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On the Cover

Renewable-energy professional Christopher Freitas at his microhydro intake, installed with help from microhydro pioneer Chris Soler. See the interview on page 44.

Photo by Josh Root Photography

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Up Front

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Photos, clockwise from opposite page, lower right: Ian Woofenden, Power-One, Stefano Paltera/U.S. Department of Energy Solar Decathlon, Topher Donahue, The Montpelier Foundation

Assessing Your Energy Options

Solar electricity is a fabulous technology—long-lasting, productive, low-impact, and cost-effective. And it's often the go-to answer when people want to move toward a more environmentally sound, resilient energy source. But home and business owners have several renewable energy (RE) options, whether their motivation is a smaller environmental footprint, stabilized energy costs, or preparation for an uncertain future.

Heating and cooling is typically a building's largest use of energy, so it's worth focusing carefully on how to reduce this load before working on covering it renewably. Insulation and air-sealing are not glamorous, but they can dramatically reduce your home's appetite for space conditioning. Blower-door testing and thermal imaging can be real eye-openers, showing how much energy is being used to heat and cool the great outdoors, and pointing to how to reduce the waste.

It's worth considering a number of RE options for heating. Passive solar design features—careful choice and placement of glass, thermal mass, overhangs, and overall home design—can supply some or most of your heat, depending on your climate. Wood heat may be an option for you as well. And the high-tech, low-energy prize might go to minisplit air-source heat pumps, which efficiently and comfortably heat and cool a home with minimal cost and intrusion into the building envelope. These modern space-conditioning systems "pump" heat from the outside air, using 1 kilowatt-hour of electricity to move 2 to 5 kWh of heat into your building.

Water heating is often a home's second largest energy load, and can be well-served by a solar water heating system. On the low-tech end, heat-exchanging coils in a wood heater can provide domestic water heating in winter. Heat pumps can also be used for this application.

Choosing and using electrical loads carefully to reduce energy consumption should be a primary component of any RE strategy. From lighting to computers to kitchen appliances, many energy-efficient models are available. Sometimes, avoiding electricity use—for example, by using a solar oven, food dehydrator, or line-drying clothes—can be your best bet.

Three basic ways of generating electricity on-site are solar-, wind-, and hydro-electricity. Hydro sites are rare, but if you have falling water on your property, it's the first resource to assess. Wind-electric systems are challenging, but may be the best option if you have a good resource, and are determined to do the maintenance. Solar energy is available to the largest number of buildings, and modern, batteryless solar-electric (PV) systems are durable and reliable.

Even if you don't have the resources or the budget to tap RE directly, you can still buy "green energy" from most utilities, or support renewable production via purchasing RE credits or "green tags," or invest in solar or wind farms.

Exploring options will show many ways to reduce energy usage through efficiency and conservation—and ways to tap clean, local RE.

—Ian Woofenden, for the *Home Power* crew

Think About It...

"Energy conservation is the foundation of energy independence."

—Thomas H. Allen

contact us

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Localizing Energy

Across the country, communities are taking energy matters into their own hands.

There are about 2,000 municipal utilities in the United States, with many dating back to the late 1800s and the early 1900s. But only 17 municipal utilities have formed in the last 10 years—the most recent (in 2013) in Jefferson County, Washington. Private investor-owned utilities (IOUs) remain the standard, distributing the majority (about 70%) of the country's electricity.

"Every year there are probably 20 communities across the country that consider public power, but only a few will get beyond a preliminary discussion. Many hesitate because municipalization can be a long and challenging process," says Ursula Schryver, vice president of education and customer programs at the American Public Power Association.

The communities that do follow through reap the rewards, often lowering retail rates and improving reliability. According to 2011 data from the U.S. Energy Information Administration (EIA), in 32 of the 48 states where both IOUs and municipal utilities exist, municipal utilities offer cheaper residential electricity. During 2011, residential customers in IOU service territories paid average rates that were 14% higher than publicly owned systems.

Municipal utilities are typically run by locally elected or appointed officials, and therefore do not carry high corporate salaries. The savings in CEO salaries alone can be substantial, considering *Forbes* found utility CEOs earned an average of $6.1 million in 2011 (excluding stock options). Operating as nonprofits, municipal utilities do not have shareholders demanding profit-making, which means any savings can be passed directly to the customer-owners or reinvested in infrastructure upgrades. Such reinvestment is part of the reason why municipal utilities are known to have more reliable service, faster restoration of service during emergency outages, and higher overall customer satisfaction.

Most municipal utilities serve smaller communities, but now the movement is gaining momentum in bigger cities. Sante Fe, New Mexico, is considering parting with utility provider PNM and running a municipal utility, and in Minneapolis, Minnesota, a coalition of organizations is leading a municipalization campaign as the city's contract with Xcel Energy nears expiration at the end of 2014.

Rising rates are fueling the effort in Minneapolis. Last year, Xcel asked for its largest-ever electricity rate hike in Minnesota. The state's Public Utilities Commission (PUC), an agency that regulates utilities, approved a smaller interim rate—Xcel's seventh rate increase since 2005. The company says it sees a need for three additional rate increases in coming years. In addition to recouping investments in nuclear and wind power projects, Xcel says the rate hikes will help absorb losses from "an erosion in sales"—a common issue throughout the power industry that has resulted from energy efficiency and renewable energy programs.

"The people of Minneapolis should not be charged higher rates for reducing their energy use and being more efficient. They should be rewarded," says Dylan Kesti, campaign coordinator for Minneapolis Energy Options. "With the franchise agreement up for renewal, it is an energizing moment to explore our options and make some needed changes. We are willing to collaborate with Xcel, and if they are willing to meet the city's goals to reduce greenhouse emissions and make more substantial

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Boulder, Colorado, is working toward municipalization for environmental reasons—to decrease the city's carbon footprint. The wastewater treatment plant also hosts a 1 MW PV system, which has produced more than 3 million kWh so far.

Courtesy City of Boulder, Colorado

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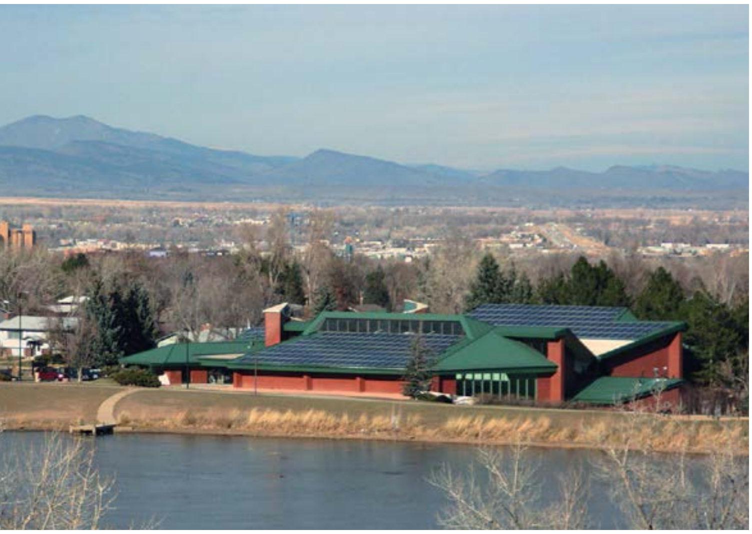


Courtesy City of Boulder, Colorado

More solar in Boulder: A rooftop array at the Boulder Recreation Center.

investments in clean, local energy, then we see no reason to kick anyone out of town. However, if they can't, then it is time for a change."

Motivation for municipalization varies, but a common thread from one city to the next is the desire for local control and accountability. Boulder, Colorado, is making history as the first U.S. city opting for municipalization for environmental reasons. After five years of study and repeated attempts to work with Xcel to reduce the community's dependency on fossil fuels, Boulder let its 20-year franchise agreement expire in 2010, in favor of exploring different models that could deliver clean, local energy.

"What makes the situation in Boulder so significant is that the community is taking steps to build the electricity system they want—one powered by renewable energy. What matters is that the system provides affordable, reliable electricity that is nonpolluting, creates economic opportunities, and avoids the cost risk of fossil fuel," says Bill Corcoran, western director of the Beyond Coal Campaign for the Sierra Club, which donated $60,000 to support Boulder's municipalization campaign.

Boulder was among the early adopters of the U.S. Conference of Mayors Climate Protection Agreement, in which cities committed to meeting or beating the U.S. emissions reduction target in the Kyoto Protocol. To help meet those targets, the city implemented the nation's first tax on electricity carbon emissions in 2007, with revenues funding a climate action plan. Despite voluntary programs and local subsidies to promote energy efficiency and renewable energy investment, the city has not met its Kyoto Protocol goals. When the city missed its initial target in 2008, municipalization talks ramped up.

"At the time, we were doing well, but we could only do so much on the demand side alone. It became clear that more needed to be done on the supply side of the equation. With over 80% of the electricity supplied by Xcel derived from fossil fuel, mainly coal, our ability to reduce our emissions was and is limited by Xcel's choices," says Jonathan Koehn, regional sustainability coordinator for the city of Boulder.

Studies have consistently shown scenarios in which Boulder could sustain rates and reliability while doubling renewables and cutting emissions in half. Yet, after nearly 10 years of legal and regulatory battles, there's still no guarantee that Boulder will build its own utility. It remains unclear as to how much the switch will cost the city. Negotiations to purchase Xcel's assets—the poles, wires, and substations surrounding the city—are underway, but should the cost exceed the $214 million cap set by a November ballot initiative, then near-term plans for municipalization will cease, Koehn says. Some estimates show the venture topping $1.2 billion when all is said and done, but the appraisal and negotiations could take up to two years.

With customers and revenue at risk, IOUs spend funds and resources to back antimunicipalization campaigns. In 2002, Pacific Gas and Electric Co. spent $2 million to defeat a grassroots ballot initiative for a municipal utility in San Francisco. Over the past couple of years, Xcel Energy has spent nearly $2.5 million attempting to kill ballot initiatives in Boulder. Despite Xcel's efforts, Boulder continues to clear hurdles and move forward with its municipalization plan, taking inspiration from success stories like Winter Park, Florida.

After years of frustration with unreliable service, the city of Winter Park initiated the municipalization discussions in 2000. Five years later, the city took over operations from utility Progress Energy Florida and began supplying community-owned power. Though the city lost money and raised rates in its early years due to bonds for capital improvements, the city is now turning a profit—about $5 million on $45 million in revenue—and using those funds to make system upgrades. The city has made strides in reliability, with the average customer experiencing 1.4 momentary interruptions per year, down from 22 per year with Progress Energy Florida.

Other cities embark on the process only to discover that forming a municipal utility is too costly. The city of Las Cruces, New Mexico, began working to create a municipal utility in 1991. In 2000, they abandoned the effort, choosing to sign a new franchise agreement with El Paso Electric after costs and legal fees mounted in the tens of millions, far beyond the city council's original estimates.

"Public power is not for every community," Schryver says. "If a community is unhappy with their utility situation for whatever reason, and if they have the opportunity to make changes—say if their franchise agreement is up for renewal—then it is worth considering the options. Municipal energy may be a good fit."

—Kelly Davidson

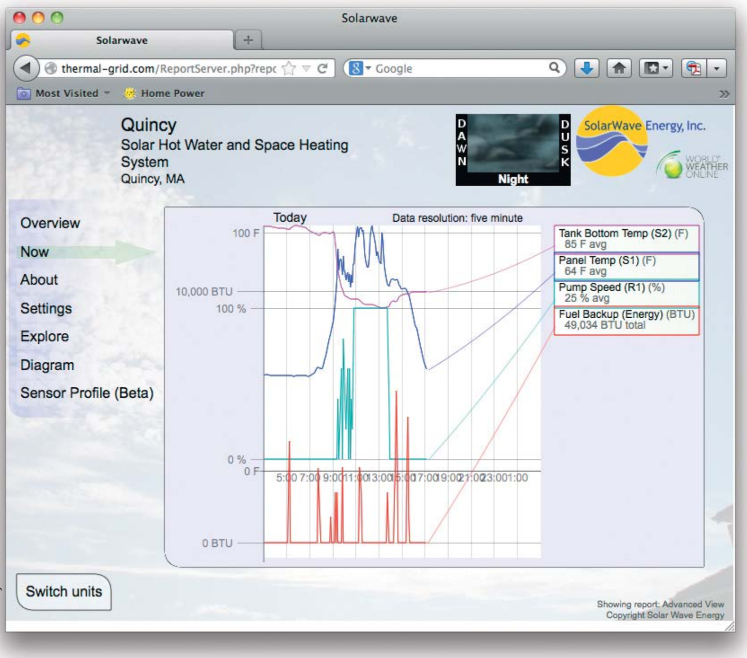
Trojan Smart Carbon Batteries

Courtesy Trojan Battery

Trojan Battery (trojanbatteryre.com) introduced a product enhancement to address sulfation issues with batteries that are cycled at a partial state of charge (PSOC)—a common RE system scenario. When batteries are not fully charged, sulfation—the buildup of sulfate crystals on the batteries' lead plates—reduces the available surface area of the lead plates, which lowers capacity and increases internal resistance. Batteries that become sulfated need to be replaced more frequently. The company's "Smart Carbon" additive, standard in its industrial and premium flooded batteries, is claimed to help decrease the rate of sulfation and improve charge acceptance. Trojan estimates a cycle life increase of up to 15% with its Smart Carbon batteries for systems that operate in PSOC.

—Justine Sanchez

SolarWave SWH Meter



Courtesy SolarWave

SolarWave Energy's (solarwave.com) Thermal-Grid is a monitor and remote energy-management tool for solar water heating, which allows real-time system examination. The Resol DL2 control/monitor stores data locally, and the Thermal-Grid plug-in allows viewing data on a computer or any other Web-connected device. The Thermal-Grid's settings can be adjusted remotely for maintenance and troubleshooting of the controlled system. Alarms can be set for conditions like a system failure and an alert can be emailed to the person responsible for the system.

—Chuck Marken

A Diamond in the Rough

In the heart of coal country, one community is bridging the gap between the RE and coal industries.

In downtown Williamson, West Virginia, the Coal House—a building erected in 1933 from 65 tons of coal taken from the nearby Winifrede Seam—stands as a symbol of the region's coal mining legacy. But next door, located in ground-floor space of the historic Mountaineer Hotel, a "smart office" is taking shape, powered by a 3-kilowatt grid-tied PV system on the building's roof. Designed to serve as a high-tech hub for the region's RE development, the office houses Sustainable Williamson (SW)—a nonprofit formed in 2010 by the city of Williamson's redevelopment authority.

Side by side, the two spaces represent a vision for Williamson's future—one in which fossil fuels and RE coexist. "We're trying to transcend the traditional conflict-based approaches. You can't make progress here with the us-against-them mentality," says Eric Mathis, the director of Strategic Initiatives for SW.

Mathis—who describes himself as an evolutionary, not an environmentalist—appreciates the hope RE represents for economically depressed Appalachian communities, but he is sensitive to the region's coal legacy. He believes there is room for both coal and RE—a belief that, he admits, makes him pretty unpopular in some circles.

"Environmentalists either love me or hate me. It is easy to say everything about coal is evil when talking about a nameless, faceless coal company you read about in the news. Here, we're talking about real people, generations of men and women who have worked hard to provide energy for this country. People are quick to forget that coal spurred the industrial revolution, and has essentially powered the lifestyles and luxuries we've enjoyed," Mathis says.

Born and raised in rural North Carolina, Mathis is among the minority in Williamson who does not have a direct lineage to the coalfields. He moved to Williamson in 2006 after graduating from Appalachian State University, where he spearheaded one of the country's first student-led RE initiatives. He worked as a data analyst at a local law firm until he saved up enough money to start The Jobs Project, a nonprofit program that provided RE job training and resources for entrepreneurs. In collaboration with the Williamson redevelopment authority, Mathis joined forces with other community groups to form SW.

The organization is tasked with the challenge of preparing Williamson for life after coal. As production in the region slows, and mining operations become increasingly automated and less labor-intensive, Williamson and other coal communities need new revenue streams and new jobs to survive.

A grid-tied 3 kW PV array on the roof of the building that houses Sustainable Williamson provides electricity for its "smart office." The installation also presented a training opportunity for this volunteer crew.

Courtesy Stonestreet Creative

Faced with a city budget gap, Williamson Mayor Darrin McCormick entered office and raised the fees for general city services (i.e., trash, fire, police, and sewer) in 2007, but he told his constituents that he would do everything in his power to avoid another fee increase. He heard about Mathis' jobs program, and began brainstorming with him about ways for the city to reduce its bills and operate more efficiently. Though he admits to being skeptical at first, he came around to the idea of RE. "A lot of Williamson residents are on fixed incomes, and rate hikes have a detrimental effect on their quality of life. I knew it was time do something, and energy efficiency and renewable energy made sense, but I knew we could not turn our backs on coal," McCormick says.

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"Coal may be a dirty four-letter word to some people, but around here, it is a way of life—how people have put food on the table and clothes on their children's backs," says McCormick. "Despite what the rest of the country believes, we realize that coal is a finite industry, and to survive, we realize that we need to create new opportunities. We're making progress here in Williamson because, instead of attacking our way of life and trying to take down coal, we're respecting it and trying to preserve it. Sustainability, energy efficiency, and renewable energy not only give our community a future after coal, but they also allow us to extend the life of the industry and have the time we need to build our new economy."

A grant from West Virginia's Department of Energy provided lighting and HVAC efficiency upgrades to city government buildings. The city also received grants and training through a redevelopment program. But Mathis says the city is trying "to steer clear of handouts and subsidies" and "rely on the market to drive financing for energy projects."

The plan is to create new jobs by diversifying the region's energy portfolio with utility-scale biomass and solar projects. The ultimate goal, Mathis says, is to convert Williamson to a microgrid system, which would draw from "integrated energy parks." There, utility-scale natural gas, biomass, and solar projects would occupy active and reclaimed mine sites. Drawing on a microgrid would allow the city greater control in choosing what energy sources are used and when they are used to meet the city's demand, and help keep utility rates down.

However, building a microgrid may take decades. For now, Mathis is focusing on ways to draw energy developers to the region. A centerpiece of the SW plan is job training. "Having a labor force skilled in sustainable technologies will make this region more attractive and viable for developers," Mathis says.

With oversight from professional installers, crews of SW volunteers and trainees have installed several PV systems, including an evacuated tube solar thermal system on the Williamson Fire Station and an 11.3-kilowatt rooftop system on the town's health and wellness center. The SW team is also engineering a pilot solar garden that will provide power for five city government buildings from a former hilltop-mining site. It will be the first of several in the region, Mathis hopes, though replicating the concept in other communities may be restricted by the state's current two-mile limitation on virtual net metering.

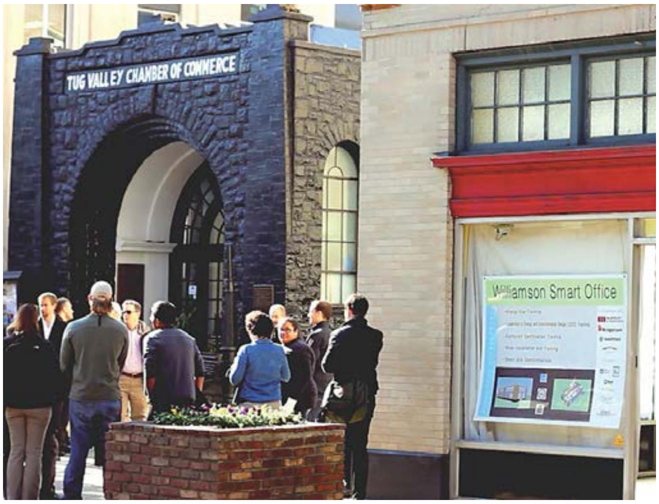
Mathis utilizes each solar installation in town as a training opportunity, inviting local contractors and electricians to participate. He also recruited several volunteers from a green-construction training program run by Coalfield Development Corporation, a nonprofit that builds green homes for low-income families. One of those volunteers was 21-year-old Josh Napier, who worked on the system at the fire department and, more recently, the smart office (see "Getting Smarter" sidebar). Napier says he is now planning to pursue additional solar training and someday start his own construction business.

Mathis is also developing a formal training program in green construction and solar installation with the Sustainability Institute at the Bridgemont Community and Technical College in Montgomery. The program will include testing through the North American Board of Certified Energy Practitioners, as well as on-the-job training. The goal is to train high school graduates, but also train out-of-work miners and coalfield tradespeople.

While Mathis' openness to coal may not sit well with some, his ideas have won national recognition. He was a 2010 recipient of the Interstate Renewable Energy Council's Innovation Award for Community Renewables and a 2012 White House Champion of Change for Greening our Cities and Towns. Naysayers may have their doubts as to whether SW can pull off all of its grand plans, but Mathis remains confident. "Change," he says, "is on the horizon."

—Kelly Davidson

A building made of coal (left) sits next to the SW office that's powered, in part, by a PV array (right).



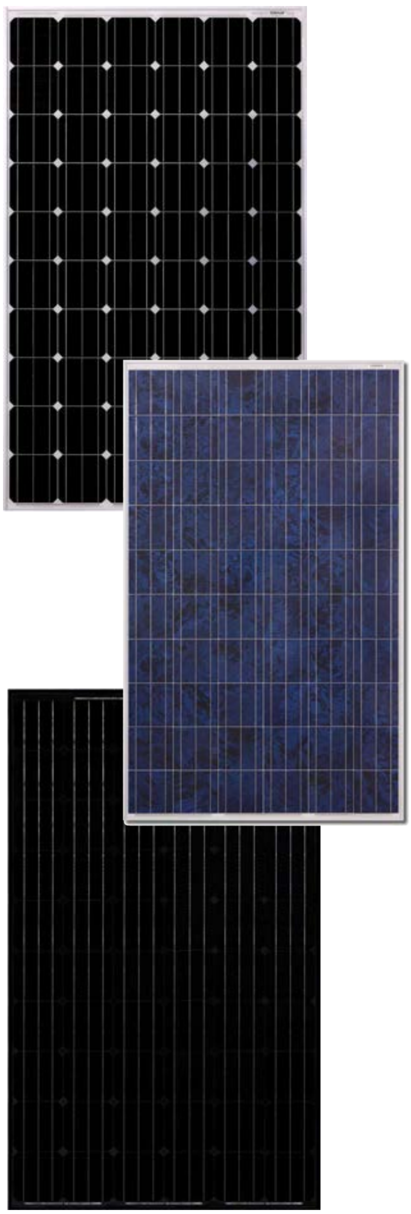
Courtesy Stonestreet Creative

Getting Smarter

According to Mathis, Sustainable Williamson's smart office is the first step in growing the town into a "living lab" that showcases renewable energy systems and green business opportunities that can be replicated in other coal communities. Upon completion, the SW office will be the first in Appalachia to meet the U.S. Green Building Council's Platinum LEED standards for commercial interiors. The grid-tied PV system and high-performance windows were installed last year, but work stalled due to lack of funding. SW hopes to secure grant funding to finish the interior retrofit this year.

The finished smart office will showcase an energy dashboard at the entrance that will track and optimize the building's energy and water use, and eventually that of other buildings and homes in the community—including the firehouse and health center that SW outfitted with computerized smart meters. The idea, Mathis says, is to show homeowners and businesses the tangible benefits and savings of demand-control management.

CanadianSolar



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Backed Up in the Rocky Mountains

Courtesy Colorado Timberframe

When Burnett and Kristin Gunter retired, they decided to pack up their life in northern California and head for Colorado's high country outside of Black Hawk. Instead of downsizing, as most empty nesters do, the couple built a 5,000-square-foot house on land that has been in Kristin's family since the 1920s. The house was built to serve a dual purpose—as the couple's retirement residence but also as a retreat for Kristin's siblings and cousins, with whom she co-owns the 150 acres.

The couple lives on the main level, occupying 2,000 square feet, while a walk-out basement, roughly the same size, has two bedrooms, two bathrooms, and a large family room to accommodate visitors. "The goal," Kristin says, "was to build a home that everyone and their families could enjoy—now and for generations to come."

Thinking about the next generation, and their utility bills, the couple wanted to harness the sun and the open solar window to offset 100% of their electricity use. Their starting point was a 2,400-square-foot workshop where Burnett rehabs cars and trucks, and stores equipment used to maintain the property. The shop was erected about one year prior to home's construction and built with a south-facing roof pitched at 34°.

The roof accommodates a grid-tied 10.92-kilowatt PV system wired to a 48-volt, 2,490-amp hour battery bank and 20 kW generator housed in the workshop's electrical room. "The system solves two needs—it generates renewable electricity and provides backup. While the grid in this area is very reliable, big snowstorms can and do happen, and we wanted to make sure we had backup power," Burnett says.

The system was sized to provide enough electricity for the home's day-to-day use, but also handle the peak use from multiple visitors. The home features a mix of LED and compact fluorescent lighting. Most of the household appliances are electric, except for a gas dryer and the range. The system also powers an energy recovery ventilator that transfers warmth from inside air that is being exhausted to the fresh air being drawn from outside.

A high-efficiency natural gas boiler with a sidearm water heater supplies the home's in-floor radiant heating and hot water. Zone heating allows the heat in the home's lower level to be kept at a minimum when not occupied. The couple supplements radiant heating with a wood-burning masonry heater in the great room on the main floor, which they fire up once in the morning and once in the evening on the coldest days.

Perched on an unprotected hillside 9,000 feet above sea level, the home had to be resilient against inclement weather and cool temperatures. Even in the summer months, day temperatures rarely top 75°F, and night temperatures may dip below 40°F. The main level walls and ceilings are 6.5-inch, R-42 structural insulated panels that are insulated with a high-density urethane foam. In the basement, 8-inch stud-framed walls are filled with closed-cell polyurethane spray foam for R-50. Double-glazed casement windows oriented to the south provide natural light and passive heat gain, while opening the home to panoramic mountain views.

Self-professed tinkerers (and retired engineers), the couple has tested the PV system in several scenarios, disconnecting from the grid and running off battery power for periods of time.

The system started generating in November 2012, providing electricity for the last leg of house construction. As of January 2013, the system has produced 13.5 megawatt-hours. The system was designed by Patty Bruton at The Solar Biz and installed by Namaste Solar in Boulder. The total came to $73,845, with the federal tax credit and a local rebate from United Power bringing the final cost to $49,442.

