your own electricity—but don't even come close to fulfilling those wild promises. For publications written by experienced RE professionals and users, check out our monthly picks here.

Biofueling a Better Future

Courtesy www.biofuels.coop

Take one small town in North Carolina, add a heaping measure of cooking oil, season with a dash of granola mind-set, mix with old-fashioned elbow grease, and you have the recipe for one of the largest and most successful biofuel cooperatives in the country.

Pittsboro's Piedmont Biofuels cooperative has humble backyard beginnings. Cofounder Lyle Estill, then a metal sculptor, would make some homebrewed biodiesel from leftover cooking oil and occasionally split a batch among friends. "It was a really good week if we all went home with a gallon or two," says Estill, who used his share to fuel his tractor.

In less than a decade, the homegrown hobby has expanded into full-scale commercial production, with two plants, two sustainable farms, and a nonprofit arm that organizes community programs and workshops. The operation now employs nearly 70 full-time workers, and uses two 1,600-gallon fuel delivery trucks and one vacuum truck for oil collection.

Going door to door, Estill and cofounders Leif Forer and Rachel Burton slowly built an oil collection network, convincing local restaurants and cafeterias to help "close the loop" and donate used cooking oil and animal fats to the cause.

Going door to door, Estill and cofounders Leif Forer and Rachel Burton slowly built an oil-collection network, convincing local restaurants and cafeterias to help "close the loop" and donate used cooking oil and animal fats to the cause. Their efforts paid off. The network includes a mix of independent and chain restaurants, as well as several corporate and university cafeterias—many of which use Piedmont's biodiesel to run diesel equipment and vehicles.

In 2005, the outfit took on a new name—Piedmont Biofuels Industrial Inc.—and relocated to new headquarters, an abandoned chemical plant acquired with help from state grants and "recycled" into a biodiesel facility. The high-production plant caters to a growing fleet of biodiesel-fueled businesses—ranging from one outfit that produces natural bug repellents from biofuel to a company that makes a biofuel-based industrial cleaner for asphalt tools.

Today, the organization supplies hundreds of residents and businesses in North Carolina's Research Triangle region with more than 1 million gallons of biodiesel annually—every drop of which is fully warranted, EPA-registered biodiesel that meets the national biodiesel quality specifications. The smaller of Piedmont's two plants serves the co-op's 550 members, producing up to 50,000 gallons of biofuel annually.

The co-op's $50 annual fee gives a member the right to purchase fuel from any of Piedmont's seven fuel stations on its "B100 Community Trail" or to have fuel delivered to their homes or businesses. Weekly fuel-making sessions also give members the opportunity to produce their own batches and learn about biofuel production.

Even with its growth, Piedmont, like so many biofuel cooperatives across the country, is always "just barely making it." The organization credits its success to diversification and a creative mix of microfinancing, fundraising, and grants.

But the latest version of the Renewable Energy Standard just may give the operation the boost it needs. According to the new legislation, biodiesel made from waste vegetable oil will be classified as an "advanced" biofuel, potentially enabling the outfit to take advantage of government incentives for renewable fuels.

Estill says that's good news for those in sustainable biodiesel production. "Our product is finally getting the recognition it deserves. And with that recognition, it should have more value."

—Kelly Davidson

Piedmont Biofuels (www.biofuels.coop) is one of many biofuel cooperatives across the country that rely on local support. You can help a cooperative in your area by becoming a member or donating your restaurant's leftover cooking oils or animal fats. Search the Web for a cooperative in your area.

Small Wind on Martha's Vineyard

Courtesy Gary Harcourt

Alexander Boyle and his family's quest to shrink their carbon footprint began in their oceanfront home. Only 150 feet above sea level, their property rises from the sea to a "Long View," overlooking Vineyard Sound to the west-northwest—the direction from which the prevailing winter winds come. The property didn't have good southern exposure for a PV system, but the winter winds would provide ample power. This set a scenario for great energy production when the family's electric/geothermal heating system requires it most.

"Our objective…was to play a tiny part in what must be a national imperative to shift our country's energy supply to renewable, sustainable sources," says Alexander. "Our home has received considerable publicity as Martha's Vineyard's first 'zero net-carbon' house. With the geothermal heating and cooling system, and with the wind turbine, this home will operate totally without gas or oil fuel, which means no net greenhouse gases."

But the site presented obstacles to a tilt-up tower installation. The steep grade of the property, as well as the location of the house, which sits in the center of the lot, meant that the only viable location for the tower was 80 feet from the property line. Zoning bylaws required the setback to be the maximum height of the machine—plus 20 feet.

That required submitting an application to the West Tisbury zoning board for a special permit—which was granted only after a lengthy hearing. In preparation for the proceedings, wind system installer Gary Harcourt of Great Rock Windpower took photos from neighboring properties, calculated the path that a shadow made by the turbine would take, and solicited letters of support from nearby residents. The hearing was attended by many neighbors and townspeople who were concerned that, besides impinging on views from other properties, the turbine would be noisy. Harcourt presented data comparing the sound of the proposed turbine—an Endurance S-250—to that of a person rubbing his hands together rapidly. After reassuring hearing participants that the turbine would be fairly quiet, especially in the typical windy conditions at the site (40 to 50 mph winds are common), the Board voted unanimously to grant the setback variance.

Our objective in installing the wind turbine was to play a tiny part in what must be a national imperative to shift our country's energy supply to renewable, sustainable sources.

PROJECT: Boyle residence

SYSTEM TYPE: Residential grid-tied wind electric

INSTALLER: Great Rock Windpower

DATE COMMISSIONED: April 2009

LOCATION: West Tisbury, Massachusetts; 41.26°N latitude

ESTIMATED ANNUAL PRODUCTION: 7,000 AC kWh

AVERAGE ANNUAL UTILITY BILL OFFSET: 90–100% (estimated)

COST OF UTILITY ELECTRICITY: $0.23 per kWh

INCENTIVE PAYMENT: $2.25 per rated watt

TURBINE: Endurance Windpower, S-250, three-blade

ROTOR DIAMETER: 18 ft.

TOWER: Endurance, tilt-up, guyed pipe, 84 ft. tall

The next obstacle was that the septic leach field occupied the only open ground on the property. Harcourt and his crew had to fine-tune the layout of the turbine foundation until the anchor points were not in the field. Last but not least, the side guy wire anchor points were about 9 feet in elevation difference. The team formed a custom-engineered concrete anchor, raising the low side to an acceptable height. The other side was excavated as low as was practical and a stone retaining wall was built to protect the soil around a prized beech tree.

It was a tight fit and the turbine sits fairly close to the house, but the Boyles are pleased—and the first month's production of 662 kWh was more than acceptable on Martha's Vineyard, where winter winds from November to March typically produce the most power.

—With Gary Harcourt

Making Adjustments

In a perfect world, all PV arrays in the Northern Hemisphere would be pointed true south. But the reality is that most sites are far from optimal. Here's how to work with what you have and estimate your solar-electric system's performance–almost anywhere.

PV Array Production (kWh/Year) for Various Orientations & Tilt Angles

	Array Tilt					
Orientation	**Horizontal**	**15°**	**30°**	**45°**	**60°**	**Vertical**
East (90°)	2,465	2,399	2,242	2,028	1,783	1,257
Southeast (135°)	2,465	2,579	2,561	2,423	2,186	1,493
South (180°)	2,465	2,672	2,725	2,625	2,371	1,511
Southwest (225°)	2,465	2,620	2,635	2,517	2,289	1,590
West (270°)	2,465	2,454	2,335	2,144	1,908	1,370

Source: NREL PVWatts, Version 1 for a 2 kW PV array in Austin, TX

PV Array Adjustment Factors

	Array Tilt					
Orientation	**Horizontal**	**15°**	**30°**	**45°**	**60°**	**Vertical**
East (90°)	0.90	0.88	0.82	0.74	0.65	0.46
Southeast (135°)	0.90	0.95	0.94	0.89	0.80	0.55
South (180°)	0.90	0.98	1.00	0.96	0.87	0.55
Southwest (225°)	0.90	0.96	0.97	0.92	0.84	0.58
West (270°)	0.90	0.90	0.86	0.79	0.70	0.50

In the Northern Hemisphere, PV arrays are generally oriented to true south with a tilt angle equal to the site's latitude for optimal year-round solar harvest. But many roof-spaces are not aligned to true south, nor are they commonly tilted to latitude. In dealing with this inconvenient reality, novice installers sometimes mount PV arrays in awkward angles from the roofline to position their arrays for optimal performance. These installations not only look unattractive to many but can expose PV arrays to high wind loading, putting additional stress on buildings.

Thankfully, two simple solutions exist for nonoptimal roof slopes and orientations. The first is to mount the array parallel to the roof, accepting the partial energy loss. This may not sound acceptable until you examine the predicted energy output for nonoptimal orientations, which can be calculated using the PVWatts online calculator (www.nrel.gov/rredc/pvwatts).

Let's look at the results for a grid-direct 2,000-watt PV system in Austin, Texas. Mounting the system at an optimal orientation and tilt at this location (orientation = south; tilt = 30°) is estimated to generate 2,725 kWh per year. Let's say our roof was oriented to the southwest (225°), with a tilt angle of 15°. PVWatts calculates an annual energy production of 2,620 kWh—96% of the energy of the optimally mounted PV array, and much better than most people expect from a "nonoptimal" situation.

Then, if needed, you can recalculate an increase in the array size to make up for these losses. We can create a adjustment table from the production table, taking the kWh/year value in each cell and divide this by the kWh/year figure for optimal orientation, in this case, 2,725.

Using the original example, divide the 2,000 W array by 0.96 to find the array size (about 2,080 W). To compensate for the nonoptimal orientation and tilt, we'd need to add 80 W of PV modules. Due to actual module sizes that are available, we would likely upsize each module slightly. For instance, if the original 2,000 W array called for ten 200 W modules, to account for losses ten 205 W or 210 W modules might be selected, since 208 W modules may be unavailable. (Note: This discussion only considers annual kWh production. Varying orientation and tilt of PV arrays to accommodate various time-of-use metering programs is not taken into consideration.)

—Justine Sanchez

SOLAR FINANCE OPTION

We enjoyed your recent article on PV system financing (*HP129*). Your readers might want to know about Permaculture Credit Union in Santa Fe, New Mexico, open to anyone who shares the permaculture philosophy. They finance alternative energy projects, including construction and retrofitting. Their Web site is www.pcuonline.org. The newsletters posted there contain articles about projects they have financed.

Frank Many & Kathy Janes •
Ukiah, California

Courtesy Gene Walker

NAME THE MODULE

I was wondering if any readers could tell me what company made this solar-electric module? My grandfather gave it to me back in the late 1970s. He had retired from a career working at General Electric's service shop in Seattle. He told me at the time that the module had been used on an offshore drilling platform to charge batteries for radio communications. He had acquired it from a coworker who had worked in the Gulf of Mexico years before and had replaced this broken module with a new one.

The module is made of 3/4-inch-thick glass and has 16 hand-soldered cells. It measures 10 inches by 10 inches and has no markings. The open-circuit voltage is 9 volts. I have used it over the years to keep my 6-volt motorcycle batteries charged.

Grampa Bonathan never missed an opportunity to show his grandkids the magic and wonder of electricity. He carried around a tattered October 1982 issue of *National Geographic* that was all about the microchip. He wanted everybody to know about this amazing breakthrough in technology, since he had witnessed the advancement from the vacuum tube to transistors to microchips. I wish he had lived long enough to see laptop computers, the Internet, and grid-tied PV systems on people's houses.

Gene Walker •
Olympia, Washington

WIND ENERGY PREDICTIONS

Your article—"How to Buy a Wind Generator" (*HP131*) was full of good advice to the consumer, but contained one glaring oversight. Your use of manufacturers' power curves to calculate annual energy output (AEO) led to a very misleading and even unfair comparison of different manufacturers' technologies.

It is well-established that some manufacturers offer promises of power output that turbines cannot live up to; some even defy the laws of physics! For *Home Power* to blindly use unconfirmed power curve data to determine energy production to guide consumer choice does not serve the consumer well. At the very least, a strong caveat to that effect should have been included in the article.

It is unfortunate that some of the AEO numbers were published—since once in writing they are taken as "the truth." This makes it very difficult for manufacturers trying to sell "the honest truth" in the marketplace. The promise of certification to a standard in the near future does not help consumers today. As test engineers, we are aware how easy it is to manipulate data and produce unrealistic and vastly overstated numbers even from actual test data. But in today's unregulated arena, manufacturers

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don't even need to use test data, they are free to use any power curve they wish—even a hypothetical one.

So what is a consumer to do? First, realize that all of the turbines presented in the article are suitable candidates for a personal renewable energy system, and the main difference in terms of energy capture is the size of

There are simple tools to calculate energy capture for a small wind turbine given only rotor area and annual average wind speed.

Courtesy www.endurancewindpower.com

the rotor area. There are simple tools to calculate energy capture for a small wind turbine given only rotor area and annual average wind speed. One such model calculates the total energy in the wind passing through the rotor area, then factors that by the overall turbine efficiency (OTE):

kWh per year = [rotor area (sq. ft)] x [annual average wind speed (mph)]^3 x 0.085 x OTE

The 0.085 is a combination of constants that include $1/2$ times air density times unit conversion factors. Empirical data suggests that the OTE will fall between 15% and 25% for small wind turbines—we suggest 20% be used as a generic guide. Readers can plug the rotor area and annual average wind speed numbers from your article into this equation and compare the result to the number your article presents. If the equation result is not within 20% of what the manufacturer claims, be very skeptical of that particular claim. Using a tool like this, consumers can separate out a wind turbine's true renewable energy potential from empty promises.

David Laino, Dean Davis •
Endurance Wind Power, Inc.

Thanks for weighing in on a really contentious issue in the small wind industry—the accuracy of the data supplied by manufacturers about their products.

I am no longer willing to use the swept area method you suggested to compare turbines—I have found that there are simply too many variables to use such a simplified equation. For example, I know of two turbines with identical swept areas and generator sizes, one of which outperforms the other on annual energy output (AEO) by more than 33%. There are clearly other design aspects of a wind turbine, other than swept area, that influence the amount of energy a wind turbine will generate.

I chose to use the manufacturers' power curves to calculate AEO, and run that data through a spreadsheet program that actually calculates the AEO, rather than using the AEO numbers supplied by the manufacturers. Incidentally, this is the same way manufacturers determine AEO—with a spreadsheet calculator. They do not determine their AEOs based on extensive field testing for a year at average annual wind speeds from 8 to 14 mph—this simply takes too long and is too involved. However, feedback from the field is sometimes taken into consideration by manufacturers after the fact, as a reality check on their advertised numbers.

Using a standard AEO calculator, I was able to apply exactly the same mathematical assumptions to all the turbines rather than accept the many assumptions of manufacturers. The only variable in this process is the veracity of the manufacturers' power curves. If manufacturers are honest with their power curves, then the resulting AEO may be accurate. If not, well…garbage in, garbage out.

At this point, we simply do not have independent verification of AEOs. I hope that will change in the near future once the AWEA Small Wind Turbine Performance and Safety Standard is adopted, and the independent review agency, the Small Wind Certification Council, certifies the results. Then, consumers will have apples-to-apples numbers to compare turbine performance. Until such time, my advice is still: "Your mileage may vary." Sometimes considerably.

Mick Sagrillo •
Lake Michigan Wind & Sun

Experts disagree, and that's a good thing. In this case, Mick decided to use a spreadsheet calculator to produce the numbers for the article. I do wish the information about the nature of the numbers had been more prominent and had emphasized that they are based on manufacturers' power curves.

I question whether using the calculator is a step forward for this article and the industry, though it's certainly one piece of information that might be useful. I would have preferred to use manufacturers' AEO projections in the article, and clearly state that we had nothing to do with the calculations. I think it's unfortunate if readers conclude that Home Power *endorses or validates these numbers. Mick is correct that if we put garbage in, we get garbage out. And if we were not concerned with the possibility that the manufacturers' numbers might be garbage, we would not be having this discussion, or trying to apply other methods to get AEOs.*

I think it's good to look at all available data, but overall, I have more faith in a generalized formula based on swept area and average wind speed. Variations of this method have been proposed and used by many well-known people in the industry, including Hugh Piggott, Jim Green of the National Renewable Energy Laboratory, Paul Gipe, Mike Klemen, and of course, David and Dean from Endurance and Windward Engineering (their wind consulting firm). All apparently have at least some mistrust of the manufacturers' power curves and AEO numbers.

But a generalized formula is a generalization—it cannot take into account all factors for an individual turbine. It does, however, take into account the two most important factors—swept area and wind resource. Beyond that, we can apply factors that tell us that a specific estimate is possible, impossible, optimistic, etc.

I agree with Mick that a standard may help, depending on how it's structured. In the end, wind generator purchasers should get all the information they can, from as many sources as possible, before making a buying decision.

Ian Woofenden •
Home Power *Senior Editor*

UNREALISTIC?

I read with great interest the letter in *HP131* from Steen Hviid, who had to "head for the hills" to escape transmission-line EMFs. He writes to warn about inverter radiation and discusses not putting PV and inverters in school buildings. "They belong in large central plants," states Mr. Hviid.

But my question to Mr. Hviid is simple: how does the energy get from the large central plant to the school or other facility? Would that not require *transmission lines*? Is solar-produced electricity on transmission lines subject to lower EMFs than fossil-fuel-produced electricity?

I am not calling Mr. Hviid a crazy person—just an unrealistic one. The "green" movement has much merit and RE can be a great function in it. But there is no cure-all that eliminates all potential risks and impacts. One must realistically see that the only way to be assured that nothing will negatively impact your health—and further that you not negatively impact the environment—is to be dead. I don't find that a reasonable way to live, so I will take my chances with life.

Tim Jamerson •
Ocala, Florida

ANOTHER VIEW ON GREEN FRAMING

I appreciate your magazine very much and have many more RE projects planned for the future. However, I do get tired of the agenda that is being pushed in the "Green Framing Options" article in *HP130*. Having grown up in Western Oregon, I would like to set straight a few inaccuracies from your author's diatribe. The authors are incorrect in their characterization of modern forestry practices. They may be happy to learn that the "tiny pockets of remaining ancient forests" are actually part of 193 million acres managed by the U.S. Forest Service (USFS). Many more thousands of acres are also privately held.

Of those lands managed by the USFS, there are about 59 million acres of roadless wilderness areas. While there are certain forest management practices that they may disagree with, I doubt if they can provide any evidence that the harvest of timber destroys the ecosystem. Additionally, I would like to see the data that shows an increase in national park usage based on a lack of diverse forest access.

I find it interesting that the authors would attack our modern forestry practices, which are renewable, and then recommend building with SIPs, which are undoubtedly manufactured from petroleum-based fossil fuels in factories that occupy ground that once hosted diverse forests. Can we all justify using SIPs because the amount of energy (nonrenewable fossil fuel) that is used in their construction is "miniscule" compared to the energy usage of a home over its lifetime? Please stick to the information for which we buy your magazine (RE) and leave the rhetoric out.

Mitch Theurer •
Buhl, Idaho

ERRATA

The Circuit Methods *piece on "Finding True South"* (HP131) *had incorrect compass illustrations. The correct illustrations can be found at www.homepower.com/webextras under "Finding True South correction."*

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PV String Sizing

I'm designing a batteryless solar-electric system, and I'm trying to figure out how to size the array and match it to an inverter. Can you give me some guidelines?

Gerald Jones • via e-mail

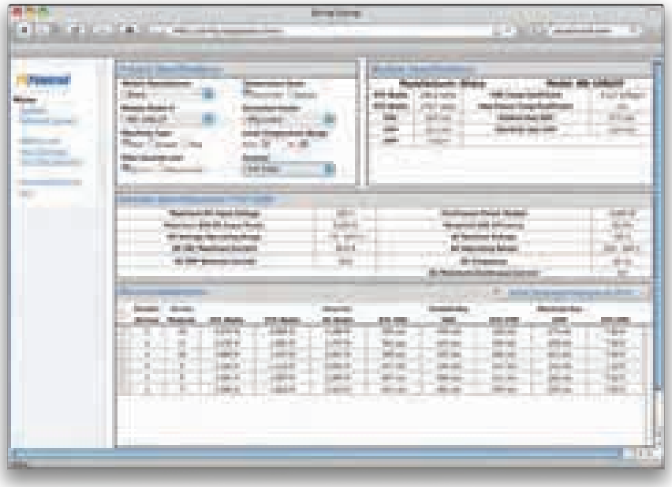
There are a few different ways you can size a PV array for a grid-direct system. You can size based on your budget, available array mounting space, or desired annual energy production. "Sizing a Grid-Tied PV Array" (*HP130*) gives examples for these three methods.

Once you have calculated your desired array size, you will have an array wattage you can work with to determine inverter capacity needed. For instance, if you determine that a 2,000-watt array will meet your needs, you can review grid-direct inverters that can accept this array size. All the residential batteryless inverter manufacturers offer inverters that will accommodate this array size. A few examples are the Fronius IG 2000, PV Powered PVP 2000 or PVP 2500, and the Solectria PVI 1800 or PVI 2500.

The model numbers of inverters commonly include their AC power ratings—the Fronius IG 2000 is rated at 2,000 W for its AC output. And you do not have to exactly match the array size to the inverter. As long as the array voltage is within the inverter's input voltage window, you can put a smaller array on a larger-capacity inverter, allowing room for future growth. Because real-world performance is lower than an array's rated output (and because the inverter consumes some power to invert DC to AC), you can match a higher array rated wattage to an inverter *rated* at a slightly lower wattage. For example, even though the Solectria PVI 1800 is rated at 1,800 W for its AC output, its maximum DC input (array) watts is 2,200—so our example 2,000 W array could work with this inverter.

Once you know your system size and your inverter options, matching the array's voltage to a specific inverter can take some estimating and calculating. PV array voltage is a moving target since it fluctuates with temperature, and the process can become a bit cumbersome if done by hand.

Thankfully, each of the inverter manufacturers has online tools that can do this calculation. First, select your PV module model and inverter model from drop-down menus, and specify your mounting method (roof, ground, or pole). Then, you enter your site's highest average high temperature and lowest historic low temperature. Both of these values can be determined by appending your zip code to the end of this Web address: www.weather.com/weather/climatology/monthly.



Courtesy www.pvpowered.com

Using an online string-sizing program, like this one from PV Powered, can help you determine the number of modules in series your chosen inverter can handle.

Then the online string-sizing program will tell you how many modules per string and the number of strings the chosen inverter can handle. Let's say you wanted to see if 10 Sharp ND-198U1F roof-mounted modules would work with the PV Powered PVP 2000 inverter in temperatures between 90°F (the highest average high) and 10°F (the lowest historic low). The PV Powered string sizing program shows that, with this inverter, one string of seven to 12 modules in series would work.

Finally, when deciding how many modules to put in a string, it is good practice to aim toward the middle or high end of the range. Over time, module (and array) voltage can decrease. If you've sized a string at the low end of the range, array voltage could eventually drop below the inverter's minimum required voltage, shutting down the inverter. In the case of our example, 10 modules is in the middle range, providing a margin of sizing safety.

Justine Sanchez • *Home Power* Technical Editor

"...when deciding how many modules to put in a string, it is good practice to aim toward the middle or high end of the range."

Efficiency & Solar Education Ideas

I am working on a project that teaches elementary-school-aged children to conserve electricity at home. Since replacing incandescent lightbulbs with compact fluorescent (CF) bulbs is one of the easiest changes to make, I'll demonstrate the energy savings by plugging in lamps to watt-meters so the children can see how much difference there is.

I'd like to come up with some other simple examples that young children can understand. I am hoping that the children will take these ideas home and convince their parents to use them.

Doug Stevenson • via e-mail

Courtesy Tor Allen & www.solarschoolhouse.org

Congratulations for focusing your energy education efforts on elementary school students. Using watt-meters to show energy use is a good approach. To compare incandescents with CFs, you can plug in two table lamps (where the bulb is hidden from view). Use a light (lumen) meter to show that the light output is the same for both—and the watt-meter to show that the energy used is not.

For additional lessons about energy use and how to use the sun to better heat, cool, and power your home, check out our *Your Solar Home* DVD and guidebook (www.rahus.org). Among the 15 activities is a model solar home exercise where students learn about thermal mass, absorption, reflection, solar electricity, orientation, and more to design efficient, comfortable homes. Parents will also enjoy this exercise as it ignites a dialogue about their family's household energy use and identifies modifications they can implement.

For the younger ones, a kindergarten teacher in La Crescenta, California, has redefined what we thought was possible to teach students. After our Solar Schoolhouse workshop, the teacher initiated several energy lessons on personal energy use. Topics included how our bodies store, produce, and use energy. The lesson discussed how walking conserves more energy, and teachers demonstrated this concept by letting children see how many laps they could walk versus run. Discussion included how to use human power instead of mechanical power to save energy—sweeping with a broom instead of using a power vacuum, and so on. Students brainstormed ways they could use less energy in their homes—such as taking shorter showers, and turning off TV and lights when not in use. Using a power strip, watt-hour meter, and a variety of appliances (lamps, CD player, toaster, and printer), the students then predict how much energy each appliance uses and record this in their journals. The kindergarten teacher also put together a home energy conservation "backpack," including a watt-hour meter to loan to students.

With a little creativity and RE know-how, the teaching possibilities are endless.

Tor Allen, Director • Rahus Institute/Solar Schoolhouse program

"...students learn about thermal mass, absorption, reflection, solar electricity, and orientation."

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Close-Quarters Water Heater

I am having a difficult time choosing a water heating system for my 800-square-foot, two-person house in Texas. We do experience some temperature extremes: 10 to 15 days a year of freezing temperatures and about five months of 95°F to 105°F weather. So if I select a solar water heating system, I think it would have to be a drainback or an antifreeze system. However, with all of the hot weather we have, I am worried that stagnation problems would result with an antifreeze system.

The natural-gas-fired water heater we have now is housed in a small closet that is 24 inches wide, 27 inches deep, and 80.5 inches tall. The system I choose also has to fit in this closet and I do not have room for anything larger than a 40-gallon tank. From what I have read, solar water systems need to store a large volume of water (80 to 120 gallons) to hold the heat.

I also need a low-maintenance system because I am in a wheelchair and cannot access the roof. I have good sun exposure on my house, and a PV system that provides most of my electricity. Would solar water heating be practical with my limited space?

Tim Silence • via e-mail

Despite the constraints, you have a couple of options. Your first option is to install an electric water heater in the closet. You can find a 65-gallon unit that will fit, though it will be tight. That will marry well with a 4- by 8-foot flat-plate solar thermal collector. A 10-gallon drainback tank with heat exchanger can be installed on a shelf above the water heater—again, it will be tight, but will likely work well. In very tight situations, extending the closet's ceiling into the attic by about 1 foot can provide additional room. See *HP96* for an article on how to make a one-tank system by converting an electric water heater into a solar storage tank.

Your other option is to use a Butler Sun Heat Exchanger, but that would need to be used with a glycol (antifreeze) system.

Courtesy Tim Silence

Keep in mind, though, that gas water heaters don't make the best storage tanks because of the uninsulated flue pipe that runs up the center of the tank and vents through the roof. For both its capability to eliminate overheating and provide a much better storage tank, the drainback system is my pick for your situation.

Chuck Marken •
Home Power Solar Thermal Editor

Cool Roofs for Your Climate?

I live in a climate that requires both supplemental home heating and cooling. That being so, how do I know whether it's better to install light-colored or dark-colored roofing material to optimize my home's comfort and energy savings?

Bob Russell • Ashland, Oregon

Assuming your roof is high-sloped rather than low-sloped (the cutoff is generally a 2:12 pitch, a rise of 2 feet over a run of 12 feet), the benefits of a light-colored roof will nearly always outweigh those of a dark roof of the same material. Even if your roof were angled perfectly toward the winter sun, your summertime air-conditioning savings from choosing a light-colored roof will most likely outweigh the heat gained in winter by using a dark-colored roof. The winter sun—which is available for a shorter part of the day, is lower in the sky, and passes through more atmosphere than the summer sun—is typically weaker than summer sunshine.

Courtesy www.flickr.com/upd42geo/

The white surface of this "cool" roof helps reflect radiation, while the PV array on top of it captures the sun's energy.

To meet energy efficiency standards for "cool roofs," manufacturers have developed special roofing coatings (invisible to the human eye) that reflect much of the sun's heat energy. The Cool Roof Rating Council (www.coolroofs.org) maintains a list of roofing materials that have been tested for both reflectance and emittance (a measure of how quickly any absorbed heat is radiated back out). Many more cool roof materials are available for low-sloped roofs than for steep-sloped ones.

The Department of Energy's Cool Roofs Calculator can help you determine roofing options and energy savings for your home (www.ornl.gov/sci/roofs+walls/facts/CoolCalcEnergy.htm). But reducing home energy use is not the only reason to use cool roofs. In cities, surfaces that absorb solar heat, including typical roofs and pavement, are abundant. They contribute to the "heat island effect," a phenomenon where the heat absorbed by those surfaces during the day is released into the air at night, resulting in warmer temperatures (6°F–8°F warmer) than in surrounding suburbs or rural areas. Warmer urban temperatures help foster the ground-level chemical reactions that create smog. So light-colored and reflective roofs are also part of the solution to mitigating urban heat islands and localized smog. For more information on urban heat islands, see http://eetd.lbl.gov/HeatIsland/pubs/painting.

Elaine Hebert, Energy Specialist • Sacramento, California

PV System Labels

The 2008 *National Electrical Code (NEC)* requires signage on various parts of PV systems. What are the specific requirements for each sign? Where can I buy these signs? I want to have them in place before the rough-in inspection.

Roger Carver • Nucla, Colorado

Section 690 of the *NEC* specifies requirements for labeling PV systems. There are multiple labeling requirements, and they are spread out among several subsections. The labels are required to be a durable, unalterable material permanently attached to the device. The most common type of labeling is engraved or etched plastic, which can be riveted or adhered to the device.

The first *NEC* requirement is that the PV power source information be posted at the DC disconnect, which can also be part of the inverter. Section 690.53 lists the posting requirements: rated maximum power-point current, rated maximum power-point voltage, maximum system voltage, and short-circuit current. According to 690.14(C)(2), if there is more than one PV DC disconnect, they should also be labeled.

The *NEC* also requires other labels for:

- The DC disconnect, noting that the line and load sides may be energized in the open position (*NEC* 690.17).
- The AC disconnect—stating the rated AC output current and nominal operating AC voltage (as stipulated by *NEC* Sections 690.14[C][2] and 690.54).
- At the location of the ground-fault protection, normally at the inverter, warning of a shock hazard (*NEC* 690.5[C]).

The *NEC* specifies labeling for PV system components. The signs in the photo meet the *2005 NEC* requirements for the PV DC disconnect. Many areas have yet to adopt the *2008 NEC* and are operating under the 2005 version.

PHOTOVOLTAIC SYSTEM DC DISCONNECT
RATED MAX. POWER-POINT CURRENT: xxx ADC
RATED MAX. POWER-POINT VOLTAGE: xxx VDC
MAXIMUM SYSTEM VOLTAGE: xxx VDC
SHORT-CIRCUIT CURRENT: xxx ADC

WARNING: ELECTRIC SHOCK HAZARD
DO NOT TOUCH TERMINALS
TERMINALS ON BOTH LINE AND LOAD
SIDES MAY BE ENERGIZED
IN THE OPEN POSITION

PHOTOVOLTAIC SYSTEM AC DISCONNECT
RATED AC OUTPUT CURRENT: xxx AMPS
NOMINAL OPERATING AC VOLTAGE: xxx VOLTS

WARNING: ELECTRIC SHOCK HAZARD
IF A GROUND FAULT IS INDICATED, NORMALLY
GROUNDED CONDUCTORS MAY BE
UNGROUNDED AND ENERGIZED

INTERACTIVE PHOTOVOLTAIC
POWER CONNECTED
RATED AC OUTPUT CURRENT: xxx AMPS
NOMINAL OPERATING AC VOLTAGE: xxx VOLTS

- Where the solar-electric system interconnects to the utility (*NEC* 690.54).