—Kelly Davidson

Overview

Project name: Robins Ranch

System type: Grid-tied PV with battery backup

Installer: Namaste Solar

Date Commissioned: November 2012

Location: Black Hawk, Colorado

Latitude: 39.8°N

Solar resource: 5.3 average daily peak sun-hours

Avg. monthly production: 950 AC kWh

Utility electricity offset annually: 100%

Equipment Specifications

Modules: Forty-two NuSun NS260- 5M, 260 W STC

Inverters: Two Schneider Electric XW6048, 6 kW rated output

Batteries: HuP Solar-One flooded lead-acid, SO-6-125-33, 48 VDC nominal, 2,490 Ah

Charge controllers: Three Schneider Electric XW MPPT 80 600

Array installation: DPW Solar Power Rail mounts on south-facing roof, 34° tilt


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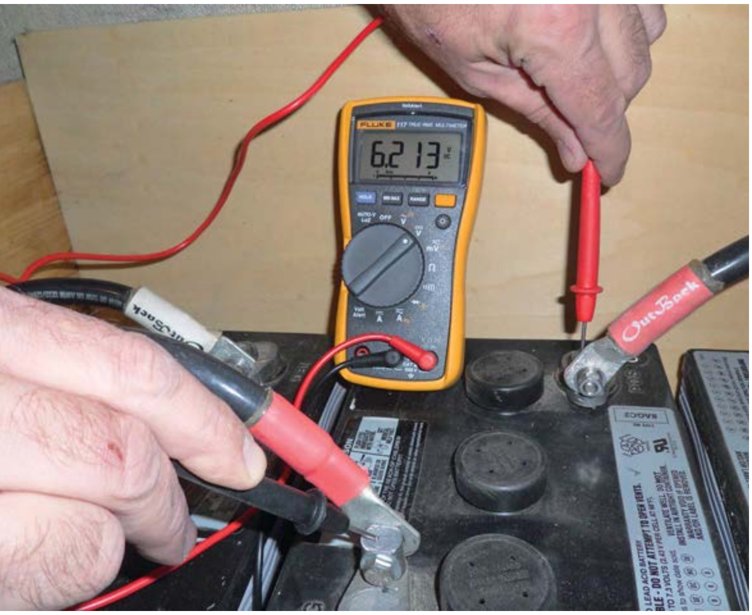
Grid/Hybrid Multi-Mode Agility

Load-Testing Batteries
Without a Load Tester

Part of a complete battery bank assessment includes testing the battery cells while they are delivering high power. We call this a "load test" (see "Battery Assessment" in *HP159*). This performance test does not require an expensive, dedicated load tester, nor any hazardous battery clamps. A heavy discharge load can be applied to the entire battery bank by simply plugging in and turning on high-draw appliances, especially electric heaters, hair dryers, hot plates, incandescent lights, etc. (Borrow these items from your on-grid friends if you must.) With a heavy and steady load applied, you can measure individual cell or battery voltages. Unequal voltages will indicate weak cells. You can also locate weak connections this way.

What is a "heavy load"? That is relative to your battery bank capacity. There is no exact requirement, but a good guideline is to divide your battery's amp-hour capacity by 5, which determines DC amps of load to apply at the battery bank. Confused? Here's another way to calculate it: Multiply your battery's Ah capacity by the DC voltage (nominal voltage: simply 12, 24, or 48), to get the capacity in watt-hours. Divide THAT by 5 to get an idea of a "heavy load" (in watts).

For example, say you have 350 Ah batteries in a 48 V string. Your Wh capacity is 16,800 Wh (350 Ah × 48 V). That number divided by 5 equals 3,360 watts. That's just a guideline, however. Two ordinary 1,500 W electric space heaters would be a good "heavy" load. If you have more than one parallel battery string, remember to multiply all this by the number of parallel strings.



Christopher Freitas

Although the exact load on the battery bank isn't critical, use at least half of the load wattage that you calculated. Most important is that the load stays constant for the duration of your test. So, during the test, unplug or disable any loads that may turn on automatically, like a refrigerator or well pump, and be sure nobody uses the toaster! Next, disconnect all charging sources, like your PV array. If you have a system monitor that shows amps (the battery current), it will indicate the heavy load, which should stay nearly constant.

Next, use your digital multimeter to measure the voltage of every cell (if you can) or every individual battery. Place the meter probes directly on the battery posts to read the cell (or battery) voltage exactly. As you read the voltages, have a friend record them on a chart to speed the process.

Any cells or batteries that show a lower voltage indicate a weak cell or battery. A difference of 0.1 volt would be significant for a 2 V cell. If you cannot access individual cells, then you will measure individual batteries, multiplying 0.1 by the number of cells. So, for a 6 V battery (consisting of three 2 V cells), a difference of 0.3 V would be noteworthy.

Significant variations may indicate the need for thorough equalization of the bank, or may indicate cell weakness and a threat of premature failure. If the battery bank has more than one parallel string, this test can also reveal inequality between strings, which will lead to premature failure of an entire string. This is a common problem with batteries in parallel strings.

With your heavy load applied, you can now use your meter to locate weak connections. Place one probe on the terminal and the other on the cable lug. Any voltage higher than 0 V will indicate voltage drop across the metal junction due to corrosion (often invisible) or a loose connection. The terminal needs to be disassembled and its surfaces cleaned, and corrosion-protective compound applied before reassembly.

For advice on parallel strings, equalizing, and corrosion prevention, refer to "Top Ten Battery Blunders" (*HP114*).

I have used this testing method many times to locate weak cells and connections, or merely to assure that all is well. Correcting problems while they are "young" is the only way to prevent premature failure of a battery bank.

—Windy Dankoff • founder (retired) Dankoff Solar Products & Dankoff Solar Pumps

Safety First:

Be sure that your multimeter probes are connected to the voltage (V) input on the meter—*not* the current (A) input. The A input will cause a dangerous short-circuit. And always remove metal jewelry and wear eye protection when working on batteries.

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Heating Choices

I enjoyed reading the article entitled "Platinum PV" in *HP158*. It was interesting to see where the designers didn't agree with the LEED standards. I would like to take issue with another of the design decisions made in this house—the choice of an electric furnace instead of an air-source heat pump.

The article mentions that it was less expensive to add PV modules to cover the electricity of the electric heat than to install a heat pump. While this may be the case, it doesn't take into account the electricity used to power the heat. Electricity is used in real time—the utility isn't storing our PV-produced power for us to use later. This electric heat unit will likely run mostly at night and during cloudy weather. This means that it will be using electricity largely produced by coal, nuclear, or natural gas—not PV-produced electricity.

So this design choice has a heating system that uses more electricity than a heat pump. And this electricity is most likely coming from conventional (nonrenewable) energy sources. It seems that a Platinum-certified LEED house would strive to use less energy overall (even if offset by PV production) and certainly less from fossil fuels. Installing an air-source heat pump would have met both of these goals and provided air conditioning for the home.

Matthew Huffman • Swoope, Virginia

Outdoor units of air-source heat pumps.

Courtesy Kristoferb at en.wikipedia.org

Pelton Birthplace

Each time I read a *Home Power* article about hydropower or peruse the advertisements for microhydro turbines, I think of Lester Pelton, the guy who invented the Pelton wheel, and a key figure in the renewable energy industry. This might seem somewhat unusual to most readers, but the reason is that I grew up in Vermilion, Ohio, the town nearest to Lester Pelton's birthplace.

Lester was born in 1829, eight years before the village of Vermilion was incorporated. Lester stayed in the area until 1850, at which time he took off for the California gold rush with some friends and relatives.

While living in Comptonville, California, he invented the now-famous Pelton water wheel. He patented the wheel and lived in California until his death in 1908. His remains were brought back to Ohio for burial in Maple Grove Cemetery, several miles south of Vermilion. This is the same cemetery my parents are buried in, so when I stop by their grave I usually stop by Lester's family plot, too!

Rich Tarrant, a friend of mine who lives in Vermilion, publishes a weekly online local history blog, *Vermilion Views* (vermilionohio.org) that has a section called "Lester's Wheel Across the World." Being a local town historian, Rich has done quite a bit of research into Lester Pelton's life.

Vermilion Views' "Lester's Wheel Across the World," includes a great synopsis of Lester Pelton's life. There are pictures of his childhood home and the one-room schoolhouse where he received his formal education, sketches used to obtain the Pelton wheel patent, and much more. I hope this will be of interest to some readers.

Richard Koontz • Sherwood, Oregon

Courtesy Daderot

A Pelton impulse turbine, circa 1880, built by the Miners Foundry of Nevada City, California.

Solar Payback

I have some feedback about article "What are You Waiting For?" ("From the Crew," in *HP159*). Are you serious to suggest in the article that homeowners should refinance or get a second mortgage to install PV on their homes? For a 15- to 20-year payback? So, at best, it's a break-even deal? (That is, if no cost is incurred during those 15 to 20 years for repairs.) Financing a PV system makes no sense as long as the local power plant is running.

A local solar installation company is advertising a 3 kW system installed for $12,000. You could spend half of that to have the average home superinsulated with spray-foam technology and save that 3 kW, summer and winter. The best way to reduce our energy usage is not use it in the first place—conservation, conservation, conservation.

A lot of your articles covering installed PV no longer show the cost of the installation. What gives? No matter how you juggle the numbers, PV systems defy common sense for someone living in southern Indiana (me). Passion for the technology can never override common sense.

What are we waiting for? I guess for the power to quit coming out of the wall.

Jock Stucki • Evansville, Indiana

Many folks look at the situation quite differently: Why pay the utility when you could be paying off your system at the same rate? Instead of giving your money away, at the end of the term you own your energy production.

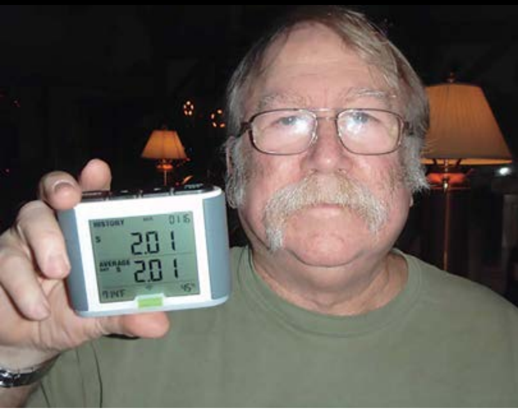
But I am in full agreement that investing in energy savings is sound, and the financial payback occurs in exactly the same way as investing in a PV system. Home Power *recommends that reasonable means to save energy be the first step, and only then does it make sense to take the next step of installing a renewable energy electric system.*

We hope to start working with authors to get the real data on their system costs. But I think you are mistaken that installing RE does not make sense economically.

Michael Welch • Home Power *senior editor*

Home Energy Monitoring

I had been looking for a whole-house AC utility monitor to track my utility electricity consumption beyond what I produce with my PV system. I wanted to be able to graph my energy usage daily, weekly, and monthly. However, none of the available data logging systems I found were user-friendly or affordable.



Courtesy Offgridnick

That changed when I found the Efergy Elite wireless electricity monitor. After a year of use, I can say this product meets my requirements nicely. It is a plug-and-play device, connected to my service panel. Two sensors encircle each of the two hot leads from the utility meter, and plug into a battery-powered transmitter, which mounts on the wall next to the main breaker box. It transmits wirelessly to the monitor that can be moved around the house. It displays power consumed in real-time by all circuits, and circuits (or individual appliances) can be turned off one by one to get consumption detail. The monitor is capable of data logging power (and energy) use in various ways, including cost at present rates. This system can also be used by off-gridders, regardless of the power supply.

This monitor suits my needs nicely, and took less than 30 minutes to install and configure. Also, the price was reasonable, at approximately $150 Canadian. Please note that I do not sell these products, nor am I affiliated with the manufacturer or distributor in any way. *Home Power* has helped me so much for so many years, and now I like to spread the word on appropriate technology when I can.

Offgridnick • via email

Errata

HP159 contained some errors that call for correction:

- In "Site Assessment for Solar Water Heating Systems" on page 70, "Methods" was incorrectly referenced—"Predicting SWH Performance with RETScreen" can be found in *HP157*.

- In "Battery Assessment" on page 82, "Methods" was cited but did not appear in that issue (but will be printed in a future issue). On page 81 under "Load Testing," load tester draws should have been listed as 250 A for a 6 V battery, and 83 A for a 2 V battery.

- In "Living Building Challenge," Matt Grocoff should have been listed as a part of THRIVE Net Zero Energy Consulting Collaborative; his house is 1,500 square feet.

- In "Efficient Heating with Wood," the table on page 45 was missing a decimal in the figure for fireplace efficiency, which should have been reported as between 5% and 15%.

In *HP158*, the schematic in "Platinum with PV" contained errors, which were corrected within the online article at homepower.com and in the digital edition.

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Optimized Production

For Your Wind Turbine

Wind Concepts

I enjoyed the article on wind turbines ("Wind-Electric Systems Simplified" in *HP148*). When it comes to governing, the concepts of "furling" and "pitch control" make sense. But I don't understand "stall," and what it has to do with making sure the turbine does not overspeed.

The article also indicates that for induction motor turbines, rotational speeds are constant, and thus stall is inherent. So in effect, do the windings act as electric braking? Does extra torque try to break away from the fixed speed, increasing voltage and generation, which also increases the electrical braking?

Don Turner • via email

You pretty much got it right: As the wind grows stronger, the machine will produce higher current and hence higher torque, but the rpm do not increase enough to maintain a usable angle of attack, so "stall-regulated" turbines limit their output and protect themselves against strong winds without any fancy mechanisms.

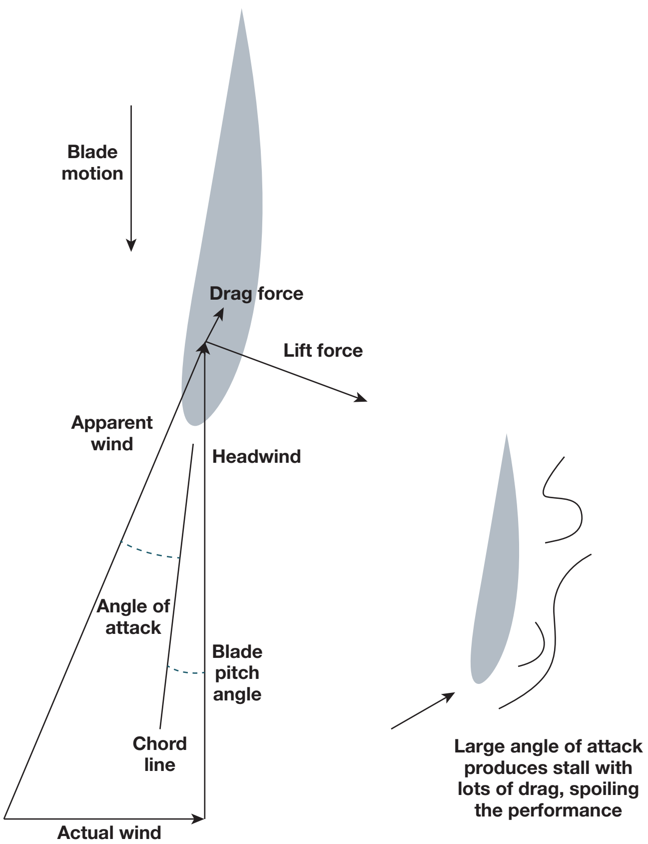
Wind turbine blades get a shove from the wind, and slow the wind down. The lift force on the blade, which drives the shaft to rotate, produces this mutual interaction. The airflow over a wind turbine is made up of two parts—the actual wind and the rather larger headwind caused by the blades' own motion, which add together to produce a diagonal "apparent wind" that strikes the blade and creates both lift and drag. Lift is at right angles to this diagonal wind direction, and drag is aligned with the apparent wind.

Only a small part of the lift force acts in the direction of the blade's movement, so it is very important that this small driving force is not countered by too much drag force. Efficient blade design therefore requires a high lift-to-drag ratio.

Lift and drag both depend on the "angle of attack" of the apparent wind on the blade. This is the angle between the apparent wind and the chord line (which is the longest line in the blade section, from leading to trailing edge). A wind turbine should be designed to load the blades carefully over a range of wind speeds so that the power consumed at each wind speed will let them run close to the ideal rpm, and hence the ideal angle of attack.

As far as the windings acting as electric braking, the turbine's working rpm depends on the balance between what the wind can do and what power is required of it. If the shaft spins without resistance, the blades will overspeed. But if there is a high torque on the shaft, the blades will slow. This reduces the "headwind," raising the angle of attack. If the angle of attack increases much beyond the optimum, the blades will stall and the lift–drag ratio will drop drastically.

Angle of Attack & Apparent Wind



By careful choice of gearbox ratio and blade pitch angle, it is possible to use the stall point to prevent overload, but stall regulation like this is only effective up to a point, after which a good brake is needed to stop the turbine in stronger winds. Passive stall is still an attractive option for some turbines when designers want to use the electrical load rather than mechanical means to protect the machine from overload. Often, in utility-scale turbines a second generator winding was used to allow generation at a lower fixed rpm in low winds.

Hugh Piggott • Scoraig, Scotland

Bluff Wind Sites

I found Mick Sagrillo's recent article ("Wind Matters" in *HP158*) very useful. However, I have an installation I'm considering that the article didn't address. I live on a bluff that rises 160 feet in elevation at a 2:1 slope on three sides. I was considering locating the tower near the edge of the ridge. What are the design criteria for this type of installation? My site is higher than anything within a half-mile.

Tommy Taylor • via email

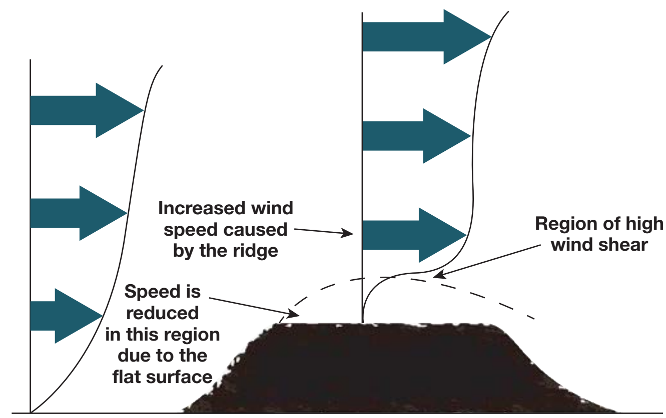
The rules for siting on a bluff can be complicated. The first rule is to never get closer to the bluff edge than 25% of the tower height, because wind turbines don't do very well in bluff-edge turbulence from updrafts. This means a 100-foot tower needs to be located at least 25 feet from the bluff edge.

The significant area of turbulence at the leading edge of the bluff top will disrupt your wind profile. The extent of this turbulent area depends on the ground cover below the bluff, which shapes the wind profile as it approaches. If the ground cover is dense trees, for example, then 25% of the height of the tower will do as a setback.

However, if the ground cover is very smooth—like open water—then site the base of the tower back from the bluff edge at a minimum of 2.5 times the tower height. For a 100-foot tower, that's 250 feet from the edge.

The next question is how tall the tower should be. If you're following the principles of "taller will always generate more electricity," then put up the tallest tower that the manufacturer offers, typically at least 100 feet. You might get by with a shorter tower, but you'll need to "experiment." Stand at the tower site, and get a kite flying as well as you can. As the kite gets off the ground, back up toward the direction of the wind at the bluff edge to keep the kite above the tower location.

Area of Wind Turbulence



In turbulence, kites will zig and zag. But once they break above the zone of turbulence, they will be in the laminar flow of air—where you want the wind turbine to be. That's your minimum tower height, and you'll need to estimate this height since there's no easy way of measuring it. This experiment is going to vary with the wind speed. But since you can't continuously readjust your tower height, you need to pick a wind speed that occurs most of the time at your site, and that will optimize your turbine's energy production.

Mick Sagrillo • Forestville, Wisconsin

Hydro Grounding

I've installed several small microhydro systems without including grounding. It doesn't seem necessary or safe to create a ground in small isolated systems that generate just one target voltage. I think it only creates an extra way to get shocked. Big systems may deliberately use the earth as a conductor and grounding protects people from high pre-transformer voltage shocks. Am I right in my antigrounding stance?

Rob Endicott • via email

If everything is properly installed and working correctly in an "ungrounded" system, it will work fine. But if something goes wrong, there is nothing there to protect the users and components. It's like driving a car without bumpers and seat belts—as long as you don't get in an accident, you are OK. Grounding is there for when things go wrong.

Grounding can be confusing, but it is important for *all* electrical systems—even in small, low-voltage hydro systems. While it is true that there is much less shock potential from a low-voltage system, that is only one reason why systems require grounding. Grounding reduces the hazard potential through several different means:

- Connecting the electrical system to grounding electrodes (ground rod) bleeds away any stray voltages so they won't damage sensitive electronics.
- Connecting all of the metal enclosures and conduit in the system with an additional grounding conductor provides a safe path for electricity to flow when a fault occurs, to prevent shock and fires.
- Connecting one of the electrical conductors (in DC systems, usually the negative conductor) to the ground system allows the breakers to trip or fuses to blow when a fault occurs. This protects the system and users, and makes it obvious if there is a problem with the system. This connection must be done at one point only in the system to avoid ground loops (unwanted current on the grounding system), which can be caused by parallel paths to ground.

The *National Electrical Code (NEC)* allows DC systems operating at 50 volts or less to be "ungrounded," but this only means the DC negative conductor is not intentionally connected to the grounding system. A ground rod and ground conductors connecting all the metal enclosures and conduit are still required. In addition, since both the negative and positive conductors are now "ungrounded," the *NEC* then requires overcurrent protection and disconnect devices in both the positive and negative conductors. This adds significant cost and complexity to a system, so grounding the DC negative conductor is usually preferred.

In summary, a microhydro system without grounding can work, but a system with proper grounding will be safer and less likely to be damaged when a problem occurs. See my article on grounding in *HP118* for more explanation and information.

Christopher Freitas • Sun Energy Power International

write to:

asktheexperts@homepower.com

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

PV String Inverters

A Buyer's Guide

by Justine Sanchez

Since our last string inverters buyer's guide was published in 2012, a few manufacturers have exited the market (Exeltech and Opti-Solar)—but some new ones have stepped in (Chint Power Systems, Danfoss, Eaton, and Eltek). This year's guide profiles each inverter manufacturer and summarizes its residential products.

The table includes single-phase, UL-listed batteryless inverters with AC output power ranging from 1.5 to 11.0 kW. They are all Go Solar California-eligible inverters (per SB1 guidelines), and are distributed in the United States.

Comment & Discuss this article @ homepower.com/160.32

Chint Power Systems (chintpower.com/na)

is headquartered in Shanghai, China, and was established in 2009. The company specializes in utility-interactive PV inverters for all market segments. Products and services include power transmission and distribution equipment; low-voltage electrical products; meters; engineering, procurement, and construction; PV modules (as Astronergy); and automotive parts. Chint Power Systems' U.S. subsidiary is based in Dallas, Texas.

Chint's original line of residential inverters (CPS-SCE) are available in 4, 5, 6, and 7 kW models. Its second-generation inverter (CPS-SCA; consisting of 3, 4, 5, and 6 kW models) includes arc-fault protection and dual MPPT inputs. Both inverter lines are transformerless and have a CEC-rated efficiency of 96.5% to 97%.

Courtesy Chint Power Systems

Notable Specifications

Inverter topology specifies the working parts inside the inverter (transformer-based or transformerless). Most past U.S. inverters included an isolation-transformer and were used with grounded PV systems. Recently, transformerless (TL or "non-isolated") inverters, which require the PV system to be ungrounded, are becoming common in the United States. Benefits of transformerless inverters include higher efficiency, increased ground-fault sensitivity, and cost less to manufacture. However, there are additional *National Electrical Code (NEC)* requirements for ungrounded systems (see "Ungrounded PV Systems" in *HP150*).

CEC-rated efficiency is a ratio of output power to input power, as computed by California Energy Commission (CEC) algorithms. Efficiency varies depending on conditions such as ambient air temperature, inverter temperature, and array voltage. An inverter's efficiency at any moment depends on how much power the inverter is processing. The CEC specification considers how long arrays normally spend at various power levels. Each inverter is tested at several power levels, and at low, medium, and high DC input voltages to calculate an average efficiency value. This weighted efficiency is independently verified and is used by designers for comparing inverters.

NEMA enclosure rating identifies the inverter casing's level of weather-proofing. NEMA 3R enclosures are intended for either indoor or outdoor mounting and provide some degree of protection from rain, sleet, and snow. NEMA 4X enclosures can also be mounted indoors or outdoors but, with their higher rating, are considered watertight and corrosion-resistant.

MPPT inputs refer to the number of maximum power point trackers (MPPTs) the inverter has. Having multiple MPPT inputs allows parts of the PV array to operate efficiently at different power levels. This is particularly helpful for arrays on multiple roof planes, or when PV strings have different numbers of modules. Multiple MPPT inputs can also be helpful for future array expansion.

Arc-fault protection is a recent PV system requirement, introduced in section 690.11 of the 2011 *NEC*. It is required for PV arrays operating at 80 VDC or greater installed on or penetrating a building. This is intended to mitigate potential fire hazards from arcing that is more likely with DC circuits.

MPPT voltage window is the voltage range that the inverter accepts to search for the array's MPP. The wider the window, the more options designers have for using various numbers and types of PV modules (with different output voltages) in their systems. A wide MPPT window also helps an inverter keep the array operating at its maximum under a variety of weather conditions—especially helpful in areas with large seasonal temperature variations. Finally, a lower low-end MPPT point can be advantageous since an array's voltage will decrease with age.

Danfoss (danfoss.us/solar) was founded in 1933 in Nordborg, Denmark, where its headquarters remain. Danfoss offers solar inverters as part of its larger focus on energy efficiency, but also offers products in refrigeration and heating. Its U.S. inverter facility is located in Loves Park, Illinois.

While Danfoss manufactures large industrial central inverters (1 and 1.5 MW) at its Illinois facility, its residential DLX string (2, 2.9, 3.8, and 4.4 kW) inverters are manufactured in partnership with Eltek and have CEC efficiencies ranging from 96.5% to 97%.

Delta (delta-americas.com) was founded in 1971 and has headquarters in Taipei, Taiwan, and in Fremont, California, with sales and manufacturing plants throughout the world. Delta manufactures power supply products for computer, telecommunication, medical, and industrial industries, as well as products for PV applications.

Delta offers the Solivia TR string inverters in the United States. This line includes four units with rated power specifications ranging from 2.5 to 5 kW, and CEC-rated efficiencies ranging from 95% to 95.5%. Delta also manufactures five transformerless (TL) models (3 to 7.6 kW), which include arc-fault protection and have a CEC-rated efficiency of 97.5%. The 5.2, 6.6, and 7.6 kW TL models have dual MPPTs. All Delta inverters have NEMA 4 enclosures.

Courtesy Delta

Eaton Corp. (eaton.com) was established in 1911. Eaton is a global power management company with headquarters in Dublin, Ireland, and U.S. headquarters in Cleveland, Ohio. Eaton's electrical sector business group includes power distribution and power quality products and services. Besides manufacturing inverters, Eaton supplies DC combiner boxes, DC and AC disconnects, and electric vehicle chargers.

Eaton's residential inverter line consists of four transformerless models ranging from 4 to 7 kW, with a CEC efficiency of 97%. These inverters have a wide MPPT input voltage window—from 105 to 500 VDC.

Eltek (eltek.com) was established in 1971 and is headquartered in Drammen, Norway, with its U.S. regional office in Plano, Texas. Eltek is an international power electronics supplier to the telecom, rail, power generation and distribution, solar, and electric vehicle industries.

The Eltek THEIA HE-t UL series inverters are transformer-based and range in capacity from 2 to 4.4 kW. The 2 and 2.9 kW models have a CEC-rated efficiency of 96.5%, and the 3.8 and 4.4 kW models are listed at 97% at 240 VAC.

Courtesy Eltek

Fronius (fronius-usa.com) was founded in 1945 and is headquartered in Pettenbach, Austria. Fronius has three divisions supplying battery-charging systems, welding technology, and solar electronics. Its U.S. subsidiary headquarters is in Portage, Indiana.

The Fronius inverters are transformer-based in three models: the IG Plus V, the IG Plus Advanced, and its newest addition—the Galvo inverter (see "Gear" in *HP159*). The IG Plus V line has seven options ranging from 3 to 11.4 kW, with CEC-rated efficiencies between 95.5% and 96% at 240 VAC output. The IG Plus Advanced line has the same capacity options and CEC efficiencies as the IG Plus V, but includes arc-fault protection. The Galvo models are smaller-capacity inverters in four options ranging from 1.5 to 3.1 kW and include arc-fault protection.

Courtesy Fronius

Ingeteam (ingeteam.com) was founded in 1972, with headquarters in Bilbao, Spain. Ingeteam specializes in electrical equipment and services for industry, marine, railway, and energy markets, with a focus on power components for wind and PV systems. Ingeteam includes a manufacturing facility in Milwaukee, Wisconsin, and a sales office in Santa Clara, California. Its U.S. product line includes PV grid-tied inverters and large-scale (100+ kW) battery-based inverter systems.

Ingeteam's residential inverters include the transformer-based Ingecon Sun Lite 5 U, a 5 kW unit with a 95.5% CEC efficiency, and five transformerless Sun Lite TL U models, which range in capacity from 3.6 to 8.6 kW, and have CEC efficiencies from 96 to 97% at 240 VAC output.

Courtesy Ingeteam

Courtesy KACO New Energy

KACO New Energy (kaconewenergy.com) celebrates its 100th anniversary this year. Headquartered in Neckarsulm, Germany, it was originally an automotive industry supplier. KACO has been designing and manufacturing power electronics for more than 60 years and provides power supplies for rail and industrial applications, custom fuel cell inverters, and combined heat and power plants. KACO's U.S. headquarters is in Grass Valley, California, and has a new manufacturing facility in San Antonio, Texas.

Transformer-based residential string inverters from KACO range from 1.5 to 5 kW, with CEC efficiencies of 95% to 95.5%. Its transformerless models are available in 6.4 and 7.6 kW capacities and have a listed CEC efficiency of 96.5%. The "M" models have Tigo Energy's Maximizer Management Unit pre-installed (see "Gear" in *HP154*).

Power-One (power-one.com) is headquartered in Camarillo, California, and also has facilities in China, Italy, and Slovakia. In July 2013, the multinational ABB Group, which provides power and automation technologies, acquired Power-One.

Power-One's residential PV string inverters include transformer-based UNO 2.0 and 2.5 kW models, which have CEC efficiencies of 95.5% and 96%, respectively. There are five transformerless PVI models ranging from 3.0 to 6.0 kW, all of which offer dual MPPT inputs and 96 to 96.5% CEC efficiency. All of the Power-One string inverters have a NEMA 4X rating.

Courtesy Power-One

Schneider Electric (schneider-electric.com)

is headquartered in Rueil-Malmaison, France, and entered the electricity industry in 1891. Schneider is a multinational corporation with a long history of manufacturing electrical motors and equipment for power stations. Schneider acquired Square D, which transformed the company into the world's largest manufacturer of electrical distribution equipment. Schneider Electric entered the solar inverter market in 2008 with the acquisition of Xantrex Technology, a well-known solar and wind inverter manufacturer in the United States offering residential and commercial products for on- and off-grid systems.

For batteryless residential inverters, Schneider Electric offers its transformer-based Conext TX, in 2.8, 3.3, 3.8, and 5 kW models, with CEC-rated efficiencies ranging from 94.5% to 96%.

Courtesy Schneider Electric

SMA (sma-america.com)

was founded in 1981 and is headquartered in Niestal, Germany. SMA Solar Technology provides inverters for all PV market segments. The company's U.S. subsidiary, SMA America, was founded in 2000 and is headquartered in Rocklin, California, and has a production facility in Denver, Colorado.

SMA offers many Sunny Boy residential string inverters. Its transformer-based series includes a smaller high-frequency (HF) model in 2.0, 2.5, and 3.0 kW capacities. These units have slim profiles (14 inches wide by 29 inches tall) and are lightweight (51 pounds, including the DC disconnect box). Their CEC efficiencies range from 96.5% to 97%. Seven low-frequency (LF) transformer-based models range between 3.0 and 8.0 kW, with 95.5% or 96% CEC efficiency depending on the model.

SMA offers six transformerless (TL) models spanning 6 to 11 kW, with CEC efficiencies (at 240 VAC output) between 98% and 98.5%. The newest TL models have 3.0, 3.8, 4.0, and 5.0 kW capacities and a 96.5% CEC efficiency. These models include dual MPPT inputs and a secure power supply feature, which allows for some daylight backup power during utility outages (see "Backup Power—Without Batteries" in *HP159*). With the exception of the HF models, all of these Sunny Boy string inverters have integrated arc-fault protection (either as a standard or optional feature).

Courtesy SMA America

Courtesy SolarEdge Technologies

SolarEdge Technologies (solaredge.com)

was founded in 2006 and is based in Israel, with offices in China, Germany, Italy, Japan, and Fremont, California. SolarEdge inverters are designed specifically for use with its module-level MPPT power optimizer system.

SolarEdge offers seven residential transformerless inverters, in 3 to 11.4 kW capacities. These inverters have integrated arc-fault protection and 97.5% to 98% CEC efficiency at 240 VAC output. Because they are specifically designed to be used with the power optimizer system, they have a built-in module-level monitoring receiver.

Courtesy Solectria Renewables

Solectria Renewables (solectria.com)

is headquartered in Lawrence, Massachusetts, and was founded in 2005, and focuses on utility-interactive grid-tied PV inverters and string combiners. However, its predecessor, Solectria Corp., acquired its power stage technology in 1989. Solectria Corp. manufactured electric and hybrid vehicles, as well as power electronics and controls for high-power systems.

Solectria's residential inverters include its PVI 1.8 and 2.5 kW transformer-based models, which have a NEMA 4X rating and a 92.5% and 93% CEC rating, respectively. Solectria's latest residential inverter is a transformerless series including a 3.8 kW version with a single MPPT input. The 5.2, 6.6, and 7.6 kW versions with dual MPPT inputs, were projected to be available in the second quarter of 2014. All of these transformerless models have a 97.5% CEC efficiency and are slated to offer optional DC arc-fault protection.

SINGLE-PHASE

Manufacturer	Model	Isolated Topology	Input Data (DC): Max. PV Power at STC (W)	Max. Open-Circuit Voltage	PV Start Voltage	# MPPT Circuits	MPPT Voltage Range	Max. Usable Input Current[1]	Max. Short-Circuit Current	Output Data (AC): CEC-Rated Power (W)	Nominal Output Voltage
Chint Power Systems chintpower.com/na	SCE4KTL-O/US	No	4,800	600	150	1	225–500	19.0	19.0	4,000	208 240 277
	SCE5KTL-O/US		6,000				200–500	26.0	26.0	5,000	
	SCE6KTL-O/US		7,200					32.0	32.0	6,000	
	SCE7KTL-O/US		8,400					37.0	37.0	7,000	
	SCA3KTL-O/US		4,000	550	200	2	200–470	16.0	12.8	3,000	208 240
	SCA4KTL-O/US		5,200					21.0	16.8	4,000	
	SCA5KTL-O/US		6,500					26.0	20.8	5,000	
	SCA6KTL-O/US		7,800					32.0	25.6	6,000	
Danfoss danfoss.us	DLX 2.0 UL	Yes	2,625	600	230	1	230–500	9.5	11.5	2,000	208 240
	DLX 2.9 UL		3,750					13.5	16.5	2,900	
	DLX 3.8 UL		5,000					18.0	22.0	3,800	
	DLX 4.4 UL		5,750					21.0	25.0	4,400	
Delta delta-americas.com	SOLIVIA 2.5 TR	Yes	3,200	600	150	1	200-500	19.0	36.0	2,500	208 240
	SOLIVIA 3.3 TR		4,000					24.0		3,300	
	SOLIVIA 4.4 TR		5,200					31.0	55.5	4,400	
	SOLIVIA 5.0 TR		6,000					37.0		5,000	
	SOLIVIA 3.0 TL	No	3,600		120	1		18.0	30.0	3,000	
	SOLIVIA 3.8 TL		4,560					20.0		3,800	
	SOLIVIA 5.2 TL		6,240			2		15.0		5,200	
	SOLIVIA 6.6 TL		7,920					18.0		6,600	
	SOLIVIA 7.6 TL		9,120					20.0		7,600	
Eaton eaton.com	PV240	No	DNR	600	150	1	105-500	19.0	DNR	3,690/3,980/3,981	208 240 277
	PV250							26.0		4,470/4,830/4,830	
	PV260							32.0		5,980/6,000/6,000	
	PV270							37.0		6,950/6,920/7,000	
Eltek eltek.com	2.0 HE-t UL	Yes	2,625	600	230	1	230–500	9.5	11.5	2,000	208 240
	2.9 HE-t UL		3,750					13.5	16.5	2,900	
	3.8 HE-t UL		5,000					18.0	22.0	3,800	
	4.4 HE-t UL		5,750					21.0	25.0	4,400	
Fronius USA fronius-usa.com	IG Plus A 3.0-1	Yes	4,500	600	260	1	230–500	14.0	18.0	3,000	208 240 277
	IG Plus A 3.8-1		5,700					17.8	22.0	3,800	
	IG Plus A 5.0-1		7,500					23.4	29.0	5,000	
	IG Plus A 6.0-1		9,000					28.1	35.0	6,000	
	IG Plus A 7.5-1		11,250					35.1	44.0	7,500	
	IG Plus A 10.0-1		15,000					46.7	58.0	9,995	
	IG Plus A 11.4-1		17,100					53.3	67.0	11,400	
	GALVO 1.5-1		2,250	420	120		120-335	13.3	20.0	1,500	208 240
	GALVO 2.0-1		3,000					17.8	26.8	2,000	
	GALVO 2.5-1		3,750	550			165-440	16.6	24.8	2,500	
	GALVO 3.1-1		4650					20.7	31.0	3,100	
Ingeteam ingeteam.com	Ingecon Sun Lite 5 U	Yes	6,500	550	150	1	200–450	30.0	30.0	5,000	208 240 277
	Ingecon Sun Lite 3.6TL U	No	5,000					22.0	22.0	3,600	
	Ingecon Sun Lite 5TL U		6,500					30.0	30.0	5,000	
	Ingecon Sun Lite 6TL U		7,400					32.0	33.0	6,000	240/277
	Ingecon Sun Lite 7.5TL U		9,250				225-450	35.0	35.0	7,500	208/240/277
	Ingecon Sun Lite 8.6TL U		10,700				250-450			8,600	240/277
	Ingecon Sun Lite 10TL U		12,300				300-450			10,000	277
KACO New Energy kaconewenergy.com	1502xi[4]	Yes	2,000	550	125	1	125–400	14.3	21.5	1,500	208 240
	2502xi[4]		3,000		200		200–450	13.5		2,500	
	3502xi[4]		4,000	600[6]			200–510	18.5	28.0	3,500	
	5002xi[4]		6,000					26.5	40.0	5,000	
	6400xi	No	8,000		320/365		320–510/ 365–510	21.0	36.0	6,400	
	7600xi		9,500					24.0		7,600	
	6400M[5]		8,000			x[7]		21.0		6,400	
	7600M[5]		9,500					24.0		7,600	
Power-One power-one.com	UNO-2.0-I-OUTD-S-US	Yes	2,100	520	200[8]	1	170–470	12.5	15.0	2,000	208 240 277
	UNO-2.5-I-OUTD-S-US		2,600				205–470	12.8		2,500	
	PVI-3.0-OUTD-S-US	No	3,500	600		2	160–530	2 × 10	2 × 12.5	3,000	
	PVI-3.6-OUTD-S-US		4,150				120–530	2 × 16	2 × 20	3,600	
	PVI-4.2-OUTD-S-US		4,820				140–530			4,200	
	PVI-5000-OUTD-US		5,300				200–530	2 × 18	2 × 22	5,000	
	PVI-6000-OUTD-US		6,400							6,000	
Schneider Electric schneider-electric.com	Conext TX 2800 NA	Yes	3,100	600	190	1	195–550	14.9/15.5	24.0	2,650/2,800	208 240
	Conext TX 3300 NA		3,500					17.5/18		3,100/3,300	
	Conext TX 3800 NA		3,700/4,200					19.5/20.8		3,500/3,800	
	Conext TX 5000 NA		4,800/5,400		235		240–550	20.5/22.5		4,500/5,000	
SMA America sma-america.com	SB 2000HF-US	Yes	2,500	600	220	1	175–480	15.0	25.0	2,000	208/240
	SB 2500HF-US		3,125				220–480			2,500	
	SB 3000HF-US		3,750							3,000	
	SB 3000-US			500	228		175–400/200–400	17.0	36.0	3,000	
	SB 3800-US		4,750	600	285		250–480	18.0		3,800	240
	SB 4000-US		4,375/5,000				220–480/250–480			3,500/4,000	208/240
	SB 5000-US		6,250		300		250–480	21.0		5,000	208
	SB 6000-US		7,500					25.0		6,000	240
	SB 7000-US		8,750					30.0		7,000	277
	SB 8000-US		10,000		365		300–480			7,680/8,000	240/277

SINGLE-PHASE

Output Data (AC)		Operation		Disconnects & Combiners				Termination Specifications				Mechanical				Listing & Warranty	
Max. Output Current	Max. AC OCPD Rating (A)	CEC-Weighted Efficiency (%)	Ambient Temp. Range (°F)	DC Disconnect	AC Disconnect	Fused Combiner	Arc-Fault Protection	# DC String Inputs	DC Wire Range (AWG)	AC Wire Range (AWG)	GEC Wire Range (AWG)	Cooling Method	NEMA Rating	Dimensions H × W × D (In.)	Weight (Lbs.)	Listing Agency	Warranty Std./Ext. (Yrs.)
18.5/18.5/16.4	25.0	97.0	-13 to 122	Yes	Yes	No	No	4	10–8	10–8	10	Active	3R	33.4 × 17 × 8.4	86	CSA	5/10
22.5/22.5/20.5	30.0														90		
30/28.5/24.6	40.0										8				101		
35/33.2/28.7	50.0								10–6								
13.5	40.0	96.5	-13 to 140			Yes	Yes		12–8		10	Passive		28.7 × 17 × 8.7	84		10
18.0																	
22.0		97.0									8						
27.5												Active					
10/8.5	15.0	96.5	-13 to 149	Yes	No	Yes	No	3	20–6	10-6	10–4	Passive	3R	28.4 × 13.9 × 6.5	49	UL	10/15, 20
14/12																	
18.5/16	25.0	97.0													51		
21.5/18.5	30.0																
12.0	12.0	94.5/95.0	-13 to 176	Yes	No	Yes	No	3	14-6	14-6	8–6	Passive	4	25.59 × 16.77 × 9.06	58.4	ETL	10/15, 20
16.0	16.0	95.0/95.5															
24.0	24.0	94.5/95.0								10–6					81.6		
		94.5/95.0															
15.0	15.0	97.5					Yes	2		14-6				17.72 × 15.75 × 6.89	43	UL	
16.0	16.0																
27.5	27.5							4		10–6				25.20 × 15.75 × 6.89	65	CSA	
32.0	32.0																
18.5/18.5/16.4	DNR	97.0	-13 to 122	Yes	Yes	Yes	No	4	14-6	10-6	14-6	Active	3R	33.3 × 17.1 × 8.3	86	ETL	10
22.5/22.5/20.5															90		
30/28.5/24.6															101		
35/33.2/28.7																	
10/8.5	15.0	96.5	-13 to 149	Yes	No	Yes	No	3	20-6	10-6	10–4	Passive	3R	28.4 × 13.9 × 6.5	49	UL	10/15, 20
14/12															49		
18.5/16	25.0	97.0													51		
21.5/18.5	30.0														51		
14.4/12.5/10.8	20/20/15	95/95.5/96	-13 to 131	Yes	No	Yes	Yes*	6	14–6	14–4	14–4	Active	3R	26.5 × 17.1 × 9.9	55	CSA	10/15, 20
18.3/15.8/13.7	25/20/20																
24/20.8/18.1	30/30/25	95.5/95.5/96												38.1 × 17.1 × 9.9	81		
28.8/25/21.7	40/35/30	95.5/96/96															
36.1/31.3/27.1	45/40/35	95/95.5/96															
48.1/41.6/36.1	60/60/45													49.7 × 17.1 × 9.9	110		
54.8/47.5/41.2	70/60/60																
7.2	20.0	94.5				No	Yes			14-6			4X	24.7 × 16.9 × 8.1	37		
9.7		95.0															
12.1																	
15.0		95.5															
24.1	DNR	95.5	-4 to 150	Yes	No	Yes	No	4	16–6	16–6	16–6	Active	3R	27.4 × 14.2 × 13.1	168	ETL	10/20
17.4		96.0												28.4 × 14.2 × 7	53		
25.5		96.5													62		
26.2		96.5															
36.1		97.0													64		
		97.5															
8.0	15.0	95/95.5	-4 to 140	Yes	Yes	No	No	3	12–4	12–4	12–4	Passive	3R	30 × 14 × 8.3	42	TUV	10/15, 20
12.5/12	20.0													32 × 14 × 8.3	52		
17/16	25.0	95.0	-13 to 140											35.9 × 14 × 9.3	69		
24.0	30.0	95/95.5										Active			70		
31/27	50.0	96.5	-4 to 140		No	Yes		4						44.1 × 14 × 8.9	95		
37/32																	
31/27			-13 to 140												108		
37/32																	
10.0	15.0	95.5	-13 to 140	Yes	No	No	DNR	2	20–6	20–6	20–6	Passive	4X	30.3 × 14.4 × 6.3	42.5	CSA	10/15, 20
12.0		95.5/96/96															
14.5/14.5/12	20/20/15	96.0						2 × 2	10–4	10–4	10–4[12]			33.8 × 12.8 × 8.7	47		
17.2/16/16																	
20.0	25.0																
27/23/20	30.0	96/96.5/96.5							8–4	8–4				41.4 × 12.8 × 8.6	60		
30/28/24																	
13/11.8	15.0	94.5	-13 to 149	Yes	Yes	Yes	No	3	14–6	14–6	12–4	Passive	3R	35 × 15.9 × 7.3	70	CSA	10
15.2/14	20.0	94.5/95													71		
16.8/16	25.0	95.5												38.9 x 15.9 x 7.3	81		
22/21	30.0	95.5/96													86		
9.6/8.3	25.0	97.0	-13 to 113	Yes	No	No	No	3	10–8	12-8	10–6	Active	3R	29 × 14 × 7	51	UL	10/15, 20
12/10.4		96.5															
14.4/12.5		96.5															
15/13	30.0	95/95.5				Yes	Yes**	4	10–6	10–6				14 × 18 × 9[13]	84[14]		
16.0		96.0															
17.0		95.5/96															
24/21/18	50.0	95.5												24 × 18.5 × 9[13]	141[14]		
29/25/22		95.5/95.5/96															
34/29/25		95.5/96/96															
32/29		96.0													145[14]		

SINGLE-PHASE, CONT.

Manufacturer	Model	Isolated Topology	Input Data (DC): Max. PV Power at STC (W)	Max. Open-Circuit Voltage	PV Start Voltage	# MPPT Circuits	MPPT Voltage Range	Max. Usable Input Current[1]	Max. Short-Circuit Current	Output Data (AC): CEC-Rated Power (W)	Nominal Output Voltage
SMA America (continued) sma-america.com	SB 3000TL-US	No	3,200	600	150	2	175–480	2×15	2×19	3,000	208/240
	SB 3800TL-US		4,200							3,800	
	SB 4000TL-US									4,000	
	SB 5000TL-US		5,300							4,550/5,000	
	SB 6000TL-US		7,500		360	1	300–480/ 345–480	20.9/18.1	45.0	6,000	
	SB 7000TL-US		8,750					24.4/21.1		7,000	
	SB 8000TL-US		10,000					27.9/24.1		8,000	
	SB 9000TL-US		11,250					31.4/27.1		9,000	
	SB 10000TL-US		12,500					35/30.2		10,000	
	SB 11000TL-US		13,750				345–480	33.3		11,000	240
SolarEdge Technologies solaredge.com	SE3000A-US	No	4,100	500	8[19]	x[7]	8–80[19]	11.0	30.0	3,000	240
	SE3800A-US		5,200					13.0		3,800	
	SE5000A-US		6,250					18.0		5,000	208/240/277
	SE6000A-US		7,500							6,000	240
	SE7600A-US		9,500					23.0		7,600	
	SE10000A-US		12,500					30.5		10,000	208/240/277
	SE11400A-US		14,250					34.5		11,400	240
Solectria Renewables solectria.com	PVI 1800	Yes	2,200	400	150	1	125–350	11.0	18.0	1,800	208/240
	PVI 2500		3,200					15.0		2,500	
	PVI 3800TL	No	4,580	600	DNR		200-500	20.0	DNR	3,300/3,800	
	PVI 5200TL		6,200			2		15.0		5,200	
	PVI 6600TL		8,000					18.0		6,600	
	PVI 7600TL		9,100					20.0		6,600/7,600	

THREE-PHASE

Manufacturer	Model	Isolated Topology	Input Data (DC): Max. PV Power at STC (W)	Max. Open-Circuit Voltage	PV Start Voltage	# MPPT Circuits	MPPT Voltage Range	Max. Usable Input Current[1]	Max. Short-Circuit Current	Output Data (AC): CEC-Rated Power (W)	Nominal Output Voltage
AE Solar Energy solarenergy. advanced-energy. com	AE_3TL-12_6-08	No	14,400	±500	±200	1	±125–450	2 × 27.5	76	12,000	480
	AE_3TL-16_6-08		19,200					2 × 33		16,000	
	AE_3TL-20_6-08		24,000					2 × 37.5		20,000	
	AE_3TL-23_6-08		27,800					2 × 40		23,200	
	AE_3TL-12_10-08		14,400	±1,000			±250–900	2 × 27.5		12,000	
	AE_3TL-16_10-08		19,200					2 × 33		16,000	
	AE_3TL-20_10-08		24,000					2 × 37.5		20,000	
	AE_3TL-23_10-08		27,800					2 × 40		23,200	
Chint Power Systems chintpower.com	SC20KTL-DO/US-480	No	27,000	600	260	2	300–550	2 × 35	2 × 45	20,000	480
	SCA 14KTL-DO/US-208		18,900				180-550	2 × 25		14,000	208
	SCA23KTL-DO/US-480		31,000	1,000	330		300-900	2 × 27	2 × 41	23,000	480
	SCA28KTL-DO/US-480		38,000					2 × 32	2 × 48	28,000	
Fronius USA fronius-usa.com	IG Plus A 10.0-3 Delta	Yes	15,000	600	260	1	230–500	46.7	58	9,995	208/240
	IG Plus A 11.4-3 Delta		17,100					53.3	67	11,400	
	IG Plus A 12.0-3 480 277wye		18,000					56.1	71	12,000	277
Ideal Power idealpower.com	IPV-30kW-480	Yes[3]	37,500	±600	±100	1	±300±450	2 × 50	2 × 60	30,000	480
KACO New Energy kaconewenergy.com	XP10U-H4-PSD	No	12,000	600	250	2	200–550	2 × 18.6	2 × 23	10,000	480
Power One power-one.com	PVI-10.0-I-OUTD-US[9]	Yes	10,500	520	200[8]	2	220–470	2 × 24	2 × 29	10,000	208/480
	PVI-12.0-I-OUTD-US[9]		12,300					2 × 25		12,000	480
	Trio-20.0-TL-OUTD-US[10]	No	22,000	1,000	360[11]		450–800		2 × 30	20,000	
	Trio-27.6-TL-OUTD-US[10]		30,000				520–800	2 × 30.9	2 × 36	27,600	
SMA America sma-america.com	STP 12000TL-US	No	15,000	1,000	188	2	300-800	2 × 33	2 × 43	12,000	480 WYE
	STP 15000TL-US		18,750							15,000	
	STP 20000TL-US		25,000				380-800			20,000	
	STP 24000TL-US		30,000				450-800			24,000	
SolarEdge Technologies solaredge.com	SE9kUS	No	11,250	500	12.5[23]	x[7]	12.5–80[23]	26.5	30	9,000	208
	SE10kUS		12,500	980	12.5[24]		12.5–105[24]	13.5		10,000	480
	SE20kUS		25,000	980				26.5		20,000	
SolarMax solarmax.com	12MT2A	No	12,000	1,000	250	2	340-850	2 × 18	36	11,700	277/480
	15MT3A		15,000	600		3	325-500	2 × 18/	46	14,550	
	18MT3A		18,000	1,000			400-850	1 × 10	46	17,460	
Solectria Renewables solectria.com	PVI 14TL	No	19,000	600	300	2	300-540	25	45	14,000	208
	PVI 20TL		27,000				300-550	35	45.5	20,000	480
	PVI 23TLM		31,000	1,000	330		480-800	27	41	23,000	
	PVI 28TLM		38,000				500-800	32	48	28,000	
Sungrow sungrow.ca	SG30KU	No	32,000	1,000	300	2	300-950	33.0	80	30,000	277/480
	SG36KU		38,280						80(40/40)	36,000	

*With Advanced (A) model. **Optional. [1]Per MPPT circuit. [2]With fans operating. [3]Isolated without transformer. [4]1502x–5002x inverters without disconnects available. Electrical specs are identical for x and xi models. [5]Integrated Tigo Energy Maximizer Management Unit. [6]Only supplies PV power at <550 VDC. [7]Module-level MPPT. [8]Adjustable: 120–350 VDC. [9]Example unit. Variations include 208, 480, and 600 (Canada) VAC outputs, pos. and neg. grounding, and DC or DC/AC switches. [10]Example unit shown. Variations include DC fuses, 2 × 8 DC input terminals, DC surge protection, and AC fused disconnect. [11]Adjustable: 250 – 500 VDC. [12]GEC not required. EGC specification listed. [13]DC disconnect dimensions: 12 × 7 × 7.5 in. [14]DC disconnect weight: 8 lbs. [15]Per MPPT tracker.