Photovoltaic systems that include batteries have a few other labeling requirements. In addition to *NEC* requirements, it is a good idea to also label other DC enclosures, the utility disconnect, and combiner boxes with fuses, while also providing information at the utility meter that there is a PV system connected.

There are multiple labeling requirements, and they are spread out among several subsections. The labels are required to be a durable, unalterable material permanently attached to the device.

Try your local sign-making or trophy shop for pricing. Tyco (www.tycoelectronics.com) makes some labels that may meet your needs. And be sure to pay attention to *NEC* Section 690 for any labeling changes that might come up.

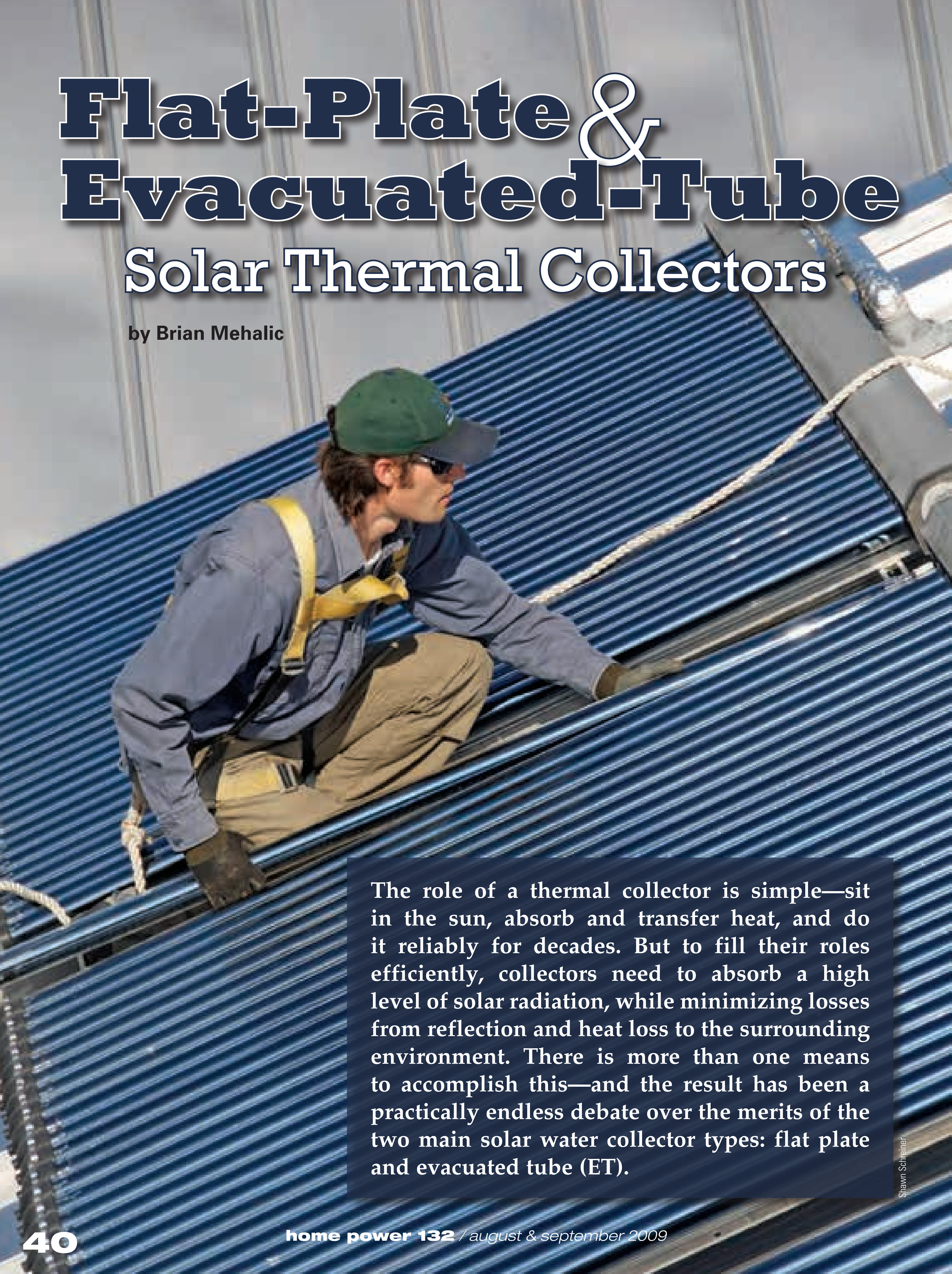
Matthew Dickey, Argand Energy Solutions • Charlotte, North Carolina

To submit a question to
***Home Power's* Ask the Experts,**
write to: **asktheexperts@homepower.com**
or, **Ask the Experts**
Home Power, PO Box 520, Ashland, OR 97520
Published questions will be edited for content and length. Due to mail volume, we regret that unpublished questions may not receive a reply.

Flat-Plate & Evacuated-Tube

Solar Thermal Collectors

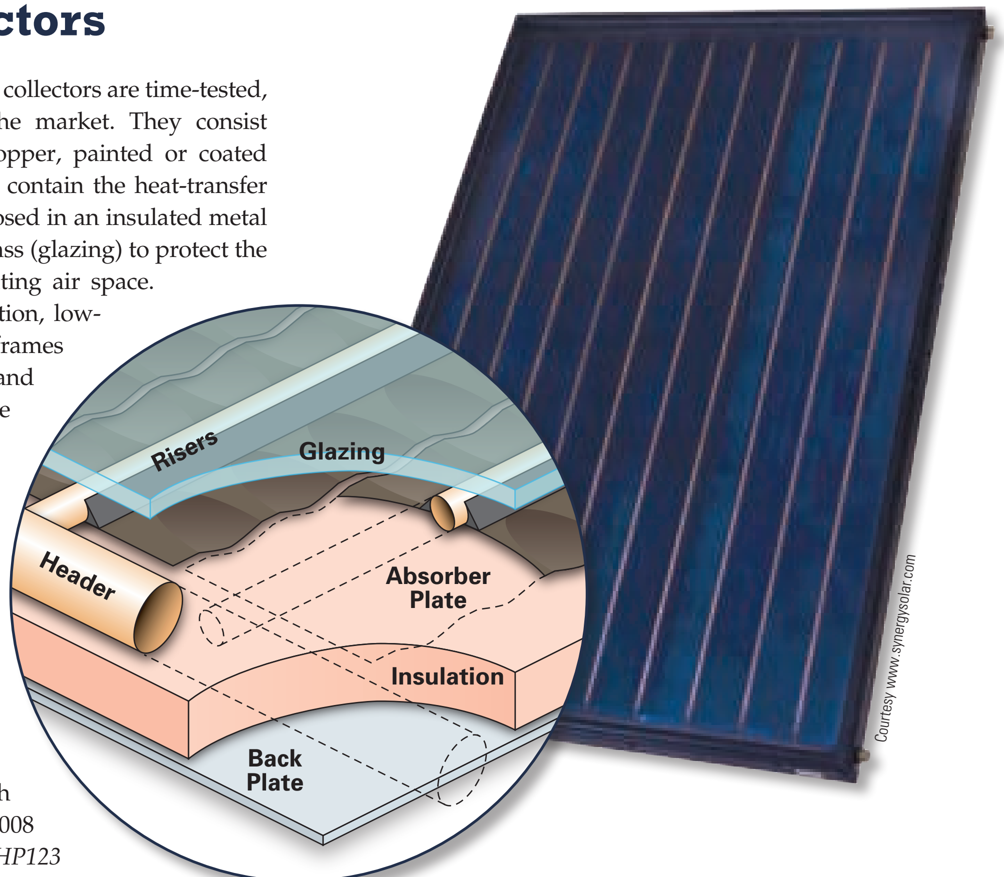
by Brian Mehalic



Shawn Schreiner

The role of a thermal collector is simple—sit in the sun, absorb and transfer heat, and do it reliably for decades. But to fill their roles efficiently, collectors need to absorb a high level of solar radiation, while minimizing losses from reflection and heat loss to the surrounding environment. There is more than one means to accomplish this—and the result has been a practically endless debate over the merits of the two main solar water collector types: flat plate and evacuated tube (ET).

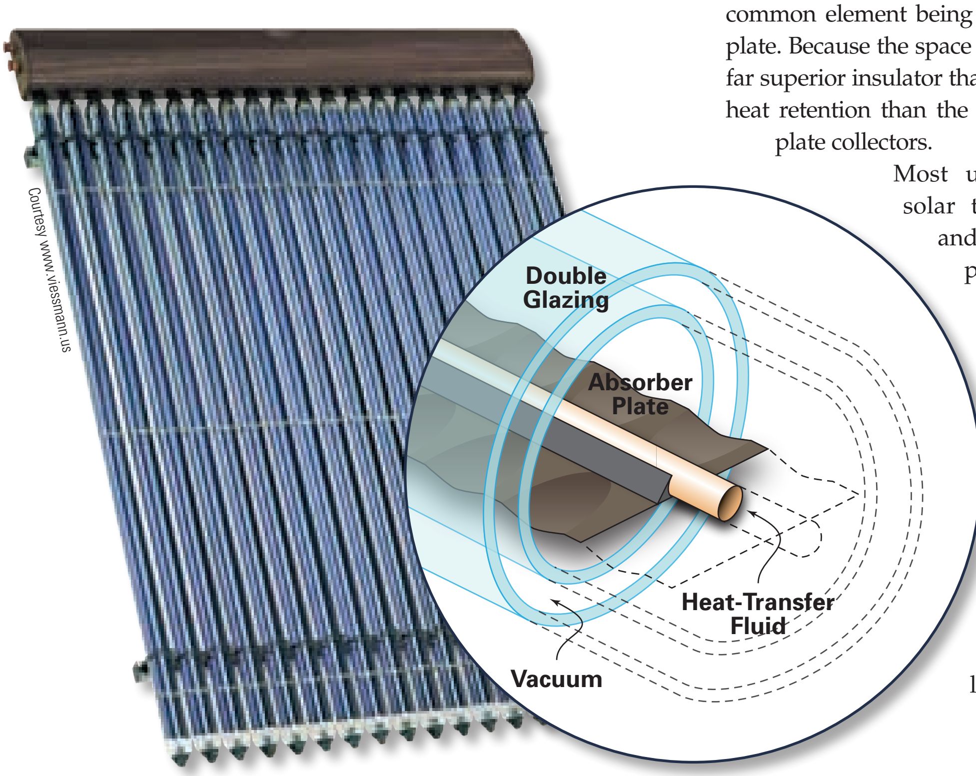
Flat-Plate Collectors



In use since the early 1900s, flat-plate collectors are time-tested, reliable, and currently dominate the market. They consist of an absorber plate—a sheet of copper, painted or coated black—bonded to pipes (risers) that contain the heat-transfer fluid. The pipes and copper are enclosed in an insulated metal frame, and topped with a sheet of glass (glazing) to protect the absorber plate and create an insulating air space. High-temperature rigid-foam insulation, low-iron tempered glass, and aluminum frames are the most common materials, and different absorber plate coatings are available, ranging from black paint to proprietary selective-surface coatings designed to maximize heat absorption and retention.

Flat-plate collectors usually range in size from 24 square feet (3 x 8 ft.) to 48 square feet (4 x 12 ft.) or more, and can weigh more than 150 pounds each. They hold a small volume of fluid, typically less than 3 gallons even in large collectors, which is circulated through for heating. See "*Home Power*'s 2008 Solar Thermal Collector Guide" in *HP123* for detailed specs on both types of collectors.

Evacuated-Tube Collectors



Evacuated-tube collectors are a more recent technology, introduced in the late 1970s. Several types are available, with the common element being a glass tube surrounding an absorber plate. Because the space inside the tube is a vacuum, which is a far superior insulator than air, these collectors have much better heat retention than the glazing/air space (R-7) design of flat-plate collectors.

Most use borosilicate glass to maximize solar transmission to the absorber plate, and use similar absorber coatings to flat-plate collectors. Frames and manifolds for paralleling multiple tubes are available and can hold 4 to 20 tubes or more. As with flat-plate collectors, multiple banks can be plumbed together to increase system capacity. While overall weights and dimensions are similar between the two types, evacuated tubes usually have an advantage in that individual tubes can be carried to the location and then assembled in place, rather than lifting an entire collector.

Shawn Schreiner

Individual evacuated tubes connect into a manifold.

Courtesy www.thermomax.com

The heat-exchanger manifold with the cover removed.

Pros, Cons & Conventional Wisdom

Efficiency. Collectors operate most efficiently when the temperature of the inlet fluid (Ti) is the same as or less than the ambient temperature (Ta) of the air. When Ti equals Ta, flat-plate collectors tend to be about 75% efficient, while evacuated tubes have an efficiency of about 50%. However, collectors rarely operate under these conditions.

In most systems, collectors operate 30°F to 80°F above ambient temperatures to produce end-use temperatures from 100°F to 130°F. As the inlet temperature increases, the potential for heat transfer from the absorber to the surrounding air increases—heat lost to the atmosphere is heat not transferred to the fluid in the collector, and the result is less efficiency. Because of the superior insulation in ETs, their efficiency curve, which shows the loss in efficiency as the difference between inlet and ambient temperature (Ti–Ta) increases, is less steep compared to flat plates. Flat plates are more efficient when Ti equals Ta, but

Selecting a Collector Type

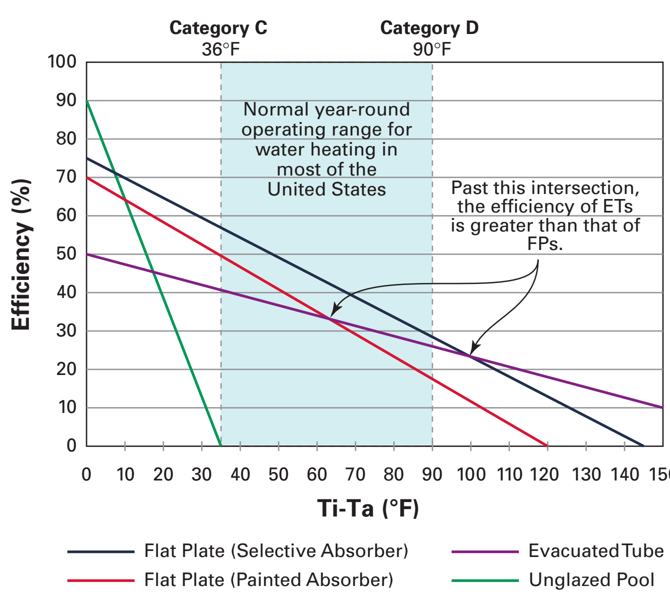
Wading through the glut of conflicting collector information can be a big chore—unless you first prepare for the task. Each type of collector has its advantages and disadvantages, and in many cases either may be suitable for the same application.

As with any system, improper sizing, design, component selection, or installation can easily trump the performance of even the most efficient collector. (See "Sizing Solar Hot Water Systems" in *HP118* for a detailed discussion on sizing; and "Solar Hot Water Simplified" in *HP107* and "Certified Solar" in *HP125* for more information on the types of hot water systems.)

Cost

Cost is often the primary consideration, especially if performance is comparable. While ETs may cost 1.2 to 2 times more, flat-plate collectors use considerably more copper and can be subject to greater price fluctuations due to resource prices. Local availability and shipping costs may also affect price differences and, in some cases, ETs may be less expensive.

Collector Efficiency



the efficiency curves of each, which decrease at different rates, intersect at some point. Past this junction, as Ti continues to rise, ETs are more efficient than their flat-plate counterparts.

When comparing ET and flat plates having similar-quality absorber plate coatings, this intersection typically occurs when the inlet temperature exceeds the ambient by 90 to 100°F or more—conditions that most systems do not typically experience. However, it does mean that ET collectors are capable of producing higher temperatures overall and can produce more heat in cold weather. ETs also perform much better under cloudy and windy conditions, again a result of the improved insulation keeping more heat "in the collector."

Unfortunately, the superb insulation that otherwise helps evacuated-tube collectors can undermine their efficiency in areas that receive a lot of snow or heavy frost. Light passing through frost or snow will heat the absorber plate of flat-plate collectors. Some of this heat radiates out and warms the glass, melting frost and creating a layer of water that allows snow to slide off. However, in ET collectors, the more effective vacuum insulation prevents the heated absorber from warming the surrounding glass, resulting in much longer "melt-off" times. Additionally, snow can pass through the spaces between the tubes and accumulate underneath, resulting in snow buildup. In some cases, evacuated-tube collectors may take half the day or more to melt snow or frost, reducing their operational time and offsetting their increased cold-weather efficiency.

Design Differences. Typically designed with an unsealed enclosure, flat-plate collectors can be prone to condensation buildup on the inside of the glass as they age. Cosmetically, this may be an issue, but the impact on performance is minimal—an increased possibility of corrosion on the collector materials and mounting components is the most serious long-term effect.

On the other hand, sealing and maintaining a vacuum is difficult, and an evacuated tube without a vacuum performs very poorly. This was a common problem that plagued early designs that relied on seals, but today the majority of ETs use a continuous piece of glass to minimize the risk of vacuum loss.

Flat-plate collectors tend to have stronger glass than ETs. If the glazing breaks, though, replacing it can be challenge. Due to the modular design of ET collectors, individual tubes can easily be replaced if they become damaged.

Siting & Other Considerations. Evacuated tubes are less sensitive to sun angle and orientation than flat-plate collectors—some tubes can even be individually rotated within the rack system to favor late or early sun. Their circular design allows sunlight to pass at a right angle through the same thickness of glass throughout the day, whereas the changing sun angle relative to a fixed flat-plate collector results in increased reflection due to the angle of incidence.

Because of aesthetics or other constraints, collectors are often mounted parallel to the roof surface. While a steeper pitch may favor winter production, many roof angles are 35° or less, and a parallel-to-roof installation can lead to collectors overheating in the summertime and under-producing during the winter. Again, for the reasons mentioned above, this has less of an impact on ET collectors than for flat plates.

In general, ET collectors are best suited for areas with low winter temperatures and/or a below-average solar resource, or when high-temperature water is required (such as in some commercial applications). Realistically, either type will work for most applications, with flat plates usually a more economical choice in Sunbelt climates. Your local solar pros should have a handle on what works best in your particular climate.

Brian Mehalic

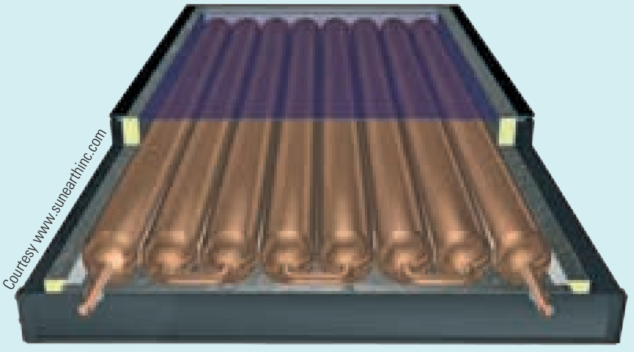
A flat-plate collector tilted to optimize winter performance.

Ben Root

While evacuated-tube collectors are less affected by angle and orientation, mounting them parallel to a steeply pitched roof will improve their wintertime production.

A Collector for Mild Climates

A third type of collector, integrated collector storage (ICS), is worth mentioning. As the name suggests, these collectors hold a comparatively large volume of fluid (40 gallons or more). Usually, though not always, this fluid is the domestic—or end-use—water, rather than a separate heat-transfer fluid. However, many ICS collectors are appropriate only for installation in areas that have record-low freeze temperatures above the single digits, and less than 30 to 40 freezes per year. While the volume of water in the collector is frequently able to hold enough heat to resist freezing, the piping to and from the collector, if not installed and insulated properly, is most likely to freeze and burst. Furthermore, cold nighttime temperatures result in heat loss, since the end-use water is stored outside in the collector.



SunEarth's CopperHeart progressive tube is one of several types of ICS collectors that work well in nonfreezing climes.

Characteristic	Flat Plate	Evacuated Tube
Proven technology	✔	✔
Typically less expensive	✔	
Less affected by collector orientation		✔
More efficient at high temperatures		✔
More easily sheds snow	✔	
More efficient in cloudy weather		✔
Suitable for drainback systems	✔	

Performance & Collector Ratings

The independent nonprofit Solar Rating and Certification Corp. (SRCC) helps consumers make educated SHW choices with its voluntary certification, labeling, and rating programs for collectors (Standard OG-100) and also for complete systems (OG-300).

For OG-100 certification, collectors from a manufacturer's production lines are randomly selected and then tested by independent, accredited labs using procedures and standards specified by the SRCC. Collectors are tested for both performance and durability, and energy output is measured over the course of the day to even out the peaks and valleys of fluctuating minute-to-minute performance. Since testing is standardized, the resulting performance ratings allow direct comparison between different collectors. (Note that not all collectors are OG-100 rated—some are only sold integrated into complete systems, which are certified under the OG-300 standard.)

Collectors are first tested for durability, including the quality of the materials and construction, the potential for leaks, and expansion and contraction due to temperature changes. They also undergo pressure, exposure, thermal shock, and post-shock pressure testing.

Thermal performance testing is only undertaken after collectors have passed the durability testing. Instantaneous collector efficiency is measured over a wide range of operating conditions, with incoming fluid ranging from near ambient temperature to 126°F over ambient. These tests are performed with sunlight within 30° of perpendicular to the collector surface. Because performance can change dramatically with sun angle, the efficiency curve is modified to account for performance based on a changing sun angle. Once the collectors have undergone these tests, they are partially disassembled to check for internal or hidden problems that may have arisen during use.

The "Directory of SRCC-Certified Solar Collector Ratings" is available at www.solar-rating.org, and is updated regularly. Collectors are listed by manufacturer and model. General information includes the supplier, model, and type; the dimensions, weight, and fluid capacity; and the materials used for the frame, cover, absorber, and absorber coating. Dimensions are provided for both the gross area, which is the full surface area of the collector including the frame, and the net aperture area, which includes only the absorber surface.

To account for different applications of the same collector, operation categories are used to distinguish performance under various conditions, and are further qualified based on sunlight conditions.

The categories (as in the example ratings table on the opposite page, top right) are based on the inlet fluid temperature minus the ambient temperature (Ti – Ta). Two categories are applicable to domestic water and space heating:

C—Water heating (warm climate); inlet temperature: 36°F above ambient

D—Water heating (cool climate); inlet temperature: 90°F above ambient

The columns show performance based on available sunlight for a standardized "type" of day:

Clear day: 2,000 Btu/ft.^{2} per day = 23 MJ/m^2 per day = 6.3 kWh/m^2 per day

Mildly cloudy: 1,500 Btu/ft.^{2} per day = 17 MJ/m^2 per day = 4.7 kWh/m^2 per day

Cloudy day: 1,000 Btu/ft.^{2} per day = 11 MJ/m^2 per day = 3.2 kWh/m^2 per day

Example SRCC Performance Data

COLLECTOR THERMAL PERFORMANCE RATING							
Megajoules Per Panel* Per Day				Thousands of Btu Per Panel* Per Day			
CATEGORY (Ti-Ta)	CLEAR DAY 23 MJ/m²•d	MILDLY CLOUDY 17 MJ/m²•d	CLOUDY DAY 11 MJ/m²•d	CATEGORY (Ti-Ta)	CLEAR DAY 2,000 Btu/ft²•d	MILDLY CLOUDY 1,500 Btu/ft²•d	CLOUDY DAY 1,000 Btu/ft²•d
A (-5°C)	47	35	24	A (-9°F)	45	34	23
B (5°C)	43	32	20	B (9°F)	41	30	19
C (20°C)	37	26	15	C (36°F)	35	25	14
D (50°C)	24	14	4	D (90°F)	23	13	4
E (80°C)	12	3		E (144°F)	11	3	

A-Pool Heating (Warm Climate); **B**-Pool Heating (Cool Climate); **C**-Water Heating (Warm Climate); **D**-Water heating (Cool Climate); **E**-Air Conditioning
*Based on a flat-plate collector gross panel area of 32.84 ft.²

Original Certification Date: December 18, 2007

TECHNICAL INFORMATION

Efficiency Equation [NOTE: Based on gross area and (P) = Ti-Ta]

	Equation			Y-Intercept	Slope	
SI Units:	$\eta = 0.7447$	-3.0285 (P)/I	-0.0198 $(P)^2/I$	0.7525	-4.1062	W/m²•°C
IP Units:	$\eta = 0.7447$	-0.5337 (P)/I	-0.0019 $(P)^2/I$	0.7525	-0.7240	Btu/hr•ft²•°F

You can use PVWatts (http://www.nrel.gov/rredc/pvwatts/) or other resources to find out the average solar resource for a specific location in kWh/m² per day, on a monthly and annual basis. (To convert, 1 kWh/m² per day = 317.1 Btu/ft.² per day.) For example, Prescott, Arizona, receives an average of 6.22 kWh/m² per day, ranging from 5 kWh/m² per day in the winter to 7 kWh/m² per day in the summer. This places this location in the "Clear" category, though overall performance in the winter is closer to "Mildly cloudy." Detailed, city-by-city data used for PVWatts can be found in the Solar Radiation Data Manual, also known as the "Redbook," available online at http://rredc.nrel.gov/solar/pubs/redbook/.

The performance rating of the collector is given per panel, per day, in both thousands of Btu and megajoules (MJ), and for each combination of operation category and type of day. This information can then be used to estimate system output (how much water will be heated) or to size systems based on heat load requirements. Information for creating a graph of collector efficiency is also provided.

Systems usually operate with the solar fluid at much higher temperatures than ambient. Because efficiency decreases as fluid temperature rises, the slope of the efficiency curve is negative, and this value is provided for the collector. The more negative the number, the steeper the curve; the steeper the curve, the quicker collector efficiency decreases relative to the increased temperature differential. Typical slopes range from -0.2 Btu/hr/ft.² per °F (a more gradual curve, typical of ETs) to -0.8 Btu/hr/ft.² per °F (a steeper curve, representing the more rapid loss in efficiency of flat-plate collectors). The slope value means that for each

Evacuated tubes are easily moved onto the roof, where they can then be inserted into the manifold and clipped into place on the rack.

Shawn Schreiner

degree Fahrenheit that the inlet fluid temperature exceeds the ambient temperature, the collector will produce "X" fewer Btu per square foot per hour.

Both the efficiency equations of the collector and the daily thermal performance rating are based on the gross area—the total collector size, including the frame and manifold (if one is required). Flat-plate collectors tend to have a higher gross-to-net collector area ratio, because less space is taken up by the frame and there aren't the airspaces that typically exist between tubes that are banked together. The standardized ratings based on gross area allow for easy comparison between collector types.

The SRCC also provides a simple methodology for comparing the value of different collectors. The assumption is that all other things in the systems are equal—the cost of the remaining components, the energy used by pumps and controllers, heat loss from piping and tanks, the system operating category, the available solar resource, and system demand. Once these potential variables are removed from the equation, it becomes a simple matter of comparing the dollars per rated Btu of the collectors in question:

Performance rating (Btu) ÷ Collector cost ($) = Btu per dollar

The more Btu per dollar, the better the value of the collector.

Making the Choice

For most residential hot water and space-heating applications, flat-plate collectors tend to be more cost-effective and more than capable of delivering the necessary temperatures. However, evacuated tubes can offer performance increases and other advantages due to their design. To further add to the confusion, not all evacuated tubes or flat plates have the same design, so generalizing about advantages can be a mistake. And while the collector usually only constitutes 10% to 20% of the full system price, different collectors may require different components in the rest of the system, and mounting requirements can vary considerably. These factors can significantly influence the overall system price, meaning that simply comparing the prices between the two types of collectors will not tell the whole story.

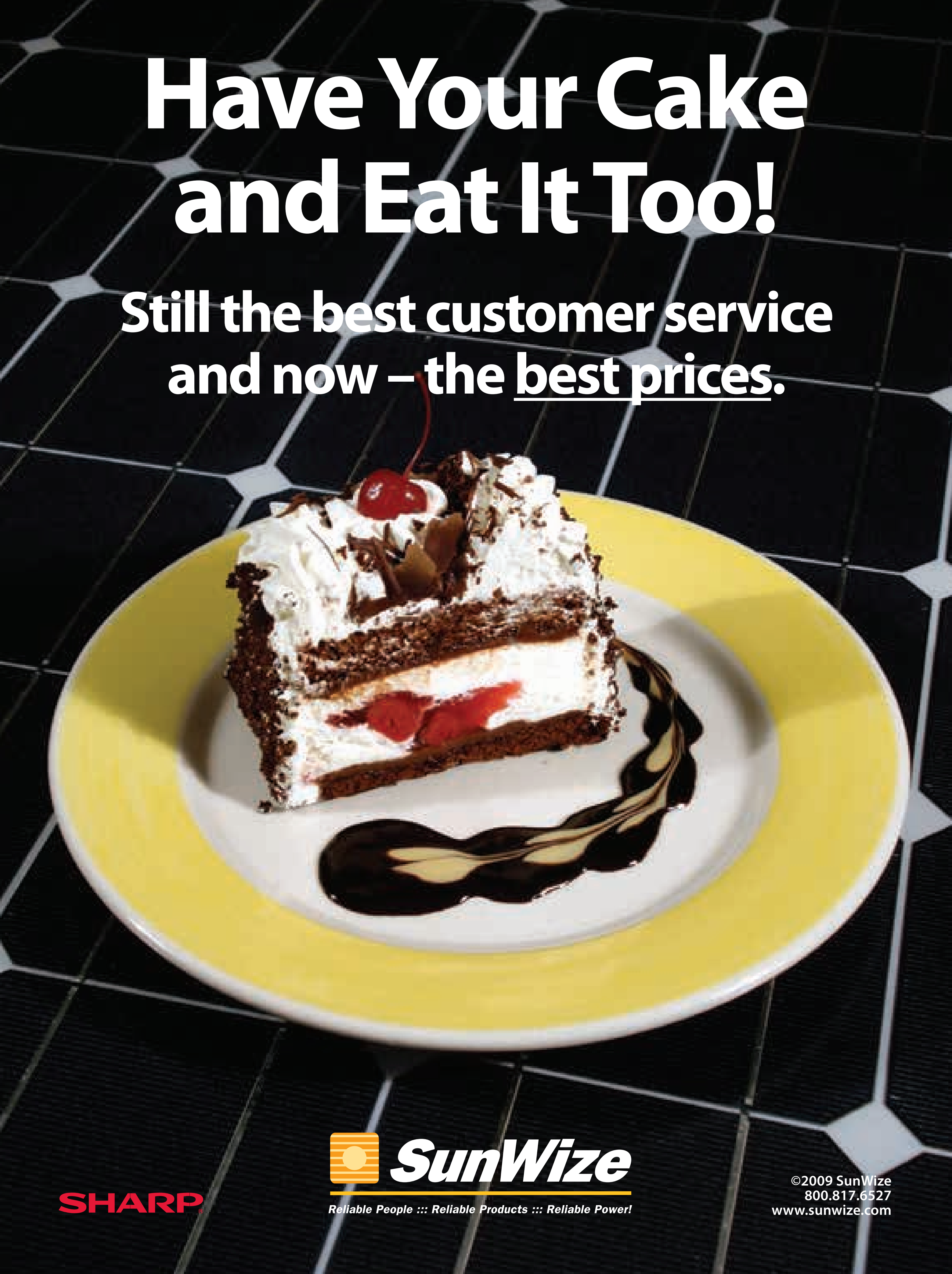
Access

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 instructs and develops curricula for Solar Energy International and lives in Prescott, Arizona. Dedicated to Charles Michael Mehalic.