SINGLE-PHASE, CONT.

Output Data (AC)		Operation		Disconnects & Combiners				Termination Specifications				Mechanical				Listing & Warranty	
Max. Output Current	Max. AC OCPD Rating (A)	CEC-Weighted Efficiency (%)	Ambient Temp. Range (°F)	DC Disconnect	AC Disconnect	Fused Combiner	Arc-Fault Protection	# DC String Inputs	DC Wire Range (AWG)	AC Wire Range (AWG)	GEC Wire Range (AWG)	Cooling Method	NEMA Rating	Dimensions H × W × D (In.)	Weight (Lbs.)	Listing Agency	Warranty Std./Ext. (Yrs.)
15.0	30.0	96/96.5	-40 to 140	Yes	No	N/A	Yes	2[15]	10–6	12-6	10–6	Passive	3R	20.5 × 19.3 × 7.3[16]	53[14]	UL	10/15, 20
16.0																	
20.0																	
22.0																	
28.8/25	45.0	98/98.5				No	Yes**	6[17]	8-2[18]	6-2	8-2	Active		24.1 × 18.4 × 9.5[16]	78[14]		
33.7/29.2																	
38.5/33.4	60.0	98.0															
43.3/37.5																	
48.1/41.7		97.5/98															
45.8		98.0															
14.0	40.0	97.5	-13 to 140[25]	Yes	Yes	N/A	Yes	2	24–6	24–6	10–6[12]	Passive	3R	30.5 × 12.5 × 7	51	ETL	12/20, 25
16.0		98.0															
25/23/20		97.5/98/98												30.5 × 12.5 × 7.5	54.7		
25.0		97.5															
32.0									14–6	8–3		Active		30.5 × 12.5 × 10.5	88		
48/42/36		97/97.5/97.5															
47.5		97.5															
8.7/7.5	15.0	92.5	-13 to 131	No[20]	No[20]	No	No	1	10–6	10–6	10–6	Passive	4X	18.5 × 13.1 × 5.6	34	TUV	5/10
12/10.4		92/93										Active		23.6 × 13.1 × 5.6	36		
15.8	DNR	97.5	-13 to 122	Yes	No		Yes**	DNR	14-6	14-6	14-6	Passive	4	17.7 × 15.8 × 6.9	42	ETL	10/15, 20
25/21.7														23.2 × 15.8 × 6.9	64		
31.7/27.5																	
31.7																	

THREE-PHASE

Output Data (AC)		Operation		Disconnects & Combiners				Termination Specifications				Mechanical				Listing & Warranty	
Max. Output Current	Max. AC OCPD Rating (A)	CEC-Weighted Efficiency (%)	Ambient Temp. Range (°F)	DC Disconnect	AC Disconnect	Fused Combiner	Arc-Fault Protection	# DC String Inputs	DC Wire Range (AWG)	AC Wire Range (AWG)	GEC Wire Range (AWG)	Cooling Method	NEMA Rating	Dimensions H × W × D (In.)	Weight (Lbs.)	Listing Agency	Warranty Std./Ext. (Yrs.)
14.5	20	97.5	-40 to 131	Yes	No	Yes	DNR	10	12–8	10–6	10–6	Passive	3R 4X	35 × 21 × 11	108	UL	5/10, 15,20
19.3																	
24.1																	
27.9		98.0															
14.5		97.5						6									
19.3																	
24.1																	
27.9		98.0															
27.3	65	97.0	-4 to 140	Yes	Yes	Yes	Yes	8	18–6	10–8	10–8	Active	3R	41.6 × 21.4 × 8.5	132	CSA	5/10, 15,20
39.0	50	96.0															
27.6	40	95.0	-13 to 140							10–6	10–6		4	23.6 × 39.4 × 9.1	122		
33.6	50	94.0															
27.7/24	35/35	95/96	-13 to 131	Yes	No	Yes	Yes*	6	14–6	14–4	14–4	Active	3R	49.7 × 17.1 × 9.9	110	CSA	10/15, 20
31.6/27.4	40/35																
14.4	20	96.0															
37.0	70	96.5	-13 to 113	No	No	Yes	DNR	2×1	1/4" stud	1/4" stud	12–6	Active	3R	36.5 × 15 × 10.8	97	ETL	10/20
12.1	20	97.0	-13 to 140	Yes	Yes	Yes	No	4	24–8	24–8	18–4	Active	4X	37 × 16.5 × 7.9	100	ETL	10/15, 20
30/14	35/20	96/97	-13 to 140	Yes	No	Yes	DNR	2×3	20–6	12–4	20–6	Passive	4X	37.7 × 25.4 × 8.7	114	CSA	10/15, 20
16.0	20	97.0															
27.0	40	97.5	-22 to 140			No		2×2	12–1/0	14–4	8–4[12]			41.7 × 27.6 × 11.5	157		
36.0	50														168		
14.4	50	97.5	-13 to 140	No	No	No	Yes	2[21]	8-2[22]	8-6	8-2	Active	3R	27.1 × 26.1 × 10.4	121	UL	10/15, 20
18.0																	
24.0																	
29.0		98.0															
25.0	40	96.5	-13 to 140[25]	Yes	Yes	N/A	Yes	2	12–6	12–6	10–6[12]	Active	3R	30.5 × 12.5 × 10.5	80	ETL	12/20,25
12.0		98.0															
24.0																	
15.0	20	97.5	-13 to 140	Yes	No	N/A	N/A	4	10–8	10–8	10–8	Active	4X	21.5 × 37.0 × 7.9	97	ETL	10/15, 20, 25
18.5	25	97.0						5							110		
22.0	30																
39.0	DNR	96.0	-13 to 122	Yes	Yes	Yes	Yes	8	DNR			Active	3R	41.6 × 21.4 × 8.5	141	ETL	10/15, 20
27.3		96.5													132		
32.0		98.0	-13 to 113										4	39.4 × 23.6 × 9.1	122		
39.0																	
40.0	50	98.0	-13 to 140	Yes	Yes	Yes	Yes	10	10 Cu/AL	4 Cu/AL	6 Cu	Active	4X	24.2 × 34.6 × 9	143	CSA	10/20
48.0	60																

[16]DC disconnect dimensions: 11.7 × 7.3 × 7.5 in. [17]With SBCBTL-6 combiner box. [18]AWG 10-6 input & 6-2 output per the SBCBTL-6 combiner box. [19]Power optimizer P400. [20]Option on panel assemblies. [21]DC string inputs with optional CU1000-US-10 combiner disconnect. [22]AWG 12-6 input and 8-2 output on the optional CU1000-US-10 combiner disconnect. [23]Power optimizer P600. [24]Power optimizer P700. [25]-40–140 version available. DNR = Did not report


Courtesy AE Solar Energy


Courtesy SolarMax


Courtesy SMA America


Courtesy Sungrow

Commercial Three-Phase String Inverters

One of the latest evolutions in the inverter industry is three-phase string inverters, for the small-to-medium commercial PV market. Electrical distribution systems in commercial buildings often have three-phase electricity (residential systems are single-phase). Until recently, small commercial PV systems used multiple single-phase inverters for three-phase service. Now, several manufacturers are offering string inverters with true three-phase output, which offers several benefits:

- Not having to balance multiple single-phase inverters across a three-phase service.
- Lower price per watt—one 15 kW three-phase inverter is about 30% less expensive than three 5 kW single-phase units.
- No AC inverter subpanel is required to combine the outputs of the single-phase inverters.
- Less required wall space and reduced installation time.

Chint Power Systems, Fronius, KACO New Energy, Power-One, SMA America, SolarEdge Technologies, and Solectria Renewables are residential inverter manufacturers that offer three-phase inverters. Here are some additional companies offering wall-mountable, three-phase string inverters:

AE Solar Energy (solarenergy.advanced-energy.com) was founded in 1981 and is headquartered in Fort Collins, Colorado. AE Solar Energy provides power conversion products used in thin-film module manufacturing and solar energy markets. The company acquired two other inverter companies: PV Powered and REFUsol.

Ideal Power (idealpower.com) has its headquarters in Austin, Texas, and was founded in 2007. Ideal Power manufactures its products in the United States, and offers inverters and converters for energy storage and EV charging.

SolarMax (solarmax.com), headquartered in Biel, Switzerland, is a pure-play PV inverter manufacturer founded in 1991. In May 2013, SolarMax announced its entry into the U.S. market and opened its Atlanta, Georgia, office.

Sungrow (sungrow.ca), headquartered in Hefei, China, builds power supply equipment for the PV and wind industry. Founded in 1997, the company's North American subsidiary, Sungrow Canada, is in Vaughan, Ontario. The U.S. sales office is in San Jose, California.

Access

Justine Sanchez (justine.sanchez@homepower.com) is a *Home Power* technical editor and an instructor for Solar Energy International. She is certified by ISPQ as a PV Affiliated Master Trainer. Justine is planning her next PV project—a backyard PV shade structure—and is currently considering her inverter options.

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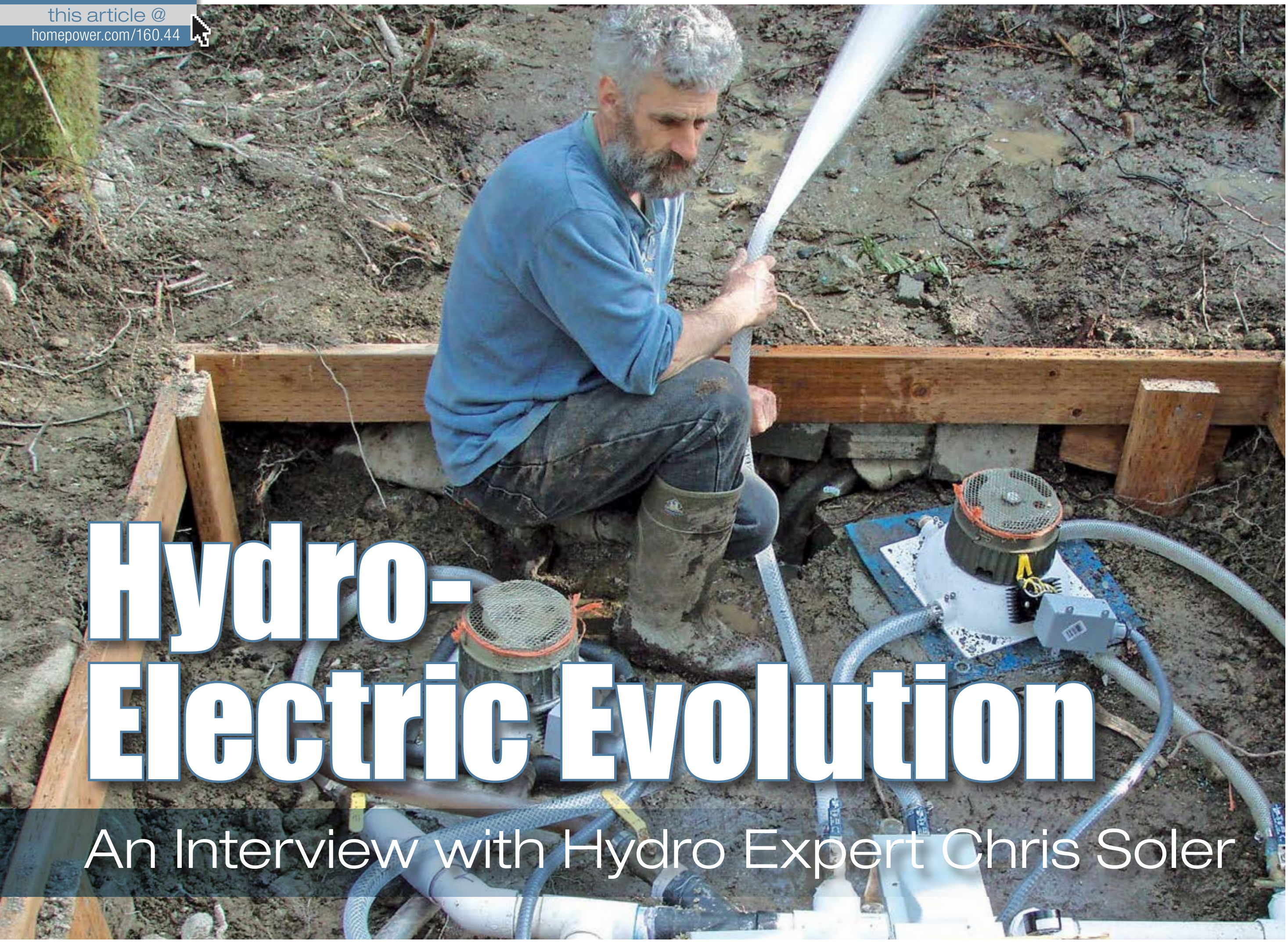


Ian Woofenden (2)

Hydro-Electric Evolution

An Interview with Hydro Expert Chris Soler

by Ian Woofenden

Chris Soler has been tinkering with small hydro-electric systems for three decades. He started by configuring homebrewed systems for himself and his neighbors, and is known for his ingenuity and creative ability to wring a few kilowatt-hours out of a seasonal stream on a low budget. Chris has been living with a custom hydro-electric system at his home in the foothills of Washington State's Cascade Mountains since 1986.

Over the years, Chris' knowledge and experience have grown, and at the same time, his clients' electrical energy needs and budgets have increased. Folks who may have been considered "backwoods" when Chris first worked with them are now in the midst of professional careers, or even starting retirement. Their originally simple homes have become more modern and complex, and require more energy. Chris has been modernizing several of his simple homebrew systems into more productive hydro-electric producers.

This history and evolution is full of lessons for potential hydro electricity users, and my chat with Chris allows *Home Power* to share some of those lessons, and the stories that go along with them.

Right: Chris "The Human Backhoe" Soler prepares for a job digging a penstock ditch. Chris has spent many days and weeks of his life scoping out hydro sites; mapping out the best locations for intakes and turbines and the best routes for penstocks and transmission lines; and digging thousands of feet of ditches to protect and secure pipelines. Above: Purging the lines.

Courtesy Chris Soler (2)

Chris' early homebrew systems used car alternators matched with homemade or cast runners, with a square plastic bucket lid sandwiched between. The bucket (with tailrace channel or pipeline) was dug into the ground, and the manifold lines terminated in simple nozzles in the bucket's sides. Snapping the lid on the bucket aligned the runner with the nozzles and set up the system for production.

Ian Woofenden

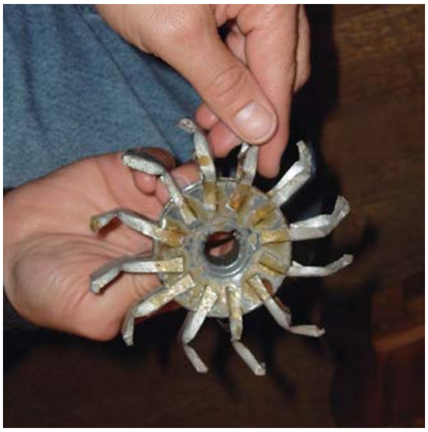
A modern Harris hydro turbine in one of Chris' upgraded systems. The square bucket lid was supplanted by a manufactured housing and the used alternator replaced with a permanent-magnet alternator that was custom-designed for hydro systems.

What was your first experience with hydro electricity, and what attracted you to the technology?

As a kid, I pretended to make electricity by damming a ditch on my family's farm. So, when as an adult on my own place in 1986, I needed to supplement my one 30-watt solar-electric module for lights in the cloudy winter, I naturally thought to try to harness water power.

I had installed a 1-inch pipe to bring water from a pond to my gardens, and it dropped 35 feet from the intake to the garden. I fitted the top end of the pipe with a fine mesh screen wrapped around the end in a cone shape, and the pipe was dug through the bank of a pond, which eliminated the need for a syphon. The pond was fed by a roadside ditch that ran heavily after a rain, but the flow quickly slowed after a few days of no rain. I fashioned buckets that slipped over the shaft of a bicycle generator, and aimed a jet of water to spin it.

Having 3 W to charge a battery for a reading light instead of relying on kerosene lamps hooked me on continuing to improve my hydro system. I upgraded to 4-inch pipes and added another 2,000 feet of pipe to gain 110 feet of drop from a second source. The higher source was runoff from a hilly pasture with flows between 10 and 200 gpm from November to June.



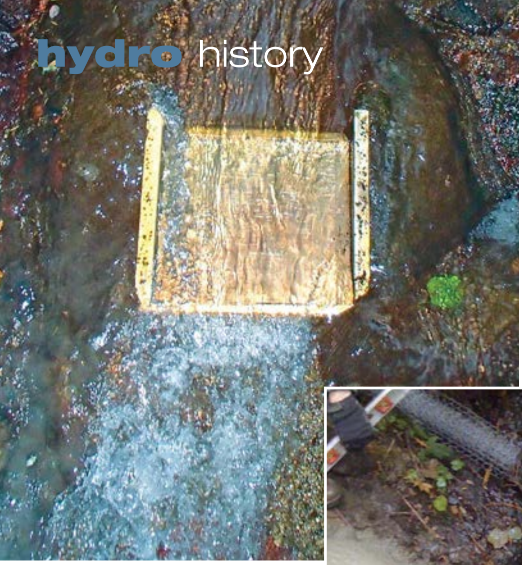
One of Chris' early homemade runners. As his understanding of hydro and his customers' budgets increased, Chris switched to manufactured runners with much higher efficiencies, capturing more energy from the same head and flow.

I upgraded to car alternators mounted on square plastic buckets, with the runner inside to direct splashing away from the alternator. Four nozzles accommodated varying stream flows. I started using a low-speed permanent magnet motor to produce 2 A at 12 V, jumping up to a 24 W output. Later, after talking with microhydro expert Don Harris, I started using 70-amp Motorcraft car alternators. After that, I bought "real" bronze Pelton wheels from him. Each change brought higher efficiencies and more power to do more on the homestead.

Describe your first few years in the industry.

The first hydro systems I put together for some local friends used a car alternator on a plastic bucket, with four nozzles and a Harris Pelton runner. I was nicknamed "the human backhoe," as I hand-trenched thousands of feet of pipeline for my clients. The first system included some old solar-electric modules to provide power during the dry summers. A Trace modified-square-wave inverter ran some AC lights, and a TV, washing machine, and water pump. Radios and chargers were run directly at 12 VDC. That allowed the inverter to go into sleep mode at night. Everything was done to make the most of the small amount of energy available.

I built a diversion controller from a circuit described by Chris Greacen in a very early issue of *Home Power* ("Homebrew Shunt Regulator" in *HP18).* Before the Internet, I would scour the articles and ads in the magazine to get ideas on how others were dealing with producing their own electricity. Innovations were being pioneered by those actually using the systems, who then told their stories in *Home Power.*



Chris learned early on that poorly designed and installed hydro intake screens can cause a lot of trouble, requiring frequent cleaning.

When self-cleaning screens became available, Chris found ways to use natural spots in the stream and a dab of concrete to set up durable, maintenance-free intakes.

How has the industry and technology changed in the decades since you started? What are the biggest advances in technology?

The microhydro business is still a small, niche market. Most products, with the exception of the turbines themselves, are adapted from the solar market. The North American turbines are from microhydro pioneers such as Don Harris of Harris Hydro; Paul Cunningham of Energy Systems & Design (ESD); and Jerry Ostermeier of Alternative Power & Machine (APM). It has been nice to be able to call up and talk directly with the people who designed and built the units. When Don Harris retired, I was worried about being able to get parts and new turbines. However, Denis Ledbetter has taken over the production of the turbines and repair parts.

In 2001, Don Harris started producing his adjustable permanent-magnet generators for his hydro turbines. I switched to those and got a 40% jump in power output. I then realized that further improvements were coming from specialized manufacturers.

Today's typical systems are much larger, and the owners are more concerned with reliability and ease of use than back in my homebrew days. Using permanent magnets eliminates the changing of brushes in alternators. Using self-cleaning intake screens (like the Coanda-type) cuts down on the time required to clean intakes. High voltage/low current (which requires smaller, and therefore less expensive, wire) is now possible with maximum power point tracking (MPPT) adapted from solar-electric systems. Specialized breakers handle the higher voltages. Sine-wave inverters run all of the AC loads without the worry of damaging sensitive electronics, which sometimes occurred with older, modified-square-wave inverters.

Walk us through a typical upgrade of one of your early hydro systems. What does an upgrade like this change, and what is the performance improvement?

Some of my older systems are still 12 V and producing modest amounts of power. Other systems have gradually added more solar-electric modules to the renewable energy mix. The hydro resource is usually limited, so higher efficiency is the only way to get more power. I look at what the owner wants to accomplish and see what improvements are possible.

Many of my hydro systems I upgraded as new products became available, and as more power or better reliability was needed. All the systems are now using permanent-magnet alternators. By continuing to use the original Pelton wheels, Don Harris was able to keep the upgrade costs low.

Some of my clients switch to higher voltage with MPPT controllers to minimize the line losses associated with increased output current. Some systems extend the pipeline to increase the head, if available. The switch to self-cleaning screens cut losses caused by plugged intakes. Upgrading to a larger-diameter penstock to cut friction loss can allow more water flow.

Ian Woofenden (4)

Above: Chris prepares low-pressure PVC pipe for the top end of a penstock.

Right: High-density polyethylene pipe is heat-welded for a high-pressure portion of a penstock.

Ian Woofenden (3)

As Chris' customers' energy needs became larger, the systems grew and improved. Upgrading from early 12 VDC systems to standard 48 VDC battery/inverter systems increased efficiency and energy possibilities.

If you could wave a magic wand to make some changes for hydro turbines and the industry, what would they be?

I would love to see some real numbers comparing the efficiency between the different manufacturers' turbines. If independent testing showed their efficiency under specific conditions, it would aid in deciding which turbine to install. There are newer products available, but I hesitate to invest in lower-cost turbines if the savings is negated by lower output.

All I have is my own tests of Harris units that back up the claims of up to 70% efficiency. I always use these turbines except for low-head sites where the Turgo wheel on the ESD turbines can handle higher flow and faster rpm. With their simpler, nonadjustable magnets, the APM turbines might be a lower-cost alternative if the efficiency is still high. PowerSpout turbines have some interesting features, including a built-in voltage clamp that works with MPPT without other electronic tricks, or with higher voltage grid-tied systems. But if their simpler, plastic Pelton runner has a lower efficiency, it may not be worth the cost savings.

Tell us more about MPPT for hydro.

The introduction of reasonably priced MPPT controllers for solar has opened up new design possibilities for small DC hydro systems. Before MPPT controllers were available, the hydro generator had to run at the battery voltage. That meant large wires, or accepting large voltage loss in the long-distance wires.

Now with the DC-to-DC conversions in the MPPT controllers, it is possible to operate the hydro at high voltage to keep the amperage low, minimizing line losses on long-distance wires. The MPPT units also allow the hydro turbine to run at the speed and voltage that produces the most power. Some small hydros allow varying the strength of the magnets to better match the varied flow of a stream, but the MPPT will unload the unit to let it speed up, and do the adjusting automatically.

The problem with using these units is they are designed for solar-electric arrays that put out a defined high-voltage limit that isn't too much higher than the system's running voltage. However, in a DC hydro turbine, the open-circuit voltage is twice the running voltage. So using an MPPT controller directly with a hydro turbine is limited to low-voltage systems.

One "bleeding edge" method is to connect the hydro in parallel with a solar-electric array at about the desired voltage, and the array will "clip" the peak voltage at about 10% above its rated open-circuit voltage. The modules act like giant zener diodes protecting the MPPT controller in high-voltage conditions. Many small hydro systems are on seasonal creeks that dry up in the summer, so a PV array is already a part of the off-grid hybrid system. The MPPT controller gets the maximum output from both components of the renewable energy system.

Modern solar controllers—with some protection and electronic wizardry—have allowed significantly better production from hydro systems. They can be used in smaller and simpler configurations (at left), or in larger, multiple-inverter systems with higher production and loads.

Upgrades like this one use manufactured components, while still keeping the budget low.

The underside of the turbine is exposed as Chris inspects the runner and nozzles. The turbine bolts on a bucket that is cemented into the ground. Note the large tailrace pipe that returns the tailwater to the stream.

Ian Woofenden (3)

What is your key advice for people who are thinking about using hydro electricity?

Educate yourself as much as possible before getting expert help. The more you know, the better questions you can ask. Read older articles in *Home Power* and online. I find the best level of expertise is on the fieldlines.com forum. I try to answer questions about hydro posted on that site.

There are a limited number of people with experience with multiple hydro systems, so you will have to choose someone who can see all the possibilities of your site and create a system that does what you need. Any RE dealer can provide the batteries and inverters, but you may have to search harder for someone local to design and install the hydro system.

What does your home system look like today?

My personal off-grid system includes two Harris hydro turbines. One is producing about 200 W at 24 VDC from 35 feet of head. The other is currently putting out about 1,000 W at 70 VDC from 110 feet of head into an OutBack Power Systems FLEXmax 80 MPPT charge controller.

During times of higher flows, the larger magnets in the second Harris turbine boost the energy output. The old configuration topped out at 920 W, and it's now more than 1,000 W. I haven't completed testing this arrangement to find its maximum output.