Further Reading:

Solar Rating & Certification Corporation (SRCC) • www.solar-rating.org

Solar Radiation Data Manual "Redbook" • http://rredc.nrel.gov/solar/pubs/redbook/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Getting Smart

by Mark E. Hazen

History is quick to remind us how far we've come—and how far we still need to go. A look back at our country's most infamous brownouts and blackouts is all it takes to remind us how fragile our electrical power infrastructure really is.

It was a simple human error that caused one of our country's largest outages—"The Northeast Blackout of 1965," which happened on a frosty November evening. That little "oops"—an incorrectly set protective relay on one of the transmission lines—left at least 25 million people in New York, New England, and portions of Pennsylvania and New Jersey without power for 12 hours.

Then, there was the blackout of August 10, 1996, when extreme summer heat set off a failure in the Western Interconnection. Power was shut down for 10 hours in nine Western states and parts of Mexico—affecting some 4 million customers.

And who could forget the night the lights went out on August 14, 2003? The massive outage shut down more than 100 power plants and caused roughly $4 billion in financial losses, and left an estimated 10 million people in Canada and 40 million people in eight states—including New York City and the surrounding areas—without power for several hours. The root of the outage: Outdated technology and training.

That blackout in particular was a real eye-opener for utility companies. According to the U.S./Canada Power System Outage Task Force, the internal control-room procedures, protocols, and technologies did not adequately prepare system operators to prevent the 2003 emergency. In fact, throughout the afternoon, there were many clues that one of the control areas had lost its critical monitoring functionality and that its transmission system's reliability was becoming progressively more compromised. Clearly, the technologies and training in place then did not provide the visualization or decision support needed to manage that scenario.

Getting Smart

The lessons learned from blackouts have prompted power companies to revamp their infrastructures with new technologies in an effort to make the grid *smart*. A smart power system is one that is capable of being monitored and controlled remotely and electronically to preempt grid failures, and to conserve energy and resources. Key to this is distributing the available energy to prevent demand overloads that cause brownouts and blackouts.

Getting the power infrastructure from where we were to where we are today—and where we need to be in the near future—can be largely attributed to two very important pieces of legislation: the Energy Independence and Security Act (EISA) and the Emergency Economic Stabilization Act (EESA). Signed into law in December 2007, EISA's Title XIII served as a catalyst for the deployment of a smart power grid system and the advanced metering infrastructure (AMI) in the United States. Title XIII also set pro-smart-grid policies

Costs of a Grid Outage

Power interruptions and disturbances cost U.S. electricity consumers at least $79 billion per year.

A recent rolling blackout caused an estimated $75 million in losses in Silicon Valley (Santa Clara Valley area of California) alone.

When the Chicago Board of Trade lost power for an hour during the summer of 2000, trades worth $20 trillion could not be executed.

Courtesy www.elsterelectricity.com

The smart meter is a key component of a smart grid, bridging the utility network to household circuits.

in place to promote deployment across the nation. Some incentives were offered, such as a 20% deployment cost reimbursement from the government and a request from the federal government to the state governments that utilities be allowed to recover smart-grid investment costs from customers. However, EISA's Title XIII did not guarantee enough incentives to encourage utilities to build the "smart grid" in earnest.

Passed in October 2008, a part of EESA provides more tangible incentives to deploy the smart grid and provided the needed jolt to the industry to improve the infrastructure. "Deploy now or lose the incentives" is the way the law is written.

The phrase "smart grid" is used loosely and is often used to describe both an entire grid and just a portion of the grid, such as local and regional power companies that connect to the main grid.

Utility Overloads

Power companies will be able to more effectively monitor their portion of the grid for trouble spots and for impending overload conditions. When a major section of a power distribution system becomes threatened with overload, power companies can now redistribute energy by remote control to meet the demand. The time-consuming tasks of manually doing so are being phased out for a more automated approach that acts *before* crisis.

Just as in a home power system where increased current flow through a wire means increased voltage loss, when a portion of the grid or a local or regional distribution system experiences a heavy electrical load, significant energy is lost in the components of that system, including the energy sources, transformers, other equipment, and transmission lines. The line voltages drop, which decreases the voltage delivered to the customers. This causes appliances to run inefficiently, further increasing current draw. If some of the loading is not shed quickly enough, that portion of the grid can go under, meaning that overload prevention mechanisms simply cut off power or system components fail (lines, fuses, transformers), creating a blackout situation. During times of extreme load, power companies sometimes deliberately create rolling blackouts to prevent the failure of a larger section of the distribution network.

Unlike a conventional grid, a smart grid takes action to preempt overloads, which include immediate and stepped load shedding, or bringing additional generating capacity on line. These strategies are typically performed without the customer being aware.

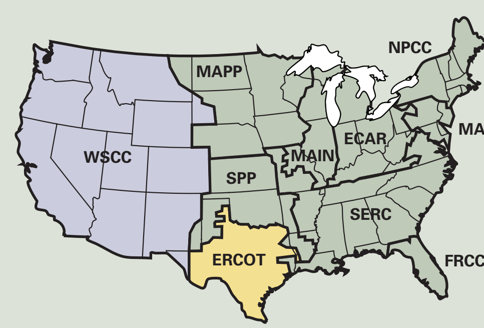
Electrical Power Infrastructure

When the term "power grid" is used, it is not just referring to a local electrical power system that feeds a city or county. Instead, it refers to an infrastructure that covers very large sections of the United States. Three main power grids serve vast areas of the country:

- **Western Interconnection**
- **Eastern Interconnection**
- **Texas Interconnection**

Each grid is referred to as an "interconnection" because the grid contains a main transmission system (trunk) to which hundreds of distribution systems (local and regional power companies and load centers) are connected. The continental United States has 10 North American Electric Reliability Corporation regions within the three main interconnections.

The trunk of each main grid enables "power pooling" from all the different sources of energy, including renewable ones. The pooled power is referred to as "system power," which is tapped and distributed throughout the grid region.



Western Interconnection **Eastern Interconnection**
Texas Interconnection

Features of a Smart Grid

- Enables active participation by consumers
- Accommodates all generation and storage
- Enables new products, services, and markets
- Anticipates and responds to system disturbances in a "self-correcting" manner
- Operates resiliently against physical and cyber attack, and natural disasters
- Provides power quality that meets a range of needs required by our new digital economy

For more info, see www.oe.energy.gov/smartgrid.htm

System-wide energy efficiency and conservation are greatly improved in a smart grid because the balance between loading and power generation can be controlled more easily and precisely. For example, instead of bringing on line more electrical generation capacity that uses more energy, the existing capacity can be made sufficient through discriminate load shedding, in which heavy-load appliances, such as air conditioning and water heating, are turned off for short periods of time. Load shedding can be distributed across a city or vast region in a rotational wave that prevents brownouts, while largely unaffecting customers.

Advanced Metering Infrastructure

The U.S. Department of Energy's National Energy Technology Laboratory has defined a massive upgrade to the electrical power system under the banner of the AMI—the convergence of many communications, automation, and data-processing technologies. The AMI provides information to consumers so that they can make wise energy-usage decisions, and allows power companies to make power-distribution decisions. Combined, these strategies are designed to reduce energy needs and conserve energy resources. The key benefits of AMI include:

For Consumers

- Gives consumers a real-time view of energy usage and cost
- Empowers consumers to make educated decisions about energy use
- Gives consumers more control over their electric bills

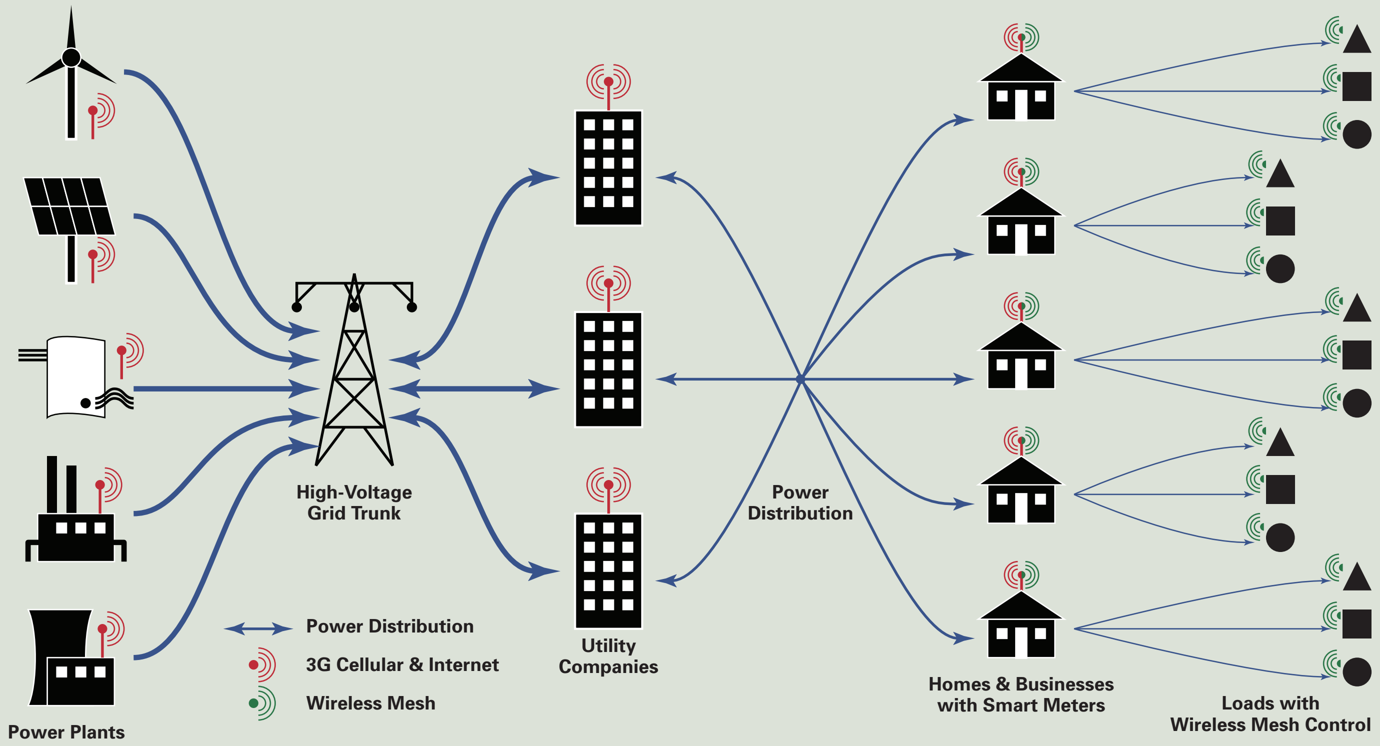
For Utilities

- Remote meter reading
- Real-time consumer usage data
- Remote load shedding inside customer premises
- Remote activation or deactivation of service

For Both Consumers & Utilities

- Real-time usage awareness and responses
- Fewer brownouts
- Fewer blackouts
- Cost savings from more efficient use of power infrastructure

Structure of the Smart Grid



Courtesy www.lsr.com

LS Research's RateSaver monitor displays energy use and related data in an easy-to-read, in-house display.

Deploying "smart meters," which have built-in technology that allows the power company to read the meters remotely and electronically, is key to the AMI initiative. With smart meters in place, power companies would no longer need traveling meter readers. Instead, smart meters would electronically transmit real-time customer usage data that power companies could use to make load-shedding decisions. Power companies could also activate service to a new customer or deactivate service to an outgoing or delinquent customer without having to go to the site.

Smart meters can also be made to serve as network access points for appliances in homes, businesses, and factories. This networking would enable outside monitoring and control, not only from power companies but also from major appliance service centers and security companies. Technology movers and shakers believe that these smart meters, serving as access points, could also provide Internet access, and be used by the power company or leased to service providers to bring in a secondary source of revenue.

Interfacing at Home

On the consumer side, electricity-use monitors show homeowners, apartment dwellers, and small businesses their energy use and cost in real time or show historical graphs. Monitors can be handheld and wireless so customers can monitor energy use from anywhere in the house. For residences and businesses that have their own grid-tied renewable energy systems, energy monitors could be designed to include system production data.

Aztech Associates Inc. is among the companies working with smart meter manufacturers to provide customer-interface devices. The company's in-home display shows the customer's total power consumption in kilowatt-hours and dollars; daily usage for the last 30 days; totals for individual time-of-use periods; instantaneous or average demand consumption; and hourly usage for the last 24 hours. LS Research's RateSaver monitor is capable of communicating with special portals within electric meters to display current energy consumption, utility rates, billing history, messages, alarms, temperature, and time. Google is even getting into the act with its PowerMeter. Its display can be added to a personal iGoogle Web page that shows how energy is being used in the home. Scheduled to be released later this year, customers will be able to access energy consumption information relayed from smart meters, so long as their power company has joined Google's PowerMeter program.

Making the Connection

Technologies developed over the past decade provide the means of information transfer to enable remote control and monitoring. Power companies often use a combination of these technologies to accomplish their goals, such as power line communications (PLC), second- and third-generation (2G, 3G) cellular communications technologies, and mesh network radio technologies.

Also known as broadband-over-power line, PLC uses a very broad spectrum of low-power digital radio signals to rapidly convey a large amount of information, even from multiple sources. This technology rides over the power grid without polluting the air with radio frequency interference. It operates bidirectionally, up and down the power lines, and is used for grid monitoring and control, smart meter communications, and Internet access. The presence of PLC signals on the power lines has no impact on the electrical energy those lines carry.

Another technology used to connect with smart meters is 2G or 3G broadband cellular, used by both smart meters and smart grid hardware.

Mesh network radio technology enables a wide range of household and industrial devices to automatically form a multilinked network. This hardware is very low power—often battery operated with sleep modes to conserve and extend battery life. It works bidirectionally for both reporting and control. All mesh devices pass data to and take commands from the smart meter.

Courtesy www.aztechinc.com

Aztech Associates' In-Home Display shows real-time power and hourly, daily, and monthly energy usage.

Who Pays for Smart Grid?

Despite all the operational, educational, and security advantages offered by a smart grid infrastructure, detractors point to its primary disadvantage: the costs are borne by us—the end users—since the government incentives to utilities come from our taxes. Plus, utilities will pass along the cost of new equipment, and the labor to install it, to us. We will also pay to maintain it. And, if that was not enough, as we become wiser energy managers, the utilities will likely sell less electricity, then charge us more to recover their loss of revenue. This will be especially true for publicly held utilities, since they have to show a healthy bottom line to the stockholders every quarter. Let's hope that the savings to utilities from eliminating their armies of meter readers and from preventing loss of equipment by eliminating overload scenarios will offset the reduction in energy sales due to conservation.

Smart Solutions

Part and parcel with smart grid/AMI is to create smart *loads* that can be monitored and controlled by the power company. Smart loads are appliances and machinery that can communicate through the smart meter with the power company. This enables the power company to monitor these internal loads and, when necessary, deactivate them temporarily to help prevent brownouts or blackouts.

Load: HVAC Systems

Smart Solution: Radio-Controlled Thermostats

Power companies know that brownouts can be avoided if they can remotely control heating, ventilation, and air conditioning (HVAC) systems throughout a region, since these systems pose major loads. During times of peak energy usage, such as hot summer afternoons and cold winter nights, a grid is often on the verge of overload. Instead of brownouts and rolling blackouts, these HVAC loads can be turned off for short periods of time, rotating throughout the region—without inconvenience or discomfort to the customers. The device that makes HVAC remote control possible is the radio-controlled thermostat (RCT) control, wirelessly linked to the smart meter.

Load: Electric Tank-Style Water Heater

Smart Solution: Radio-Controlled High-Power Control Box

Another home and business load that can be made "smart" is the electric tank-style water heater. This load can be turned off and then back on—without the customer even being aware—with a radio-controlled high-power control box, such as the Converge Digital Control Unit. Like the RCT, this interface device receives wireless signals via the smart meter, which then signals the utility. Other possible loads to be controlled include dishwashers, clothes washers, clothes dryers, and swimming-pool pumps.

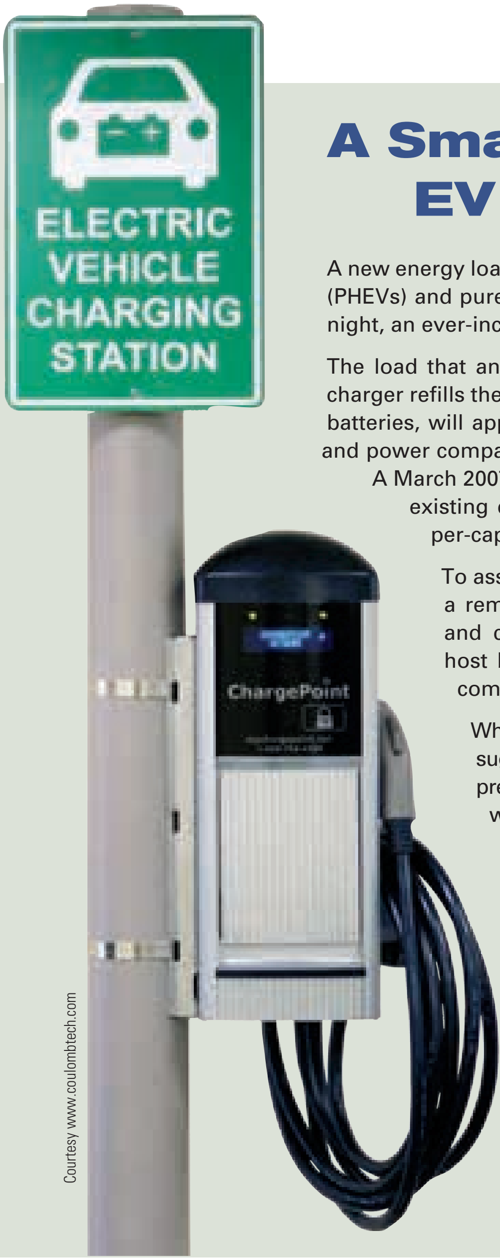
All of this new technology adds up to energy conservation and cost savings for power customers. In 2007, the Department of Energy's (DOE) Pacific Northwest National Laboratory launched a year-long energy-use study of 112 households. They found that advanced technologies enable consumers to be active participants in improving power grid efficiency and reliability, while saving money in the process. On average, consumers who participated in the project saved approximately 10% on their electricity bills.

"As demand for electricity continues to grow, smart grid technologies such as those demonstrated in the Olympic Peninsula [NW Washington state] area will play an important role in ensuring a continued delivery of safe and reliable power to all Americans," says Kevin Kolevar, DOE Assistant Secretary for Electricity Delivery and Energy Reliability. "The department remains committed to working with industry to research, develop, and deploy cutting-edge technologies to power our electric grid and help maintain robust economic growth."

Now, that's truly smart.

Energate's radio-controlled thermostat syncs to the smart meter, providing utilities with the option for remote load-control management, such as changing temperature settings or even idling the heating or air conditioning system for a short period of time to help avoid brownouts.

A Smart Grid Challenge: EV Charging Stations



Courtesy www.coulombtech.com

A new energy load is being added to the power grid—battery chargers for plug-in hybrid electric vehicles (PHEVs) and pure electric vehicles (EVs). While most chargers operate during the evening and into the night, an ever-increasing number will operate all day long at public charging stations.

The load that an EV charger presents to the grid varies widely, depending on the rate at which the charger refills the batteries in the vehicle. Typical chargers, used for nickel metal hydride and lithium ion batteries, will appear as significant loads, comparable to household water heaters or air conditioners, and power companies worry about their proliferation—and what it means for maintaining grid stability. A March 2007 report by the National Renewable Energy Laboratory (NREL) projected that, based on existing electricity demand and driving patterns, a 50% penetration of PHEVs would increase per-capita electricity demand by 5% to 10%.

To assist with this increased demand, charging station manufacturers are working to provide a remote, utility-controlled function for networked charging stations, allowing monitoring and control options for three levels of stakeholders: subscribers who use the stations; host businesses that have the stations on their property as a revenue source; and utility companies that wish to monitor and manage these loads.

While the 2007 NREL report acknowledges increasing electricity loads from PHEVs, it also suggests the possibility of PHEVs passing energy *onto* the grid. If made practical, this could help prevent auxiliary power sources from being brought on line during peak daytime periods. This would require the cooperation of the auto makers and the expertise of power engineers to interface PHEVs with synchronous inverters in parallel with the onboard chargers, as well as all of the control and communications intelligence.

Vehicle owners would have to understand and agree to this feature too, since only they would know what battery capacity is needed to accomplish the day's errands. Imagine returning to your vehicle only to find that the batteries have been drained, limiting your range of needed travel. In addition, there is the problem that vehicle owners might be charged for the period of time it took to have their batteries drained—and then have to pay again to restore the charge.

CoulombTech's ChargePoint electric-vehicle charging station is networked to provide many options for charging and payment—even accurate bidirectional energy flow.

Access

Mark Hazen (mail@evhelp.com) is an electronics engineer and the author of several electronics textbooks, plus a book about renewable energy. Mark created evhelp.com in 2007 to help others convert petroleum-based vehicles to electricity.

Smart Metering Devices:

Aztech Associates Inc. • www.aztechinc.com • In-home display

Energate • www.energate.ca • Radio-controlled thermostat

GE Energy • www.geenergy.com • Smart meters

Google • www.google.org/powermeter/ • PowerMeter

HomePlug Alliance • www.homeplug.org

LS Research • www.lsr.com/smartenergy/ • RateSaver monitor

Additional Resources:

National Energy Technology Lab, U.S. Department of Energy (DOE) • www.netl.doe.gov

Energy Independence and Security Act (EISA) of 2007 • www.govtrack.us/congress/bill.xpd?bill=h110-6

Emergency Economic Stabilization Act (EESA) of 2008 • www.financialstability.gov

"National Energy Technology Laboratory, A Systems View of the Modern Grid—Improved Interfaces and Decision Support," Appendix B5 • www.netl.doe.gov/moderngrid/docs/ASystemsViewoftheModernGrid_Final_v2_0.pdf

"National Energy Technology Laboratory, A Systems View of the Modern Grid—Advanced Components," Appendix B3 • www.netl.doe.gov/moderngrid/docs/Advanced%20Components_Final_v2_0.pdf

Olympic Peninsula Project • www.pnl.gov/news/release.asp?id=285

A Peek Inside PV

by Rebekah Hren

Copper, aluminum, and silver are conductors—that is, electricity easily flows through them. Conversely, plastic and porcelain are insulators that resist the flow of electricity. But semiconductors, such as the silicon used in the majority of PV cells, reside in the hazy middle ground between insulators and conductors. To enable semiconductors to easily donate or accept electrons, vital to their function in making electricity, they must be "doped"—adding impurities to the pure semiconductors' atomic lattices to make them more receptive to electron transfer.

In a PV cell that uses silicon as the semiconductor, the most common dopants are boron and phosphorous. Doping silicon with boron creates a material that can easily accept electrons (positive, p-type; the "absorber" layer) and doping silicon with phosphorous creates a material that can easily donate electrons (negative, n-type; the "emitter" layer). In a PV cell, the junction between p-type and n-type regions results in an electric field known as the cell's positive/negative (P/N) junction. Photons of sunlight energy give electrons the push they need to hop onto the conductors (traces or grid lines) and into the electrical flow of the circuit. The P/N junction helps keep the electrons from simply recombining with an electron hole within the cell itself. The "pull" of the electrons toward the positive layer is what keeps the flow going: Give them a less resistive pathway to follow and they'll gladly take it.

Most PV cells fall into one of two basic categories: crystalline silicon or thin-film. Crystalline silicon modules can be fashioned from either monocrystalline, multicrystalline, or ribbon silicon. Thin-film is a term encompassing a range of different technologies, including amorphous silicon, and a host of variations using other semiconductors like cadmium telluride or CIGS (copper indium gallium diselenide). Thin-film technology generates a lot of the current R&D chatter, but crystalline modules currently capture more than 80% of the marketplace.

Courtesy www.recgroup.com (2)

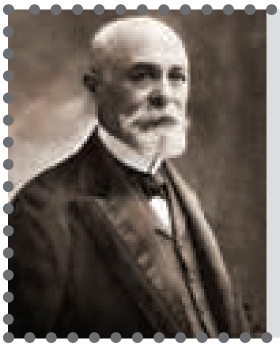
A single-crystal ingot, just drawn from the silicon-boron melt.

Crystalline Cell Manufacturing

Monocrystalline (also called monocrystal or single crystal) cells are the most efficient cells available on the market, although they are also the most energy intensive to manufacture. The highest performing, commercially available monocrystalline modules have the ability to convert about 20% of the energy in photons of sunlight into electrical current.

The monocrystalline manufacturing process starts with melting highly purified silicon along with a boron dopant. The purified silicon is the result of a chain of manufacturing that starts with quartz sand, processed into metallurgical-grade silicon, which is further refined into solar-grade silicon. The Czochralski process, one method for growing the crystals, pulls a seed crystal from the top of an approximately 2,500°F silicon/boron melt, and the crystal structure accretes and solidifies as the seed is slowly drawn from the melt. The result is a boule—a long, cylindrical crystal. The boule (usually 5 or 6 inches in diameter) is sawn into thin, round wafers that become the cell's building block—the p-type layer (as the positive dopant, boron, has been previously added to the purified silicon). The n-type layer is created after wafer sawing, usually by coating the wafer with phosphorous and using heat to allow the phosphorous atoms to partially diffuse into the silicon. Monocrystalline cells all start out life round in shape, but are often squared off to maximize efficient cell coverage in modules. The downsides of monocrystalline cell manufacturing are the very high heat needed, the slow drawing-out process, and the waste from the sawing process, which can account for up to a 50% loss of the original boule.

Monocrystalline boules created using the Czochralski process.



The Photovoltaic Effect

Discovered in 1839 by French physicist Alexandre-Edmund Becquerel, the photovoltaic effect describes the way in which PV cells create electricity from the energy residing in photons of sunlight. When sunlight hits a PV cell, the cell absorbs some of the photons and the photons' energy is transferred to an electron in the semiconductor material. With the energy from the photon, the electron can escape its usual position in the semiconductor atom to become part of the current in an electrical circuit.

Multicrystalline Silicon Cells. The process for creating multi- or polycrystalline cells takes a slightly different, less energy intensive (and less expensive) approach, although the cells themselves are about 4% less efficient than monocrystalline cells.

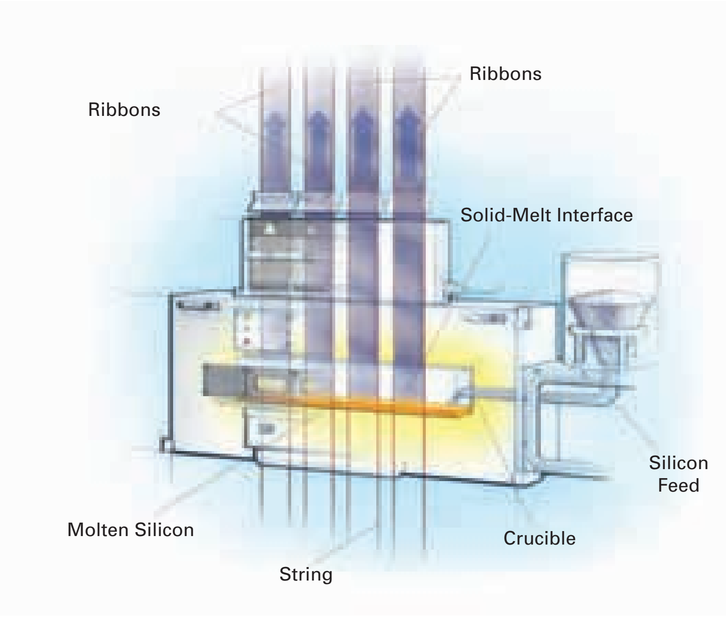
Purified molten silicon and boron are cast in a large block, which cools into an ingot. Instead of creating a monocrystal, the resulting structure has randomly oriented crystalline regions, which causes the lower efficiency and the cell's random-shard appearance. To create the cells, the ingot is sawn into square wafers, with the n-layer applied the same way as for monocrystals.

Ribbon Silicon Cells. Another type of polycrystalline cell is produced using string-ribbon technology. In this process, a thin strip of p-type crystalline silicon is slowly drawn up out of the silicon melt between parallel strings. The molten silicon is drawn up with surface tension, much like a soap bubble. This thin strip of silicon cools and then solidifies, and a laser cuts the ribbon into individual cell lengths. This technology is less expensive than creating standard polycrystalline cells because it eliminates the sawing process (and related waste) and the PV ribbon is thinner than standard sawn cells, which also saves silicon.

Courtesy www.recgroup.com

A poured multicrystalline ingot, ready to be sawn into cell-sized wafers.

Ribbons are produced when strings are drawn through molten silicon, and the silicon stretches thinly across, like soap on a bubble wand. Bottom: Cut lengths of ribbon cell material, awaiting further manufacturing.



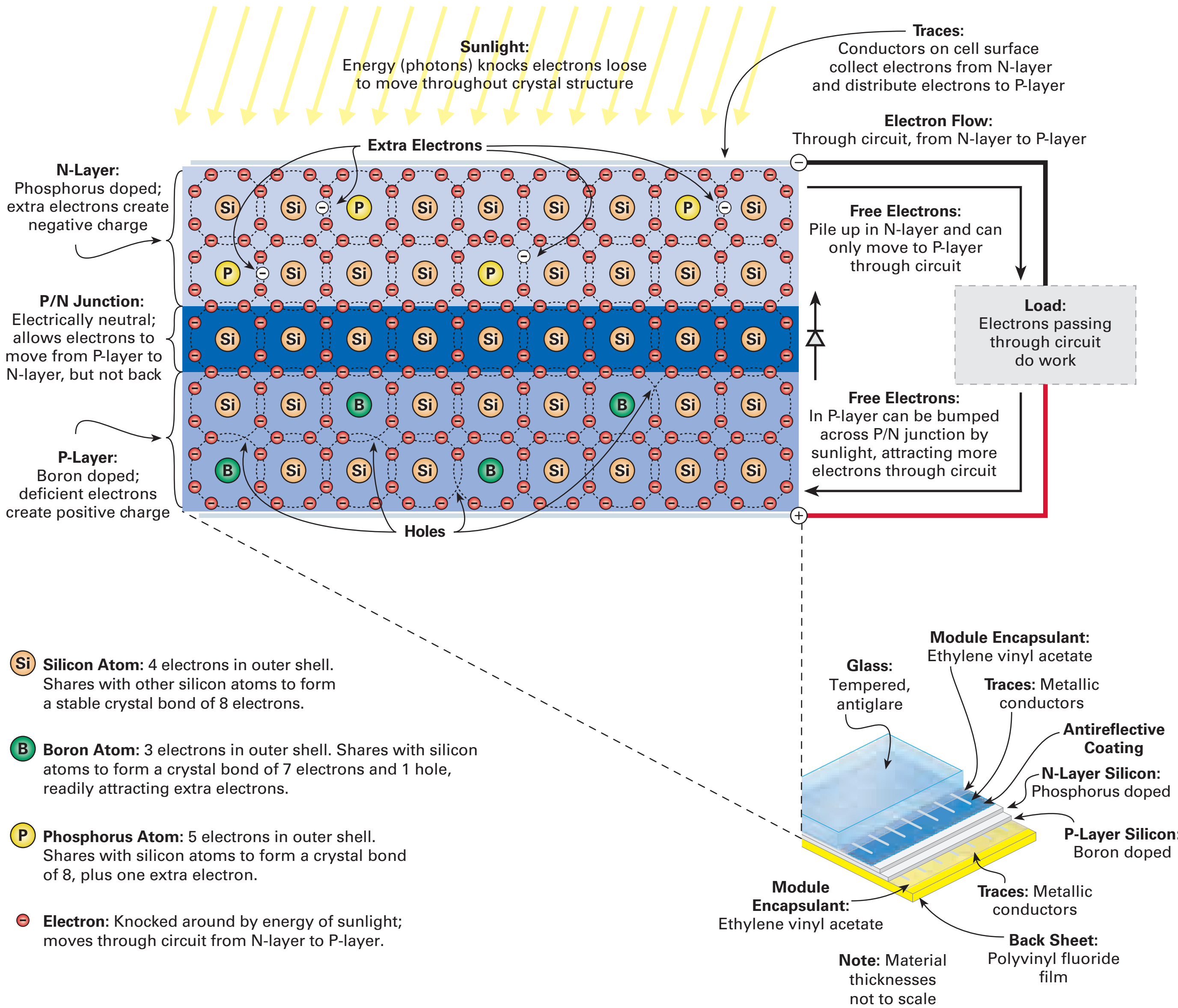
Courtesy www.evergreensolar.com (2)

The Scoop on the Silicon Supply

The price of purified silicon (referred to as polysilicon or solar-grade silicon) is estimated to account for approximately 40% of the price of a crystalline PV module. With such a high dependence on one input, the supply/demand balance for polysilicon looms over the PV industry—with shortage-driven price increases, manufacturing constraints, volatile silicon markets, and plenty of grist for the PV rumor mill. PV competes with the computer chip industry for available polysilicon, and polysilicon prices skyrocketed from 2004 through 2008—from less than $50 per kilogram to more than $400 per kilogram—as producers struggled to keep up with demand from the exploding PV industry.