To keep the unit cooler at high output, I carved a fan blade from a piece of 2-inch PVC pipe and slid it on the upper shaft inside the alternator. A digital pressure switch turns on several Belimo 24 V electric valves to automatically adjust the number of jets sending water to the Pelton. The stream flow varies daily and this allows maximum use of available water. I am also experimenting with a small needle-valve nozzle (an adjustable nozzle) to vary the effective size of one jet, but need a way to get it closer to the Pelton wheel for higher efficiency. My intake screens are 15-gallon barrels with dozens of slots cut all around the barrel, located in a hole off the primary stream flow.

Do you have any other RE systems to complement your hydro systems?

I have 1,500 W of PV modules charging through a Xantrex XW-MPPT60 charge controller, and more than 1,000 W of modules wired directly to the battery with diversion loads using surplus power to control the voltage. My house still has many lights and a refrigerator running at the original 12 V. A Vanner 24-to-12 V battery equalizer powers that part of the system. The battery bank is eight 360 Ah Surrette batteries in series–parallel for 24 V. The inverter is an OutBack Power Systems FX2824T with a thermostat-controlled exterior fan to increase capacity.

Chris, along with many other hydro contractors and users, owes a large debt to retired hydro pioneer Don Harris, who helped a whole generation of people with his excellent equipment and generous technical support.

Dump loads include DC heating elements in a 50-gallon hot water tank controlled by a TriStar 45, DC air heaters in the kitchen run by a Xantrex C40 and a 24 V, 1-gallon countertop water heater set at 190°F turned on by the auxiliary output of the FLEXmax 80.

Have you implemented any innovations into your home system?

I have the auxiliary output of the OutBack inverter programmed to turn on a relay sending electricity to two heat pumps. The automatic controls can turn one or both heat pumps on. On sunny winter days with the hydro running at full output, the two heat pumps can draw up to 2,000 W. On low-output days, the smaller of the two heat pumps can draw as little as 300 W. If enough electricity is available, I can heat our earth-bermed house to above 70°F and heat our domestic water to more than 150°F. We cook all our meals with insulated electric pressure cookers, an electric frying pan or a 120 V convection/microwave oven. We use a converted 12 V refrigerator and a chest freezer with added foam insulation to cut our electricity consumption. The computer and TV are on plug strips to eliminate "standby" electricity usage when they are not in use. When hydro and PV input is lower, we use wood from thinning the trees around our orchard and garden to heat the house and water.

I continue to tinker with my system, and improve the efficiency of how the energy is used. All of our cooking and water heating is done with renewable energy—our propane tank has been shut off for 10 years. And I keep decreasing the amount of firewood needed to keep our house comfortable.

Even the chainsaw and lawn mower are powered with electricity from the system. My goal when I moved here in 1984 was to demonstrate that it was possible to live comfortably without fossil fuel, which is getting more expensive as the easy-to-obtain supplies are used up. Now I am helping others make the same transition.

Access

Chris Soler (hydrosoler@gmail.com) helps his neighbors with small hydro systems as Soler Hydro-Electric, from his home in Bow, Washington, where he has lived off-grid since the 1980s.

Home Power senior editor Ian Woofenden (ian.woofenden@homepower.com) teaches and consults on hydro and other renewable energy systems in North and Central America, while enjoying site visits to those blessed with hydro resources.

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U.S. DEPARTMENT OF ENERGY SOLAR DECATHLON

2013 Winning Solar Designs

by Ryan Mayfield

With the creative design power of approximately 3,000 university students from 19 universities, the U.S. Department of Energy's Solar Decathlon is nothing short of awe-inspiring—presenting modern solar house designs that push the envelope for efficiency and cost-effectiveness.

Although the focus of the Solar Decathlon is designing functional, small houses—each house must be 600 to 1,000 square feet and must have working plumbing, electricity, and appliances—the key purpose is to provide an education for both the participating students and the general public on the benefits of clean-energy products and efficient house designs. As part of this education, the houses must be able to demonstrate the energy-efficient and renewable energy systems commercially available today.

Students and their advisors use their imaginations and research to incorporate innovations into their houses—at their campus, over the course of two years. The houses are then disassembled and shipped to the Solar Decathlon site. Once there, the students are given about eight days to reassemble the house.

During the nine-day competition, the houses are tested for various efficiency measures and scored by DOE staff and experts from associated industries. The teams also conduct public tours of their houses on the weekends that flank the main week of the Solar Decathlon.

My first exposure to the competition was at the second Solar Decathlon in 2005, when I had the opportunity to tour the houses as a member of the public. In 2013, for the first time, the Solar Decathlon left the Capitol Mall in Washington, D.C., for a sunny site in Irvine, California. And this year I took on a professional role, reviewing the solar-electric system designs and inspecting the electrical systems during the houses' construction.

Winning Team Requirements

According to the Solar Decathlon website (solardecathlon.gov), the winning team produces a house that:

- Is affordable, attractive, and easy to live in;
- Maintains comfortable and healthy indoor environmental conditions;
- Supplies energy to household appliances for cooking, cleaning, and entertainment;
- Provides adequate hot water; and
- Produces as much or more energy than it consumes.

Determining the Winners

The Solar Decathlon includes 10 contests, each worth 100 points and scored either by a task completion, monitored performance, or a jury evaluation. (More in-depth coverage of each contest and the final results are available on the Solar Decathlon website; see Access.)

The Solar Decathlon 2013 teams join together before the start of the competition at Orange County Great Park in Irvine, California.

Courtesy Stefano Paltera/U.S. Department of Energy Solar Decathlon

Architecture

A jury of professional architects evaluates each team's architectural approach, including architectural elements, overall functional design, lighting, inspiration, and documentation. The jury looked for elements such as scale and proportion of room features, connections between the indoor and outdoor living spaces, and linking of various house elements, for example, incorporating the PV array into a shade structure.

The AIR House from the Czech Republic's Czech Technical University won the architecture competition with its clean-lined design. The house was built using primarily wood, including the load-bearing structure, wood-fiber thermal insulation, façade, and furniture. The spacious deck that is adjacent to the main entrance allows occupants to easily incorporate outdoor features into the living areas.

Large sliding glass doors bring ample natural light into the AIR House's interior.

The AIR House's simple geometric design helped earn its win in the architecture competition.

Students from Czech Republic's Czech Technical University celebrate their first-place win in the architecture category.

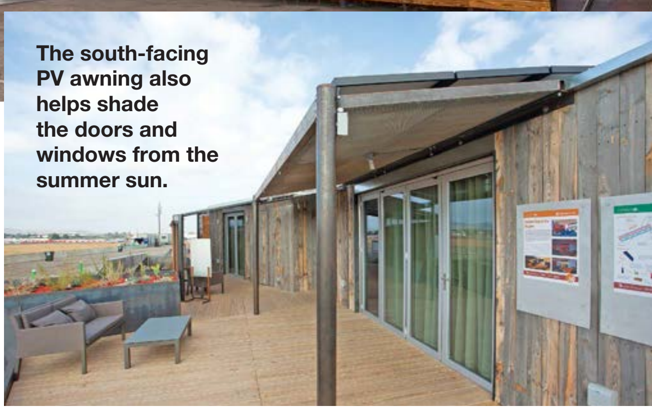
Courtesy Stefano Paltera/U.S. Department of Energy Solar Decathlon

The Ecohabit house, which featured a lush living wall of plants, came in second in the architecture competition.

Courtesy Jason Flakes/U.S. Department of Energy Solar Decathlon (3)

With a design similar to the box-in-a-box AIR House, the L-shaped Ecohabit house from Stevens Institute of Technology came in second place. A green roof covers a portion of the house, providing insulation while aiding in rainwater collection. The PV system uses solar shingles to help the array blend into the structure. These types of integrated features, along with an energy management system that monitors weather patterns and energy consumption habits, helped the team meet the design philosophy of a house that "cohabits" with its occupants.

UNLV's DesertSol house took first place for market appeal.



The south-facing PV awning also helps shade the doors and windows from the summer sun.

Courtesy Stefano Paltera/U.S. Department of Energy Solar Decathlon

Students from UNLV celebrate their victory in the market appeal category with their DesertSol house.

Market Appeal

For this contest, each team defined a target home buyer and the jury of homebuilding professionals assigned a score based on the responsiveness to that hypothetical client. The jury evaluated the teams' drawings, construction specifications, audio-visual presentations, and market appeal narratives, and performed an on-site evaluation of the finished houses.

University of Nevada, Las Vegas' DesertSol house, envisioned as a vacation home in the Mojave Desert, was the winner of this category. Their passive solar design also incorporated rainwater harvesting for irrigation and cooling through an outdoor misting system. A southern canopy fitted with PV modules prevents the high-angled summer sun from entering the house. A retractable shade screen is also included for summer shading. These design elements, along with a combination of closed-cell, open-cell, and spray-foam insulation in the walls, ceiling, and floors, help achieve the thermal goals of the house.

One of the more unique markets identified was Team Capitol DC's Harvest Home—a habitat for "renewal and regeneration"—that specified war veterans as their market. Besides providing interaction with the house's energy systems and edible garden, Team Capitol DC integrated a network of activity sensors to provide physical-therapy data and to analyze living habits for energy management. After the completion of the event, the house was donated to the Wounded Warrior Homes program, a nonprofit dedicated to serving the same target clients.

Team Capitol DC specified war veterans as the intended market for their Harvest Home—a habitat for "renewal and regeneration."

Courtesy Jason Flakes/U.S. Department of Energy Solar Decathlon (3)

Above: The ECHO house's innovative use of an integrated mechanical system for space heating, cooling, and water heating helped it earn first place in the engineering contest.

Computer-controlled motorized shades function automatically to control solar gain through the south-facing windows of the ECHO house.

Courtesy Stefano Paltera/U.S. Department of Energy Solar Decathlon

Team Ontario gathers to claim their first-place win in the engineering category.

Engineering

The engineering contest is juried by engineers who evaluate the houses' innovations—but not at the expense of functionality. The jury considers not only if the engineering features function properly, but if they are efficient and reliable.

Engineering contest winner Team Ontario built the ECHO house, designed for their heating-dominated Canadian climate. The wall structures use vacuum-insulation panels with an insulating capacity of about R-60—more than twice that of stick-framed homes with conventional fiberglass insulation. An integrated mechanical system provides heating, cooling, dehumidification, and domestic hot water. The house also includes a predictive shading system using weather forecasts and computer simulations to control solar gain via motorized shades located on the wide, south-facing windows in the kitchen.

Other interesting engineering applications included several innovations incorporated into the University of North Carolina at Charlotte's UrbanEden house. UrbanEden uses a lower carbon-footprint geopolymer cement to replace Portland cement in its precast concrete walls. Its retractable roof-mounted solar array allows the house occupants to adjust the array's position to provide shading or allow sunlight to the southern patio. And an innovative radiant heating and cooling system uses a single pump, along with the high-mass concrete walls and a rooftop heat exchanger, to control interior temperatures. The capillary tubes are embedded in the concrete walls as well as set in plaster in the ceiling. The tubes are plumbed to flat-plate heat exchangers on the roof to allow heat transfer for heating and cooling.

The precast concrete walls of UrbanEden, designed by students at the University of North Carolina, Charlotte, contain capillary tubes plumbed to roof-mounted flat-plate heat exchangers to allow heat transfer for heating and cooling.

Courtesy Jason Flakes/U.S. Department of Energy Solar Decathlon (3)

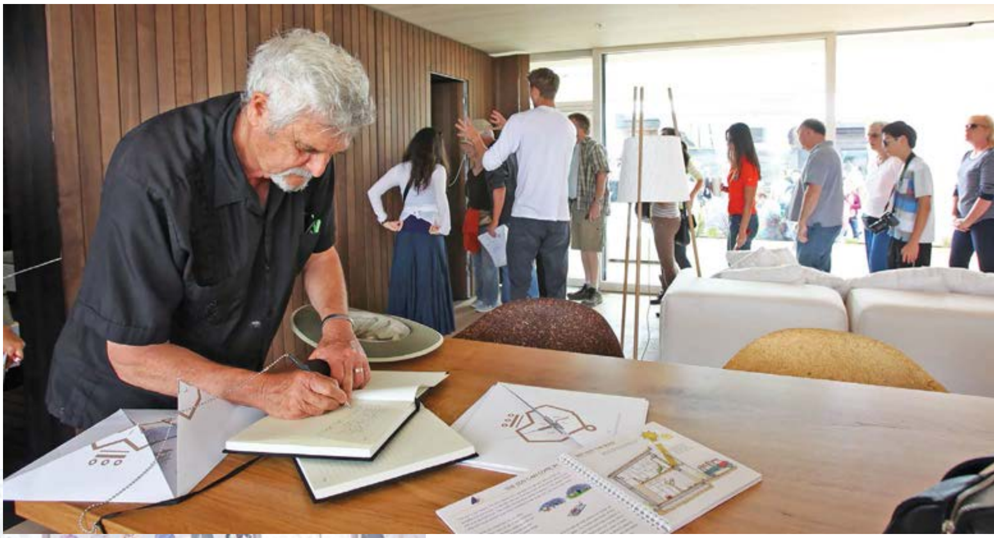
Communications

Without effective marketing, the greatest innovations and inspiring concepts can be built into a house and still be unappreciated. The communications contest judges how well the teams educated the public about their houses. All of the teams were required to develop multiple materials, including websites and an audiovisual presentation that walks viewers through the house while informing them of key features. For the on-site tours, teams were judged on their abilities to present information in different time formats based on the number of visitors present.

Team Austria won this contest. Along with their online presentations and information, they capitalized on the long entrance ramp of their house, using a series of displays to inform visitors about different aspects of the house.

Courtesy Eric Grigorian/U.S. Department of Energy Solar Decathlon (2)

Walter Kohn, center, recipient of the Nobel Prize in chemistry in 1998, takes a guided tour of Team Austria's house with students Philipp Klebert, left, and Claus Andreas Schnetzer, right.



Right: Raymond Neutra, son of an Austrian–American modern architect, signs the guest book during a tour of the Team Austria house.

Lower right: Visitors line up to tour the Team Austria house.

Below: Jakob Doppler, left, explains details of the Team Austria house to Volker Loeser.

Courtesy Stefano Paltera/U.S. Department of Energy Solar Decathlon (2)

Coming in well under the allocated construction budget earned Norwich University its win in the affordability contest.

Courtesy Eric Grigorian/U.S. Department of Energy Solar Decathlon

Affordability contest juror Richard Anderson, left, consults with Stanford University's Robert Best during the affordability contest walk-through.

Affordability

One of the goals for the Solar Decathlon is to design and build houses that are innovative, yet affordable to some individuals who want to build a small custom home. The target construction costs were set at $250,000. A metric of cost-per-square-foot was not used, as it's the final dollar amount that determines if a homeowner would purchase the house. In addition, larger houses tend to have a lower cost per square foot, given the wall-to-floor ratio. The final cost estimates include all building materials, including Americans with Disabilities Act-compliant items and fire-suppression systems—things that may not be routinely found in the consumer marketplace. The cost also includes estimated costs of hiring a contractor to build the house as documented; transportation of the house; and any unique foundation system. The teams were required to declare the target construction cost and those costs were verified by a professional cost estimator. If the information to complete a thorough estimate was missing, the estimators were to err on the high side of construction costs to accommodate for uncertainty.

Only three teams earned the available 100 points by not exceeding the $250,000 goal: Norwich University ($168,385), Stanford University ($234,092), and Kentucky/Indiana ($248,423). Norwich University made affordability a primary design component by targeting clients who earn 20% less than a Vermonter's median income. Norwich University took the approach of reducing costs from the very beginning stages through the home's final construction, minimizing skin-surface-to-floor-area ratio; using wood as the sole material for the superstructure; and choosing readily available cellulose and mineral wool batts for insulation. The team also prioritized conservation and efficiency so that the resulting PV and solar thermal systems could be as small (and inexpensive) as possible.

On the opposite end of affordability was the University of North Carolina, Charlotte home, which came in at $350,686. Some of the increased costs for their home may be attributed to the unique building materials and complex PV racking and control system.

Stanford University also stayed within the Decathlon's budget criterion, earning the full 100 points for the affordability category.

The Kentucky/Indiana team's home was also constructed for less than $250,000, capturing all of the available points in the affordability contest.

Courtesy Jason Flakes/U.S. Department of Energy Solar Decathlon (3)

Comfort Zone

The comfort zone contest measures the temperature and humidity values during specified time periods during both the day and nighttime hours. Houses received full points by maintaining indoor temperatures between 71°F and 76°F, and relative humidity below 60%.

Comfort zone winner Santa Clara University used a hydronic system embedded in the plasterboard of the ceiling for heating and cooling. To obtain adequate air changes and dehumidification, a low-flow ducting system was built into the wood subfloor. One interior wall, coated with a natural earthen clay plaster, helps regulate humidity by absorbing excess moisture in the house. It can also be misted with water to help cool the interior. A whole-house control system provides real-time energy performance data while simultaneously controlling the heating and cooling system, lights, sliding doors, windows, and blinds, to maintain indoor comfort.

Santa Clara University's house won the comfort zone contest.

A coating of earthen clay on the interior of the wall behind the bed helps keep the bedroom cool by absorbing and releasing moisture based on indoor humidity levels.

An in-ceiling hydronic system embedded in the plasterboard and barely visible in the home helps keep interior temperatures comfortable in the Santa Clara University team's home.

Courtesy Jason Flakes/U.S. Department of Energy Solar Decathlon (3)

Courtesy Jason Flakes/U.S. Department of Energy Solar Decathlon (3)

Southern California Institute of Architecture and California Institute of Technology's solar hot water system consists of evacuated tubes on an innovative mounting system.

Flat-plate solar collectors on the Missouri University of Science and Technology's house helped it tie with six other teams for first place in the hot water contest.

Hot Water

To receive full points in this contest, the house needed to provide 15 gallons of water heated to 110°F (average temperature) in no more than 10 minutes. Several times over the course of the event, event judges drew hot water from each of the houses. These draws were designed to simulate typical clothes washing, dishwashing, and bathing at various times of the day, with no more than three draws in a 24-hour period.

Six teams tied for first place in this category, earning the maximum number of points. Teams took multiple approaches for their hot water needs, although most integrated solar water heating systems. Some teams chose to use heat pumps and heat recovery units to heat their domestic water. For their water heating, Team Austria tapped into the two high-efficiency air-to-water heat pumps that also provide space heating and cooling. They also included a heat-recovery system for the shower to reduce water-heating energy use for that task. For teams that incorporated solar thermal systems, typical strategies were to use two or three 4-by-8-foot flat-plate collectors.

Courtesy Eric Grigorian/U.S. DOE Solar Decathlon

Scott Kollwitz of the Kentucky/Indiana team conducts a hot water draw.

The University of Calgary's Team Alberta home was another that used evacuated-tube collectors to meet its water-heating needs.

Appliances

The appliances competition helps ensure that the house has standard components—an operable refrigerator, freezer, dishwasher, and clothes washer and dryer. During the contest, the appliances were required to be used on a set schedule and the results were monitored. The refrigerator and freezer were required to maintain defined temperatures; the clothes washer was required to complete cycles within a specified period of time and the clothes needed to be fully dried—either by active or passive means and within a certain amount of time. The dishwasher was monitored for completing a cycle within a set period while maintaining minimum water temperatures.

The University of Southern California scored nearly perfectly in this category with four other teams—Team Capitol DC, Stanford University, Santa Clara University, and Stevens Institute of Technology—scoring more than 99 of the available 100 points. All of the teams used standard off-the-shelf appliances. Other kitchen appliances and lighting systems were used and measured in the home entertainment category.

Stevens Institute of Technology shared first place in the appliances category with four other teams.

The University of Southern California shared first place in the appliances category using standard, off-the-shelf models.

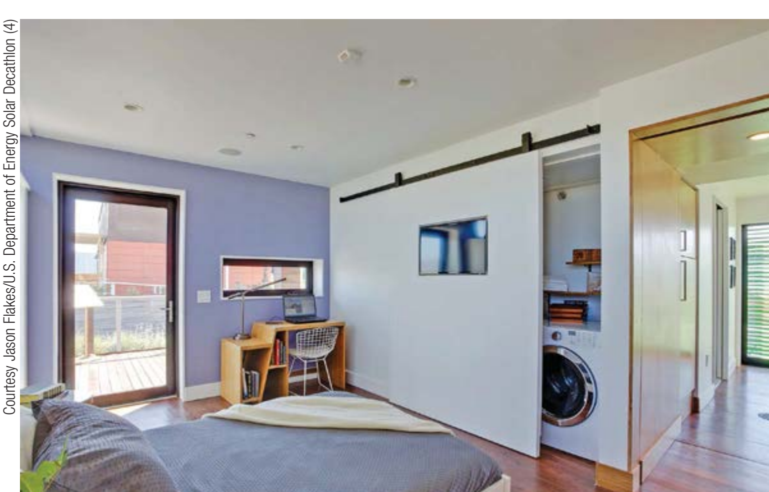
Courtesy Stefano Paltera/U.S. Department of Energy Solar Decathlon

Nick Jensen of Santa Clara University explains the strategic location of the washer and dryer to Solar Decathlon visitors.

Stanford University's appliances made the grade for first place.

Team Capitol DC used a sliding wall to hide the washer and dryer from view when not in use.

Courtesy Jason Flakes/U.S. Department of Energy Solar Decathlon (4)



Home Entertainment

The home entertainment contest and its five sections—lighting, cooking, dinner party, house electronics, and movie night—were quantified and juried. The lighting, cooking, and house electronics portions all have defined criteria, such as minimum durations for lights operating, vaporizing a set amount of water, or minimum use of specific appliances.

The dinner party and movie nights require that each team host their neighbors for two dinners and one movie night, with the idea that the teams have to use the houses as if they were living there. For the dinner parties, the team hosted six neighbors (two guest team members from three different teams) and up to two VIPs. The guests then judge the host based on the quality of the meal, ambiance, and overall experience. The movie nights are a little less formal, yet the host team is still required to have a movie running and cater to the guests. The guests score their experiences; the final score is the average of all three.

While having competitors judge each other sounds odd, the results indicate the teams were fair in their scoring methods, since only two teams scored less than 90 points. From my experience at the Solar Decathlon, this is indicative of the overall spirit of the competition. Of course, every team is there to win, but at the same time, the teams are very collaborative and supportive of one another. That said, to make sure there isn't any "gaming" of the system, each judge is required to provide written justification for the score they provide, allowing DOE organizers to evaluate the scores, follow up as necessary, and even throw out scores. Santa Clara University was the overall winner in this contest with their Italian- and Mexican-themed meals and comfortable house.

Courtesy Eric Grigorian/U.S. Department of Energy Solar Decathlon

Ana Toledo of the Stevens Institute of Technology team prepares a meal for the home entertainment contest.

Energy Balance

The energy-balance contest, which compares the total amount of energy consumed to the total amount of energy produced by the house's solar-electric system, is the one I helped judge. In the early years of the Solar Decathlon, the houses were supplied by off-grid solar-electric systems, greatly increasing the complexity compared to grid-tied systems. The event is now supplied with a microgrid and all the PV systems in this event were grid-tied, batteryless systems.

The sunny Southern California weather was on hand for the majority of the event and the production from the PV arrays reflected that. Every team tied for first by producing more energy than their houses consumed during the competition period. Given the variability in PV technologies and array installations, I was impressed, yet not surprised, with each team for maximizing their points. The houses are designed to produce at least as much energy as they consume. Given that many of the houses are designed for less-than-ideal climates, the PV systems may have been larger than necessary for the Southern California locale. In previous Decathlons, this contest was more difficult to ace since the fall weather in Washington, DC, can be highly variable.

All the teams used standard, readily available PV components in their systems. This was a little disappointing in the sense of wanting to see cutting-edge technology. At the same time, it was uplifting to see the PV industry being able to supply components for these houses without any special modifications. There was an even mix of microinverters and string-inverter systems. A handful of teams used DC optimizers to help boost their systems' power output.

Courtesy Stefano Paltera/U.S. Department of Energy Solar Decathlon

The sloped exostructure of Team Ontario's house accommodates a flush-mounted PV array.

Courtesy Amy Vaughn/U.S. Department of Energy

Once teams passed the necessary inspections, their houses were connected to the village grid for the remainder of the homes' construction and for the competition.

Solar Decathlon Components & Materials

Teams	Team Austria	Univ. of Nevada, Las Vegas	Czech Republic	Stevens Inst. of Tech.	Stanford Univ.	Team Ontario	Team Capitol DC	Middlebury College	Team Alberta
Total Points	951.922	947.572	945.142	939.176	933.125	926.478	920.267	920.262	913.574
Renewable Energy									
Inverters	Fronius IG Plus 3.0-1; SolarEdge SE5000A-US	Power-One MICRO-0.25-I	SMA America 5000-US	Dow Powerhouse	SMA America SB6000TL w/ Tigo optimizers	Sparq S215NA2240 microinverters	Enphase M215 microinverter	Power-One Aurora Uno PVI-6000-TL	Enphase M215 microinverter
PV modules	Kioto PV/ Alternative Energie Sys. polycrystalline	SunPower SPR-225-BLK-U, monocrystalline	Aide Solar XZST-185W/24V monocrystalline	Dow shingles CIGS thin-film	Stion STN-150 CIGS thin-film	Eclipsall Energy NRG60M 260 W, monocrystalline	Yingli Solar YL245P-29b polycrystalline	Lumos Solar LSX250 monocrystalline	Canadian Solar CS6P-250M polycrystalline
Solar thermal collectors	—	SolarUS SL-30, evac. tube	—	—	—	Enerworks flat-plate	SunMaxx flat-plate	Heliodyne Gobi flat-plate	Apricus AP-20, evac. tube
Appliances									
Refrigerator-freezer	Siemens	Liebherr HC 1010	Electrolux ENG2917AOW	LG LTC19340	Frigidaire FFHT1826L	GE	Summit FFBF285SS	Whirlpool WRT359SFYM	Blomberg BRFB1040
Cooking appliances	Elektrabregenz MISS 6081	Wolf Appliance CY15I/S; Miele H4044BM	Electrolux EHH6340FOK; EOB8851AOX; EMS26204OX	LG LMV1683; LCE30845; LWS3010ST	Frigidaire FGEW3045K; FFEC3024LB	GE; Whirlpool; Bosch HMB8050	Frigidaire FPIC3095MS; FFEW3025LS	Bosch NIT3065SUC; HBN3450UC; HMB8050	Bosch NIT3065UC; HBL3350UC
Dishwasher	Siemens	Bosch SHV7ER53YC	Electrolux ESL6810RO	LG LDF8072ST	Fisher & Paykel DD24DI7	Fisher & Paykel	Fisher & Paykel DD36SFTX2	Bosch SHX3AR75UC	Bosch SHE23R55UC
Clothes washer	Elektrabregenz WAF 8146A	Bosch WAS20160UC	Electrolux EWF1687HDW	LG WM2655HVA	Samsung WF457ARGSGR	Maytag	Frigidaire FAFS4073NW	Frigidaire FAFW3801LW	Bosch WAS20160UC
Clothes dryer	Elektrabregenz TKF 83320A	Bosch WTV76100US	Electrolux EDH3487RDW	LG DLEX2655; DLGX2656V	Samsung DV457EVGSGR	Maytag	Frigidaire FASE7073NW	Frigidaire FAQE7001LW	Bosch WTV76100CN
Space Conditioning									
HVAC system	Hydronic	Uponor, hydronic	Multivac Sonovac 25 DS, hydronic	Arduino Mini 328-5v/16MHz, forced-air	W.A. Call Mfg. forced-air	Ducted	Ducted	A.O. Smith, ducted	—
Heat generator	ClimaLevel multifloor underfloor HVAC system	Mitsubishi MUZ-FE09-18NA minisplit heat pump	Regulus; Drazice KPG1; S2 Solar 30 + SRS3; UKV 102	Trane XL20i, heat pump	Mitsubishi MSZ-A minisplit heat pump	WaterFurnace Envision water-source heat pump	Hydronic Heating Supplies WA19x20 heat exchanger	Mitsubishi, air-source heat pump	Lennox XP21 air-source heat pump
Cooling generator			Daikin RXR28E FTXR28E heat pump			Cancoil HPAH30 water-air handler for heat pumps	Miami water-source heat pump PHWW041SS		
Exterior & Envelope									
Roof insulation	Isocell cellulose, R-6 per in.	Foam-plastic boards; glass-fiber blankets; open- & closed-cell polyurethane foam; R-55 ceiling, R-30 walls	Steico wood-fiber insulating board, R-7 per in.	Dow RS Series, polyurethane spray-foam; R-46 roof R-24 walls	SIPs w/ EPS insulation; R-29 ceiling R-14.1 walls	Expanded polystyrene, R-29	SIPs, R-38	National Fiber UltraTouch cellulose; R-30 ceiling R-21 walls	Roxul rock wool/ mineral fiber, blanket; R-38
Wall & ceiling insulation	Gutex Thermoflat wood-fiber insulating board; R-8.5 per in.					StyroRail SR.P100, extruded polystyrene panels & closed-cell polyurethane spray-foam	SIPs, R-20		Polyurethane R-42; fiberglass; Roxul PlusMB rock wool; R-39.5 walls, R-26 floor
Exterior doors	Josko	NanaWall WA67, folding glass wall	Schuco ADS 70.HI	A&L Windows & Doors	Chase Doors Saino 3100; Andersen	Jeld-Wen	Western Windows 900 Entry; 600 Slide	Intus Windows Eforte	Innotech Windows & Doors
Windows	Josko Fenster wood	NanaWall wood	Schuco ASS70.HI; AWS70.HI	Pella	Andersen Series 100		Western Window Systems Series 600 & 700		
Roofing	Gutex Thermoflat	Atlas Roofing	Fatrafol 804/810 membrane roof	Firestone RubberCover, EPDM	Sheffield Metals, standing seam	Ideal Roofing, metal	EPDM	LiveRoof, hybrid living roof system	Elastomeric membrane
Water Heating									
Water heater	CLEEN Solair T tank	Stiebel Eltron DH C-E 1 tankless	Regulus R2DC-300 tank	AirGenerate AT150/AT166 tank	GE GEH50DNSRSA tank	Rheem tank	StorMaxx SunMaxx Solar 50 SKE, tank	Bradford S-SW2-115R6DS; tank	Bradford S-DC-DW2-55R6SW; tank

Univ. of S. CA	Santa Clara Univ.	Norwich Univ.	Univ. of North Carolina, Charlotte	Southern Cal. Inst. of Arch./ Caltech	Kentucky/ Indiana	Missouri Univ. of Science & Tech	AZ State Univ. & Univ. of NM	Team Texas	West Virginia Univ.
906.203	888.929	876.928	870.210	868.666	850.079	840.455	823.165	776.454	774.742
Enphase M215 microinverter	SMA America SunnyBoy 8000TL-US	Solectria PVI-6500	Power-One PVI-3.0; PVI-6000	SMA America 6000-US w/ Tigo optimizers	Schneider Electric Conext 2800	Sunergy ELV 240; KACO new energy 1502xi	Power-One PVI 5000	Schneider Electric Conext TX5000	Enphase M215 microinverter
Bosch Solar Energy c-Si M 60 NA42117 monocrystalline	Bosch Solar Energy c-Si M 60 NA30119 monocrystalline	SoloPower SP1 9 CIGS thin-film	Bosch Solar Energy c-Si M 60 NA42117 monocrystalline	Hanwha SF160-24-M190 monocrystalline	Sanyo HIT Power monocrystalline	tenKsolar monocrystalline	SolarWorld Sunmodule	Prism Solar B245 245W monocrystalline	SolarWorld Sunmodule SW 260 W monocrystalline
Bosch Solar FKC-1 flat-plate	Free Hot Water FHWFC1005 flat-plate	—	—	SolarUS SL-30 evac. tube	—	—	—	Cinco Solar CS40 evac. tube	—
Bosch B30BB830SS	Sun Frost RF12	Frigidaire FFTR1814L	Blomberg BRFB0900L	Liebherr HC1001	GE PSHS6PGZSS	Frigidaire FFHT1513L	Viking RDDFF236	Whirlpool GB9FHDXWS	LG LFC31995ST
Bosch NIT8065UC; HBL8450UC; HMB8050	Bosch HBL3350UC; NIT3065UC	Frigidaire FFEF3015LM; FFCM0734LS	Frigidaire FGIC3067M; FGEW3045K; FGM0205K	Bosch NET8054UC; HBL8450UC	GE PHP960SMSS; PSB2201NSS; PT916SRSS	Frigidaire FPIF3093L	KitchenAid KESK901SSS	Samsung; LG LSCI307ST; Alto-Shaam ASC-2E; GE PSB1201NSS	LG LRE3027ST; Bosch HVB5050
Bosch SHX8ER55UC	Bosch SHX2AR55UC	Frigidaire FFBD2407LM	Frigidaire FFBD1821M	Fisher & Paykel DD36ST12	GE PDWT180VSS	Frigidaire FPHD2491KF	GE ZBD1870NSS	Samsung DMT800RHS	Bosch SHV68R53UC
Bosch WAS24460UC	LG WAS20160	Summit SPWD1800	Frigidaire FAFW3921NW	Bosch WAS24460UC	GE GFWH1400D	Frigidaire FAFS4474L	Maytag MHWE201YW	LG WM3455HS	LG WT6001HV
Bosch WTV76100US	LG WTV76100US		Frigidaire FAQE7001LW	Bosch WTE86300US	GE GFDS140ED	Frigidaire FASE7073L	Maytag MEDE201YW		GE GFDN240GL
Deflect-o, ducted	Audubon Plumbing Supply, hydronic	Lunos Luftungestechnik, ductless HRV	Ducted	Ducted	GE, ducted	Unico, ducted	Beka	Hydronic	Mitsubishi MSZ-GE09NA-8, ductless minisplit
Daikin; AO Smith EKSOLHWBAVJU; A0SQE50010; air-source heat pump	Messana Air-Ray Ray Magic Panel; Standard; radiant heating panels	Mitsubishi MXZ-2B2ONA-1; MXZ-FE09NA-8, minisplit heat pump	Trane 4TXK8509-A10N0BA; 4MXW8509-A10N0BA minisplit heat pump	Daikin Altherma; heat exchanger	Honda GX390, air-source heat pump	Unico 1218 air handler/ ventilator	Bell & Gossett BPX BPN400-18	Whispergen, heat pump water system	Mitsubishi MSZ-GE09NA-8 minisplit heat pump
Daikin EBLQ036BA6VJU	Daikin ERLQ018BAVJU, EKHBX030BA3VJU air-to-water heat pump	Sauermann SI3100 mini condensate pump		Daikin Altherma heat pump		Unico UniChiller RC	Trenton TCS002S2A		
Bonded Logic UltraTouch cellulose, R-30	Icynene MD-C-201, spray-foam R-43	National Fiber RDSLF9256, Cel-Pak, cellulose, R-59	Dow EPS/EPS; Metromont CarbonCast insulated cladding (precast concrete + foam insulation panels); R-55 ceiling, R-30 walls	CertainTeed CertaSpray, closed-cell spray-foam; R-30 roof, R-23 walls	NCFI Polyurethanes, spray-foam, R-60	Dow, rigid foam or spray foam	Demilec Heatlok Soy 200, closed-cell spray foam	A.O. Smith, polyurethane core; R-54 roof, R-42 walls	Johns Manville B-390, fiberglass batts; R-30 roof, R-30 walls
Owens Corning, fiberglass; R-19 walls, R-30 floor	Icynene Mid-C-200, closed-cell spray foam R-26	National Fiber cellulose; Roxul TopRock DD Plus & ComfortBoard rock wool			Roxul rock wool; R-33 walls, R-20 floors				
NanaWall SL45 W, SL48; 1070, 1050	Masonite SHD & MHD; Marvin 12068	Prestige Windows & Doors WS 1-01	Intus Windows; NanaWall	Arcadia ULT-5820	Marvin IOFD3068 XL; IOFD6068 XXR	Therma-Tru	Western Window Sys., 900; Alpine Overhead Doors	NanaWall SL45	Zola; Reliabilt
Milgard Series 920	Intus Windows	Intus Windows Eforte	Intus Windows		Marvin ICA & IAW	Crystal Windows & Door	Western Window Sys. 700	Jeld-Wen 4030	Zola
Versico VersiFlex, PVC membrane	Laiwu Starring Trading Co., PVC membrane	Firestone; Georgia-Pacific UltraPly TPO membrane	Sika Sarnafil G410 roofing membrane	Naizil; Apollo Roof Opening System	Johns Manville, TPO roofing membrane	Atlas EPS	Atlas Roofing	Aluminum-zinc alloy-coated sheet steel	Atlas EPS
Rheem RHE PRO-40-2; tank	Daikin EKHWS050BA3VJU; tank	Stiebel Eltron 94922100658; tankless	Vaughn S50WHPT3838I; tank	Daikin tank	GE GeoSpring; tank	Rheem RTE 18' tankless	AirGenerate AirTap	A.O. Smith SUNX-80; tank	Velux tankless

And the Winner...

The 2013 Solar Decathlon winner was the Living Inspired by Sustainable Innovations (LISI) house by Team Austria's Vienna University of Technology. The house's nested façades offered an innovative way to adapt the house to changing outdoor conditions. The passive-solar design incorporated an automated screen and awning system to regulate gain through the envelope.

The heating and cooling came from a subfloor system using active water and air systems. The centralized electrical and mechanical component helped increase efficiency and minimize the area required to house all the components. To best utilize local resources, they used wood as the primary building and insulation component for the structure. They also utilized otherwise-wasted material by using wood bark for the seats of their barstools and for wall coverings in the bedroom and bathroom.

One of my favorite aspects of the LISI house was how the team worked together. I observed 19 different houses under construction, each with their own team dynamics, and Team Austria had noticeable team cohesiveness. They always took meal breaks together—not just the members from the different "trades," but everyone. I later learned that this was the approach they took from the beginning. Due to space restrictions at their campus, they had to build their Solar Decathlon house at a site that was hours away from campus. This resulted in the team living together for days at a time—their teamwork and dedication showed in their final product.

Courtesy Stefano Paltera/U.S. Department of Energy Solar Decathlon (2)

Left: Team Austria's Philipp Klebert, center, celebrates with his teammates after their unique curtained home (below) captured first place in the 2013 Solar Decathlon.

Courtesy Jason Flakes/U.S. DOE Solar Decathlon

This year, a new award—the Byron Stafford Award of Distinction (created in memory of Solar Decathlon site manager Byron Stafford)—was awarded to Norwich University for being "honest, caring, humble, intelligent, fair, reliable, steadfast, and genuine."

The other special recognition this year was delivered to the University of North Carolina at Charlotte for the People's Choice award. Their garden-rimmed deck and beautiful interior made the house a favorite among the public who toured the Solar Decathlon houses.

The University of North Carolina at Charlotte took home the Solar Decathlon People's Choice award.

Courtesy Carol Anna/U.S. Department of Energy Solar Decathlon

Access

Ryan Mayfield is the principal at Renewable Energy Associates, a design, consulting, and educational firm in Corvallis, Oregon, that focuses on PV systems. After this year's Solar Decathlon, he now hopes to inspire his own children to become solar decathletes.

Solar Decathlon • solardecathlon.gov

Solar's future is a shining star in an otherwise dark economy.

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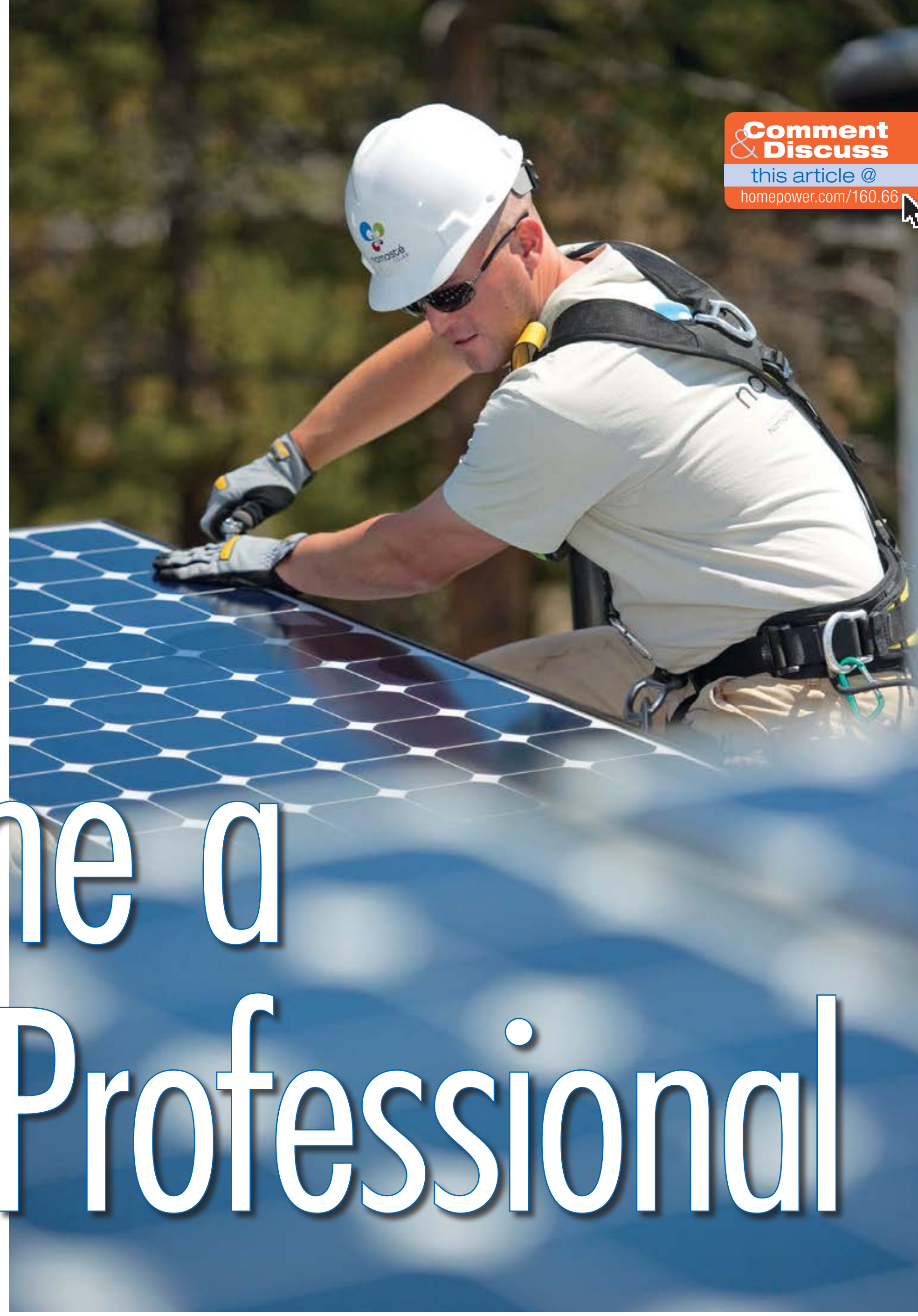
Become a Solar Professional



Topher Donahue

by Vaughan Woodruff

In 2012, the solar industry saw a 13.2% increase in employment in the United States—nearly six times higher job growth than in the rest of the U.S. economy. And in 2013, the industry experienced a 20% growth in solar jobs—10 times higher than the national employment rate. This trend is expected to continue as increasing demand for solar will require new professionals involved in the installation, design, sales, and manufacturing of solar heating and photovoltaic (PV) systems.

Industry Inroads

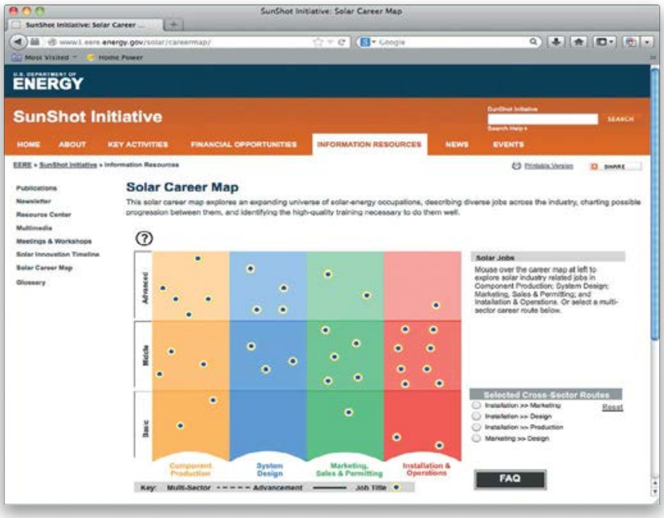
If you're looking for career in renewable energy, now's the time to assess your skills and interests, which will help you choose your pathway into the solar industry. An electrical contractor will have a more direct path to becoming a PV installer than an individual without trades experience who is finishing an unrelated college degree. Not having experience or a related degree may mean a longer or more difficult path.

Solar employers tend to favor those with bachelor's degrees and related work experience. Roughly 40% of the new solar positions in 2012 required a bachelor's degree, and 50% required related work experience—some required both.

Aspiring solar professionals can readily attain "related work experience." Applicants with experience in general construction, roofing, electrical, plumbing, or heating have attractive overlapping skill sets. Since the design of solar systems is complementary to many engineering disciplines, traditional design backgrounds provide relevant work experience and training for system and equipment designers. Experience in other industries related to sales, marketing, manufacturing, or accounting can also be assets for particular jobs.

Mapping Your Path

The Interstate Renewable Energy Council (IREC) and the U.S. Department of Energy collaborated on a tool for learning about diverse jobs within the solar industry. The Solar Career Map details common job descriptions, the skills and experience required for these positions, and pathways for career advancement within the solar industry.



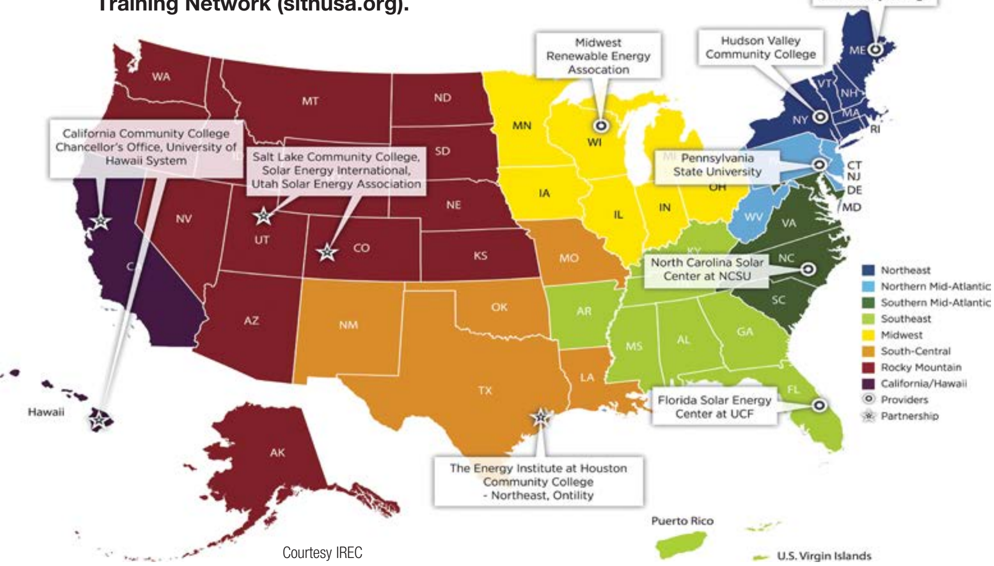
Access the Solar Career Map at bit.ly/SolarCareerMap.

College-Bound

If you're entering college, consider earning a degree in a related discipline (engineering, construction management, building trades, business, etc.). You may also choose a program focused on solar technologies.

A number of these schools have been involved with the Department of Energy's Solar Instructor Training Network (SITN), developed to increase the quality and accessibility of training across the country. Nine regional training providers train instructors and support the development of solar training programs at schools and other training institutions.

Find a list of partnering institutions at the Solar Instructor Training Network (sitnusa.org).



Courtesy IREC

Courtesy Ben Lehman, SEI

Hands-on classes offered by qualified training programs, such as Solar Energy International, will help you gain confidence as you expand your knowledge base.

NABCEP Entry-Level Program

If you have limited solar experience, you can increase your formal knowledge and receive an industry-recognized PV or solar heating credential through the North American Board of Certified Energy Practitioners (NABCEP).

The NABCEP Entry Level program is a collaboration between NABCEP, industry professionals, and training organizations. The program is based on "Entry Level Learning Objectives" developed by subject matter experts and used as the basis for training content.

Upon completion of training from a NABCEP Entry Level provider, you can take the PV or Solar Heating Entry Level exam. If you successfully complete this exam, NABCEP sends you an acknowledgement of your passing score, which can be used to demonstrate your knowledge to prospective employers.

Achieving an Entry Level acknowledgment is an appropriate first step for a career in installation, design, manufacturing, and sales. It is also great for complementary industries that may encounter solar projects. For example, architects and engineers in a market with numerous solar installations can benefit greatly from increasing their solar literacy through the NABCEP Entry Level program. Find a current list of approved Entry Level providers at nabcep.org.

Licensing & Certification

In some locales, an installer is required to be licensed. A license is issued by a jurisdiction (typically a state licensing board). Most jurisdictions require an

Adequate training of a renewable energy industry professional usually requires both theoretical training (above) and hands-on experience (right).

NORTH AMERICAN BOARD OF CERTIFIED ENERGY PRACTITIONERS®
CERTIFIED Solar PV Installer

NABCEP offers the most widely recognized certifications in the industry for solar heating and PV installation professionals.

electrical or plumbing contractor's license if they are being paid to install wiring or potable water piping. This helps protect public safety by assuring training, experience, and knowledge of the regulations.

Solar contractors in some jurisdictions must pass a business exam and a solar exam, as well as document the minimum amount of field experience for the credential. Different states have different requirements of their licensed contractors. For example, licensed electricians in Florida may install PV systems, but they may be required to subcontract roofers to install the PV array. Visit **irecusa.org** to access the Interstate Renewable Energy Council's solar licensing database, which details the local licensing requirements for installing solar energy systems.

Certification, on the other hand, is voluntary. But the line between *voluntary* and *required* can be thin in jurisdictions where certification qualifies installers for utility or state incentives. In these cases, while a license might be sufficient to legally install a system, it would be difficult for an installer to compete with the access to incentives covered by certification. Also, policies such as this promote quality by offering solar-specific credentials in areas where solar licensing is not available.

NABCEP offers the most widely recognized certifications in the industry for solar heating and PV installation professionals. To become certified, installers must document field experience and pass a rigorous exam based upon a job-task analysis developed by experts in each discipline. These analyses describe the specific skills required to install and maintain solar energy systems. The PV Installation Professional Certification requires that participants document training in workplace safety and solar technology to be eligible for the exam. NABCEP certification is valid for three years and can be renewed by fulfilling requirements for continuing education and work experience.

While the NABCEP Entry Level exam is offered by individual training institutions upon completion of their courses, the NABCEP Certification exams are proctored twice per year at select regional sites. To qualify for the exam, applicants must document their professional experience and training prior to an application deadline. For example, installers who would like to take the October 4, 2014, certification exam must submit their applications by July 18.

Solar sales professionals, site assessors, financial analysts, or application engineers may pursue NABCEP PV Technical Sales certification, which requires solar sales experience and some formal training. The type and extent of required training depends upon the applicant's professional experience. NABCEP has seven qualifying categories that are a combination of experience and training. An applicant needs to meet one of these categories to qualify to take the exam.

Even licensed electricians find solar-specific training important to expanding their career into the renewable energy industry.

Courtesy Ben Lehman/SEI (3)

Certificates vs. Certification

Some training programs issue a certificate upon completion of a training course. The certificate may be from a manufacturer, trade association, public institution, or private trainer. While the certificate may add to your résumé, it only holds value if the industry or public recognizes it as high-quality. If you receive a certificate for listening to a manufacturer's two-hour sales pitch, it won't be as valuable as a 40-hour course in which you had to demonstrate your learning in a training lab and pass a formal assessment.

Certificates also differ from the professional certifications offered by third-party organizations. Subject-matter experts and an independent, standardized application and examination process makes professional certification a more objective and precise measure of qualifications compared to a typical training program.

Offering a certificate program that has been reviewed and approved by an independent organization can give training programs some recognition in the industry. The Midwest Renewable Energy Association (MREA), for example, developed a certificate program for professional solar site assessment. They opted to have their program accredited under the American National Standards Institute (ANSI)-IREC program. This third-party certification makes the MREA training program attractive because it gives participants a certificate with value in the industry.

Check out the IREC database of certificate and other training programs at bit.ly/IRECtraining.