As prices increased, solar-grade silicon manufacturers worked furiously to add capacity. Today, polysilicon market prices are dropping as a result of supply increases and market turmoil. Production for 2009 may reach 80,000 metric tons, up from 36,000 metric tons in 2005. Reports indicate that close to 60 new companies plan to enter the supply stream in 2009, whereas in 2008 more than 90% of polysilicon was supplied by just seven companies. As the global economy unwinds, many are wondering if the roller-coaster ride will lurch from overdemand to oversupply. But as polysilicon prices decrease, we can expect module prices to decline as well, which sounds like good news to us!

Anatomy of a PV Cell



Multicrystalline cells, with electrical traces added, are ready to be assembled into PV modules.

Courtesy www.recgroup.com

Crystalline Module Manufacturing

Because the power output of an individual cell is relatively small (typically a few watts), multiple PV cells are electrically connected in series and parallel to make a module that's more usefully sized. Whether mono-, multicrystalline, or ribbon silicon, the process leading from cell to finished module is similar.

Cells are overlaid with a conductive grid to carry the electrical current. The grid looks much like a transport network, with side roads to carry electrons branching out over the cells, and main highways connecting the cells in series and parallel configurations. Traces are most frequently made of silver that's screen-printed onto the cell. As the top grid can shadow the cell from some sunlight, efficiency can be gained by keeping the traces thin or laying the grid in laser-

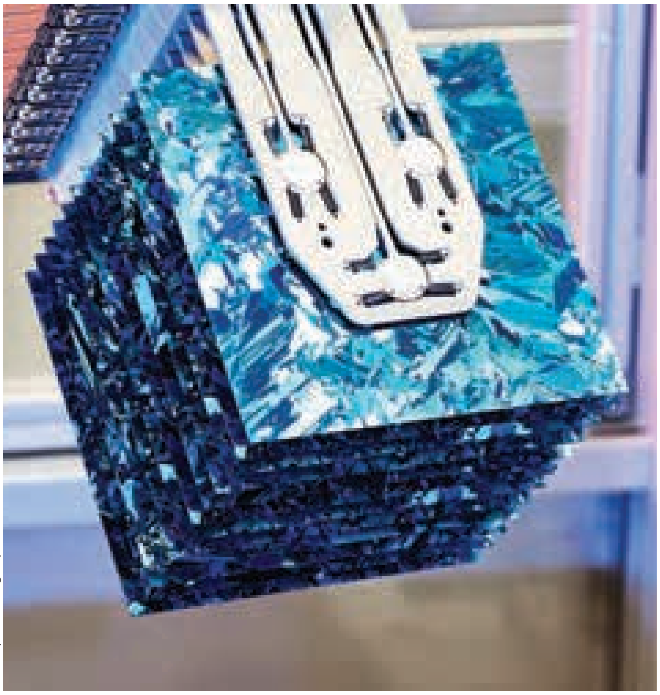
etched grooves—or even moving the grid entirely to the back of the cell, the process used in SunPower Corp.'s cell design.

Next, an antireflective coating is applied to the top of the cells. Reflection is the enemy of the solar cell, as the more light that is reflected (rather than absorbed), the lower energy production will be. Various means are used to conquer reflectivity as the module is fabricated. Silicon starts out as a shiny-gray, highly reflective material. The gray color is modified by changing the thickness and refractive index of the antireflective coating material (typically silicon monoxide), so the cell appears blue or black. Multiple layers of antireflective coating can reduce reflectivity to less than 4%. An additional antireflective technology is acid etching, which creates a textured cell-top surface, like miniature valleys and mountains, which can help capture rays of light.

After the antireflection coatings are dry, the final step in crystalline module production is encapsulation for weatherproofing. Tempered glass is commonly used as a clear top protector. Tedlar, a polyvinyl fluoride film, is frequently used as the module backing, although glass can also serve this purpose. Ethylene vinyl acetate (EVA) laminate is used to seal (or glue) the front and back of the cells to the glass and Tedlar. Modules are enclosed in a mounting-ready frame, usually aluminum, that is riveted or screwed together. Finally, the positive and negative electrical connections are installed on the back of the module.

Above: A robot with pneumatic suction prepares to place a series string of cells.

Below: Delicate silicon wafers are best handled by robotics.



Courtesy www.recgroup.com (2)

Focus On: The Environment

As Chinese module production has ramped up in the past two years, clean manufacturing techniques are struggling to keep up. *The Washington Post* reported in March 2008 that a Chinese plant manufacturing purified polysilicon—the major crystalline PV module input—improperly disposed of tons of silicon tetrachloride, a toxic by-product (4 tons of silicon tetrachloride are produced for each ton of polysilicon). The toxic waste was reportedly being dumped on fields in villages neighboring the plant, making the soil infertile and potentially creating clouds of poisonous hydrogen chloride gas. There is a recognized, safe, nonhazardous process for recycling this by-product, but the high-heat recycling process nearly doubles per-ton production costs. Doubtless, this particular manufacturer was trying to save time and money by avoiding recycling, with a high social and environmental cost.

Concerns have also been raised about the newer generation of thin-film cells manufactured with cadmium or indium. Cadmium is a naturally occurring metal, and it is also a by-product of zinc refining. However, it can be extremely toxic to humans. Short-term exposure causes vomiting and fever, while long-term effects include kidney and lung damage. PV manufacturers claim that the cadmium used in PV modules is entirely encapsulated, so will pose no health dangers to consumers, and can be recycled at the end of the modules' life spans. However, considering the lax regulatory environment in some countries, the health of the industrial workers and the communities surrounding the manufacturing plants must also be considered. Indium, like cadmium, is another thin-film input that comes mainly from zinc ore. Indium has received some publicity due to a perceived danger of supply shortages, and plants in China (where 40% of the world supply of indium comes from) have been shut down in the past due to pollution concerns.

Caveat Emptor

While there is no doubt that PV modules can provide decades of nonpolluting renewable energy, questions about the environmental impact of manufacturing PV modules should go hand in hand with questions about the return on energy invested in modules. Modules that rely on less energy-intensive manufacturing processes and use less raw material offer lower embodied energy and a shorter payback path to clean, free energy.

However, awareness of environmental *shortcuts* that make manufacturing less energy-intensive, but create additional pollution (such as the improper recycling of by-products) is also important. One proposed solution is an organization modeled along the lines of the Forest Stewardship Council, which, through a chain of custody, certifies wood as coming from properly managed forests. A "sustainable PV" stamp could include calculations of embodied energy, and assure consumers that the manufacturing supply chain was well regulated.

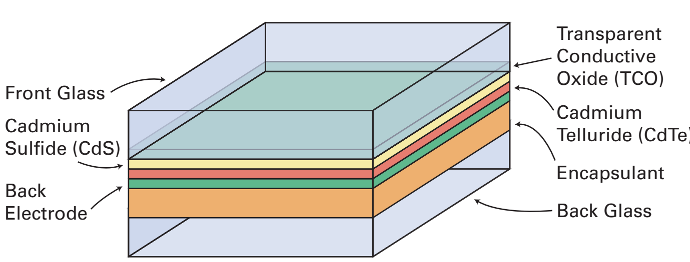
While addressing these issues is important, it shouldn't overshadow the overall positive effect of using PV (or other renewably generated) electricity. Electricity derived from coal and natural gas will never outweigh the energy and continual resources required to produce it. Additionally, there are the associated environmental impacts of global warming and air, water, and soil pollution due to the emissions from fossil-fuel based power plants, and the environmental impacts of mining, drilling, and transporting coal and natural gas. Unlike conventional energy sources, PV systems produce clean electricity for decades after achieving their energy payback in three or fewer years—this is truly the magic of PV technology.

Thin-Film Cells & Module Manufacturing

"Thin-film" applies to a very broad range of PV module manufacturing techniques. Basically any PV module for which a crystal has not been grown can be classified as thin-film. Instead of a seeded or cast crystalline structure, the semiconductor is deposited (sprayed, through vapor deposition, or even printed) as a film on various substrates. Without a fragile crystalline structure to protect, thin-film applications can be applied to materials like glass, flexible plastic, or stainless steel and other metals.

Materials such as copper indium gallium diselenide (CIGS) or cadmium telluride (CdTe) can be used as the semiconductor material. Silicon-based thin-film products

Anatomy of a Thin-Film PV Cell



PV Evolution?

The search for higher efficiencies for silicon-based thin-film is focused on nanocrystalline technology (also called microcrystalline, because of its small crystalline grains), which can be combined with amorphous silicon to create what are known as micromorphous cells; and black silicon, which has low reflectivity. On another front, the dye-sensitized solar cell (DSSC, or Grätzel cell, a type of "organic" solar cell) suggests the possibility of reasonable efficiencies at a low production cost. The DSSC building block is photosensitive nanoparticle dye, which releases electrons that diffuse across an electrolyte to create electric current. Due to the small size of the nanoparticles, the modules can be semitransparent. Potential roadblocks include dye degradation when exposed to UV light and reported cessation of power production at low temperatures if the electrolyte freezes. An interesting facet of this technology is the ability to use colored dyes, which allows printing of solar logos, designs, or even artwork that creates clean energy!

One of the biggest attention-grabbing thin-film companies, Nanosolar, remains focused on large-scale "municipal power plant" installations, not residential roofs. Nanosolar makes CIGS thin-film PV modules, but with a proprietary (and carefully guarded) process: CIGS nanoparticle ink is deposited (through a "printing" procedure) on thin sheets of flexible metal foil, which acts as the conductive bottom electrode. The sheets are cut to size and encased in glass. Nanosolar claims that the proprietary CIGS nanoparticle ink creates just the right mix of the four element nanoparticles (cadmium, indium, gallium, and selenium) and retains that mixture when the ink is printed. Because of claims of up to 14.6% cell conversion efficiency (verified by the National Renewable Energy Laboratory), and also the claim to have the lowest production-cost panel on the market (reportedly less than $1 per watt), Nanosolar has become a media darling. But don't get your hopes up that you can have the first Nanosolar panels in your neighborhood: Production is sold out for years in advance to large-scale installations, mostly in Europe.

are most commonly called amorphous silicon. Amorphous silicon manufacturing techniques use silane gas, instead of highly processed polysilicon. Plasma-enhanced chemical vapor deposition is a common method used for amorphous silicon manufacture—a process in which silane gas can be deposited on the chosen substrate within a surprisingly compact laboratory machine.

Thin-film PV cells generally measure only a few micrometers thick, and are comprised of thin layers of semiconductors and dopants, where each layer is subsequently "sprayed" or "printed" on top of the previous layer. Along with the deposition process, a transparent, conductive oxide is overlaid on the entire module surface to serve as the conductive path. In some cases, the first layer applied on the encapsulant will be the conductive path,

PV Technology Comparison

Technology	Typical Conversion Efficiency	Lowest Cost Per Watt
Monocrystalline	15–20%	$3.48
Multicrystalline	12–15%	3.29
Thin-film	4–14%	2.47

Source: www.solarbuzz.com

depending on manufacturing technique. Thin-film modules are made monolithically, where all the layers are deposited in a sheet, creating one large PV cell. Later in the process, the cell is divided up into smaller cells by laser etching.

There are several cost savings realized with thin-film: manufacturing is a faster, lower-temperature process that eliminates the need for growing crystals and does not depend on highly purified silicon; and much less semiconductor material is used. But thin-film currently has much lower energy conversion efficiencies than crystalline technology, ranging from about 4% to 14%. In addition, amorphous silicon thin-film modules undergo significant power decreases after the first few weeks of deployment (between 15% and 35%). This is something that installers need to be aware of so that they can install wiring and components able to handle the initial higher output, yet base energy production predictions on the lower stabilized output.

On the Horizon

PV module manufacturing is following a trajectory similar to the semiconductor device industry, which ramped up in the 1960s and is still viewed as a fleet-footed industry. Much of the equipment used by PV manufacturers is similar to, if not a repurposed version of, existing semiconductor device equipment. The major costs involved in PV manufacturing are much like all manufacturing, including personnel, operations and facilities, equipment, utilities, and material inputs. But what makes the PV industry special is the astonishing growth rate: According to Solarbuzz.com, PV market installations reached 5.95 gigawatts in 2008, which represents a 110% growth over 2007. Whatever shape PV takes in the future, we can rest assured that the quest for higher efficiency modules combined with lower manufacturing costs will continue unabated.

Access

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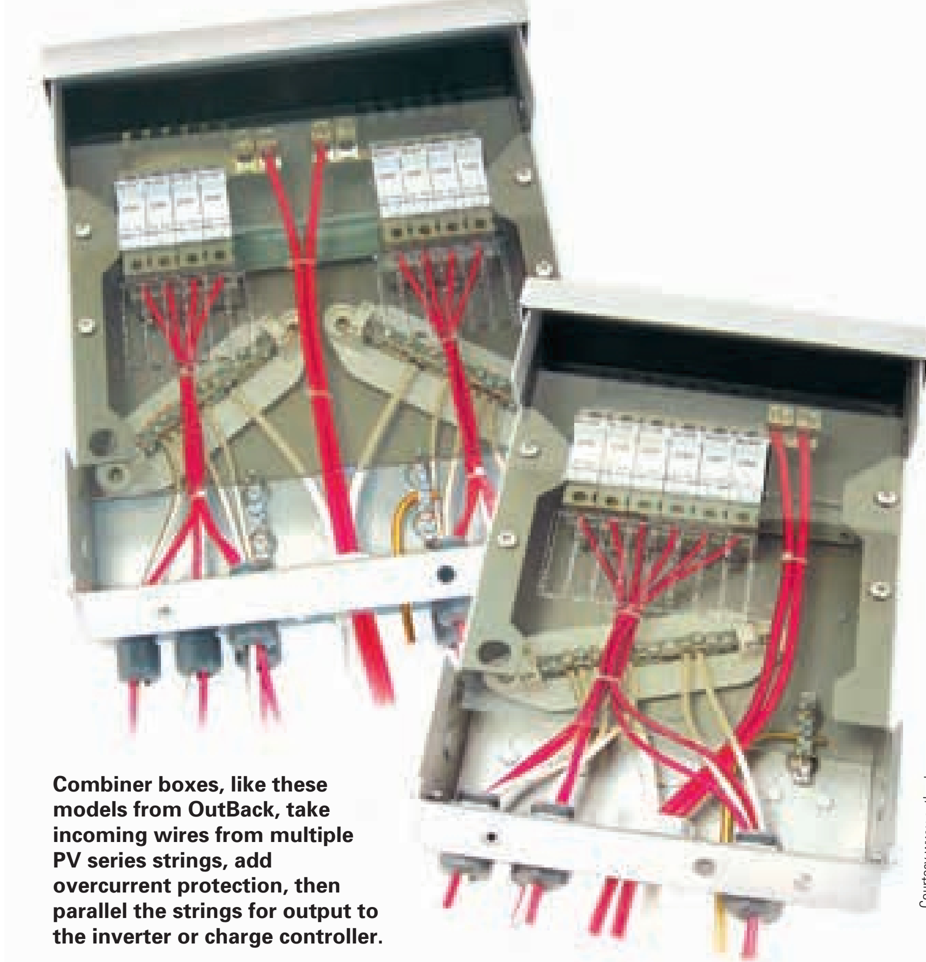
PV Combiner Box Buyer's Guide

by Lena Wilensky

Combiner boxes are an integral part of many PV installations, serving as the "meeting place" where the wiring from array series strings come together in parallel connections.



Combiner boxes, like these models from OutBack, take incoming wires from multiple PV series strings, add overcurrent protection, then parallel the strings for output to the inverter or charge controller.

Courtesy www.outbackpowersystems.com

In all but the smallest PV systems, modules are wired together in series strings, where the positive leads of one module are connected to the negative leads of the next module. This results in cumulative voltage output, with current (amps) staying the same. The box where the output wires from multiple series strings are joined is the combiner box. Rated for outdoor use, it contains overcurrent protection devices (OCPDs) and the necessary bus bars and terminals for combining the inputs.

Many installers used to build their own combiner boxes for lack of availability, but now there are plenty of commercial products to choose from. Some manufacturers will custom-build combiner boxes to meet specific system requirements. Article 690.4(D) of the *2008 National Electrical Code* includes PV combiner boxes as equipment that must be identified for appropriate use and listed by an approved testing laboratory, such as Underwriters Laboratories (UL) or ETL labs. The days of "homemade" combiner boxes are quickly disappearing.

If you live in a locale where the *2008 NEC* is in effect, your electrical inspector will likely *require* one that is listed by an approved testing laboratory, as mandated by *NEC* Article 690.4(D).

Grid-Direct Systems

Every inverter and charge controller, whether in a utility-interactive or stand-alone system, has a DC input voltage window that must be adhered to. In batteryless grid-tied systems, inverters require relatively high DC input voltages, from 150 to 600 V (typically 7 to 13 modules wired in series).

Small grid-tied PV systems (less than 5 kW) often have only one or two series strings of modules. With few wires and no need for series fusing, a PV combiner box isn't necessary: Strings can be terminated directly in the inverter (see the "Why Series Fusing?" sidebar). However, larger residential systems (between 5 and 10 kW) often have three or more series strings, and will likely need fusing. Systems above 5 kW also typically have more wires to deal with, which can mean more installation time, larger conduit, and increased wire costs if *all* the wires need to be run to the inverter. A combiner box offers a place to house series fuses and parallel the series string inputs, reducing the number of array output wires needed to run to the inverter location.

Some grid-direct inverter manufacturers include series fusing within the inverter or its attached disconnect box, which

AMtec Solar's Prominence 6R controller offers fuse overcurrent protection for up to six series strings' input.

may eliminate the need for a separate combiner box. However, using a PV combiner box located close to the PV array gives you easy access to the wires for each series string. This can be handy for troubleshooting a malfunctioning PV array without having to run back and forth to the inverter area.

Grid-Direct Systems

Let's look at a grid-tied PV system with three series strings of 10 modules each. Three series strings mean three sets of wires—three positives and three negatives, with one ground wire—coming from our PV array. Even though some inverters have multiple DC inputs, they may not include series fusing capability. Then it's likely that series fusing will be needed. Even if all the necessary input fusing is provided within the inverter, a combiner can be used to eliminate running seven wires all the way from the PV array to the inverter—possibly reducing wiring costs and installation time.

Why Series Fusing?

Modules are built to withstand only a small amount of current—generally about 15 A—and can fail catastrophically if they are exposed to higher current (for example, via backfed amps from paralleled modules or strings of modules). Backfeeding from other strings is most likely to occur if one series string of modules stops producing power due to a damaged circuit or cell.

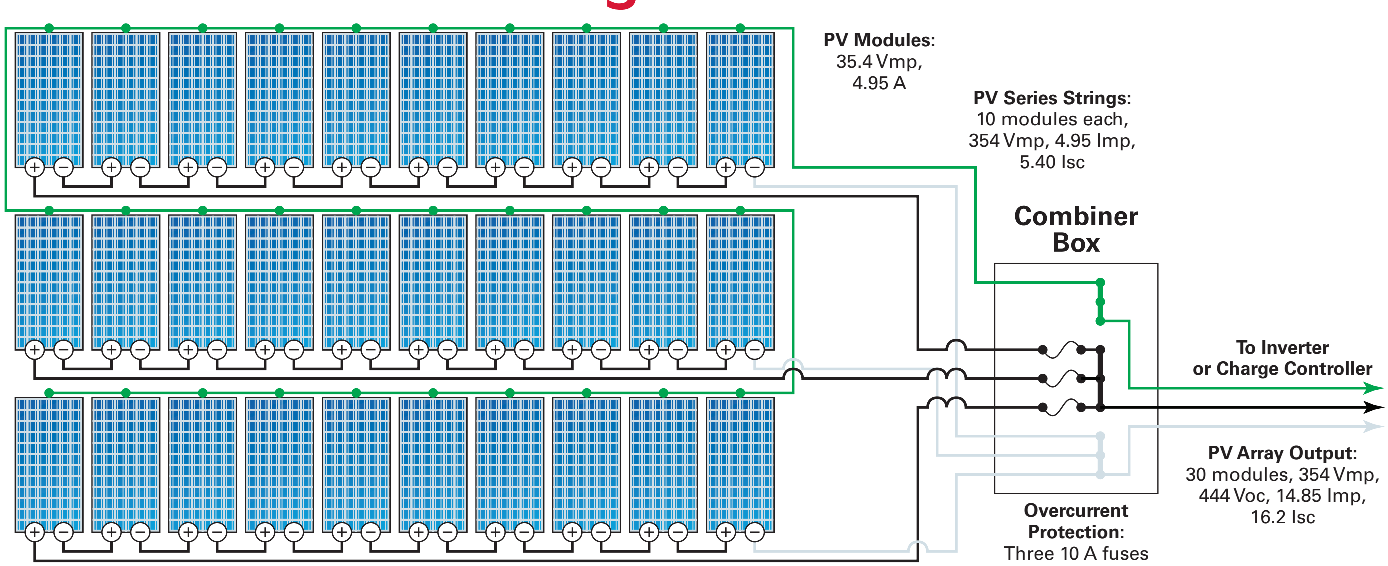
Because PV modules are current-limited, there are some cases where series fusing may not be needed. For a single-string array, there is nothing that can backfeed into it, and thus no series string fuse is needed. In the case of two series strings, if one string stops producing power and the other string backfeeds through it, still no fuse is needed—each module is designed to handle the current of the remaining string. Some PV systems can even use three strings or more with no series fuses, due to an exception in *NEC* Article 690.9(A), Exception b, for situations when the series fuse rating is substantially higher than the short-circuit current (Isc) of the modules. Every PV module has a series-fuse rating included in its specifications, per UL-listing requirements.

Other than the exceptions above, to avoid the catastrophic scenario of unwanted current flow, overcurrent protection devices (circuit breakers or fuses) are added to the PV source-circuit conductors.

Battery-Based Systems

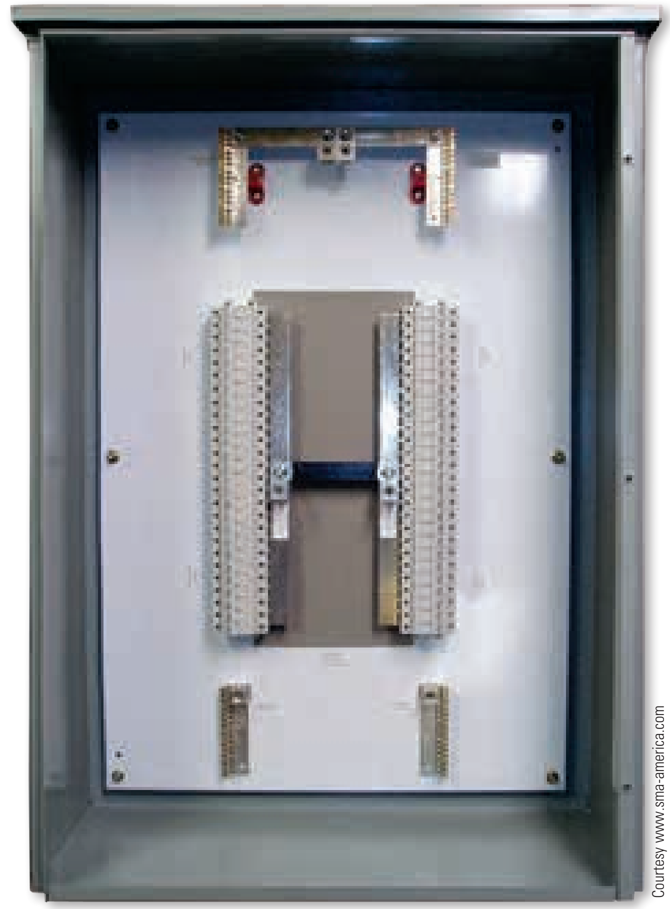
Battery-based systems (off-grid and grid-tied with battery backup) have lower DC system voltages than grid-direct systems (although higher-voltage charge controllers are expected to hit the market soon). Historically, this voltage ranged from 12 to 48 V nominal to match battery voltages, but step-up/down MPPT

Combiner Box Wiring



Courtesy www.solarbos.com

This SolarBOS combiner accepts up to four series-string inputs in a compact package.



Courtesy www.sma-america.com

The SMA SCCB-52 is the largest combiner listed in this article, accepting 52 separate inputs.

charge controllers now allow arrays with higher voltages to charge lower-voltage battery banks, making higher array voltages more common (with open-circuit voltages usually limited to 150 V). Even with the use of step-up/down charge controllers, typically only one to six modules are placed in a series string, which means combining more strings in parallel to get the desired power output, which necessitates a combiner box.

In addition, charge controllers typically have only a single set of input wire terminals. For off-grid systems, it's often wise to have enough room in the combiner for adding more strings of modules in the future. If the combiner and its output wires are sized accordingly, and the charge controller has been sized to handle the additional amperage, wiring more PV modules into the system can be as easy as terminating the new wires in the PV combiner box.

Safety Features

In the past, most PV combiner boxes simply had removable lids that covered the OCPDs and wiring inside. Although this configuration worked, with the box opened it didn't protect users troubleshooting a blown fuse or tripped breaker. A misplaced screwdriver or finger could suddenly become an unwelcome conductor for 500 volts!

A "dead front" is a cover that allows access to the fuses and breakers, while shielding the operator from live wires and terminals. This cover may be a tinted or opaque polycarbonate plate (sometimes treated with flame retardant), which covers the entire opening except for the OCPDs (on OutBack and MidNite models), or simply small, clear plastic sheets that keep fingers and tools from accidentally touching live components (on AMtec models). Dead fronts are required on AC breaker panels, and we may soon see the requirement extended to DC combiners as well.

Many homeowners (and inspectors) require that all disconnects be lockable to keep out unwanted guests like vandals or curious children. It's a good idea to be able to use a small padlock or something similar on the combiner box cover to restrict access.

The dead front on this MidNite combiner protects handlers from live wire terminals. The same unit is shown open, at right.

The Specs

The "Specifications" table on the following pages summarizes the main features common to most PV combiner boxes. We included products that are currently available to consumers in the U.S. market.

Maximum DC Voltage (Max. VDC)

Each combiner is rated to accommodate up to a specific DC voltage. Residential grid-direct systems generally accommodate DC voltages up to 600 V, while most battery-based PV system DC voltages are lower, typically maxing out at 150 V.

Maximum Number of PV Input Circuits

Combiner boxes come with a certain number of terminals where PV source wires can be attached and an equivalent number of OCPD spaces. Residential PV combiners usually need no more than 12 inputs. Grid-direct systems require fewer inputs, while battery-based systems can require more. Additionally, battery-based PV systems commonly have multiple charge controllers, and each may have its own combiner box.

Maximum OCPD Rating

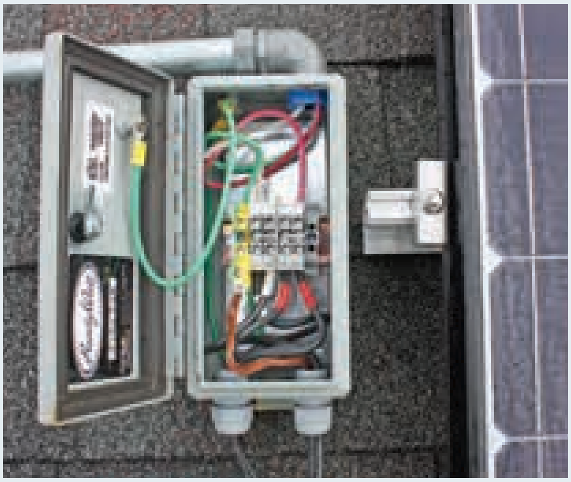
The overcurrent protection devices (OCPDs—fuses or circuit breakers) chosen for the particular combiner cannot exceed this rating. PV module nameplates list the required series fuse rating.

MidNite Solar's MNPV12-250 is the first of a new breed of combiner boxes, with 300 VDC breakers in anticipation of higher-voltage MPPT controllers for battery-based PV systems.

Courtesy www.midnitesolar.com (2)

Transition Boxes

Another specialty junction box, found especially in roof-mounted PV systems, is called a transition or pass-thru box. Some residential grid-direct systems that employ two or even three series strings may not require series fusing. This is determined by specific module and inverter operating characteristics. In these cases, installers often use pass-thru boxes to transition from the more bulky and expensive USE-2 or PV wires (rated for outdoor use without conduit) that come from the modules, to THWN-2 wire (less expensive and less bulky, but needs to be run in conduit). Most of these transition boxes are low-profile, and intended to mount directly on the roof or on an extended end of a mounting rail. They often have wire terminations already built into the box, or you may need to use your own multi-tap connector. Transition boxes provide a great spot for troubleshooting and make the transition from one wire type to another easier. These boxes must be able to endure the potentially harsh conditions found on rooftops, and should stand up to the 25-year design life of a PV system. Generally metal or fiberglass is preferred over plastic, which will degrade under long-term exposure to strong UV rays.



Courtesy Benjamin Root

OCPD Type

Combiner boxes come with OCPDs, usually either a form of "touch-safe" fuse holders or DC-rated circuit breakers. Since grid-tied systems can generate up to 600 VDC—well above the 150 VDC rating of most available circuit breakers—fuses are almost always necessary. OCPDs found in combiner boxes are generally limited to battery-based systems. Most fuse holders are not rated to be opened under load, so they cannot be used as a DC disconnect. This is an especially important consideration for high-voltage DC systems: Trying to open a fuse holder *without* first opening the circuit (which can be safely done via the main DC disconnect), will likely draw an electrical arc that can cause a fire and burn and/or shock you.