Courtesy OutBack Power Systems

Manufacturer-sponsored trainings can be great for learning the details and operation of particular equipment.

Courtesy Penn State University

Penn State University offers RE-specific degrees, including an online masters program.

Underwriters Laboratories (UL) offers licensed electricians its PV System Installer certification. Like the NABCEP PV Installation Professional certification, candidates for UL certification must document safety training and pass a solar-specific exam. Unlike NABCEP certification, UL does not require documentation of experience as a PV installer.

While certification may not be required to access solar incentives in some jurisdictions, installation professionals may pursue this path as a way to differentiate themselves from their competitors. Professional certification can demonstrate to an employer that the installer is ready for a larger leadership role or it may serve as a marketing tool if the installer wants to start their own business or qualify their existing one.

Training

Obtaining a professional credential requires on-the-job experience and often requires completion of formal solar training. For industry positions that require higher than entry-level technical expertise, there are solar-specific courses at community colleges, private training organizations, trade associations, and through manufacturers.

Keep in mind that there can be a significant difference in the quality and value of training programs and instructors. Research the training institution, instructor, and course syllabus to be sure that you are getting the training and industry acceptance you need.

If you plan to use the training to qualify for certification or licensure, be sure to review these requirements. NABCEP requires a specific number of course hours to qualify for certification, and the course content often must be aligned with the relevant job task analysis.

IREC's credential for training programs and instructors can be helpful in selecting a solar training provider. IREC accreditation signifies that the training program has met a rigorous third-party standard in curriculum delivery and program administration. Experienced instructors with subject-matter expertise can become IREC certified. While an IREC credential does not guarantee that a training program or instructor is better than their uncredentialed competition, it definitely means that the credential holder meets industry-developed standards.

What Path Will You Choose?

Topher Donahue

Shawn Schreiner

A job with an installation company may require a host of skills, ranging from basic carpentry to engineering and design.

Installation

Installation firms employ nearly one-half of the workers in the solar industry. These companies manage a number of responsibilities, including:

- Selling systems
- Coordinating system design
- Obtaining components and materials
- Acquiring building permits
- Installing the systems
- Servicing and maintaining systems
- Coordinating paperwork, such as customer billing, and managing incentives

Most installation companies are small, employing two to three workers. They resemble traditional electrical, plumbing, and heating contractors. The owner often handles the majority of the sales, purchasing, design, and administration; while employees handle the installation and service work.

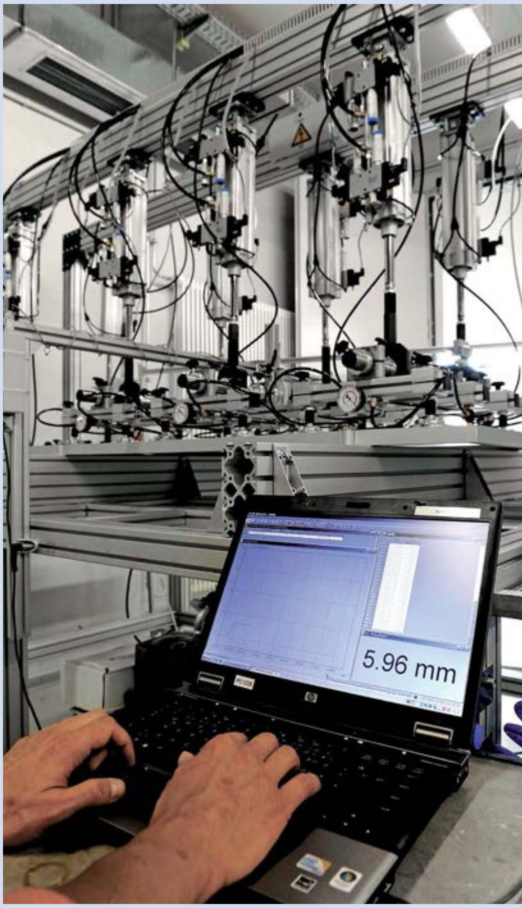
In larger installation firms, jobs may be more specialized. These companies manage multiple work crews, using lead installers and installation helpers. They have an administrative staff to manage and oversee the larger volume of projects. Administrative positions may include salespeople, designers, warehouse workers, marketing professionals, and general office staff.

Manufacturing

The manufacturing sector employs approximately one-quarter of the solar industry. Companies range from the obvious—such as PV module and solar collector manufacturers—to those that manufacture components such as glass, ingots, heat-transfer fluids, pumps, and balance-of-system components like inverters. If you're interested in manufacturing, you might find yourself working for a solar-specific manufacturer or for a manufacturer that has a solar division. Jobs in manufacturing include positions in sales, production, accounting, marketing, and engineering.

The availability of manufacturing jobs in the PV industry has been more volatile than in other sectors due to economic pressure from the steep drop in the price of PV modules over the last several years. While this price drop has driven significant industry growth, it has also led to some manufacturers going out of business.

Courtesy SolarWorld



Highly trained engineers may choose to specialize in product or equipment design.

Sales & Distribution

Sales and distribution companies act as wholesalers (and, sometimes, retailers) of solar equipment. They may be solar-specific or offer solar equipment in addition to their traditional electrical, plumbing, heating, or hardware selection.

This portion of the industry is dominated by positions in sales and marketing. There is also significant demand among these companies for individuals with engineering expertise to help customers with their designs. While this sector represents only 13% of the total jobs in the solar industry, it grew by 50% between 2010 and 2012.

Courtesy Sun Light & Power

All types of jobs are available throughout the supply chain—from manufacturing and design, to sales and marketing, to distribution and installation, and education.

Courtesy Rebekah Hren

Other Jobs

As the solar industry grows, more professions benefit from individuals with solar-specific expertise. Likewise, the solar industry benefits from the expertise and experience of complementary trades. Experts in finance, law, and taxation are needed in those peripheral areas. For example, third-party ownership models (like leases) drive significant growth in the solar industry. Engineers, architects, utility representatives, energy analysts, code officials, lenders, real estate appraisers, and large infrastructure development firms also need people with solar knowledge.

SEIA Solar Energy Industries Association®

AMERICAN SOLAR ENERGY SOCIETY

SEIA and ASES are membership organizations that may provide you with valuable connections to others in the solar industry.

Finding a Job

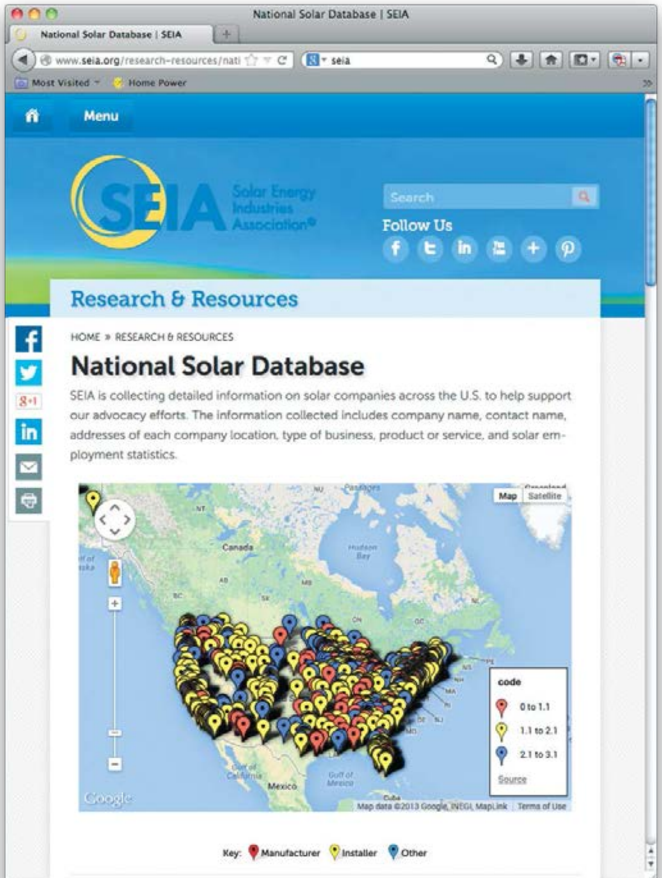
Amidst the considerations of credentialing and training, it is helpful to know what jobs might be available. If you are interested in a solar manufacturing job, for example, the number of opportunities will be heavily dependent upon location. Visit the Solar Foundation at **solarfoundation.org** to view its Solar States Job Map, which illustrates the current number and types of solar jobs within each state.

If you have enough experience to look for a job, focus some of your energy on networking. Over half of the solar firms in the United States rely on word-of-mouth and referrals for finding candidates. Let people in your social and professional circles know what you are looking for. If you have friends in the solar industry, seek their help in finding your position. Even if they are in another state, they may be able to link you up with professionals in your area. Since the industry is still relatively small, solar professionals tend to network extensively across the country. These professional relationships can be huge assets in your job search.

If you don't know anyone in the industry, it is important to start meeting a few. Consider these approaches:

Contact area professionals. Cold-calling strangers can be difficult, but people tend to be pretty open if you ask them for advice rather than a job. You can find local installers using NABCEP's database of certified professionals, through state energy offices, or with a Web search. Research each company's website, including job postings. If no one in your area is hiring, contact some of the installation companies and ask about what they look for in an employee. Remember that their time is valuable, so keep the call as short as possible. Another approach may be to contact a trade association, such as a local Solar Energy Industries Association (SEIA, seia.org) or American Solar Energy Association (ASES, ases.org) chapter. Installers may also be found through solarreviews.com and findsolar.com.

Attend networking events. Many organizations and communities organize energy fairs or expositions. These are great opportunities to meet local professionals. Again, many companies are there to sell systems to the public, so respect their time. See whether there are any "green drinks" social events in your area, where individuals interested in sustainability gather to talk shop and network.



Online job boards and industry databases can be great places to research both local and national job openings.

Social networking. Online social networking is a supplement—not a substitute—to building professional networks. Activity on social networking sites can help keep you abreast of developments and opportunities in your local industry. Social networks can also help you obtain some visibility, though you'll want to be sure that anything you post is beneficial and not an annoyance or a liability as you further your career.

Some companies—especially the larger ones—utilize online job postings. You may find it useful to scan online job boards such as those at *Home Power*, *SolarPro*, SEIA, and ASES.

Finally, you may find that a great investment in a solar job is to design and install a system at your home. You'll learn some nuances of system installation and operation, accelerate your learning, and gain hands-on experience that is critical for any role you might take in the solar industry.

Access

Vaughan Woodruff is a NABCEP-certified solar heating installer and trainer based in Pittsfield, Maine. Vaughan has been intimately involved with SITN, IREC, and NABCEP in various capacities.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CELEBRATING 35 YEARS OF SUSTAINABLE EMPOWERMENT

Improving Window Performance

istockphoto/Justin Horrocks

Windows play a unique role in our houses. They provide views to the outdoors, introduce natural light, deliver passive solar heat, and provide natural ventilation.

But they are expensive. A top-quality window can cost $50 per square foot or more—$600 for an average-size (3- by 4-foot) window. A state-of-the-art, triple-glazed replacement from Germany can cost more than $1,000. Count up the old windows in your home, and you'll quickly see that replacement can be expensive, often costing thousands—or tens of thousands—of dollars.

With 130 million houses, mobile homes, and apartments in the United States—and a majority of them with poorly performing windows—it's unrealistic to think about replacing most of them. This article looks at alternatives to replacing windows while still significantly boosting their energy performance.

There are affordable options for reducing heat loss in the winter and reducing unwanted heat gain in the summer and in warmer climates year-round. Some treatments can do both. And if implemented well, such window treatments or attachments can enhance a home's appearance.

Applied Window Films

Transparent films can be applied to windows to reduce unwanted solar heat gain and reduce heat loss. These plastic films, which are typically made of polyester, are usually applied directly to the interior glass surface, though some products are for the exterior. They are most commonly installed in southern climates to reduce solar heat gain, though some newer, low-e films are more transparent and help reduce heat loss.

While there are window-film kits for do-it-yourselfers available at home centers, the best installations are done professionally by trained installers. Most films are 2 to 7 mils (0.002 to 0.007 inches) thick and come in 36- to 72-inch-wide rolls.

Applied window films are fairly permanent modifications. They cannot be adjusted like most other window treatments, and they are difficult to remove.

The energy performance of applied films is certified by the National Fenestration Rating Council (NFRC). In fact, this is the only window treatment with NFRC certification. Ratings are provided for U-factor (a measure of the heat loss through windows); solar heat gain coefficient (a measure of how much solar heat enters through the window—which can be desirable or undesirable); and visible transmittance (a measure of how significantly films affect visibility through the windows). Tinted films, for example, will dramatically reduce solar heat gain and visible transmittance, but have little impact on U-factor, while newer low-e films may reduce the U-factor (lower U-factor means less heat loss) with minimal impact on the visible transmittance.

Courtesy Solar Gard

Installing window films without leaving bubbles can be tricky—it's usually a job best left to professionals.

Benefits

- For cooling-dominated climates, films are useful for reducing solar heat gain
- Use of low-e films reduces heat loss
- Some films are designed specifically to reduce glare
- Blocks 95% to 99.9% of UV light
- Enhances privacy (especially films with high reflectance or "mirroring")
- Enhances security and safety (some films designed specifically for these benefits)
- No operation or maintenance required

Drawbacks

- Undesirable interior "mirroring" with interior films that have high reflectance
- Reduced winter solar heat gain
- Does not remedy air leakage
- May reduce daylight penetration, so supplemental daytime lighting may be needed
- Films require special procedures and chemicals to remove (should be done by professionals only)

Aesthetics

- Darkening of windows (dependent on product—more transparent films result in little change in light transmission)

Tips & Cautions

- Look for an NFRC rating label to verify performance properties
- Look for a transferable lifetime warranty
- Have films installed by a professional

When To Consider

- Solar gain through existing window results in overheating or uncomfortable glare
- Blockage of views with awnings or other window attachments is a concern
- Large areas of glass that would be difficult or prohibitively expensive to replace or treat with other retrofits, such as storm windows or insulating blinds
- Concern about UV fading of artwork and furnishings near windows

Where to Use

- In sunny, clear-sky climates where overheating is a concern
- For non-low-e films, use in climates with moderate to significant cooling requirements
- Low-e films are suitable for use in all climates

Cost

- $80 to $125 per window, contractor-installed; less for do-it-yourself

New window putty helps seal a window pane and minimize air leakage.

Window Restoration

A comprehensive repair can dramatically reduce air leakage through existing windows—and air leakage is often the biggest problem with older windows. Repairs typically include installing new seals or gaskets where the sash and frame intersect. It also may involve replacing the putty, which holds the window panes in place; and sealing and insulating window counterweight pockets (in older double-hung windows).

While skilled homeowners can undertake the work, it is usually best left to specialized contractors. In Europe, consumers can find patented systems for upgrading existing windows, including the Ventrolla System and Quattro Seal, but in North America this work is typically done by specialized contractors—found in areas where historic home preservation is popular.

When to Consider

- Preserving the appearance of existing windows is a priority
- Exterior storm windows are already in place
- Existing windows are drafty
- In cold climates, when eliminating drafts is a priority

Benefits

- Saves energy
- Improves comfort
- Restores window operation at a reasonable cost
- Maintains aesthetic of existing windows

Drawbacks

- Does not reduce solar gain or conductive heat loss through window
- Usually requires specialized contractor

Cautions/Tips

- Lead paint may be present; follow lead-safe repair practices
- Make sure that operability of windows is not harmed

Cost

- Average: $200 per window (2.5 ft. by 5 ft.)

Replace or Improve?

Sometimes, window replacement is the only option that makes sense. Below are some of the conditions for which replacement of old windows with new may be warranted.

When wooden window frames have degraded to this degree, it's time to consider replacement.

- **Rotten or broken frames.** Windows are supposed to resist wind and wind-driven rain. If the wooden window sash or frames are degraded to the extent that they can't serve this function, they must be replaced. In some cases, efforts to protect windows have done just the opposite—some paints trap moisture in wood windows and cause decay. Inadequate roof overhangs often allow repeated wetting of windows that also leads to decay.
- **Seal failure.** With insulated, multipane windows, seal failure is revealed by moisture between the panes. If only one insulating glass unit (IGU) has failed, just that IGU could be replaced, but with multiple failures it may make more sense to replace the sashes or windows.
- **Inadequate functionality.** Most of us want windows to be operable so that we can let in the cooling summer breezes. Windows that won't open because the tracks are worn out or casement mechanisms are broken may be candidates for replacement if their components can't be fixed.
- **Substandard energy performance.** In exceptional cases, the energy performance of windows may be so poor—through air leakage or heat conduction—that replacement is the only wise solution. Jalousie (louvre) windows, for example, are leaky by virtue of their design. Steel- and aluminum-framed windows without thermal breaks in their frames are notorious energy wasters due to their conductivity. And some windows may not accept weather-stripping to reduce air leakage. If you're unsure about your window's energy performance, consider hiring an energy auditor or building contractor to evaluate the windows.
- **Lead paint.** Many pre-1970 windows are coated with lead paint. When that paint can't be safely stripped or sealed, they may require replacement. The biggest concern for exposure is when the paint is subject to abrasion from sliding action.

Exterior Storm Windows

The oldest strategy for improving a window's energy performance—used by Thomas Jefferson more than 200 years ago—is to add storm windows on the outside of the existing windows. A fairly recent development is the availability of low-emissivity (low-e) storm windows, which have special transparent coatings that reflect heat back into the house.

Exterior storm windows can be fixed, requiring seasonal installation and removal; triple-track, which have moveable upper and lower sashes, along with a moveable screen; and double-track, in which only the lower sash and screen are operable—significantly reducing the crack length and air leakage, compared with triple-track. Most exterior storm windows are aluminum; higher-quality ones are available with a durable anodized finish. Fixed storm windows are often made of wood.

123RF Stock Photo

Fitting exterior storm windows in preparation for colder weather is often a rite of fall.

When to Consider

- Existing windows are in good shape but have poor energy and thermal comfort performance
- Integrated screens are desirable for keeping insects out
- Protecting existing windows from the elements is important
- In cold climates, where existing windows are single-glazed or double-glazed but lack low-e coatings

Benefits

- Increases airtightness and insulating properties of window assembly
- Protects existing windows
- Improves comfort near window
- Most storm windows offer convenient, easy operation of sash and screen

Drawbacks

- May conflict with historical codes or condominium regulations that prohibit changing windows' exterior appearance
- May interfere with existing window operation
- Fixed storm windows require seasonal installation and removal

Aesthetics

- Low-profile and high-quality storm windows are often more attractive than standard triple-track storm windows
- Often available in variety of colors to match existing windows

Tips & Cautions

- Look for a specific term warranty (e.g., five-year) or a transferable lifetime warranty, because longer warranties are indicators (though not assurance) of more durable products
- Unless venting is required at the top of the window, choose double-track storm windows with just one operable glass sash
- If living in a condominium or historic district, check with authorities before proceeding
- Follow manufacturer's cleaning instructions. The low-e coatings used on storm windows are much tougher than the low-e coatings used in most IGUs, but some coatings may not be completely smooth, so a lint-free cloth is recommended
- Keep weep holes in storm windows open at the sill to reduce condensation; keeping the most airtight layer to the interior of the entire window assembly reduces condensation potential
- Check with manufacturer on the emissivity of the low-e storm window; the lower the value, the better the insulating
- Consider how storm windows will affect egress (the ability to escape through the window in an emergency)
- Use caution in combining exterior low-e storms with double-pane windows that have low-e or tinted surfaces, because the combination may produce temperatures high enough to damage the IGU

Cost

- For average-quality storm windows, about $150 per window

Operable awnings can provide summer shade, yet be retracted for winter solar access, wind protection, or to avoid snow accumulation.

Courtesy NuImage/FutureGuard (2)

Awnings

Awnings are attached to the house above the windows to provide shade. They typically have UV-resistant fabric stretched over metal frames, and can be fixed or operable. Some are fabricated from aluminum slats. Awnings block direct sunlight and glare from the window opening to reduce summer cooling needs. The greater the unwanted solar heat gain, the more cost-effective this retrofit will be. It is better to prevent sunlight from entering the home rather than try to mitigate its heat effects after it has already passed through the window.

Retractable awnings offer the advantage of easy operability and stowing during windstorms that could cause damage. Typically, the fabric rolls up into a valance at the top of the window, keeping it out of the way when not in use. Motorized controls are available for some higher-end retractable awnings. Awnings can also be installed over decks and patios to create shaded outdoor living space during the summer.

Benefits

- Blocks most solar heat gain while maintaining much of the view
- Controls glare
- Reduces UV damage to home interiors
- May enhance building's appearance
- Directs rain away from the window
- Maintains window egress

Drawbacks

- Customization needed for optimum performance in some cases, particularly for fixed awnings
- May negatively affect aesthetics
- If deep enough to block most direct solar heat gain on east and west, may block more daylight and view than desired (adjustable awnings may be better)

Aesthetics

- Highly variable, depending on house style and homeowner tastes
- Wide variety of colors, materials, and configurations available

Tips & Cautions

- During design and sizing of awnings, use computer modeling to show shading patterns on the windows throughout the day and seasons
- If you're living in a condominium or historic district, check for possible restrictions on the installation of awnings
- With fixed awnings, removal may be advisable before storms to prevent damage (retractable awnings need to be retracted)

When To Consider

- Glare is a significant issue
- Climate results in unwanted solar heat gain through large glazing area

Cost

- About $200 per window for an average-quality fixed awning; $375 for retractable awnings

Exterior Window Shading

A wide range of exterior roller shades, screens, hinged shutters, and roller shutters can block unwanted sunlight. Roller shutters, common in Europe but uncommon in North America, can also provide security and some insulation benefit. In coastal areas, both hinged and roller shutters can protect against severe weather. All of these systems also provide privacy, though interior shades (see below) are easier to control.

Roller shades roll down from the top of a window to provide shade. They typically are made from screening material (often PVC-coated polyester) to block most solar gain while still allowing some view to the outside. Non-roller shade screens can be mounted in a rigid frame that fits into routed grooves in exterior window casings or applied with Velcro. Hinged shutters are commonly installed on houses as decorative features, but operable shutters can provide protection against storms as well as control of solar gain. They can be made of wood, vinyl, or aluminum. Roller shutters typically have tubular, rigid aluminum slats that fit into side tracks and roll up into a valance at the top of the window.

As with awnings, blocking sunlight before it gets through the windows (as these exterior window treatments do) is more effective at controlling heat gain compared to interior shading. Some products also allow partial visibility and daylight—this is denoted by the *openness factor*, which typically ranges from 3% to 30% with exterior window shades. Shade screens typically have higher openness factors than exterior roller shutters, which often block all light penetration (0% openness factor).

Roller products, including shades, screens, and shutters, roll up into valances at the top of the windows. Motorized options are available with most of these exterior treatments. Hinged shutters are usually made of wood or vinyl.

Benefits

- Reduces solar gain through windows
- Increases thermal comfort
- Reduces glare
- Protects existing windows
- Increases security (roller shutters)
- Protects against storm damage (roller and hinged shutters)
- Protects against wildfire primarily by reducing the likelihood of glass breakage (roller shutters)

These hinged shutters also have adjustable slats to let in some light and view.

Courtesy Rollac (2)

Roller shutters can provide effective shading and some ventilation.

Drawbacks

- Most require manual operation; some may be automated
- Expensive (roller shutters and any automated roller products)
- Can be damaged by wind and ultraviolet radiation—especially fabric and polymer-coated screen
- Blocks view and daylight when deployed (a greater issue with shutters than shades and screens)

Aesthetics

- When deployed, change home's appearance dramatically

Tips & Cautions

- Check to see if local historic or aesthetic approvals are required with these treatments. If so, find out what treatments are acceptable
- If installing interior cranks for exterior shades or roller shutters, seal carefully around the wall penetration

When To Consider

Exterior Window Shades & Shutters

- Hot climates where there is unwanted solar gain (particularly east- and west-facing windows)
- Shading, view, and ventilation are desired

Exterior Roller & Hinged Shutters

- Security is a high priority
- Storm protection is a priority

Cost

- Huge variation: from as little as $25 for DIY Velcro-applied screens to more than $350 for custom, motorized roller shades and shutters

Interior Glazing Panels

Often referred to as "interior storm windows," interior glazing panels are an inexpensive way to add a layer of glazing to a window to boost energy performance. They function much like exterior storm windows, except that they don't provide additional protection against the elements. Most are designed to be removed in the summer, though some include operable panels on tracks.

Most interior glazing panels are lightweight with plastic glazing or clear plastic film. The most common glazings are acrylic (such as Plexiglas) or polycarbonate (such as Lexan). Polycarbonate is stronger than acrylic, but softer, so more scratch-prone. Acrylic now contains ultraviolet light inhibitors that slow yellowing. Glass is sometimes used and is the most durable, as long as it doesn't get broken, but is also heavier. With glass, including a low-e coating may be possible, which will boost energy performance significantly (unfortunately, low-e often isn't an option).

The frames are most commonly aluminum, but can be vinyl, wood, or steel. Steel frames may come with rubber-encased magnetic weatherstripping, for a tight seal to window frames or metallic strips added to the window casings. At least one manufacturer of interior glazing panels produces a double-glazed panel with thin plastic film stretched taught around a tubular aluminum frame. Do-it-yourself kits are available with frames and heat-shrink plastic film that is stretched taut over frames using a hair dryer.

For moisture management, it is preferable to have the inner layer of glazing be the most airtight, since this allows trapped moisture in the window system to escape. This is a benefit of tightly fitting interior glazing panels when the prime windows are old and leaky.

Courtesy The Montpelier Foundation

Interior glazing panels are an inexpensive way to boost a home's energy performance without compromising its architectural integrity.