(continued on page 74)

PV Array Combiner Box Specifications

Manufacturer	Model	Max. VDC	PV Source Circuits: Max. Input Circuits	Max. OCPD Rating (A)[1]	OCPD Type	Wire Range (AWG)
AMtec Solar www.amtecsolar.com	Prominence 6R	600	6	15	Fuse	18–8
	Prominence 6	600	6	20	Fuse	18–8
	Prominence 8M	600	8	20	Fuse	18–8
	Prominence 12	600	12	15	Fuse	18–8
	Prominence 16M	600	16	20	Fuse	18–8
	Prominence 24	600	24	15	Fuse	18–8
	Prominence 36	600	36	15	Fuse	18–8
Blue Oak www.blueoakpvproducts.com	HCB4	600	4	15	Fuse	14–6
	HCB8	600	8	15	Fuse	14–6
	HCB12	600	12	15	Fuse	14–6
groSolar www.grosolar.com	ReadyWatt 10x10 LV	150	6	20	CB	14-6
	ReadyWatt 10x10 HV	600	5	20	Fuse	18-8
	ReadyWatt 12x12 LV	150	16	20	CB	14-6
	ReadyWatt 12x12 HV	600	8	20	Fuse	18-8
MidNite Solar www.midnitesolar.com	MNPV3	150	3	30	CB	14–6
	MNPV3	600	3	30	Fuse	14–6
	MNPV6	150	6	30	CB	14–6
	MNPV6	600	4	30	Fuse	14–6
	MNPV12	150	12	30	CB	14–6
	MNPV12	600	10	30	Fuse	14–6
	MNPV12-250	300	6	20	CB 300 V	14–6
	MNPV16	600	16	30	Fuse	14–6
	MNPV16-250	300	12	20	CB 300 V	14–6
OutBack Power Systems www.outbackpower.com	FWPV-8	150	8	60	CB	14–6
	FWPV-8	600	6	30	Fuse	14–10
	FWPV-12	150	12	60	CB	14–6
	FWPV-12	600	8	30	Fuse	14–10
SMA America www.sma-america.com	SCCB-6	600	6	15	Fuse	10–6
	SCCB-10 – SCCB-16	600	10–16	20	Fuse	10–6
	SCCB-18 – SCCB-28	600	18–28	15	Fuse	10–6
	SCCB-52	600	52	8	Fuse	10–6
SolarBOS www.solarbos.com	CS-4 – CS-12	600	4–12	30	Fuse	16–4
	CS-12/12	600	4–12 (x2)	30	Fuse	16–4
	CSK-4 – CSK-12	1,000	4–12	30	Fuse	16–4
	CD-4 – CD-12	600	4–12	30	Fuse	16–4
	CD-14 – CD-24	600	14–24	30	Fuse	16–4
	CDK-14 – CDK-24	1,000	14–24	30	Fuse	16–4
	CCS-2 – CCS-8	600	2–8	30	Fuse	16–4
	C225-12[8]	600	12	30	Fuse	16–4
Solectria Renewables www.solren.com	STRCOM 8X – 12X	600	12	15	Fuse	12–8
	STRCOM 13X – 24X	600	24	15	Fuse	12–8
	STRCOM 25X - 30X	600	30	15	Fuse	12–8

1. Designer must calculate the number of input circuits vs. specified OCPD rating vs. output circuit max. continuous current
2. Maximum current rating before any required derating, per *NEC*
3. NEMA 4X fiberglass or stainless options
4. NEMA 4 powder-coated steel & 4X stainless options
5. HCB8-M monitored option has 6-250 output circuit wire range

PV Output Circuit(s)						
Max. Output Circuits	Max. Continuous Amps[2]	Wire Range (AWG or KCMIL)	Data Monitoring Capabilities	Weatherproof Rating NEMA Type / Material	Mounting	Listing
1	90	14–4	No	4 / Black Powder-Coated Steel[3]	Vertical – Horizontal	ETL to UL 1741
1	120	6–3/0	No	4X / Fiberglass[4]	Vertical – Horizontal	ETL to UL 1741
1	160	6–350	Monitored Only	4X / Fiberglass[4]	Vertical – Horizontal	ETL to UL 1741
1	180	6–350	No	4X / Fiberglass[4]	Vertical – Horizontal	ETL to UL 1741
1	320	6–350 (x2)	Monitored Only	4X / Fiberglass[4]	Vertical – Horizontal	ETL to UL 1741
1	360	6–350 (x2)	No	4X / Fiberglass[4]	Vertical – Horizontal	ETL to UL 1741
1	540	6–350 (x2)	No	4X / Fiberglass[4]	Vertical – Horizontal	ETL to UL 1741
1	60	14–1/0	No	3R / Powder-Coated AL	Vertical – 14°	UL 1741
1	120	6–350	Yes[5]	4X / Fiberglass	Vertical – Horizontal	UL 1741
1	180	6–350	Yes	4X / Fiberglass	Vertical – Horizontal	UL 1741
1	100	14–1/0	No	3R / Painted Steel[6]	Vertical – 14°	ETL to UL 508A[7]
1	100	14–1/0	No	3R / Painted Steel[6]	Vertical – 14°	ETL to UL 508A[7]
2	100	14–1/0	No	3R / Painted Steel[6]	Vertical – 14°	ETL to UL 508A[7]
2	100	14–1/0	No	3R / Painted Steel[6]	Vertical – 14°	ETL to UL 508A[7]
1	60	14–1/0	No	3R / Powder-Coated AL	Vertical – 14°	ETL to UL 1741
1	60	14–1/0	No	3R / Powder-Coated AL	Vertical – 14°	ETL to UL 1741
2	120	14–1/0	No	3R / Powder-Coated AL	Vertical – 14°	ETL to UL 1741
1	120	14–1/0	No	3R / Powder-Coated AL	Vertical – 14°	ETL to UL 1741
2	200	14–2/0	No	3R / Powder-Coated AL	Vertical – 14°	ETL to UL 1741
2	200	14–2/0	No	3R / Powder-Coated AL	Vertical – 14°	ETL to UL 1741
2	164	14-2/0	No	3R / Powder-Coated AL	Vertical – 14°	ETL to UL 1741
1	240	6–250	No	3R / Powder-Coated AL	Vertical – 14°	ETL to UL 1741
1	240	14-2/0	No	3R / Powder-Coated AL	Vertical – 14°	ETL to UL 1741
1	120	14–2/0 (x2)	No	3R / Powder-Coated AL	Vertical – 14°	ETL to UL 1741
1	120	14–2/0 (x2)	No	3R / Powder-Coated AL	Vertical – 14°	ETL to UL 1741
2	180	14–2/0 (x2)	No	3R / Powder-Coated AL	Vertical – 14°	ETL to UL 1741
2	180	14–2/0 (x2)	No	3R / Powder-Coated AL	Vertical – 14°	ETL to UL 1741
1	90	6–350	No	3R, 4 / Painted Steel	Vertical	ETL to UL 1741
1	200–320	6–350 (x2)	No	3R, 4 / Painted Steel	Vertical	ETL to UL 1741
1	270–420	6–350 (x2)	No	3R, 4 / Painted Steel	Vertical	ETL to UL 1741
1	333	6–350 (x2)	No	3R, 4 / Painted Steel	Vertical	ETL to UL 1741
1	310	6–350	Yes	3, 3R, 4, 4X / Steel or Fiberglass	Varies by Enclosure Type	ETL to UL 1741
2	620	6–350 (x2)	Yes	3, 3R, 4, 4X / Steel or Fiberglass	Varies by Enclosure Type	ETL to UL 1741
1	310	6–350	No	3, 3R, 4, 4X / Steel or Fiberglass	Varies by Enclosure Type	ETL to UL 1741
1	310	6–350 (x2)	Yes	3, 3R, 4, 4X / Steel or Fiberglass	Varies by Enclosure Type	ETL to UL 1741
1	400	6–350 (x2)	Yes	3, 3R, 4, 4X / Steel or Fiberglass	Varies by Enclosure Type	ETL to UL 1741
1	400	6–350 (x2)	No	3, 3R, 4, 4X / Steel or Fiberglass	Varies by Enclosure Type	ETL to UL 1741
1	100	14–2	No	4X / Fiberglass or Polycarbonate	Vertical – Horizontal	ETL to UL 1741
1	225	6–350	Yes	3, 3R, 4, 4X / Steel or Fiberglass	Varies by Enclosure Type	ETL to UL 1741
1	144	4–250	No	4X Powder-Coated Steel[10]	Vertical – Horizontal	ETL to UL 1741
1	288	1/0–350[9]	No	4X Powder-Coated Steel[10]	Vertical – Horizontal	ETL to UL 1741
2	340	1/0–350[9]	No	4X Powder-Coated Steel[10]	Vertical – Horizontal	ETL to UL 1741

6. NEMA 4 painted steel & 4X fiberglass options
7. ETL to UL 1741 listing pending
8. Built-in 600 VDC contactor for remote disconnect
9. Dual lug up to 250 kcmil
10. NEMA 4X stainless option available

Courtesy www.midnitesolar.com

The result of opening a fuse holder without disconnecting the circuit.

Wire Range: Size of Input & Output Terminals

Wire terminals are rated to fit a range of wire sizes, in both bus bars and the OCPDs. Because the output circuit is carrying the combined ampacity of all the incoming series strings and also may have to be oversized due to voltage drop for longer wire runs in lower-voltage systems, it may be necessary to connect a relatively large-diameter wire to the output terminals.

Maximum Number of Output Circuits.

Sometimes it is appropriate to use multiple inverters or charge controllers with a single array—like two of four strings into one inverter and the other two into a second inverter. For this, you'll need either multiple combiners, or one combiner that can accommodate two separate output circuits. Of all the combiners listed, only a handful offer two output circuits.

Solectria manufactures 21 combiner box models for PV arrays with anywhere from eight to 30 series strings.

Courtesy www.solren.com

Sizing a Combiner Box

For this sizing example, assume the following:

- 6.8 kW grid-direct PV array
- Forty 170 W PV modules—four series strings of 10 modules each
- Module Voc: 21.6 VDC
- Module Isc: 8.7 A
- Series fuse rating: 15 A

The PV modules are wired in four series strings, so we will need to use series fusing (see the "Why Series Fusing?" sidebar). We also want to combine output wires to simplify the wire run (three output wires are much easier to work with than nine).

To determine the needed maximum combiner box voltage rating, find the maximum system voltage of a series string by multiplying the Voc of one module by the number of modules in the string, times a temperature correction factor. The module Voc temperature coefficient is commonly used in this calculation, but for simplicity we use *NEC* Table 690.7's worst-case temperature correction factor of 1.25:

21.6 VDC x 10 modules x 1.25 = 270 VDC

The PV modules have a series-fuse rating of 15 A, so we need a combiner box that can accommodate at least four 15 A OCPDs. For four 15 A OCPD, our PV combiner box must have a maximum rated output current of at least 60 A.

Given the above, we have many options, including the AMtec Solar Prominence 6R, Blue Oak HCB4, groSolar ReadyWatt 10x10HV, MidNite MNPV12-250, OutBack FWPV8, or SMA SBCB-6.

Maximum Continuous Output Current

Each combiner has a rating for the amount of output current that it can safely handle. Depending on the size and number of OCPDs in use, it may be possible to overload the combiner's bus bars. For example, in a combiner with sixteen 20 A circuit breakers, 320 A could flow into the output circuit, overloading the bus bar if it is rated at 100 A. To ensure this does not happen, use a combiner with a high enough output rating.

Data Monitoring Capabilities

While individual string monitoring is generally used in commercial, rather than residential-scale, systems, some homeowners are interested in tracking the performance of each string of PV modules to ensure the system is working optimally. Combiner boxes with data monitoring capability are often referred to as "smart" or "intelligent" combiners, and allow easy, quick installation of data monitoring systems.


Courtesy www.blueoakpvproducts.com

This Blue Oak combiner comes in 4-, 8-, and 12-circuit models.

Weatherproof Rating

Most combiner boxes are installed near their PV arrays (that is, in the weather), and require appropriate outdoor ratings. Installations are expected to last at least the lifetime warranty of PV modules (about 25 years), so installing durable, long-lived equipment that will stand up to the environment in which it is placed is critical.

Every approved electrical enclosure has a National Electrical Manufacturers Association (NEMA) rating associated with it. The ratings on PV combiners include NEMA 3 and 3R (rated for outdoor use in limited orientations); and NEMA 4 and 4X (includes additional protection so boxes can be mounted in any orientation, from vertical to horizontal). Wiring must enter the box through a cord grip that will properly seal the penetration and uphold the weatherproof rating of that combiner box.

Listing

The *NEC* requires that all electrical equipment have a valid safety-test listing to ensure safety for the general public. In the United States, most of this testing is performed by UL, an independent nonprofit, although there are other independent laboratories that will test to UL standards. One such lab is Intertek, which offers the ETL-listed mark. All of the PV combiner boxes in the table have a current or pending listing.

Access

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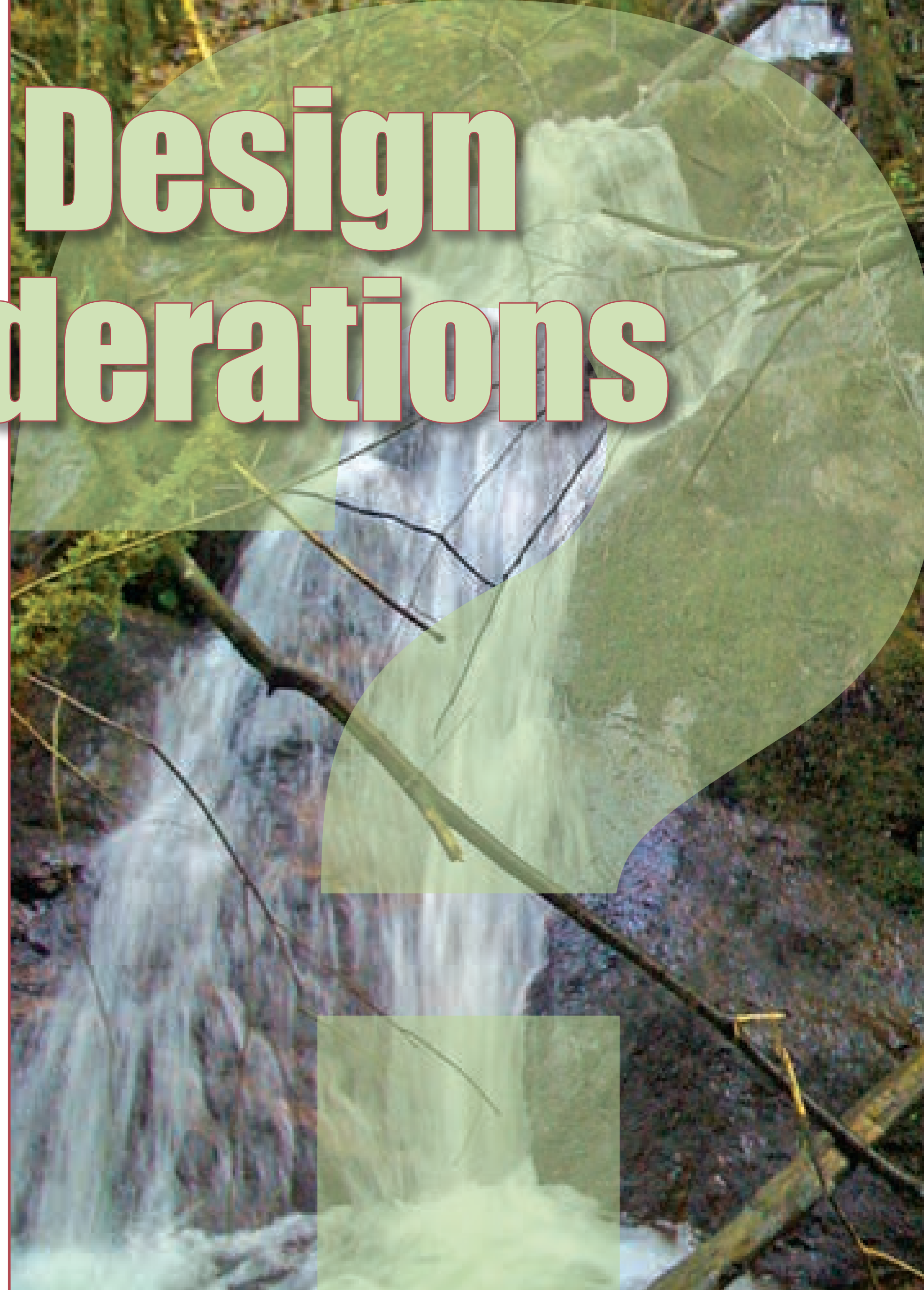
Hydro Design Considerations

by Ian Woofenden



If you are blessed with water flowing downhill on your property, you are fortunate indeed. Small-scale hydro-electricity can be the most cost-effective and reliable form of renewable energy (RE) for your home. But tapping this resource responsibly requires careful planning and implementation.

Assessing Head & Flow

Hydropower is the result of two basic characteristics inherent in the stream you tap. The first is the vertical drop, commonly called "head." This correlates directly with the pressure available, since every 2.31 feet of vertical drop equals 1 psi. The other factor is flow, and specifically, the amount of the stream's flow that you are comfortable with or allowed to take. For home-scale systems, this is typically measured in gallons per minute (gpm). For background on hydro system basics and measurements, see articles in *HP103, 104, 105,* and *117*.

When measuring the head and flow at your hydro site, it's a good idea to plot your results on a map of your property. Perhaps you have a site with 220 feet of total head over a projected pipe run of 1,200 feet. The cost of 1,200 feet of pipe is high, and it may not be cost-effective to tap all of the head. Mapping the head in segments will give you the information needed to make the best decision about where your intake and hydro plant should be.

Perhaps you gain 150 feet of head in 400 feet of run, but gaining the other 70 feet of head requires 800 more feet of pipe. In this case, you might decide not to tap all of your head. In a more extreme case, you might have a 50-foot waterfall where you gain 50 feet of head with 60 feet of pipe. You might have another 20 feet of head on your property, requiring several hundred feet of pipe to tap. Often the decision is clear—tap the head that is cheapest or easiest. In other cases, the head may be gradual; with low-flow situations especially, you may be pushed toward tapping every foot of head available, from property line to property line.

Flow can vary across a property, too. Tributaries join streams as they move downhill. Water can be lost to seepage, and whole streams can go underground for portions of their course. It's important to take flow measurements at the top of each segment you're mapping, so you can calculate power (watts) and energy (kilowatt-hours) for each scenario. Factors you should consider are:

- Head gained per 100 feet of pipe
- Flow
- Pipe cost
- Energy needed
- Location of loads relative to the turbine

Choice of Intake & Location

In a hydro system, the "intake" is where water is diverted from the stream. It consists of some sort of screen to remove debris, and also helps remove suspended air bubbles from the water. The preferred intake options are simple, durable, self-cleaning, and safe for stream life.

Too often, microhydro intakes are scaled-down versions of utility-scale hydro intakes, with a dam, a "stilling pond" or reservoir, perhaps a trash rack, a diversion channel, and then a final screening. These civil works are very expensive, intrusive, and often unnecessary. When possible, find a spot in the stream to incorporate a modest self-cleaning screen that will only minimally disturb the natural flow of the watercourse. For instance, 1 square foot of the Hydro-Shear screen, which can accommodate flows up to 200 gpm according to the manufacturer, is adequate for most home-scale hydro systems. Often, existing rocks can be incorporated into the structure—I've seen intakes that only use a few cubic feet of concrete to cement in a screened intake at a narrow, natural drop in the stream.

Look for a place where the stream drops naturally and you can slip a screen underneath the falling water. Ideally, the stream will be narrow and stable at this point, so it will be unlikely to change course with winter floods. If there is some nonturbulent water upstream from the intake, all the better—this will allow the sediment to settle. One practical consideration for installation is selecting a spot where stream water can be temporarily diverted while you construct the intake.

In addition to the screened intake itself, you need to consider the penstock (pipeline) and, especially, how to get it out of the streambed. Though a tough screen cemented in at an appropriate angle can withstand heavy flooding and battering from logs and boulders, a penstock exiting the screen box may be more vulnerable. Have it exit the stream and stream bed as quickly as possible, being sure to keep it lower than the level of the intake. If the pipe is not kept below the level of the intake, the flow will be impeded and a siphon will need to be created. Protect the pipe with rock and concrete where it leaves the intake and as far down as it may be subjected to damage. For more information on hydro intakes, see the article in *HP124* and the letter in *HP125*.

Ian Woofenden (3)

Complex and expensive intakes are sometimes necessary (inset), but more often, a simple and inexpensive, self-cleaning intake right in the stream flow (above) does the trick.

Pipe Sizing

If a hydro turbine is the "engine," the penstock is the fuel line, delivering the power of water to the turbine. For optimum performance, it's critical that this pipe be sized properly. Using too small a pipe could mean losing much of the potential energy to friction. Too big of a pipe, and you'll be spending more money than needed for no significant increase in energy.

To balance cost with efficiency, hydro designers typically aim for 10% to 15% pipe friction loss (also called "head loss"). Measuring the pressure (psi) at the bottom of the full penstock with no water flowing gives the "static pressure." When the valve is opened and water flows at the rate the turbine requires, you can measure the "dynamic pressure," or net head. The difference between these two numbers is the friction loss of the penstock, which can be identified in psi or feet of head.

To size pipe correctly, you need to know the total static head, the design flow—the amount of water you will take out of the stream (which will generally be some fraction of the stream flow)—and the penstock length. Friction- or head-loss tables give losses in feet per hundred feet of pipe for various pipe types and sizes, so you can do the math to figure out what pipe to buy. If you're on the fence between two pipe sizes, round up!

Here's an example: Let's say you have a fairly steep site with 120 feet of head in 500 feet of run, and a design flow

Step-By-Step Pipe Sizing

1. Measure head
2. Measure flow
3. Measure penstock length
4. Consult charts for friction loss per 100 feet of pipe
5. Multiply by number of 100-foot sections in pipeline
6. Calculate head loss percentage, aiming for 15% or less
7. Repeat on other sizes and pipe types until choice is clear

of 100 gpm. Tables for PVC pipe show head losses of 14.53 feet per hundred feet for 2-inch pipe, 2.125 for 3-inch pipe, and 0.578 for 4-inch pipe. Multiplying the head loss by 5 (for 500 feet of pipe) gives 72.65 feet for 2-inch, 10.625 for 3-inch, and 2.89 for 4-inch. Dividing these by the 120 feet of static head, we get about 61% loss for 2-inch, about 9% for 3-inch, and less than 3% for 4-inch. In this example, the right pipe to choose is 3-inch, as head loss is significantly lower than the 2-inch pipe option, and the higher cost of the 4-inch pipe will probably outweigh the minimal 6% decrease in head loss.

Pipe Choice

You'll also need to choose the type of pipe to use. Hydro penstocks can be made out of steel, PVC, or polyethylene (usually high-density polyethylene—HDPE). Pipes of the same material can come in different wall thicknesses to handle different amounts of pressure. Your choices will depend on the pressure rating required, the size of your pipeline, what is available locally, friction losses, and your budget.

Penstocks must have appropriate pressure rating! When you map out the head, you can also convert to psi at various stages along the pipe run, adding a 40% safety factor. Most often, you'll buy one type of pipe that can handle the highest pressure in the system, which is at the turbine. But if the pipeline is long or the pipe is costly, you may opt to use pipe with a lower pressure rating at the top of the penstock, and switch to an appropriately higher pressure-rated pipe as it gets closer to the turbine.

Pipe availability depends on local demand. If you live in an agricultural area, you'll find a wide variety of irrigation and other pipe available. PVC sewer pipe in the 3- to 8-inch range can be a low-budget option for lower-head systems. However, it is not pressure-rated, so you'll have to get some inside advice on what it will actually handle. Standard schedule 40 PVC pipe is often a readily available option, and bell-and-socket gasketed versions are commonly used. PVC is subject to ultraviolet light degradation and physical damage, so it is normally buried, covered, or sometimes painted. HDPE is the toughest of the

(continued on page 82)

Friction Losses Per 100 Feet of Pipe

PVC Schedule 40 at Various Sizes

Flow (GPM)	2-In. Pipe		3-In. Pipe		4-In. Pipe	
	PSI	Ft.	PSI	Ft.	PSI	Ft.
10	0.09	0.208	0.01	0.023	—	—
20	0.32	0.739	0.05	0.116	0.01	0.023
30	0.68	1.571	0.10	0.231	0.03	0.069
40	1.15	2.657	0.17	0.393	0.04	0.092
50	1.74	4.019	0.26	0.601	0.07	0.162
60	2.44	5.636	0.36	0.832	0.11	0.254
70	3.25	7.508	0.48	1.109	0.13	0.300
80	4.16	9.610	0.61	1.409	0.16	0.370
90	5.18	11.966	0.76	1.756	0.20	0.462
100	6.29	14.530	0.92	2.125	0.25	0.578
110	7.51	17.348	1.10	2.541	0.29	0.670
120	8.82	20.374	1.29	2.980	0.34	0.785
130	10.23	23.631	1.50	3.465	0.40	0.924
140	11.74	27.119	1.72	3.973	0.46	1.063
150	13.33	30.792	1.95	4.505	0.52	1.201
160	15.03	34.719	2.20	5.082	0.59	1.363
170	16.81	38.831	2.46	5.683	0.66	1.525
180	18.69	43.174	2.74	6.329	0.73	1.686
190	20.66	47.725	3.02	6.976	0.81	1.871
200	22.72	52.483	3.33	7.692	0.89	2.056

Source (also includes tables for other pipe types): www.hunterindustries.com/Resources/PDFs/Technical/Domestic/LIT091w.pdf

4-Inch Pipe of Various Materials

Flow (GPM)	Plastic		New Steel		Corroded Steel	
	PSI	Ft.	PSI	Ft.	PSI	Ft.
10	0.00	0.01	0.01	0.01	0.01	0.03
20	0.01	0.03	0.02	0.04	0.04	0.09
30	0.03	0.06	0.04	0.09	0.09	0.20
40	0.05	0.11	0.07	0.16	0.15	0.34
50	0.07	0.16	0.11	0.24	0.22	0.51
60	0.10	0.23	0.15	0.34	0.31	0.72
70	0.13	0.30	0.20	0.45	0.42	0.96
80	0.17	0.38	0.25	0.58	0.53	1.23
90	0.21	0.48	0.31	0.72	0.66	1.53
100	0.25	0.58	0.38	0.88	0.80	1.86
120	0.35	0.81	0.53	1.23	1.13	2.60
140	0.47	1.08	0.71	1.63	1.50	3.46
160	0.60	1.38	0.91	2.09	1.92	4.43
180	0.75	1.72	1.13	2.60	2.38	5.51
200	0.91	2.09	1.37	3.16	2.90	6.69
250	1.37	3.16	2.07	4.78	4.38	10.11
300	1.92	4.43	2.90	6.69	6.13	14.17
400	3.26	7.54	4.93	11.39	10.44	24.12
500	4.93	11.39	7.45	17.22	15.78	36.45

Source: www.tasonline.co.za/toolbox/pipe/velfirc.htm

Example Hydro Placement Scenarios

Icehouse Creek, North Fork Options

	Pipe Section	Scenarios 1	2	3	4	5	6	7	8	9
Head (Ft.)	A–B	18	18	18	18	18	–	–	–	–
	B–C	13	13	13	13	13	–	–	–	–
	C–D	–	14	14	14	14	14	–	–	–
	D–E	–	–	18	18	18	18	18	–	–
	E–F	–	–	13	13	13	13	13	13	–
	F–G	–	–	–	13	13	13	13	13	13
	G–H	–	–	–	–	12	12	12	12	12
	Total Head	31	45	76	89	101	70	56	38	25
	Flow (GPM)	60	60	60	60	60	60	60	60	60
	Power (W)*	143	208	351	411	466	323	258	175	115
	kWh/Day	3	5	8	10	11	8	6	4	3
	Penstock Length (Ft.)	200	300	500	600	700	500	400	300	200
	Wire Length (Ft.)	1,360	1,420	1,470	1,500	1,550	1,550	1,550	1,550	1,550

Icehouse Creek, Middle Fork Options

	Pipe Section	Scenarios 10	11	12	13	14	15	16	17	18
Head (Ft.)	A–B	12	12	12	12	12	–	–	–	–
	B–C	15	15	15	15	15	–	–	–	–
	C–D	–	16	16	16	16	16	–	–	–
	D–E	–	–	13	13	13	13	–	–	–
	E–F	–	–	–	0	0	0	–	–	–
	F–G	–	–	–	30	30	30	30	–	–
	G–H	–	–	–	25	25	25	25	25	–
	H–I	–	–	–	25	25	25	25	25	–
	I–J	–	–	–	–	25	25	25	25	25
	J–K	–	–	–	–	20	20	20	20	20
	Total Head	27	43	56	136	181	154	125	95	45
	Flow (GPM)	85	85	85	85	85	100	100	110	110
	Power (W)*	177	281	366	889	1,183	1,185	962	804	381
	kWh/Day	4	7	9	21	28	28	23	19	9
	Penstock Length (Ft.)	200	300	400	800	1,000	800	500	400	200
	Wire Length (Ft.)	500	610	700	880	1,300	1,300	1,300	1,300	1,300

*P (W) = [Head (Ft.) x Flow (gpm)] ÷ 12

Choosing intake and turbine location often becomes a balancing act between the energy needed and the cost of the pipeline and wire. Note that flow increases along the length of the Middle Fork while it remains the same on the North Fork. See text starting on page 79 for more information.


Shawn Schreiner

The double-cup design of the Pelton runners is best for a very high head-to-flow ratio.


Courtesy www.microhydropower.com

The design of the Turgo runner performs better with more flow than a Pelton runner, but is also a pressure-dependent design.

plastic options. This material can be fused together with a "welder," and is tough enough to drag behind a tractor or mule to get it into place.

Aluminum and steel pipe are used less often because of cost and higher friction losses. They can sometimes be found surplus and are very durable, though there are concerns with rust and corrosion. I've seen steel used for the lower ends of penstocks, where the pressure is higher, and at high-wear points like road crossings and places where the pipeline comes to the surface. Common aluminum irrigation pipe cannot handle much pressure, nor can it be buried, since it will corrode.

Every hydro designer has their own pipe preferences, based on the site, experiences, and values. For exposed penstocks 3 inches and larger, I lean toward HDPE. For buried pipelines, the additional expense may not be warranted. Evaluate your situation, educate yourself about the benefits and costs, and make a choice that will serve your needs.

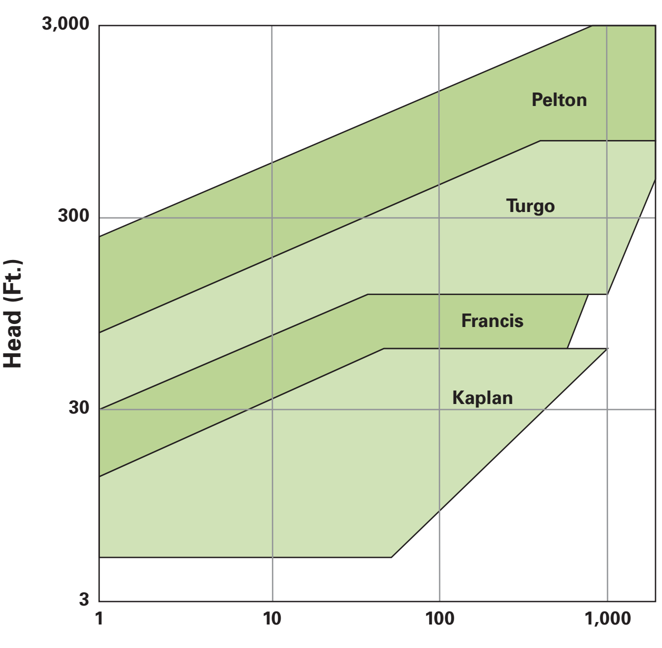
Turbine & Runner Selection

Most home-scale hydro sites in North America are "high-head" systems, with drops from 10 feet to hundreds of feet. While there are many potential "low-head" (18 inches to several feet) sites, they require more flow and can be subject to more political challenges, since the complete stream or river flow is often diverted, requiring a dam across the whole water course. We'll primarily focus on high-head systems.

A hydro turbine includes a "runner"—the wheel that receives the water's kinetic energy to drive a shaft. Two types of runners—the Pelton and the Turgo—are used in most of the small, high-head turbines. In general, the Turgo tends to work more effectively at lower heads and higher flows than the Pelton. But there is a broad range of overlap between the two runners, and each turbine manufacturer will have a preference and point of view. Other runner types, such as the Francis, propeller, and cross-flow, are generally used in low-head, high-flow conditions, and may be appropriate for your site. Pumps used as turbines are another option that some designers use in a number of different situations.

When deciding on turbine type, ask the manufacturers for information and get more than one opinion. Most of us will never be experts at selecting the perfect runner for a specific site, and most hydro homeowners only make this decision once or twice. Most manufacturers will fully disclose their products' limitations, and in this small industry, a few phone calls can net you much of the available information. Ask the suppliers what they recommend for your site. Look at what

Turbine Runner Choices



Choices shown are for one manufacturer's line of turbines. Courtesy Tyco Tamar.

they offer, and whether they have choices of different runners in their lines. And realize that different runners can do a reasonable job on the same site.

System Configurations

Home-scale hydro systems have four basic configuration possibilities. **A stand-alone system with batteries** looks very much like an off-grid PV or wind-electric system. It's not important how the batteries get charged—hydro, wind, PV, or generator. You'll need a controller to protect the batteries and a diversion load to accept excess energy as the batteries approach full.

A batteryless stand-alone system, or AC-direct system, is only appropriate for larger hydro plants (rated at 3 kW or more), to provide the peak power required to start motors and make sure there is enough power to run all the concurrent loads. In these systems, there is no storage, buffer, or surge capacity. To keep the turbine fully loaded all the time and keep the combined load consistent, a load-control system turns staged diversion loads on and off depending upon how heavily the home is loading the system. The fewer loads that are turned on in the home, the more dump loads will be switched on.

A battery-based grid-tie system closely resembles a stand-alone system with batteries. You'll need the charge controller and diversion load, but these will really only come into play during grid outages. While the grid is up, the grid-tied inverter will regulate the batteries, and any surplus hydro electricity will be fed to the utility grid.

Batteryless grid-tied systems can take at least two different forms, depending on the size of the system and local connection regulations. Larger systems may use induction motors and directly tie to the grid, and they rely on controllers to divert or shut off the water flow if the grid goes down. Smaller systems will likely use a modified batteryless PV inverter, sometimes with added electronics, and also use a controller and dump load for grid outages.

Take a look at what your goals are, how close the grid is, and the scale of your system. Then build a robust system to work within those parameters. See articles on going off-grid or staying on-grid in *HP128*, and on basic hydro system configurations in *HP117*.

Choosing Nozzles

Once your system is installed, you'll need to learn the nuances of operating it. Many systems have variable flow over the seasons and varying loads. This means that you won't necessarily be able to run the turbine in the same way or at full output year-round. Pelton and turgo turbines offer the option of varying the number or size of nozzle to adjust the flow. If you don't wish to take the time and effort to adjust nozzle sizes and numbers, you should find a single flow level to run the turbine so you will always have enough energy. In times of higher flow, this means you'll be sacrificing additional available energy for the benefit of simplicity. Most streams undergo periods of flooding and times of low flow due to freezing or low precipitation. This can create a design challenge, since you want a turbine that can run at reasonable efficiency over a range of flows.

Four different-sized nozzles on this turbine allow 15 possible combinations of flow and power.

Christopher Freitas (2)

Four valves control flow to the four nozzles, while a pressure gauge monitors system head.

While the total head, available flow, and pipe friction affect the amount of water hitting your runner, the nozzles are the primary flow regulators. These precision-made pieces direct a jet of water at the runner's cups through holes that can be 1/8 to 1 inch in diameter. The nozzles control the flow, and you can determine the flow through each size of nozzle from information available from your turbine manufacturer (see "Nozzle Flow Rates" table for an example).

Small turbines can have one to four nozzles, each controlled by a valve. By installing a variety of nozzle sizes on the multiple inputs, a wide variety of flow configurations are available. This minimizes nozzle changing, which can be cumbersome with some turbines and setups, and uncomfortable depending upon the season. Often, it's useful to buy a turbine with three or four nozzles even if you will only use one or two at a time, just to be able to microadjust the flow to the runner based on the amount of water available.

Penstocks should have a pressure gauge installed just upstream of the stop valve(s) or turbine manifold, where the pipeline is divided to go into multiple nozzles. When all nozzle valves are shut, the gauge will show the static pressure. When

Nozzle Flow Rates

Head (Ft.)	Pressure (Psi)	Flow (Gpm) Per Nozzle Diameter (In.) 1/8	3/16	1/4	5/16	3/8	7/16	1/2	5/8	3/4	7/8	1
5	2.2	—	—	—	—	6.2	8.4	11.0	17.1	24.7	33.6	43.9
10	4.3	—	—	3.9	6.1	8.8	11.6	15.6	24.2	35.0	47.6	62.1
15	6.5	—	2.7	4.8	7.4	10.7	14.6	19.0	29.7	42.8	58.2	76.0
20	8.7	1.4	3.1	5.5	8.6	12.4	16.8	22.0	34.3	49.4	67.3	87.8
30	13.0	1.7	3.8	6.7	10.5	15.1	20.6	26.9	42.0	60.5	82.4	107.0
40	17.3	1.9	4.4	7.8	12.1	17.5	23.8	31.1	48.5	69.9	95.1	124.0
50	21.7	2.2	4.9	8.7	13.6	19.5	26.6	34.7	54.3	78.1	106.0	139.0
60	26.0	2.4	5.4	9.5	14.8	21.4	29.1	38.0	59.4	85.6	117.0	152.0
80	34.6	2.8	6.2	11.0	17.1	24.7	33.6	43.9	68.6	98.8	135.0	176.0
100	43.3	3.1	6.9	12.3	19.2	27.6	37.6	49.1	76.7	111.0	150.0	196.0
120	52.0	3.4	7.6	13.4	21.0	30.3	41.2	53.8	84.1	121.0	165.0	215.0
150	65.0	3.8	9.0	15.0	23.5	33.8	46.0	60.1	93.9	135.0	184.0	241.0
200	86.6	4.3	9.8	17.4	27.1	39.1	53.2	69.4	109.0	156.0	213.0	278.0
250	108.0	4.9	10.9	19.9	30.3	43.6	59.4	77.6	121.0	175.0	238.0	311.0
300	130.0	5.3	12.0	21.3	33.2	47.8	65.1	85.1	133.0	191.0	261.0	340.0
400	173.0	6.1	13.8	24.5	38.3	55.2	75.2	98.2	154.0	221.0	301.0	393.0

a valve or valves are open, the gauge will show the dynamic pressure. Under normal operation, by watching the gauge, you'll be able to record baseline pressures for various flows. Then, if you turn on too many nozzles, which causes too much water to be taken in and the pipe to empty, the decreasing dynamic pressure and loss of power will alert you that you should switch to a smaller nozzle. The dynamic pressure can also help you diagnose problems with the system: too high can mean a plugged jet, and too low can mean a clogged intake.

Hydro Design

After you've completed some basic research and reading (see Access), consulting with local and regional hydro dealers/installers is an excellent next step. Turbine manufacturers' Web sites often have extensive planning information available at no charge.

Designing and operating a small hydro-electric system is not simple. A number of key decisions are involved in both design and operation. But thinking ahead can save you time and money, and help you tap your valuable resource carefully and responsibly.

Access

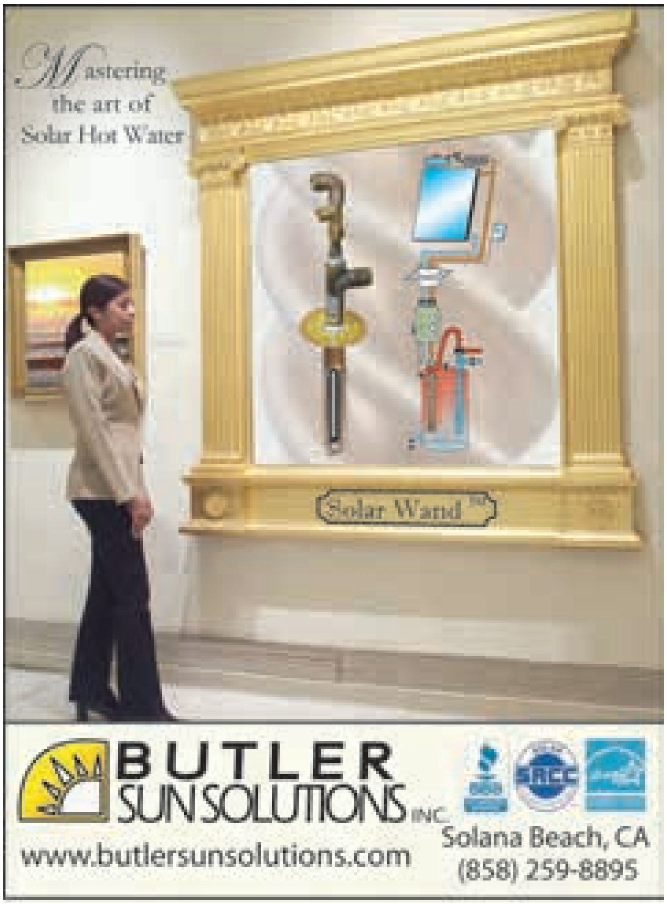
Ian Woofenden (ian.woofenden@homepower.com) can only dream of hydro electricity from his flat-island home. He plays in other people's streams in western Washington and Central America.

Recommended Reading:

"Intro to Hydropower" by Dan New, *HP102, 103* & *104*

"Microhydro-Electric Systems Simplified" by Paul Cunningham & Ian Woofenden, *HP117*

Articles on hydro intakes, pipelines, and transmission by Jerry Ostermeier and Joe Schwartz can be found in *HP122, 125* & *126.*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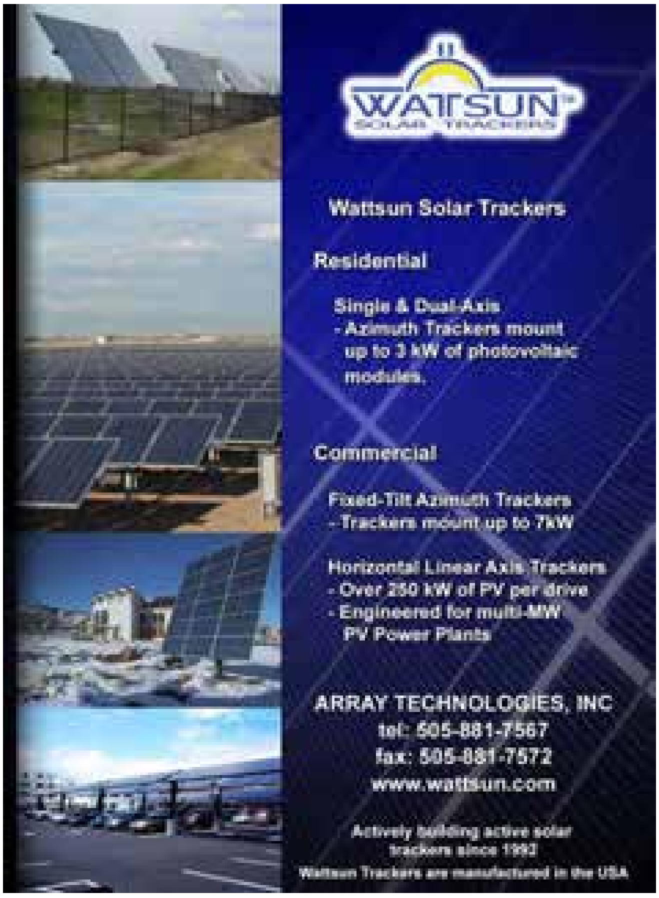
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MONITORING
Grid-Tied PV Systems

by Kyle Bolger & Justine Sanchez

You're pretty sure your grid-tied PV system is working—but how well? And how can you tell? Here's how to keep tabs on your system to ensure optimal performance.

The first place most system owners look to assess their grid-tied PV system's performance is their electricity bill. But examining bills won't give you the big picture. Since most electric companies offer net metering, you'll only be provided with the information *they* measure: how much electricity you import from the grid and, depending on the utility meter, how much your system exports to the grid. Because your bill won't typically show how much PV-generated energy the home consumed, you won't be able to determine how much energy your PV system produced overall by using the bill as your only guide. But you can get your hands on this information with data-monitoring solutions from inverter manufacturers and third-party providers.

Inverter-Direct Monitoring

For some, an inverter's basic display is informative enough. It is easy to access—right on the front of the inverter—and provides a basic level of monitoring, which often includes instantaneous power output, daily energy production, and total to-date energy production. Depending upon the inverter, readings may also include voltage characteristics of the utility grid and PV array voltages. Some inverters will even translate the PV system's production (in kilowatt-hours) to pounds of carbon dioxide (CO_2) offset to give homeowners insight on how their systems are shrinking their carbon footprints. System owners can view this information at will, just by checking the inverter display.

Remote display options offered with some inverters can provide the same basic system performance information in a portable device, allowing homeowners to be armchair data-junkies. An example of wireless onsite monitoring is the Fronius Personal Display. Simple graphics illustrate the data, such as instantaneous watts; DC and AC volts and amps; daily, yearly, and total kWh; the dollar value of the energy produced; and pounds of CO_2 saved.

If you wish to compare daily outputs without recording this information by hand, most inverter manufacturers offer data-monitoring software that can run on your personal computer. Typically, a cable is connected between the inverter and the PC to collect system data, which can be formatted and accessed at your convenience. This strategy offers a relatively inexpensive data-collection solution, but it requires that the PC be connected and running anytime you want to collect data.

A wireless remote display lets you monitor instantaneous and cumulative data without going to the inverter.

Courtesy www.fronius.com

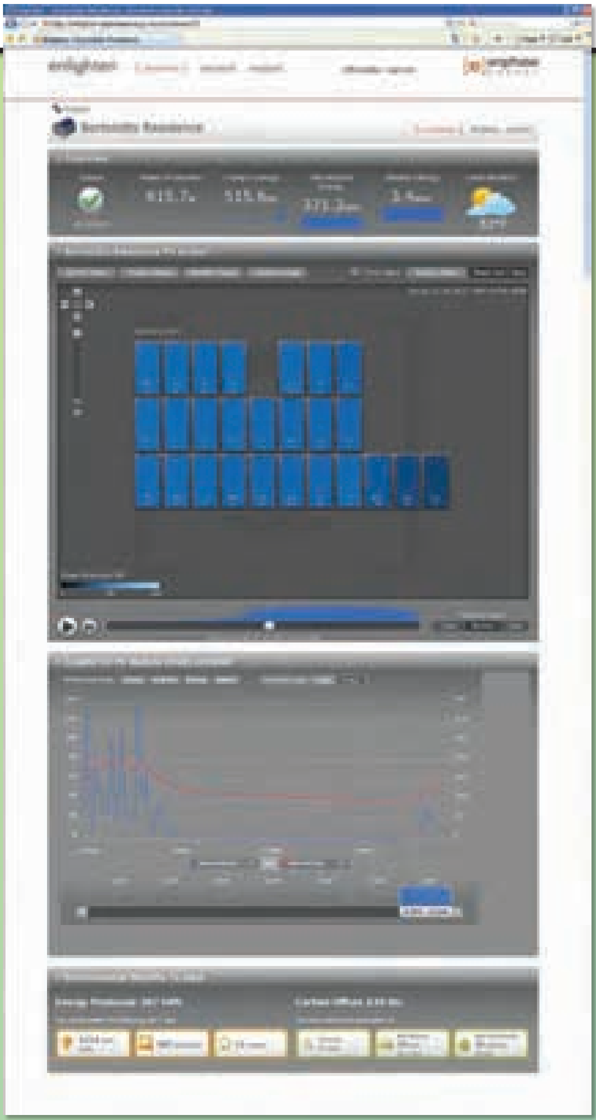
Data Logging Hardware & Web Monitoring

Inverter manufacturers also provide data logging solutions that can store performance data without a PC and some even offer online data monitoring using network-savvy portals. System owners, installers, and equipment manufacturers can track system performance from any Internet-connected computer. Some packages can even send automated e-mails to the installer and the system owner in the event of a system fault. If the system has multiple inverters or string-level monitoring, you also may be able receive warnings of discrepancies in energy outputs.

For this convenient and sophisticated data-collection approach, additional data logging and communications hardware is required, which ranges in price from $400 to $1,300. This hardware is installed internally to the inverter or simply connected to the inverter via cabling. These enhanced data-management systems often offer add-ons, such as sensors for measuring irradiance, module temperature, and wind data. This information can also be accessed via the Internet. This level of data monitoring is rarely needed for small-scale systems, but solar geeks, data junkies, and owners of large PV systems will appreciate having this capability to fully assess system performance.

Inverter-direct, Web-based data monitoring usually uses Cat-5 communications cable (Ethernet cable), connected between the added data logging and communications hardware (mounted internally or externally to the inverter) and an Internet portal and router on your local network. From there, system data is sent to the manufacturer's Web server. Sometimes this hosting service is free of charge, but make sure you understand what the cost is (now and in the future) before you make your purchasing decision. The costs for the required hardware and Web-hosting fees can be small in comparison to the rest of a larger PV system, but can be overkill for small- to medium-sized residential PV systems.

Here is an overview of each company's inverter-direct data monitoring options. While we do show prices for some of these data-monitoring solutions, prices and terms will vary depending on the equipment distributor.



Courtesy www.enphaseenergy.com (2)

ENPHASE ENERGY...

Enphase Energy's microinverter system offers its Envoy communications gateway hardware (MSRP: $495) that facilitates access to system data via the company's Enlighten Web site. Enphase's products are unique for a few reasons. No additional cabling is required since communication is sent through each inverter's AC output to the Envoy via the wall outlet it is plugged into. Installing the data-monitoring system is as simple as plugging the Envoy into any standard wall outlet and connecting its cable to the household's Internet router.

Data (instantaneous watts plus daily, monthly, and cumulative kWh) is collected for each PV module/inverter pair. On the Enlighten Web site, this information is presented numerically, and dynamically—with daily graphics representing how much power each module is producing in real-time. This allows owners to easily identify underperforming modules. The Web site also allows users to view historical performance data and will generate energy production reports. While access to the Enlighten Web site may be free initially (typically for 90 days), extending the subscription costs $2 per microinverter, per year. The Envoy can also display data over a local network without the official Enlighten Web site.

FRONIUS USA...

Courtesy www.fronius.com (3)

Fronius USA offers several data-monitoring options for onsite data logging and monitoring, or Internet-based data monitoring. Each option requires a COM card (MSRP: $143) and one data logger ($445 for the data logger EASY card for onsite monitoring for one inverter; $1,350 for the Datalogger Web for online monitoring of up to 100 inverters). Fronius also offers an internal sensor interface card ($689) or an external sensor box ($737). Both can collect data from irradiance sensors, module and ambient air temperature sensors, and wind-speed sensors (purchased separately).

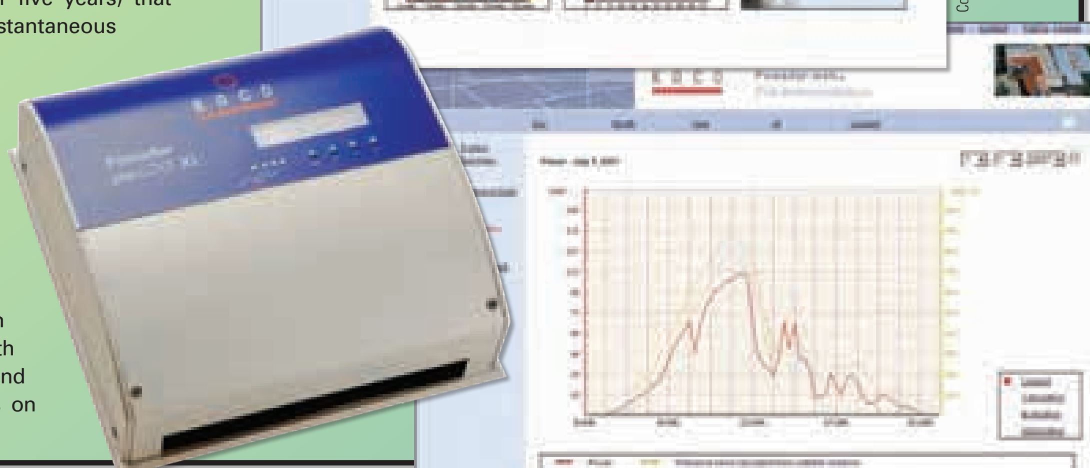
Online data access is provided via Fronius' free SolarWeb portal, where users can view graphs of real-time power, and daily and lifetime kWh, along with sensor data (if installed). Archives of past data are also available.

KACO SOLAR...

Kaco Solar currently offers onsite and Internet-based data monitoring via proLOG hardware (MSRP: $855 for the proLOG M with LED display and one sensor port; $1,375 for the proLOG XL, with an LCD display and four sensor ports). Optional irradiation, temperature, and current sensors are available. Each data logger can monitor up to 32 Kaco inverters. Online monitoring is accessed via Kaco's Blueplanet server ($60 for five years) that displays information such as instantaneous watts and daily, monthly, and yearly kWh.

Kaco recently released a more affordable monitoring option—the WatchDog ($400)—which can monitor up to three inverters. The WatchDog mounts inside the new 02 Series inverters and is connected to an onsite Internet router. Users can access power output along with hourly, daily, weekly, monthly, and annual energy production graphs on the Blueplanet Web portal.

Courtesy www.kacosolar.com (3)



POWER ONE...

Power One offers the Aurora Easy Control hardware for onsite, PC-based system monitoring in either Pro (MSRP: $1,300), Basic ($1,200), or Light ($700) versions. The Pro version has four sensor inputs and can monitor up to 31 inverters, while the Basic has one sensor input and can monitor up to 31 inverters. The Light version has one sensor input and can monitor up to five inverters. Options include irradiance, ambient and module temperature, and wind speed sensors. The PC-based Communicator monitoring software shows daily power output, along with daily, monthly, yearly, and lifetime energy production.

Courtesy www.power-one.com (4)

THIRD-PARTY MONITORING

Some rebate programs (especially production-based incentive programs) require an additional production meter to track output. An independent meter may also be required to count your solar renewable energy credits (SRECs or "green tags"), where organizations may pay system owners for the right to claim ownership of every green kilowatt-hour the system produces in addition to the net-metering credits earned with the local utility company.

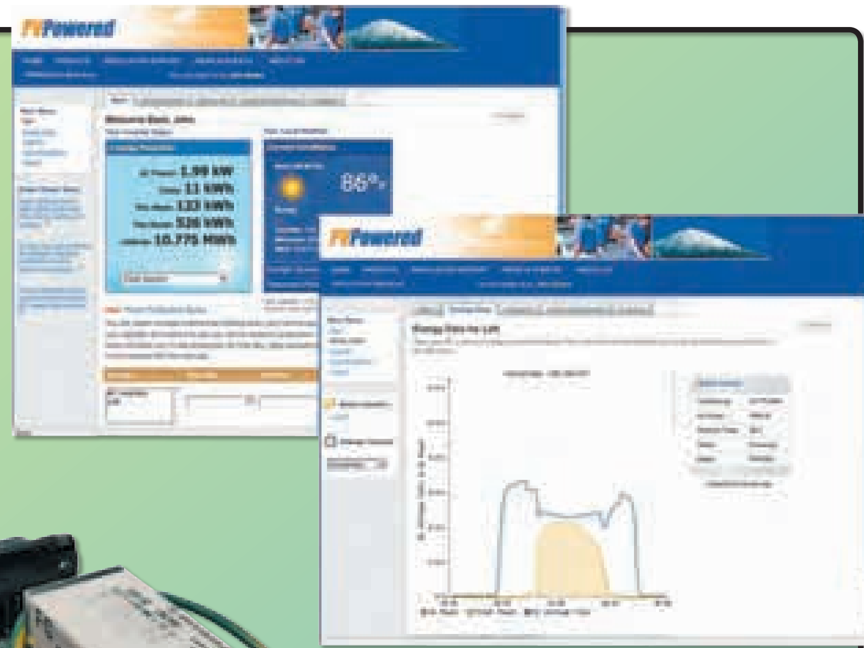
A utility-grade meter installed on the output side of the inverter(s)—before they reach the distribution panel—is the simplest method and usually requires a standard utility-type meter base. These meters are affordable, durable, and easy to read—so long as you're standing right in front of them. Most SREC/green tag incentive programs allow these meters, but they require the added effort of regular, manual data recordings, which need to be faxed or e-mailed to the incentive program's coordinating agency.

A more sophisticated, less time-consuming approach is to employ a third-party data monitoring system (see Access) that can record the system's performance independent of the inverter and transmit the information to the Web—with minimal effort from the system owner. Solectria offers their revenue-grade option specifically for this purpose. Additionally, some inverter companies, such as PV Powered, offer third-party data monitoring packages pre-installed within the inverter. These operate independently from the inverter, while saving space and installation time, since system monitoring hardware doesn't have to be installed separately.

One company that took the watchdog concept to market is Fat Spaniel Technologies (FST), one of the leaders in third-party monitoring. Along with precise, automated SREC monitoring and reporting, their system presents useful energy information—often in an entertaining format. For instance, one report translates energy values in terms of cups of coffee that could be brewed with the solar energy produced. And like many of the inverter-direct monitoring products, FST offers other advanced features, such as data-syncing with environmental sensors to record wind speed, irradiance values, ambient temperature, and PV cell temperatures. These values are graphed alongside production values to display real-time performance analyses of the system's modules and inverters. More committed conservationists will also appreciate FST's ability to monitor a home's energy usage throughout the day and identify specific load-profile patterns that can then be tweaked to further improve a home's energy efficiency. (MSRP: Call FST for pricing.)

PV POWERED...

PV Powered's PVM 1010 data-monitoring module (MSRP: $399) mounts inside the inverter—one per inverter. When connected to the Internet, PV Powered offers free online monitoring at MyPVPower.com. Information displayed includes current system output power (and regional weather conditions), daily kWh production, and system lifetime energy production. Hourly, daily, weekly, and monthly graphs of voltage versus power output are also accessible. Comparing historical trends is as easy as selecting a date range to export detailed data in a spreadsheet format.



Courtesy www.pvpowered.com (3)

SMA AMERICA...

SMA America offers the Sunny WebBox (MSRP: $675) that can monitor up to 50 inverters. The hardware is external and connects to the inverter via a required RS485 card ($150). Also available is the Sunny Sensor box ($520), which comes with an internal irradiance sensor and external module temperature sensors (optional sensors include ambient temperature and wind speed).

Data is accessed via the free SMA Sunny Portal Internet site. Online displays include daily power curves and daily, monthly, annual, and lifetime energy production graphs.

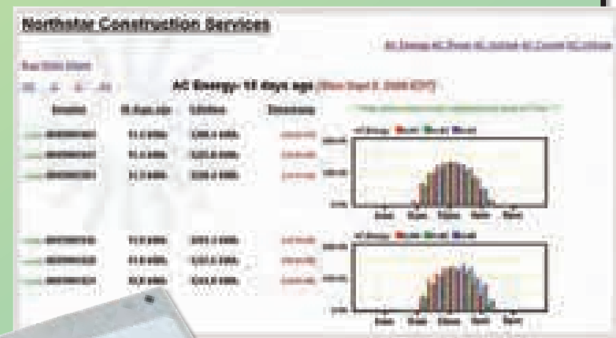
Courtesy SMA America (3)

SOLECTRIA RENEWABLES...

Solectria Renewables has Internet-based system monitoring using the Solrenview Gateway hardware, which handles up to 16 inverters. They offer a few different monitoring options, including inverter-direct and revenue-grade energy production packages. Also offered for the commercial industry are building energy demand, subarray monitoring, and weather station packages. All monitoring packages are accessed via the Solrenview Web site.

The inverter-direct package is comparable to the other inverter Web-based products, and offers daily power curves and daily, weekly, and monthly energy production graphs, along with AC voltage and current and DC voltage curves. All data is available for up to five years and downloadable in spreadsheet format. A standard three-year contract for the Web package is included with the initial purchase, with options to extend to five- or 10-year packages.

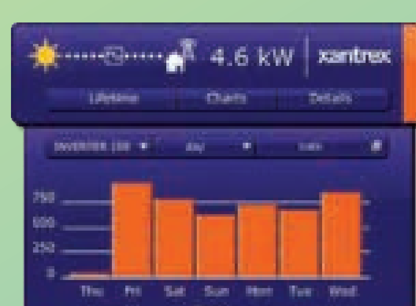
The revenue-grade energy production option will connect to certain utility production meters so the Solrenview Gateway can monitor the utility-meter pulses and every kWh produced by the system. This data then can be automatically reported to the SREC agencies (see "Third-Party Monitoring" sidebar). Additionally, this option can be used with non-Solectria inverter systems. (Note: This does not cover inverter-direct monitoring, as the Solrenview Gateway is connected only to the production meter and not to the non-Solectria inverter.)

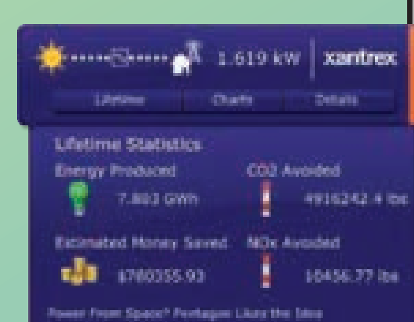


Courtesy Solectria Renewables (3)

XANTREX...

The Xantrex Communications Gateway option (MSRP: $650) will log system data that can be used for PC-based/onsite monitoring. A proprietary cable (included) connects the inverter to the gateway hardware. An Ethernet connection between the gateway and the onsite Internet router is required for setup, but can be removed for wireless operation (between the gateway and the router) thereafter. Data is then accessed via the PC after you have installed both a Yahoo! Widget and Solar Monitor Widget on your computer. Currently, Xantrex does not host a Web site for accessing data online. However, users can retrieve data remotely by "port forwarding," which enables a computer from an external IP address to view system data, or by e-mailing data.





Courtesy Xantrex (4)

Growing with the Grid

As the grid-direct PV industry grows, new and exciting options for monitoring system performance seem to be springing up just as fast. While researching your options, check out the user-friendliness of the various Web sites and displays offered. Talk to system owners and installers who have experience with these products. Also inquire about each company's customer service record—if you invest in these monitoring systems, you will be depending on their service as you keep tabs on your system's performance for years to come.

Access

Kyle Bolger (kbolger@srec.us) began his career in solar energy in 2004 and has been dedicated to renewable development ever since. He has an Oregon Renewable Energy license and NABCEP certification and he's an IREC/ISPQ-certified PV instructor for Solar Energy International.

Justine Sanchez (justine.sanchez@homepower.com) is a NABCEP-certified PV installer, *Home Power* Technical Editor, and Solar Energy International instructor. Justine dreams of one day installing her own Web-based PV monitoring system and weather station, but for now keeps tabs on her on-grid PV system with a Fronius Wireless Personal Display.

Inverter-Based Monitoring Hardware/Software:

Enphase Energy • www.enphaseenergy.com

Fronius USA • www.fronius.com

Kaco Solar • www.kacosolar.com

Power One • www.power-one.com

PV Powered • www.pvpowered.com

SMA America • www.sma-america.com

Solectria Renewables • www.solren.com

Xantrex • www.xantrex.com

Third-Party Monitoring Systems:

Draker • www.drakerlabs.com

Energy Recommerce • www.energyrecommerce.com

Fat Spaniel • www.fatspaniel.com

Noveda • www.noveda.com

OFF-GRID INVERTER buyer's guide

by Kelly Larson

Living or working off-grid means you are responsible for all your own energy needs—you produce, store, and process every kilowatt-hour you consume. One part of that processing is converting the DC energy in your batteries to AC energy for use in standard AC appliances. This conversion is accomplished with an inverter.

There are several off-grid (a.k.a. "stand-alone" or "remote") inverters to choose from. Modern inverters are reliable, quiet, and come in a variety of sizes. This article will help demystify the inverter selection process so you can choose an inverter that is appropriate for your needs. We have restricted our list to residential-sized inverters (those that produce 1 to 6 kW), but the same process applies to larger systems. Only inverters that meet Underwriters Laboratories (UL) 1741 standards, as tested by a recognized certifying agency, are included in the list.

THE SPECS

All of the specifications listed in the table were provided by the manufacturers. Note that some published specifications are not third-party verified, i.e., by UL or an equivalent testing agency, and there have been instances in the past when some manufacturers published incorrect values—like the no-load draw, for example.

One "spec" that is not shown in the table is a comparison of how long each inverter has been in the field. This can be important since it is possible that newer models have not had sufficient testing prior to release. Also, new equipment may have software bugs or integration issues that might not yet have been discovered—which may make you an unintentional beta-tester. So if you are on the fence between two choices of inverters, you might consider how long the inverters and companies have been around before you make your decision.

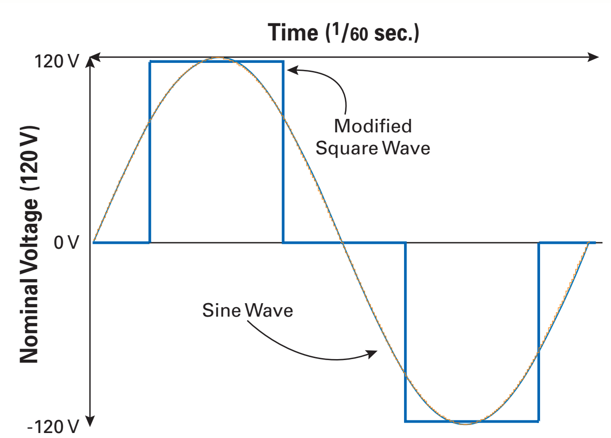
Waveform (sine wave vs. modified square wave). Modern off-grid inverters are sold with two waveform options: sine wave and modified square wave (sometimes called "modified sine wave"). Sine wave output, which has low total harmonic distortion, will power virtually any type of load, even sensitive audio electronics. Although almost all residential inverters have sine wave output, a couple of modified square wave inverters made our list for budget systems. For instance, a typical 2,800-watt sine wave inverter costs about $2,100, while a modified square wave inverter with the same output retails for about $1,500. However, modified square wave inverters may not run some types of loads satisfactorily, and some loads won't run at all (see "Problem Loads" sidebar).

Problem Loads with Modified Square Wave Inverters

Take heed if you're considering buying a modified square wave inverter to shave a few bucks off your system costs. A whole raft of modern appliances won't run as well and some not at all on this waveform:

- Laser printers, photocopiers, and anything with an electrical component called a thyristor
- Anything with a silicon-controlled rectifier (SCR), like those used in some washing machine controls
- A few laptop computers
- Some fluorescent lights with electronic ballasts
- Some battery chargers for cordless tools
- Some new furnaces and pellet heaters with microprocessor controls
- Digital clocks with radios
- Appliances having speed/microprocessor controls (like some sewing machines)
- X-10 home automation systems
- Medical equipment such as oxygen concentrators

In general, because the total harmonic distortion is higher in modified square wave inverters, motors will run hotter (less efficiently), and likely not last as long. Additionally, a modified square wave inverter will often cause a "buzz" to be heard from audio devices and sometimes other appliances like ceiling fans and microwave ovens.



OutBack FX series inverters also come in integrated packages.

Courtesy www.outbackpower.com

Total harmonic distortion (THD) is the measure of how closely the waveform matches a perfect sine wave. Glitches, transients, harmonics, spikes, and distortion all describe alterations to the waveform shape. Inverter electronics produce steps to approximate a true sine wave—the greater the number of steps, the less THD an inverter will have.

A THD of 0% is a perfect sine wave, and the larger the percentage, the farther it deviates from a sinusoidal waveform. Sine wave inverters typically show a THD of 5% or less, while the THD of modified square wave inverters may range from 10% to 40%. Because THD for modified square wave inverters varies and depends on the type of loads running, values given from manufacturers are hard to compare fairly, so these numbers are not listed for modified square wave inverters.

It is important to note that grid electricity also can have waveform distortions due to activity from all the different loads on the grid (such as large motors starting), which can cause transients in the utility waveform. Because of this continual variation of grid activity, sine wave inverters often have even less THD than grid electricity.

Rated Continuous Output Power. An off-grid inverter must supply enough power to meet the needs of all the appliances running simultaneously. Before selecting an inverter, you must know the loads you will power—and their power and surge needs. (Surge specifications are discussed separately.)

Sizing an inverter for an off-grid system, which is based on instantaneous load, is very different from sizing a grid-direct inverter, which is determined by the RE power source (i.e., PV array watts). A grid-direct inverter's job is simply to convert all the DC from the PV array into AC power, which is fed back into the house electrical system—then onto the grid if production exceeds household energy consumption. In a grid-direct system, the inverter is not responsible for meeting the AC loads, since practically unlimited utility power is available. For example, a 2,000 W grid-direct PV system would require choosing an inverter that *accepts* 2,000 W of PV on its DC input.

In the case of an off-grid system, the inverter is usually responsible for providing energy to *all* the AC loads. Say you need to simultaneously power 2,000 W of AC loads. For an off-grid system, you'd need an inverter that could *supply* at least that amount. Note that the PV array size does not enter into this inverter sizing. (For more details, see "Off-Grid Inverter Sizing" sidebar on page 99.)

Nominal Battery Voltage(s). Each inverter has a nominal battery voltage that it can be connected to. Common off-grid inverter battery voltage options are 12, 24, or 48 volts.

Smaller systems are typically matched with lower power inverters and lower battery voltages. The converse is true for bigger systems. For example, several 2,000 W inverters have a 12 V nominal battery bank voltage; 4,000 W models generally have 24 or 48 V battery bank voltages; and 5,000 W units are typically matched to 48 V battery banks only.

For the same power, higher nominal battery bank voltage means lower amps (watts ÷ volts = amps) in the battery cables—which translates to less energy loss for the same-sized cables, or smaller-diameter, less expensive cables and smaller overcurrent protection for those cables.

Some inverter companies offer models in unusual voltages. Exeltech's line of inverters, for example, includes models that can connect to 32, 66, or even 108 V battery banks. These inverters are used in various industries, such as the telecommunications industry.

Output Voltage. We've only listed inverters used in the United States to power 60 Hz 120 or 120/240 V loads. For other countries, inverter models with other output specifications do exist, often in the same model lines as listed. Most off-grid inverters have 120 V output, although some have 120/240 V ouput, which allows the inverter to power both 120 V and 240 V loads. Inverters with 120/240 V output cannot supply all their output on one leg. They are usually derated by 75% or so

Courtesy www.magnumenergy.com

The Magnum MS Series inverter is one of several models with a remote display option.

Courtesy www.xantrex.com

A Xantrex XW series inverter. At 6 kW, it's the largest inverter in the lineup.

for single leg (120 V) output only. To maximize performance, be sure to balance the loads on both legs when running 120 V loads. Inverters with 120/240 V input also can accept both legs of a 240 VAC generator, enabling you to get maximum capacity for battery charging with a single inverter.

Peak Surge. Some loads (like motors) require significantly more power during startup than they need to run. To start these loads, inverters will briefly "surge" or run at higher than their continuous power rating. Surge ratings include the maximum amperage and a time period that the inverter can run at that high power level without sustaining damage or turning off to protect itself.

Inverters may have several surge ratings (stated in either AC amps or watts), each corresponding to a specified time period. Most load surge happens in the first few milliseconds of startup. For inverters with several surge ratings, generally it is fine to consider the shortest one. For instance, OutBack Power Systems' VFX3648 can surge to 70 amps for 1 ms. Typically this is the rating you would use to determine if the inverter can supply enough power for your surges. If in doubt, talk to the inverter manufacturer to make sure the unit can supply the surge capability you need.

Loads with induction motors, like washing machines, pumps, and power tools, can have large startup surges—up to seven times the running wattage. Look for "VA" on the nameplate, "locked-rotor amps," or "surge rating" for clues that the load may have a high surge. To determine the surge of a particular appliance, either measure the load's maximum amps with a recording clamp-on ammeter, look for "start amps" in the specification sheet, or call the appliance manufacturer.

Stackability. Some off-grid inverters include the capability to connect several units together to operate as a single, larger unit. Various stacking options allow 120 V inverters to work together to power 240 V loads (such as well pumps). These inverter configurations can accept both 120 V legs of a 240 VAC generator, allowing for full usage and balancing of the AC generator output, just like a single inverter with a 120/240 V output is capable of.

Stacking setups can allow one inverter to "sleep" while power needs are low, which helps reduce standby energy loss. Series stacking 120 V inverters means that the inverters have a 120/240 V output from two inverters. Parallel stacking two inverters means the inverters will output 120 V at double the amps of a single inverter. Some inverters can be stacked to supply three-phase power, often used for heavier machinery.

Some inverters have a 120/240 V output available from a single inverter (discussed previously), so series stacking is not necessary. They can be stacked in parallel to offer more capacity (higher amps).

Inverter Peak Efficiency. Efficiency is measured as the ratio of the inverter's AC power output to the DC power input from the batteries. Higher efficiency means that the inverter wastes less power while converting DC into AC.

Note that "peak" efficiency doesn't necessarily represent actual *operating* efficiency, which changes with the size of the AC loading on the inverter. Peak efficiency is typically reached at about two-thirds of the inverter's continuous output rating, and decreases as the continuous output rating is approached. Most inverter manufacturers publish efficiency curves in their documentation. It is wise to choose inverters that have high efficiency ratings across a wide range of output wattages.

(continued on page 102)

Off-Grid Inverter Sizing

Sizing an inverter is an important part of off-grid system design. Choose an inverter that's too small and you won't be able to run all of your loads, or it might not handle startup surges. One that's too large will be a waste of some of your purchase money and an inverter that operates under its maximum efficiency—which translates to needing more energy input.

Inverter sizing starts with adding up the power needs of the loads in your off-grid system, as shown for an example home in the table. When sizing the battery and array, also be sure to account for inverter efficiency loss in the calculation. A 10% loss is standard for off-grid inverters, since they often operate at less than maximum efficiency.

Example Inverter Power Loads

Load	Operating Power (W)	Surge Power (W)
5 CF lights, 15 W lights	75	*
Refrigerator	100	300
Laptop computer	45	*
Microwave	1,400	3,000
TV	140	200
DVD player	35	*
Vacuum cleaner	1,000	2,000
Totals	**2,795**	**5,500**

*Negligible surge

Surge loads are also noted, so that an inverter with enough surge capacity to start them can be selected. For our scenario, an inverter that can handle at least 2,795 W is needed. Ensure that the chosen inverter will surge sufficiently for the loads. It is best to use actual surge values for each appliance, by either measuring or obtaining specifications from the appliance manufacturer. Then add the total run watts to the maximum surge that might occur at any given time. In this example, if all the surging appliances happen to start at the same time the other appliances are on, the surge capacity will need to be 155 + 5,500 = 5,655 W. Another way to roughly guesstimate surge requirements would be to take your maximum simultaneous watts and multiply by three—in this case, that would be about 8,400 W (70 A).

If your budget is small, you can plan for load management so you can specify a smaller inverter. It is usually easy to remember that the inverter will not handle, for example, running both the microwave and the vacuum at the same time, which would reduce the inverter size needed to 1,795 W. However, although restricting the larger loads can be effective, this strategy gets more difficult to implement with each additional person in the household.

Also consider future expansion: Power needs grow in almost all systems, and upsizing to a somewhat larger inverter usually makes sense. Choosing an inverter that can be "stacked" with additional inverters to increase continuous output power will enable easier future expansion. Finally, off-grid inverters typically run most efficiently running at about two-thirds of their rated power. Rather than maxing out its load capacity, choosing a slightly larger inverter could allow it to operate in a more efficient power range. In the long term, this could offer better value—the loads will take less energy out of your system and the inverter will run cooler, subsequently lasting longer.

Possibilities

For our example home's loads, there are many possibilities that will work, including:

- Using load management: When simultaneous loads total less than 2,000 W, a 2,000 W inverter, like Exeltech's XP2000, is a relatively inexpensive choice. These inverters are easy to install and have a very accurate sine wave output. However, this choice offers no ability for expansion, greatly restricting system flexibility.
- OutBack's VFX3524 (a 3,500 W inverter) may be a good choice, since it has a higher power rating and a surge capability of 70 A.
- If 12 VDC loads are also part of the system, choose an inverter that will work with a 12-volt battery, like Magnum's MS2812, 2,800 W inverter. Most modern homes do not have DC loads. But if wire runs are short, continuous DC loads, such as an answering machine or fan, can run directly off the battery bank. Running continuous loads on DC allows the inverter to spend more time in its power-saving mode. The Magnum MS2812 has a 30 W no-load draw, but only draws 7 W in sleep/search mode.

Other Considerations

Waveform—Only budget systems have modified square wave inverters. Are there any loads on your list that won't run on a modified square wave? If so, rule out modified square wave inverters. For instance, in our example, the loads with motors, like the refrigerator, microwave, and vacuum, will run hotter and may not last as long running on a modified square wave inverter. Also, as side effects of the modified square waveform, interference may show up as lines on some TV displays or be heard in audio outputs. Some households choose to use a modified square wave inverter/charger, and separately supply more finicky audio-visual loads with a small pure sine wave inverter.

AC Output Voltage—If there is a generator with 240 VAC output or there are 240 VAC loads, consider inverters that have 120/240 V output to balance the generator output when charging batteries. These inverters can also provide 240 VAC to the loads *without* having to run the generator. Options here include the Apollo Solar TSW3224 or Xantrex XW4024. Alternatively, you can stack some 120 V inverters for 240 VAC output, or use a single inverter in conjunction with a 120/240 VAC step up/down transformer.

If a generator is used in the system, an AC battery charger will be needed to charge the batteries when RE is not available or the batteries need an equalizing charge. Most off-grid inverters have integrated AC battery chargers. A battery charger that's too small (compared to the generator's maximum output) will waste fuel and take a long time to charge the batteries. A charge rate that's too high will charge the batteries too fast and heat them up, causing harm to the battery bank, so be sure the settings on the AC battery charger are adjusted to the battery manufacturer's specifications.

Off-Grid Inverter Selection Guide

Manufacturer	Model	Wave-form	Max. THD (%)	Rated Continuous Output Power (W)	Nominal Battery Voltages	Output Voltage	Peak Surge (AC Amps)	Stackability	Inverter Peak Efficiency (%)
Apollo Solar www.apollosolar.com	TSW3224	Sine	5	3,200	24	120/240	80 A for 1 ms @ 120 V	Parallel	93
	TSW3648	Sine	5	3,600	48	120/240	80 A @ 1 ms, 120 V	Parallel	95
Exeltech www.exeltech.com	XP K (1100)	Sine	2	1,100	12, 24, 48	120	18.8 A for 3 s	No	89
	XP X (2000)	Sine	2	2,000	12, 24, 48	120	37.6 A for 3 s	No	89
	MX	Sine	2	1,000	12, 24, 48	120	17.1 A for 3 s	Series, parallel, 3-phase	89
Magnum Energy www.magnumenergy.com	MS4024AE	Sine	5	4,000	24	120/240	120 A for 1 ms @ 120 V	Parallel	93
	MS4448AE	Sine	5	4,400	48	120/240	120 A for 1 ms @ 120 V	Parallel	94
	MS2012	Sine	5	2,000	12	120	50 A for 1 ms	No	93
	MS2812	Sine	5	2,800	12	120	70 A for 1 ms	No	94
	MS4024	Sine	5	4,000	24	120	120 A for 1 ms	Series	91
	RD2212	Mod.	—	2,200	12	120	60 A for 1 ms	No	95
	RD1824	Mod.	—	1,800	24	120	70 A for 1 ms	No	95
	RD2824	Mod.	—	2,800	24	120	100 A for 1 ms	No	94
	RD3924	Mod.	—	3,900	24	120	150 A for 1 ms	No	93
OutBack Power Systems www.outbackpower.com	FX2012T	Sine	5	2,000	12	120	56 A for 1 ms	Series, parallel, 3-phase	90
	FX2524T	Sine	5	2,500	24	120	70 A for 1 ms	Series, parallel, 3-phase	92
	FX3048T	Sine	5	3,000	48	120	70 A for 1 ms	Series, parallel, 3-phase	93
	VFX2812	Sine	5	2,800	12	120	56 A for 1 ms	Series, parallel, 3-phase	90
	VFX3524	Sine	5	3,500	24	120	70 A for 1 ms	Series, parallel, 3-phase	92
	VFX3648	Sine	5	3,600	48	120	70 A for 1 ms	Series, parallel, 3-phase	93
SMA America www.sma-america.com	SI 4248U	Sine	3	4,200	48	120	140 A for 5 s	Series, parallel, 3-phase	95
	SI 5048U	Sine	3	5,000	48	120	150 A for 100 ms	Series, parallel, 3-phase	95
Xantrex Technology www.xantrex.com	XW4024	Sine	5	4,000	24	120/240	75 A for 20 s @ 120 V	Parallel	95
	XW4548	Sine	5	4,500	48	120/240	70 A for 20 s @ 120 V	Parallel	95
	XW6048	Sine	5	6,000	48	120/240	105 A for 7 s @ 120 V	Parallel	95
	TR1512	Mod.	—	1,500	12	120	50 A for 10 s	Series	90
	TR2412	Mod.	—	2,400	12	120	80 A for 10 s	Series	92
	TR1524	Mod.	—	1,500	24	120	50 A for 10 s	Series	92
	TR2424	Mod.	—	2,400	24	120	80 A for 10 s	Series	93
	TR3624	Mod.	—	3,600	24	120	120 A for 10 s	Series	94

*If out of warranty: $100 flat-rate fee applies for any repairable failure

No-Load Draw (W)	Search Power (W)	Battery Charger Max. Current (DC Amps)	Battery Temp. Sensor	Generator Start	Metering	Remote Display	Integrated System Available?	Dimensions (In.)	Weight (Lbs.)	Warranty (Yrs.)
27	5.0	100	Yes	Optional	Yes	Optional	Yes	22.5 x 9 x 7.25	49.0	5
27	5.0	70	Yes	Optional	Yes	Optional	Yes	22.5 x 9 x 7.25	49.0	5
10 (Optional)	—	No	No	No	No	No	No	3.6 x 7.7 x 15.1	10.0	1*
12	—	No	No	No	No	No	No	4 x 9 x 18	15.0	1*
20	—	No	No	No	Optional	Optional	No	Various x 7 x 15	7.5	1*
27	<6.0	105	Included	Optional	Optional	Optional	No	13.75 x 12.65 x 8	54.5	2
25	<8.0	60	Included	Optional	Optional	Optional	No	13.75 x 12.65 x 8	54.5	2
25	7.0	100	Included	Optional	Optional	Optional	No	13.75 x 12.65 x 8	42.0	3
30	7.0	125	Included	Optional	Optional	Optional	No	13.75 x 12.65 x 8	55.0	3
25	7.0	105	Included	Optional	Optional	Optional	No	13.75 x 12.65 x 8	55.0	3
20	2.4	110	Included	Optional	Optional	Optional	No	13.75 x 12.65 x 8	38.0	2
12	7.2	50	Included	Optional	Optional	Optional	No	13.75 x 12.65 x 8	38.0	2
19	7.2	80	Included	Optional	Optional	Optional	No	13.75 x 12.65 x 8	42.0	2
25	7.2	105	Included	Optional	Optional	Optional	No	13.75 x 12.65 x 8	45.0	2
20	6.0	80	Optional	Yes	Yes	Optional	Yes	16.25 x 8.25 x 13	62.6	2
20	6.0	55	Optional	Yes	Yes	Optional	Yes	16.25 x 8.25 x 13	62.6	2
23	6.0	35	Optional	Yes	Yes	Optional	Yes	16.25 x 8.25 x 13	62.6	2
20	6.0	125	Optional	Yes	Yes	Optional	Yes	16.25 x 8.25 x 12	61.0	2
20	6.0	85	Optional	Yes	Yes	Optional	Yes	16.25 x 8.25 x 12	61.0	2
23	6.0	45	Optional	Yes	Yes	Optional	Yes	16.25 x 8.25 x 12	61.0	2
22	<4.0	100	Included	Yes	Yes	Optional	Yes	15.35 x 23.23 x 9.65	86.0	5
25	<4.0	100	Included	Yes	Yes	Optional	Yes	18.4 x 24.1 x 9.3	139.0	5
24	<8.0	150	Included	Optional	Yes	Optional	Yes	23 x 16 x 9	115.0	5
26	<8.0	85	Included	Optional	Yes	Optional	Yes	23 x 16 x 9	115.0	5
28	<8.0	100	Included	Optional	Yes	Optional	Yes	23 x 16 x 9	125.0	5
26	4.2	70	Included	Optional	Yes	Optional	Yes	8.5 x 7.25 x 21	40.0	2
25	4.2	100	Included	Optional	Yes	Optional	Yes	8.5 x 7.25 x 21	42.0	2
25	4.1	35	Included	Optional	Yes	Optional	Yes	8.5 x 7.25 x 21	40.0	2
24	4.1	70	Included	Optional	Yes	Optional	Yes	8.5 x 7.25 x 21	45.0	2
24	4.8	70	Included	Optional	Yes	Optional	Yes	8.5 x 7.25 x 21	45.0	2

SMA America's Sunny Island 5048U can function as a stand-alone battery-based inverter or integrate with Sunny Boy inverters to create an AC-coupled system.

Exeltech inverters have very clean sine wave forms, but do not include battery chargers.

No-Load Draw. This is the power used by the inverter just to keep running when there is no load. No-load draw can be surprisingly high in some models (up to 30 W). Since there may be long periods of time when no power is required by the loads, this can add up to a substantial energy drain on the system. For instance, an inverter with a 30 W no-load draw will consume a minimum of 720 Wh daily. On small systems, this load can have a significant impact, especially in the winter when solar-made energy is at a premium.

Search Power. Most off-grid inverters have a power-saving feature called "search" or "sleep" mode to power down the high-energy-use components of the inverter when there are no loads on. Search mode also requires power, but much less than the no-load draw. In this mode, the inverter periodically tests the circuit for active loads and powers up only if a load is detected. But homes that have continuously running AC loads (like a telephone answering machine's 2 W wall cube) are unable to take advantage of this feature and are stuck with a minimum of the no-load draw. Some off-grid homeowners will strive for always-on loads to be DC-powered to allow their inverters to spend more time in energy-conserving search mode.

Battery Charger. Many off-grid inverters have an integrated battery charger that can be used to charge the batteries from an AC source, such as an engine generator. This feature negates the need for a separate external battery charger. Having an integrated charger is especially helpful during periods when an RE power source cannot keep up with household loads, such as during the short and often cloudy days of winter. The battery charger is also used to "equalize" batteries by giving them a controlled overcharge, making sure that even the weakest battery cells are occasionally brought up to full.

Chargers are usually rated in DC amps, but may be stated as AC amps, so read the documentation carefully. In the table, AC battery charger maximum current has been converted to DC amps.

Battery Temperature Sensor. The internal resistance of a battery increases as temperatures drop and decreases as temperatures rise, affecting battery voltage. At a given charge rate, at low temperatures batteries can get undercharged and at high temperatures they can get overcharged. To properly charge batteries where the temperature strays from the ideal 77°F, a temperature sensor provides data to the charger so it can adjust the voltage set points for higher and lower temperatures.

Generator Start. Some inverters can start and stop a generator based on several criteria, such as battery voltage, battery state of charge (SOC), load draw, and time of day. Generators can have either a "two-wire" or "three-wire" start mechanism. A two-wire start refers to two positions—on and off—and requires only a simple relay and a signal from a controller in the inverter/charger.

A three-wire start—a crank position, run, and stop—is more complex. There may also be pre-crank and other settings, as needed for diesel engines. Facilitating a three-wire start usually requires a separate controller from the generator manufacturer. Typically, inverters that advertise automatic generator start can be assumed to provide only the signal for a two-wire start. (For more information, see "Engine Generator Basics" in *HP131*.)

Metering. Several inverters offer metering as an optional accessory. Metering can provide helpful information about the system, including battery voltage (lets you know if the battery

The Apollo TSW series inverter, with charge controller and breaker panel, comes in 24 V (3,200 W) or 48 V (3,600 W) versions.

Courtesy www.apollosolar.com

Courtesy www.outbackpower.com

OutBack Power Systems offers components to put inverters, charge controllers, and other required balance-of-system components together in one neat installation.

is being charged or discharged), AC load amps (indicates the size of the AC loads), battery charging amps (from the AC power source), and even error codes (helpful for inverter troubleshooting).

With programmable inverters, the meter is often also a user interface for controlling other functions, such as turning the inverter on/off, starting a generator, or adjusting battery charger settings.

Remote Display. Usually the inverter is installed away from living spaces, and remote metering allows users to easily monitor their systems from a location away from the balance-of-system components. Often, remote displays show various other system metering details and have a switch to shut off the inverter. Aftermarket meters are available that can supplement the information available, like provide accurate battery SOC readings.

Integrated System Components Available. Some inverters can be part of packaged systems to ensure that individual parts—such as metering, charge controllers, and circuit breaker/disconnect boxes—work together and physically fit together.

Integrated system components offer a few advantages. First, the unit is engineered so the components fit together easily. Second, proper wire sizes are accommodated in appropriately sized boxes, and knockout holes that match up in the boxes and components. Often, a mounting plate that supports the whole system and provides the layout for the components is included. These systems can be prewired by the factory or distributor to meet the specific needs of an installation—all the installer needs to do to the integrated components is properly wire the inputs and outputs.

Electronic and communications integration can optimize operations such as battery charging and load support, eliminate the duplication of sensors (such as battery temperature sensors for both charge controllers and inverters), and provide a means for external data collection. A central control/meter can display system settings and data values, and simplify the user interface. Operations like generator start-and-stop controls can easily access needed parameters and data values, such as PV input, loads, and battery SOC.

Weight. Most of the weight of an off-grid inverter comes from the iron core transformer, which gives high surge capacity—an iron core can store energy for a few cycles, creating a flywheel effect to carry the inverter through surges.

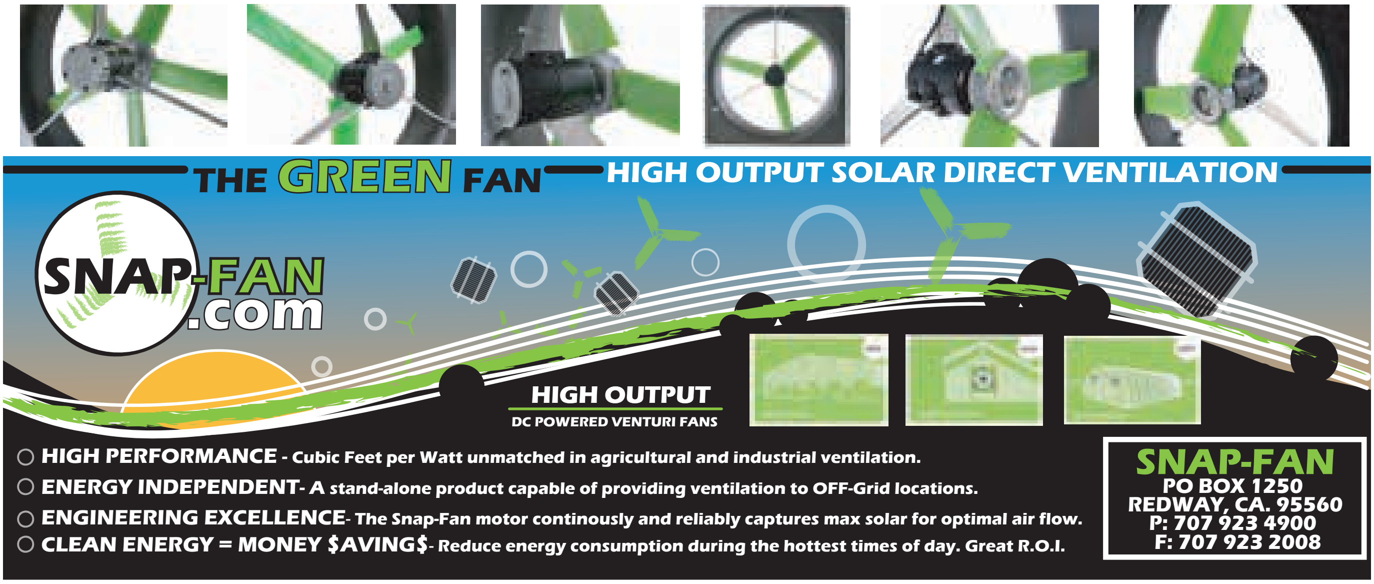
If you are running only small electronics that have negligible surges, a lightweight inverter may serve you well. For instance, Exeltech inverters are very light, so they don't provide much surge capacity—yet they have a very fine waveform for finicky electronics, such as audio or telecommunications equipment.

If you are powering loads with high surges, like induction motors, seek a heavier inverter—and ensure that it is securely mounted to support its weight.

Warranty. Off-grid inverters are warranted against defects in materials and workmanship for up to five years, and extended warranties are sometimes available. Inverter manufacturers are typically quite responsive to addressing inverter failure and malfunction. Your installer or dealer can help with warranty problems and will be the initial contact.

ACCESS

"Solar Kelly" Larson is a NABCEP-certified PV installer and a licensed electrical contractor working in Mendocino County, California. Kelly has been teaching RE classes since 1996, and delights in simplifying complex concepts for students of all ages and abilities.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Model	Max VDC	PV Source Circuits: Max # of Input Circ.	PV Source Circuits: Max OCPD Rating Amps	PV Source Circuits: OCPD Type	PV Source Circuits: Wire Range AWG	PV Output Circuits: Max # of Output Circ.	PV Output Circuits: Max Cont. Current amps	PV Output Circuits: Wire Range AWG	Approved Mounting Orientation	Enclosure Type / Material	Listing
MNPV3 (LV)	150	3	20	CB 150V	14-6	1	60	14-1/0	90 to 14°	3R / Alum	UL1741
MNPV3 (HV)	600	3	20	FUSE	14-6	1	60	14-1/0	90 to 14°	3R / Alum	UL1741
MNPV6 (LV)	150	6	20	CB 150V	14-6	2	120	14-1/0	90 to 14°	3R / Alum	UL1741
MNPV6 (HV)	600	4	20	FUSE	14-6	2	80	14-1/0	90 to 14°	3R / Alum	UL1741
MNPV12 (LV)	150	12	30	CB 150V	14-6	2	200	14-2/0	90 to 14°	3R / Alum	UL1741
MNPV12 (HV)	600	10	40	FUSE	14-6	2	200	14-2/0	90 to 14°	3R / Alum	UL1741
MNPV12-250	300	6	50	CB 300V	14-6	2	168	14-2/0	90 to 14°	3R / Alum	UL1741
MNPV16 (HV)	600	16	15	FUSE	14-6	1	240	250MCM	90 to 14°	3R / Alum	UL1741
MNPV16-250	300	12	20	CB 300V	14-6	1	240	14-2/0	90 to 14°	3R / Alum	UL1741

Inverter Ins & Outs

by John Wiles

The utility-interactive inverter is a key element in a grid-tied PV system, and helps ensure safe and automatic operation of the system.

The output power of a PV array depends on the load that is on the array. No loading (0 amps) operates the array at its open-circuit voltage point (Voc), while the heaviest loading (a short-circuit) would operate the array at the short-circuit current (Isc) point. At either of these points, no power output from the array is available. However, for every condition of sunlight intensity (irradiance) and array temperature, there is a load that will extract the maximum power from the array. And a utility-interactive inverter will find that peak power point and readjust loading to maintain maximum power as sunlight and temperatures vary throughout the day. This is called maximum power point tracking and is a part of all grid-tied inverters.

Automatic Operation

Utility-interactive inverters are designed, manufactured, tested, and certified/listed to operate automatically. They seamlessly convert DC from the PV array into AC that is fed into the premise's AC wiring system. The output of the inverter is connected in parallel with this wiring and the utility service.

One of the most important aspects of the inverter is the anti-islanding circuit, which is designed to keep the premise's wiring and utility feeder de-energized in the event that utility power is not available—like if the grid is being serviced or has suffered an interruption.

Unlike an engine-driven generator which, if improperly installed, can feed power into a blacked out/disconnected local utility feeder system, the anti-islanding system prevents the inverter from energizing a "dead" electrical system. Anti-islanding prevents the inverter from delivering AC if the utility voltage and frequency are not present, or if they are not within narrowly defined limits. This circuit monitors the voltage and frequency at the inverter's output. If the voltage varies +10% to -12% from the nominal output voltage the inverter is designed for (120, 240, 208, 277, or 480 V), the circuit prevents the inverter from sending power to the output terminals. In a similar manner, if the frequency varies from 60 Hz—more than 60.5 Hz or less than 59.3 Hz—the circuit also prevents the inverter from sending power to the AC output.

When the voltage and frequency from the utility return to specifications for a period of 5 minutes, the inverter is again enabled to send PV power to the AC output. When the inverter is not processing DC PV power into AC output power, it essentially disconnects from the PV array by adjusting the load on the PV system to a point where there is no power, usually the array's Voc point.

Circuit & Array Sizing

Sizing the DC input circuit to the inverter is based on the DC short-circuit current (Isc) in those conductors. Although full ampacity calculations are too complex to cover in this article, the current rating for the DC input circuits is near 1.56 times the Isc (*NEC* Section 690.8). Normally, the PV array is rated in watts at standard test conditions of 1,000 watts per square meter of irradiance and a cell temperature of 25°C.

In most cases, the array will average a lower power output due to increased inefficiencies as PV cells heat up. For this reason, inverter manufacturers typically suggest sizing the PV array 10% to 20% greater than the inverter's AC output rating. If an oversized array is used, the inverter will spend more operating time each day closer to the rated power output than an inverter rated the same as the array's STC rating. The penalty for designing an oversized system is increased initial costs (more modules), some potential for lost power on sunny, cool days, and possibly some slight reduction in the inverter life due to longer operation at higher temperatures.

An inverter's AC output circuit must be sized at 125% of the inverter's rated output current (Section 690.8). Some inverter manufacturers specify the rated current or a range of values (due to varying line voltages from nominal). If this specification is not given, then the rated power may be divided by the nominal line voltage to determine a rated current. For example, a 2,500 W inverter operating at a nominal voltage of 240 V would have a rated current of 10.4 A (2,500 W ÷ 240 V), so the output circuit would need to be sized to handle 13 A (1.25 x 10.4). In this case, a 15 A breaker would be used.

Grid-tied inverters are not capable of providing sustained (more than 1 second) surge currents, so the rated output current is all that can be delivered. When faced with a short-circuit, the rated output current is all that can be delivered—but more than likely, the reduced line voltage due to the fault will cause the inverter to shut down.

Dedicated Circuit

NEC Section 690.64(B)(1) requires that the inverter output be connected to the utility power source at a dedicated disconnect and overcurrent protective device (OCPD). In most systems,

GFCIs & AFCIs

The AC output of a utility-interactive inverter should not be connected to a GFCI or AFCI breaker, as these devices will be damaged if backfed. These devices have terminals marked "line" and "load" and have not been identified/tested/listed for backfeeding.

this is a backfed breaker in a load center [Section 690.64(B)]. Inverters may not have their outputs connected directly to another inverter or directly to a utility-supplied AC circuit without first being connected to a dedicated disconnect/OCPD. (Utility-interactive microinverters and AC PV modules are an exception to this rule, since they are tested and listed to have multiple inverters connected in parallel on a single circuit with only one OCPD/disconnect device for the entire set of inverters.)

The AC output of a utility-interactive inverter should not be connected to a GFCI or AFCI breaker, as these devices will be damaged if backfed. These devices have terminals marked "line" and "load" and have not been identified, tested, or listed for backfeeding.

The OCPD must be sized at a minimum of 125% of the rated inverter output current (or, in the case of multiple microinverters or AC PV modules, their total rated output current). This OCPD must protect the circuit conductor from overcurrent from the utility-side connection. It is usually not a good idea to install a larger OCPD than the minimum required value because the inverter may, as part of the listing/instructions, be using the OCPD to protect internal circuits. However, rounding up to the next standard breaker size is allowed per *NEC* 240.4(B), and is often needed.

Is it a Branch Circuit?

In every practical sense, the utility-interactive inverter AC output circuit is just like a branch circuit. Consider the typical residential branch circuit:

- It is protected by an OCPD at the source of power (the utility) that can damage it.
- If the breaker protecting the branch circuit is opened, it becomes deenergized.
- If the branch circuit suffers a solid ground fault or a line-to-line fault, the OCPD will open and protect the conductor.
- The branch circuit may be wired with Type NM cable in residential applications.

Now consider the circuit between the utility-interactive inverter and the dedicated disconnect/OCPD (usually a breaker).

- It is also protected by an OCPD at the source of power (the utility) that can damage it. Since the circuit is sized at 125% of the rated output current of the inverter and the inverter current is limited to the rating, the inverter is not a source of power that can damage the conductor.
- If the breaker protecting this circuit is opened, it becomes deenergized.
- If this circuit suffers a solid ground fault or a line-to-line fault, the OCPD will open, protecting the conductors—plus, the inverter will shut down.
- In residential applications, it also may be wired with Type NM cable.

So these AC output circuits from the utility-interactive inverters can be wired like any other branch circuit in a residence. Of course, the inverters are surface-mounted devices and there may be the possibility of exposed Type NM cables being subject to physical damage. If they are, then conduit or another wiring method would be required.

NEC *Typo*

Section 690.31(E) in the 2005 and 2008 editions of the *NEC*, which addresses how PV circuit conductors enter a building, contains a typo. The first sentence starts: "Where direct-current source or output circuits *of* [emphasis added] a utility-interactive inverter from a building-integrated or other photovoltaic system…"

The word "of " should have been "to" and will be corrected in the *2011 NEC*.

Access

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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

Nuke Plants

An Endangered Species?

by Michael Welch

Are nuclear-powered plants on their way to becoming the woolly mammoths of the U.S. electrical-generating world? That has long been the hope of many renewable energy activists and concerned citizens, and recent news items may be heralding the early days of this species' demise.

Every spring, the anniversaries of two of the most catastrophic nuclear reactor events (Three Mile Island and Chornobyl) cause me to reflect upon the value of nuclear energy relative to the risks inherent in the technology. The fear of and results from those catastrophes—and the knowledge that they will likely happen again—turned me into a keen hunter of the nuclear mammoth. Depending upon the source, the radioactive releases from the Three Mile Island meltdown either caused no human health effects (Pennsylvania Department of Health) or caused a 600% increase in cancer deaths and a statistically significant increase in infant mortality (TMI Public Health Fund). Likewise, the Chornobyl meltdown either killed 57 workers and emergency personnel (International Atomic Energy Agency) or an additional 130,000 residents (Ukrainian Ministry of Public Health).

In 1976, three nuclear engineers quit their high-paying jobs with General Electric's Nuclear Energy Division. Having once been excited about the prospect of a "limitless" source of energy, Dale Bridenbaugh, Greg Minor, and Richard Hubbard soon testified before Congress' Joint Committee on Atomic Energy that "we could no longer justify devoting our life energies to the continued development and expansion of nuclear fission power…" They believed this energy source to be so dangerous that "it now threatens the very existence of life on this planet." They went on to state that deficiencies "in the design, construction, and operation of nuclear power plants make a nuclear power plant accident…a certain event. The only question is when and where."

That question was answered three years later in Harrisburg, Pennsylvania—and again a mere 10 years later in Chornobyl in the Ukraine. While some of the consequences of the meltdowns have been acknowledged, the horribly unfortunate thing is that the real lessons were overlooked, making the "certain event" likely to happen again.

The fear of accidents is enough to turn many citizens against the use of nuclear energy, and was the impetus that spurred me—and many others—into relentless "hunters" of the industry. Many other factors heap even more fodder onto the "No Nukes" side of the argument.

- No effective method exists to deal with reactors' high-level radioactive waste, which will remain dangerous for hundreds of thousands of years.
- Huge amounts of public money invested in nuclear energy take funding away from other cleaner, cheaper, and less centralized technologies.
- Nuclear energy is more expensive than any other commonly used source of electricity.
- Siting, licensing, and construction lead times on plants can span a decade.
- It's the most centralized form of electricity production, since reactors must be humongous to approach justifying their economics, and they must be located away from populated areas (where the electrical loads are) for safety reasons.
- It produces "waste" materials that can be used to build nuclear weapons and "dirty" bombs.
- The processing of uranium into reactor fuel is a dirty and hazardous procedure.
- The mining of uranium exploits uninformed workers in developing nations, and leaves huge amounts of dangerously radioactive tailings and dust behind.
- Nuclear power plants require vast amounts of cooling water, and the return of the heated water back to its source affects the flora and fauna in those waters.
- Nuclear reactors are attractive targets for terrorist attacks.

Despite the seemingly overwhelming evidence condemning the use of nuclear energy, this has not been enough to kill it. It turns out that the industry is a hearty breed and able to survive by using propaganda and undeserved political influence. Although pronuclear faithfuls were in the minority for many years—reducing the likelihood that new nuke plants might be built—human-caused climate change has breathed new life into the nuclear industry with a new source of propaganda to exploit: Compared to fossil-fueled power plants, nuclear power plants produce less carbon dioxide while operating.

But this industry is one that should be allowed—no, *encouraged*—to go extinct, for the sake of all the real species living on Earth. And hunters of the nuclear industry are celebrating recent events that are indications of the declining nuclear species.

Jon Wellinghoff is the new chairman of the Federal Energy Regulatory Commission—one of two major federal agencies that deal with energy. In April, he stated that we may never need to build a new nuclear power plant, claiming that nuke plants were too expensive. He said, "The last price I saw for a nuke was north of $7,000 a kilowatt. That's more expensive than a solar system." He explained that renewables and improved energy efficiency will meet future demand and that, in the meantime, natural gas can fill in.

Over the past four presidential administrations, Nevada's Yucca Mountain has been the only potential permanent repository for high-level radioactive waste. But despite tens of billions of dollars spent and a Congress seemingly willing to spend $50 billion more, the project has never held much promise—mainly because the siting and concept were bad ideas from the beginning. The site was not chosen on its merits, but rather because there was less political power in Nevada opposing the site—even though other states had potentially more appropriate geology for a repository that needs to last for a thousand centuries.

The Obama administration intends to terminate the project, and has removed from its budget request any monies needed to move forward. In the meantime, the administration says they will explore other ways of dealing with reactor waste storage. My guess is it will pile up at the plant sites, while bureaucrats and the nuke industry hope for some kind of technological breakthrough for dealing with dangerous nuclear waste—the same hope they've had since the 1950s.

Another foretelling of the dying nuke industry is its recent inability to get what it needs for a resurgence: lots of free or "cheap" money. Time after time, the industry has tried to slip into legislation billions of dollars in federally guaranteed loans so that its financing problems will go away. Lenders consider repayment of nuclear financing so risky that money is not available to the nuke industry. But if the industry could get taxpayers to guarantee the loans, lenders would be more than willing to make the money available since there would be no risk to them. Then, when a nuke plant fails for whatever reason, taxpayers will pay off its loans. At least four times this year, nuke loan guarantees have made it into legislation—and three times, grassroots efforts have been successful at having them removed before passage. As I write this, another attempt was slipped into the Clean Energy Bank bill that would make unlimited loan guarantees available to the nuke industry. Activists are working hard to fight this, and the wording will likely be eliminated—showing once again that the nuclear mammoth is on its way out.

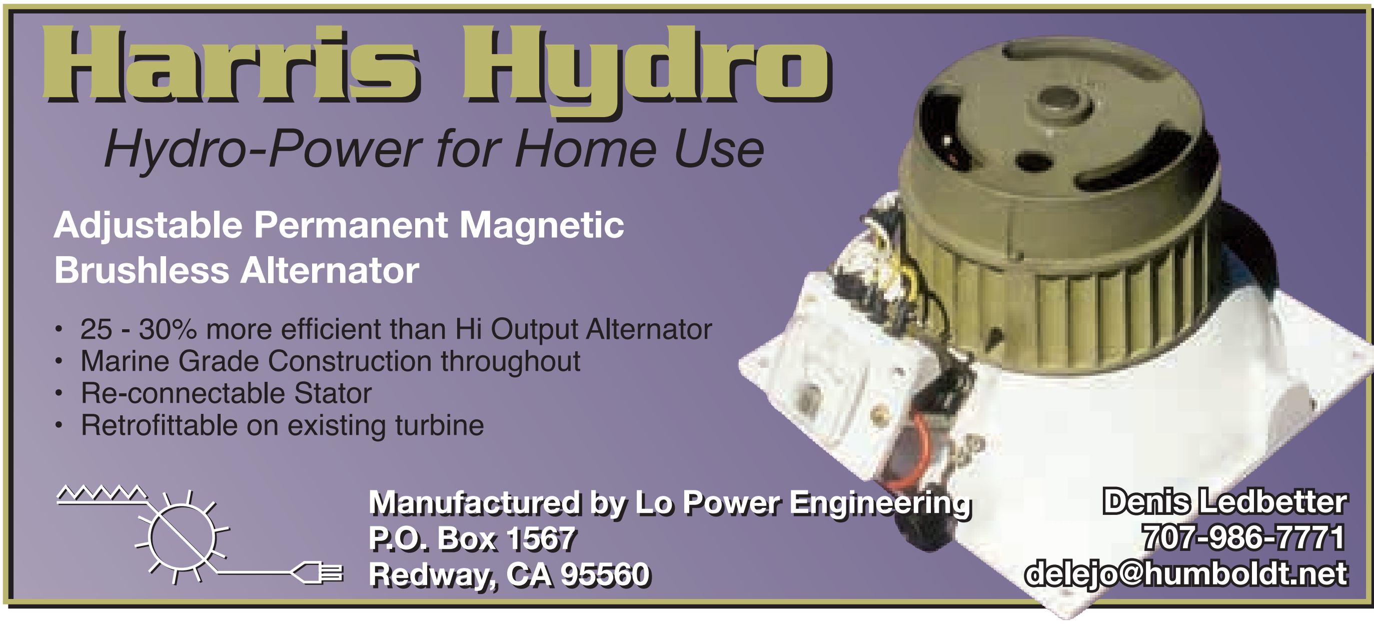
In a monumental grassroots victory, local activists have halted the planned construction of a nuclear power plant in Missouri. Utilities that want to build expensive new power plants have long counted on being reimbursed for construction work in progress (CWIP). This allows them to recoup their investment as a plant is built, thus shifting the risk and financial burdens to ratepayers without providing them with any electricity. But Missouri activists passed a state law banning CWIP, which applies to high-cost, long lead-time nuclear power plants. After failed attempts by the nuke industry to have the law overturned, utility AmerenUE cancelled its plans to construct a new French Areva reactor at the Callaway, Missouri, site.

There has not been a single nuclear power plant that has started construction in the United States since Three Mile Island, and the overall percentage of U.S. electricity coming from nuclear has been on the decline ever since solar and wind (competing species) have gained a foothold in nuclear energy's territory.

The nuclear industry continues to lobby for government funding, and still tries to convince the public that the technology is safe. Like the woolly mammoth, though, it is not aware of its impending demise as the citizens and government support truly renewable, sustainable energy sources. The extinction of the mammoth was due in part to pressure from hunting. So also goes the nuke industry, as modern humans keep up the pressure and sharpen their hunting skills by using the political system and improving grassroots organizing around the issue.

Access

Michael Welch (michael.welch@homepower.com) is keeping his political spear well honed and aimed at the heart of the nuclear industry.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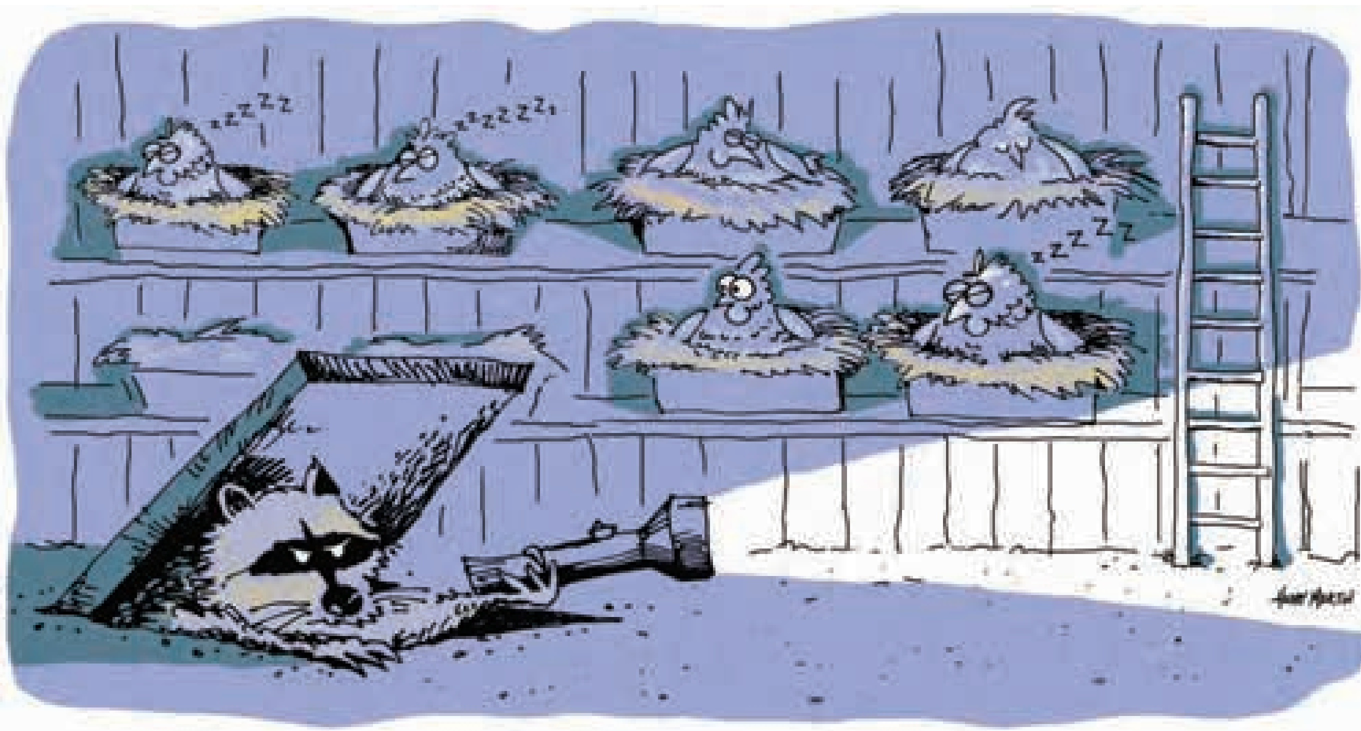
The Chicken

House of Murder Mystery

by Kathleen Jarschke-Schultze



In *HP101*, I recounted my attempt to build a varmint-proof chicken house. I was very proud of the poultry palace that resulted and thought I had achieved my goal. For the past couple of years, I had a nice, small flock of chickens. They could not free-range during the day because of my Airedale terrier, Emma, but they were happy.

Poultry Palace

A small tunnel, fabricated from a square tomato cage wrapped in 1-inch chicken wire, connects my chicken house to a fenced garden area. Inside the coop, a small door, hinged on the bottom, drops down to create a ramp into the tunnel. This door is locked with a spring-loaded hook-and-eye fastener. One end of the tunnel is stitched onto the coop with baling wire. It is a very stout attachment.

When the garden was not growing vegetables for us, it was the chickens' playground. There was plenty of room for them to roam. When the garden was being used, I fenced a smaller area just outside the tunnel so the flock could get into some dirt outside the coop. All the garden weeds were tossed into their outdoor run. Chickens love them.

Through time, I gained and lost chickens. Some succumbed to MCD (Mystery Chicken Death) and when they jumped the fence, a few died of DOG. Still, I had a nice flock that laid enough eggs for us—and to sell to eager friends.

Hawkeye

I was in the house one spring day—when the flock still had the run of the garden—when I heard an explosion of squawks. I thought maybe they had spotted a snake and set up an alarm, so I went outside to investigate. A hawk was sitting on my newly erected pea trellis, eyeing my hens. The hens were freaking out and trying to find cover. I ran down to the garden, yelling and making as much noise as I could.

The hawk watched me coming for a moment and then flew off, but only to a nearby tree. Most of the chickens darted for the tunnel. One hen got herself stuck, headfirst, between the slats of a compost bin made out of wooden pallets. When I went to extricate her by pulling from behind, she almost fainted. I really think she was in shock. I carried her back to the coop and locked the birds in for the rest of the day.

So later on, when I found a dead hen in the garden, I figured it was the hawk. I erected a shade structure over their yard. This, I thought, would end the problem. But it didn't. One by one, something continued to kill my chickens. I knew it was a varmint because the hens were eviscerated and their bodies left. I kept the surviving flock in the locked coop. Certainly my wonderful poultry house would keep them safe. My friends suspected that a weasel or some other varmint that could squeeze itself through a very small opening was the culprit. I scoured the whole building, looking for breaches. I used U-shaped fencing nails and tacked down every bit of chicken wire on the coop. Only a mouse could get through the 1-inch openings, but a mouse could not kill a chicken, nor would it try.

Last Stand

Even inside the coop run, more birds succumbed to the mystery predator. I was down to two hens. During the day, I kept them in the coop run. At night, I locked them in the inner coop.

Three days later, they were both dead. The modus operandi of their killing was the same as the others. I gave up on the idea of having chickens. I started using the coop to store yard equipment and let it go at that.

It's been several years now. I had determined that if I was to have chickens again I wanted a free-range flock. That meant I could not even consider a new flock while Emma, my dog, was alive. Sadly, she passed on last December.

Mystery Solved

One day in early spring, my sister Tamra called. One of her hens had hatched chicks. As it always seems to happen, there was a preponderance of roosters. For a while she had the Three Amigos. But as they got bigger, her rooster, Bobnoxious, began picking, or pecking, on them. Now, Bobnoxious placed fourth in the National Rooster Crow Championship last year, so Tamra had some chicken connections and it was not hard to find homes for two of the three. She wanted me to have Ned, the third Amigo.

I had to get ready—fast. I cleaned the coop run out. I found the waterer and feeders, and cleaned them. I had been avoiding the coop and nest boxes. I cleaned them and composted the well-aged litter and straw.

That's when I found the hole. You see, I thought I was being clever by laying empty feed sacks on the coop floor, under the roosts. As the droppings collected on top, I would cover them with straw or cedar shavings—all the better to compost later. I figured that putting the paper sacks down first would make the cleanup process easier.

What it did was allow a varmint to push a loose board up from the bottom underneath the coop and enter that way—without my notice. How could I have missed this? Easily, apparently. I took my hammer and nailed the heck out of those floorboards.

Flock Finding

For awhile, Ned was alone in the coop. I felt sorry for him and would sit with him for a bit every day. I took him vegetable scraps, and he would pick them up, then drop them and call to me like I was a hen. "Here's food for you," he'd say. I would hold him in my lap and feed him chicken scratch out of my hand. We became buddies.

I found three barred rock pullets for sale in a nearby town and brought them home. Pullets are young hens not yet laying. I named them Dora, Cora, and Nora, or Flora, Mora, and Lora. It really doesn't matter because I can't tell them apart. Ned had his flock. I picked up a few more pullets, but one turned out to be a rooster. Darn it, we may have to eat him.

The good news is that these chickens are a free-ranging flock. They travel the whole yard, picking and pecking along. No bug on the ground is safe. And even though it is tick season, I have only found one tick on me. There's a funny thing about this flock: All my other chickens I called by making "chk, chk, chk," noises. These birds ignore that. I stand in the yard and yell, "Chickens, chickens!" and they come running. Happy poultry to me.

My flock is not laying yet; they are too young. But they will soon and when they do, the yolks of their eggs will be orange, like the sun (as only a natural diet can produce) from their far-ranging foraging. After a day of eating bugs for protein, and grasses and weeds, they return at dusk to the now-fortified, varmint-proof Chicken House of Contentment.

Access

Kathleen Jarschke-Schultze (kathleen.jarschke-schultze@homepower.com) is starting another clucking adventure at her off-grid home in northernmost California.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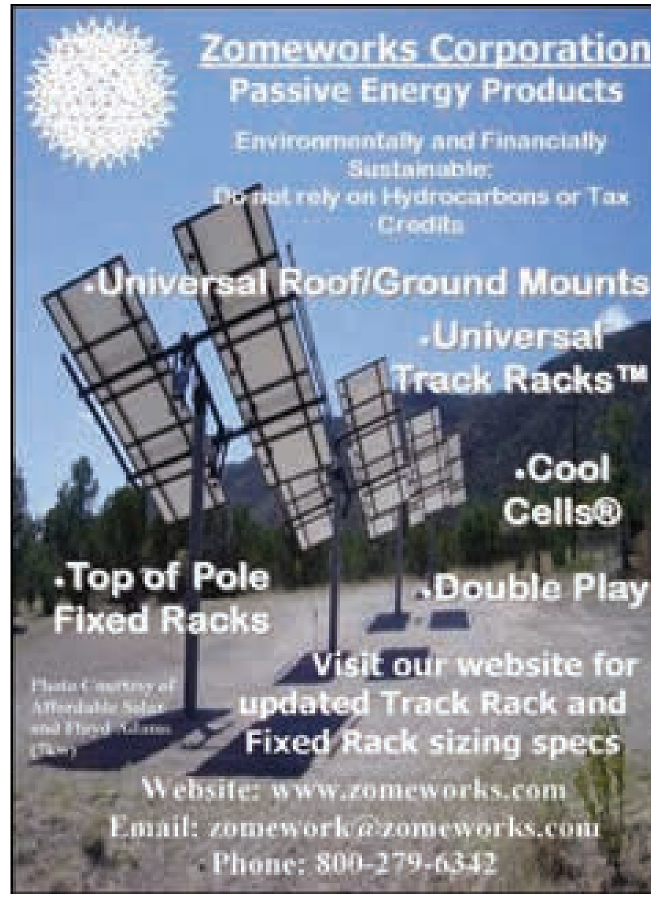
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Iowa City, IA. Iowa RE Assoc. meetings. Info: 319-341-4372 • irenew@irenew.org • www.irenew.org

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Six NMSEA regional chapters meet monthly, with speakers. Info: NM Solar Energy Assoc. • 505-246-0400 • info@nmsea.org • www.nmsea.org

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Saxapahaw, NC. Solar-powered home workshop. Info: Solar Village Inst. • 336-376-9530 • info@solarvillage.com • www.solarvillage.com

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Philadelphia Solar Energy Assoc. meetings. Info: 610-667-0412 • rose-bryant@verizon.net • www.phillysolar.org

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El Paso Solar Energy Assoc. Meets 1st Thurs. each month. Info: EPSEA • 915-772-7657 • epsea@txses.org • www.epsea.org

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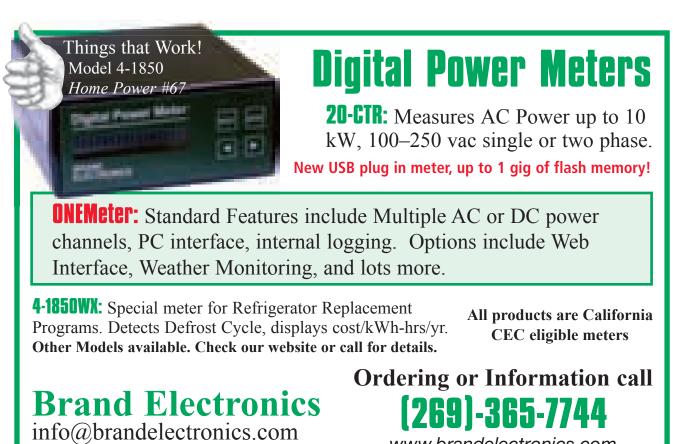
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A Better Measure than Wind Generator Power Curves

Wind generators produce electricity at varying levels, depending on rotational speed (rpm). Graphing generator output (in watts) against wind speed (mph or m/s) yields a "power curve" for the wind generator (see the "Power Curves" graph).

The untrained eye is drawn to the top of the curve—the peak power. For gasoline-powered generators, this is useful information. As long as it's supplied with gasoline and a load, it continues to produce at or near its rated output.

Peak power for a wind generator is very different—at most sites, the wind speed at which a turbine generates its peak power occurs only a very small percentage of the time. A wind "distribution" plots the frequency of each wind speed (see "Distribution" graph). For example, a site may experience 15 mph winds 18% of the time and 40 mph winds less than 2% of the time. If you assume that a wind generator will give you peak power most of the time, you'll have wildly exaggerated energy output expectations.

A crucial fact to understand is that the power available in the wind is related to the cube of the wind speed (V^3). For instance, doubling the wind speed gives eight times the power: a 20 mph wind has eight times the energy (20 x 20 x 20 = 8,000) of a 10 mph wind (10 x 10 x 10 = 1,000). If a wind generator produces 3,000 watts at 24 mph, it will produce only about 375 watts in a 12 mph wind. Understanding the V^3 law and a wind distribution curve helps you look at power curves—and wind energy—more appropriately.

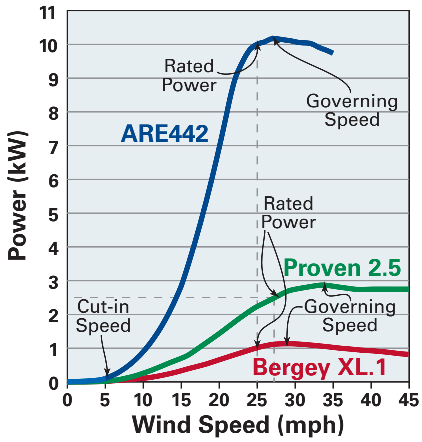
For most people, wind generator power curves only create confusion about performance. When we buy a car, most of us don't look at the displacement of the cylinders or the cold cranking amps of the battery. We turn to more important overall measures like fuel economy. So we should leave power curves to the number nerds, and stop distracting ourselves from the prize—energy output.

Trying to compare one wind generator to another using the peak from power curves is a common mistake. While there is some useful information in the curves, it's not a simple comparison. For example, I've had two turbines with about the same peak power rating, yet one produced 2.3 times more energy than the other in similar conditions.

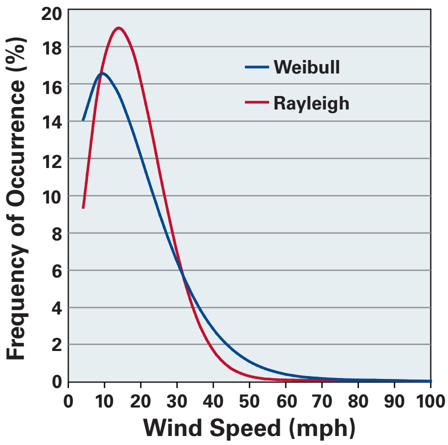
Instead of using power curves, look on the manufacturers' Web sites or in their literature for *energy* curves or graphs (see the example below). With an estimate or measurement of the average wind speed at your site, these curves can help you project the energy yield (kWh) from a particular turbine. Then you can determine how that projection matches up with your energy needs, determine which (and if) wind generator is right for your site, and get on with the job of designing and installing your wind-electric system.

—Ian Woofenden

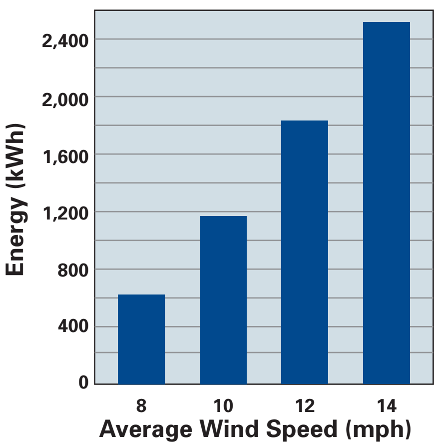
Power Curves for Three Turbines



Wind Speed Distribution



Sample Energy Curve



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