Benefits

- Reduces heat loss and air flow through windows to improve comfort
- Reduces risk of condensation if panels are tight-fitting
- Helps dampen outdoor sound transmission
- Usually relatively low-cost

Drawbacks

- May hamper egress
- Usually requires seasonal installation and storage when not in use
- May affect visibility (plastic panels may not be optically clear)

Aesthetics

- Most, but not all, panels are relatively unobtrusive

Tips & Cautions

- Clean windows and interior panels before installing
- Use only cleaning agents appropriate for the type of glazing—check with manufacturer; be careful not to scratch plastic panels
- Label panels for reinstallation to the correct windows and allow space for seasonal storage

When To Consider

- If historic codes, covenants, or condominium association rules preclude installation of exterior storm windows
- If you need additional window insulation on an upper floor where installing exterior storm windows would be difficult
- If you are renting and don't want to invest in more-permanent window treatments, such as exterior low-e storm windows
- If existing windows are leaky
- If climate is moderate or cold, and additional window insulation during the heating season is desirable
- If window egress is not an issue

Cost

- $60 per window (plastic); $120 per window (low-e glass)

Interior Insulated Shades & Blinds

Insulated shades and blinds can be installed on window interiors to increase insulation and provide glare control. Products without side tracks typically add R-1 to R-2 to a window's performance, while products with side tracks may add as much as R-4. Most common are insulated cellular shades that expand when deployed, but can draw up, accordion-like (usually at the top of the window, though some offer bottom-up and top-down deployment). Some of these products contain multiple layers and produce a honeycomb-like cross-section when lowered. The shades are made to fit fairly tightly in the window jambs to limit airflow around them (and reduce convective heat transfer). Metalized Mylar film in the cellular structure insulates much like reflective bubble-pack.

Quilted window blinds roll up or fold into pleats like an accordion (and are usually hidden in a valance). They can be lowered at night to provide insulation or used during the day to block unwanted sunlight. Fill sewn into the quilted fabric provides insulation. A layer of reflective Mylar in the fabric helps keep heat in the room. The blinds' edges fit into tracks to stop most air leakage.

Insulated cellular shades and quilted blinds only save energy and improve a home's thermal comfort when they are used—and they have to be operated manually. To realize that benefit in the winter, for example, they have to be lowered at night and raised during the day.

Benefits

- Provide privacy
- Reduce nighttime heat loss
- Minimize cold drafts
- Reduce unwanted day and summer solar heat gain
- Control daylight

Drawbacks

- Require homeowner involvement to raise and lower
- Fully deploying blinds eliminates views through windows
- Less effective at blocking solar heat gain than exterior shading

Courtesy Insolroll Window Shading Systems Inc.

Quilted window coverings and their valances can provide an attractive method to reduce heat loss through windows.

Courtesy Hunter Douglas

Insulated cellular shades contain multiple layers that produce a honeycomb-like structure that can add from R-1 to R-4 to a window's thermal performance.

Aesthetics

- Quilted blinds objectionable to some because of utilitarian appearance
- Greater variety in colors and styles available with cellular blinds than quilted blinds

Tips & Cautions

- Consider product warranty; some companies offer term warranties (like five-year) or the better transferable lifetime warranties
- Consider professional installation to ensure proper measurement and fit
- Potential damage to IGU when insulated shades or blinds are deployed during the daytime with high-performance prime windows, because very high temperatures can be reached at the windows

When To Consider

- If existing windows are old, leaky, and in relatively poor shape
- If climate is cold and reducing heat loss in the winter months is a top priority

Cost

- Approximately $225 per window for quilted blinds to more than $500 per window for designer cellular shades

Access

Alex Wilson is the founder of BuildingGreen, the Brattleboro, Vermont-based publisher of *Environmental Building News*, *GreenSpec*, and LEEDuser.com. He is also president of the Resilient Design Institute.

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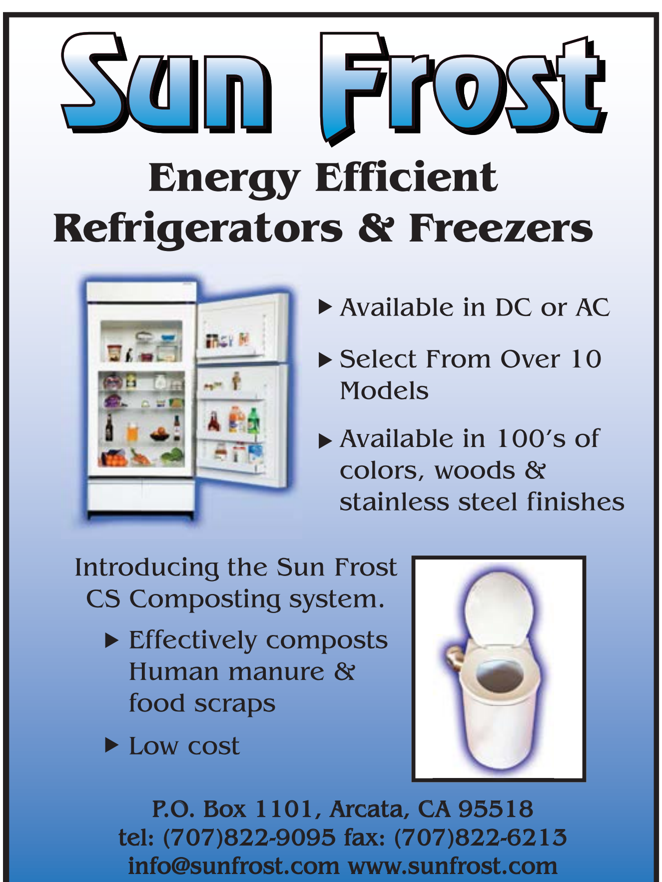
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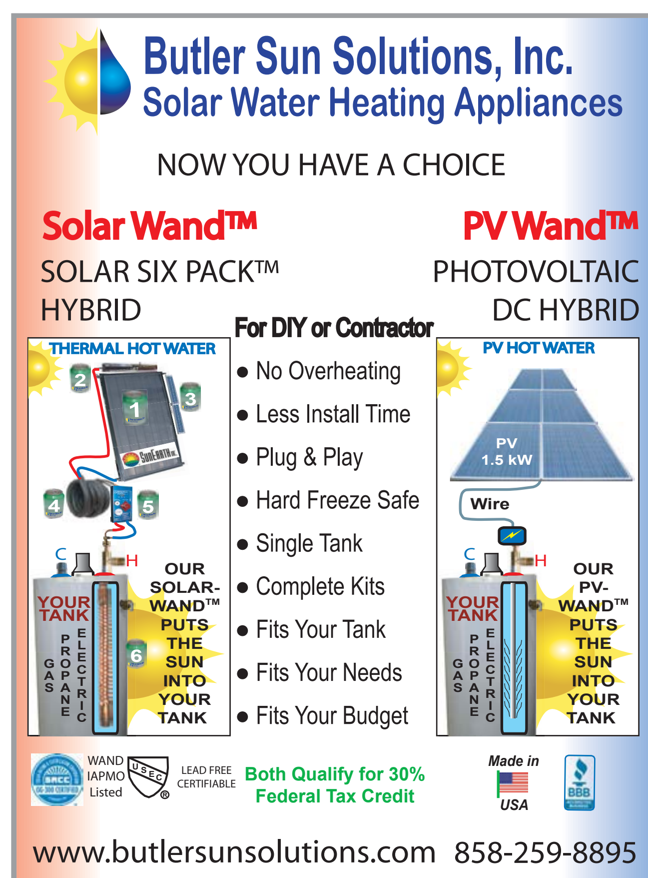
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More 2014 *Code* Changes

In "Code Corner" *(HP158)*, some of the changes to the 2014 *National Electrical Code* were highlighted. Part two continues this discussion.

by Brian Mehalic

Wiring Methods

Many of the new sections in Article 690, Part IV, "Wiring Methods," were moved from other locations. There also are some new requirements. Previously, DC conductors had to be installed in raceways on arrays with a maximum voltage greater than 30 V that were installed in "readily accessible locations" (e.g., ground mounts). Now, Section 690.31(A) allows them to be guarded—"covered, shielded, fenced, enclosed, or otherwise protected…[which] removes the likelihood of approach or contact by persons or objects to a point of danger." This means that screening, some wire-management systems, or even lattice-wrapping the exposed sides and back of an array may be acceptable, rather than having to use a raceway or render the array inaccessible (such as with a fence, or by making it high enough to require a ladder). The authority having jurisdiction (AHJ) will have the final word on acceptability of individual strategies.

Section 690.31(B) now requires that DC PV circuits (both source and output) be separated by a partition from any other conductors when they share a raceway, junction box, or "similar fitting." A gutter box installed below an inverter and the inverter's external AC and DC disconnects must have a partition between AC and DC wiring; it will not be permissible for them to cross over each other.

Cable tray is a popular wire-management device for all sizes of systems, but the requirements in other sections of the *Code* about its use with smaller conductors, such as those used for PV source circuits, were confusing. Section 690.31(C)(2) now explicitly allows use of cable tray for PV-source and output circuits if they are listed PV wire, even when it's not marked for use with cable tray. The enhanced durability of PV wire led to this allowance, along with the realization that, especially on commercial rooftop systems where thermal movement and expansion and contraction can wreak havoc, conduit may not always be the best installation method for conductors. The conductors in cable tray must be supported at least every 12 inches, and secured at least every 4.5 feet.

The increased use of microinverters also has led to new *Code* wiring additions. Section 690.31(D) permits TC-ER and USE-2 cable to be installed on utility-interactive inverters in

Courtesy 02 Energies/Rebekah Hren

New allowances in Article 690 make it easier to use cable tray for PV source- and output-circuit wire management.

Courtesy Texas Solar Outfitters/Brady Miller

Due to the amount of exposed AC conductors typical of most AC module and microinverter systems, AC arc-fault protection is now required.

locations that are not readily accessible—for example, as the AC output conductors connected to microinverters behind PV modules. This section also specifies that there must be an equipment grounding conductor in the cable, and requires the cable be supported at least every 6 feet.

Continuing efforts to harmonize language with the *International Fire Code*, Section 690.31(G) extends requirements for conductors *inside* a building to those *on* a building. The label, "Warning: Photovoltaic Power Source," must be applied on conduit (exposed raceways) at least every 10 feet, and on cable trays and junction boxes on roofs or exterior walls. As with the rapid shutdown label requirement, this is more specific than 110.21 field applied hazard marking guidelines, specifying reflective, white capital letters, at least $^3/8$ inch tall, and on a red background.

Ungrounded PV Systems

Ungrounded PV systems are becoming increasingly common, and additional wiring methods are now allowed in Section 690.35(D). Both metallic and nonmetallic jacketed, multiconductor cables are now allowed for PV source-circuits, along with cables that are buried, provided they are identified as appropriate for direct-burial. New language in 690.47(B) provides clarity by allowing the AC equipment grounding system to be used as the ground-fault detection reference for ungrounded systems, along with the allowance in 690.47(C)(3) that the conductor providing the bond to the AC equipment grounding system be sized as an equipment-grounding conductor per Table 250.122.

Auxiliary Array Grounding Electrodes

Deleted in the 2011 edition of the *NEC*, Section 690.47(D), which requires additional auxiliary electrodes for array grounding, is back in 2014. This is a contentious issue, with experts questioning whether the additional grounding electrodes are being mandated as lightning protection; if so, whether this requirement should fall under *NEC* jurisdiction; and whether there are legitimate merits in requiring this for rooftop systems in addition to ground- and pole-mounted systems, or at all. Expect this section to be reexamined in future code cycles as well. See "Additional Electrodes for Array Grounding," in *SolarPro* magazine 1.1 for more information. Note that many experts agree that any electrode added to a building should be bonded to the existing grounding electrode system. This is not a requirement for auxiliary electrodes (see 250.54), but can lead to dangerous differences in potential in the event of a surge or lightning strike.

Battery Disconnects & OCPDs

Section 690.71(H) has new requirements for disconnects and overcurrent protection for systems with batteries or other energy-storage devices. When the output conductors connected to the battery (or energy-storage device) are longer than 5 feet, or pass through a wall or partition, there must be a disconnect and overcurrent protection (breaker or fused disconnect) at the battery, on the ungrounded conductor. The battery must connect to the "line" side terminals of a fused disconnect. Disconnects and OCPDs cannot be installed in an area where explosion is possible (for instance, in a battery box with vented lead-acid batteries). If the battery disconnect is not visible and within 50 feet of the connected equipment (inverter and charge controller) then another disconnect is required at the equipment (for example, at the inverter). When the PV system AC and DC disconnects are not within sight of the battery disconnect, directories (descriptive text and a diagram is ideal) showing the location of all disconnects are required on each disconnect. This ensures that all sources of power are identified and can be isolated.

Courtesy Century Roof and Solar/Tony Diaz

A partition is now required between AC and DC conductors, even if connected to the same inverter (such as in the gutter box shown here).

Section 705.12(D)

The most significant changes in Article 705 are in 705.12(D), which further clarifies the ways a PV system can be connected on the load side of the AC service disconnecting means, particularly 705.12(D)(2), "Bus or Conductor Ampere Rating." Under earlier editions of the *Code*, busbar calculations were performed using the rating of the overcurrent protection devices (OCPDs) that were supplying power to the busbar (the main, or supply breaker, plus any back-fed breakers connected to grid-tied inverters).

One significant change is that 125% of the inverter's rated AC output current, rather than the actual back-fed breaker size, is used for busbar calculations. The advantage is that the installed OCPD size is usually larger than the calculated minimum OCPD size (since, if the calculation doesn't result in a standard size, it has to be rounded up), but 125% of the inverters' rated output current (typically a smaller value than the installed OCPD size) can be used in busbar calculations, potentially allowing larger PV systems to be interconnected on the load side of a service.

For example, consider a 7 kW, 240 VAC inverter with a rated output current of 29.2 A. The minimum breaker size, as well as the value for busbar calculations, is 36.5 A; the interconnection breaker would be 40 A, as it is the next larger standard size above the calculated minimum—but the 36.5 A will be used to ensure that the sources supplying current to the busbar don't exceed 120% of the busbar's rating.

Further clarification on busbar calculations is provided in 705.12(D)(2)(3), with four options:

- 125% of the inverter's rated current + the rating of the OCPD protecting the busbar ≤ the busbar rating. The location of the back-fed inverter breaker is not stated, and the "120% rule" is not being applied.

- 125% of the inverter's rated current + the rating of the OCPD protecting the busbar ≤ 120% of the busbar rating. The breakers must be at opposite ends of the busbar so that current from the two sources will not be additive at any point on the busbar, in the same manner that the "120% rule" was applied in the 2011 *NEC*.

- The sum of the ratings of all the overcurrent protection devices, both supply and load, but excluding the rating of the overcurrent device protecting the busbar from the utility supply ≤ busbar rating. This allowance is for inverter AC combiner subpanels, in which the output of multiple inverters are connected and run through a single, larger OCPD to the point of interconnection. By counting both supply and load breakers, this section makes provisions for load circuits such as data monitoring, security systems, or other associated loads to be fed from a panel being used to combine the output of multiple inverters. Note that in this option the calculation is based on the inverter's back-fed breaker size, not 125% of the inverter's rated current. The combination of supply and load breakers being less than the rating of the busbar ensures that it cannot be subject to overcurrent. This will allow smaller subpanels, since the OCPD protecting the busbar from the utility source is not counted.

- Engineering studies, including busbar loading and fault studies, can be performed for center-fed panel boards or load centers with multiple-ampacity busbars. Although center-fed panels are common in some areas of the country, there was previously no guidance for making load side connections to them. Under the 2011 *NEC*, the sum of all supply breakers had to be less than the busbar's rating (inverter breaker(s) + OCPD protecting the busbar from the utility supply, no allowance for the 120% rule, since the "opposite" end of the busbar from the utility supply OCPD could not be defined), effectively limiting the size of PV system that could be connected to this equipment.

Other Changes

Article 705 includes a requirement for AC arc-fault protection for utility-interactive inverters with wiring harnesses rated at 240 VAC and 30 A or less, unless the harnesses are installed within an enclosed raceway. This requirement—in 705.12(D)(6)—is aimed at microinverters and AC modules.

Section 705.31 stipulates that overcurrent protection for supply-side interconnections must be located within 10 feet of the point of interconnection, unless cable limiters (devices that isolate conductors from short circuits, but don't necessarily provide overcurrent protection) or current-limited circuit breakers are installed. This helps reduce the risk from fault current sourced from the primary electricity source (the utility).

Access

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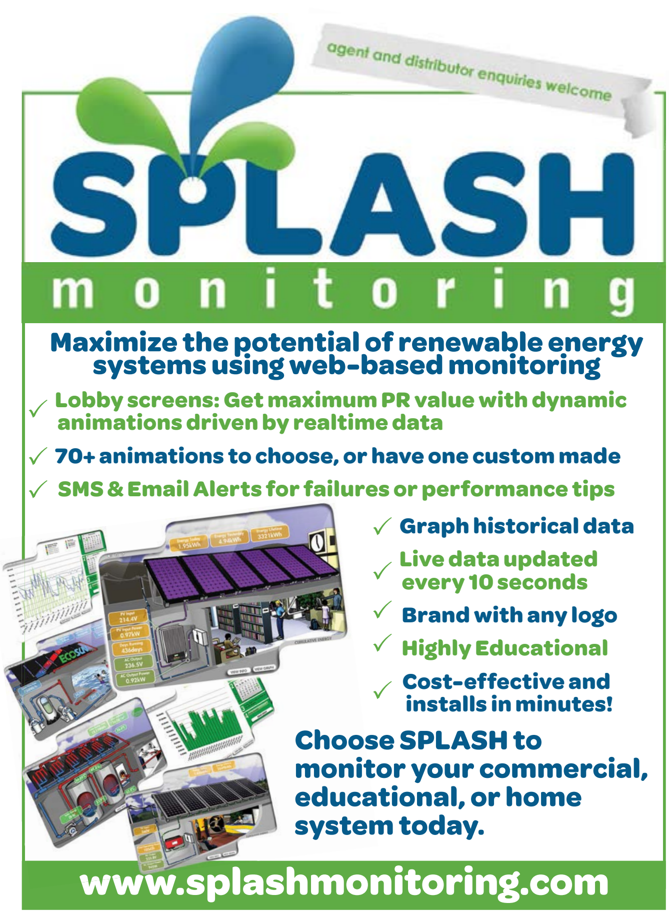
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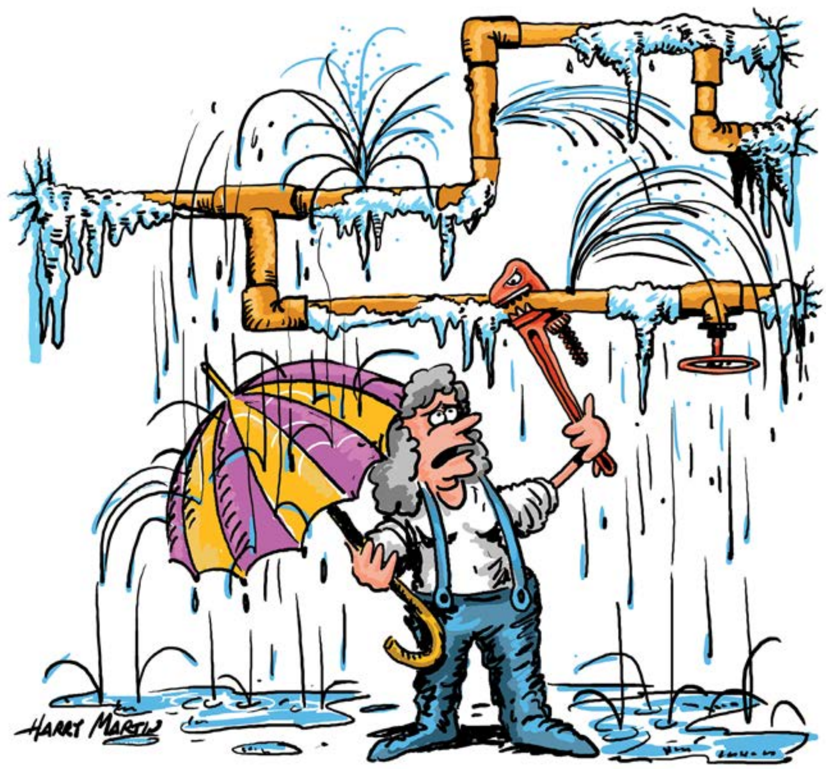


by Kathleen Jarschke-Schultze

I frequently get posts on my Facebook page from a group called, "A Gathering For Kindred Souls Looking to Live Off the Grid." There is usually a swell picture of some tiny rustic cabin out in the woods, on the prairie, or on the shores of a lake. Right away the questions come to mind:

Where is your woodshed? Where is your workshop; your boneyard? Is your vehicle four-wheel drive? Does it have a garage? In your 15-by-15-foot cabin, just how big is your pantry? How often do you think you will be going to town for supplies? How far away is town? Do you have to commute to a job? Where is your garden? What are your power sources?

Reality Checks

Call me jaded, but it is hard for me to look at a tiny home in the middle of nowhere and not think of how many things can go wrong—and of all the safety nets needed. Even after 28 years of living off-grid, my husband Bob-O and I are not immune to inevitable "adventures," as we like to call them.

When people ask me what it is like to live off-grid, I tell them it is wonderful—and it is. I describe our canyon—so small that we cannot see neighbors. Living off-grid means you do for yourself. You take the responsibility for your own life. Instead of writing a check for water, garbage, and power services, you do for yourself.

No water at the tap? Go find your plumber's wrench. You sustain your water supply. If water stops coming to your house, it is up to you to go find the problem and fix it. It's good to have an assortment of tools and spare plumbing parts on hand. That's where a well-stocked boneyard comes in.

Full trash cans and recycling bins? Load up the truck! Nobody comes to take away your trash. You have to haul it to the landfill or transfer station. Recycling is part of this life. The more you recycle, the less garbage you generate. We have a small shed lined with barrels for the various recyclables. Twice a year, a local recycling program hosts a plastic round-up, when we can take in all the odd-numbered plastics for recycling. When a container gets full, we load it up and take it to the recycling center in town. Sometimes we can get a little money for the glass or cans. Sometimes that money pays for the trip gasoline. Like recycling, composting lessens garbage and the payoff is excellent soil for your garden. Coin of my realm, you could say.

No electricity? Don your deerstalker, Sherlock, the mystery is yours to solve! By using solar, wind, and microhydro power, our electrical systems are honed to our microclimate and our lifestyle. Depending on the time of year, I could have excess energy every day or we could be running our generator to charge the batteries. When we have excess electricity, I play it fast and loose, doing laundry every day and using my new induction cooktop, with the TV on in the background to keep me company. On those days, I can be happy-go-lucky about my energy usage. But when the water and wind are gone and the sun is only peeking through the clouds, I can rein in my energy consumption to almost nothing

Winter Carnival

Unusually cold weather is another battle that off-gridders occasionally face. Even though the acorn crop was not abundant this year—the theory being that a plentiful crop means plentiful cold during the next winter—we got some really cold weather for an extended period of time. And that means potential freezing of our water supply, even though we have taken precautions.

We have insulated and used heat tape on every water pipe we can reach, and with the microhydro running in the wintertime, we have the energy to run the heat tape at night. It's a good system and has worked well for us.

December 2013, however, included a cold snap that brought temperatures dropping to -3.4°F and 7 inches of snow on the first night alone. For five nights, temperatures dropped below zero, and daytime temperatures only rose to the mid-20s. Our water pipes froze. The main water line coming to the house froze.

Now, this wasn't our first rodeo. We watch the weather, so we knew the cold front was coming. I had two big plastic buckets of water sitting in the shower, ready to use for flushing the toilet. In the kitchen, filtered water for drinking and cooking filled two 5-gallon water containers. My biggest canning pot stood full of water on the wood heater so we had hot water when we wanted it. Knowing we would need to pour hot water on frozen pipes, I also filled all my stockpots with water.

The fourth day of the cold snap, our hydro's 5-inch penstock pipes froze and burst in more than a dozen places. Bob-O found the breaks after scouting along the creek, trying to figure out why the turbine had stopped. Replacing 160 feet of pipe along the freezing creek was not a pleasant job, but knowing it had to be done, Bob-O purchased the parts. With our friend Mike's help, he got the pipe run repaired and full of water again. The hydro started making power again 11 days after the hard freeze.

But that wasn't the end of our water woes. The pipes that feed water to our house were also freezing. Although we tried pouring boiling water on strategic domestic pipe connections, the extended below-zero temperatures thwarted our every attempt. Our house water comes from a spring, and is piped across the creek and up a hill. The line that spans the creek had been our weak link, but with liberal use of insulation and heat tape, we had solved that problem many years ago.

What stopped our water this time was the line freezing along its buried length. Bob-O determined that our house pipes were unfrozen except in one corner. Using the boiling water, he was able to thaw that juncture. We were able to connect a hose to the outdoor house faucet, switch over to our well pump, and charge the house system. That is how we found out our basement had also gotten so cold that our "on-demand" water heater had also frozen. There were multiple splits in all of the small copper tubes. We had to order and wait for a new one.

By shutting some valves, we were able to isolate the water heater. We went back to using the well. When the sun was hitting the pump's PV array and a faucet was kept running in the sink to keep the pressure regulated, I was able to refill all my jugs and buckets and do a cold-water laundry load.

When the new water heater arrived, Bob-O installed it right away. Now, when we ran the array-direct well pump to charge the house we could take hot showers, too. Oh, joy; rapture! Hot, running water is a miracle not to be underappreciated.

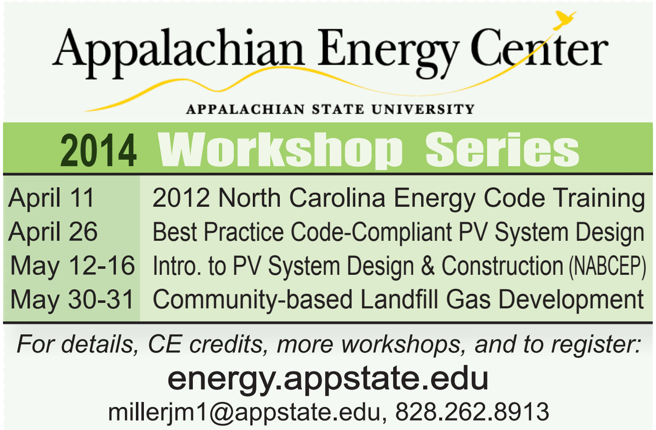
With our microhydro turbine running again, we were able to turn on the heat tapes again, hoping the water being thawed in the pipes would reach underground where the ice blockage was, allowing spring water to flow to the house once again.

On the 15th day, the kitchen faucet came on when Bob-O tried it. We thought it might be merely the pipes draining and the flow would soon stop. But as we watched, hopeful, the slow stream of water continued for several minutes, coughing and snorting occasionally as the ice shards moved along the pipes. Ten minutes later, our house water was running freely.

How is it living off-grid? It's wonderful! I wouldn't trade it for anything. That's my story and I'm sticking to it.

Access

Kathleen Jarschke-Schultze (kathleen.jarschke-schultze@homepower.com) is doing a rain dance at her off-grid home in northernmost California.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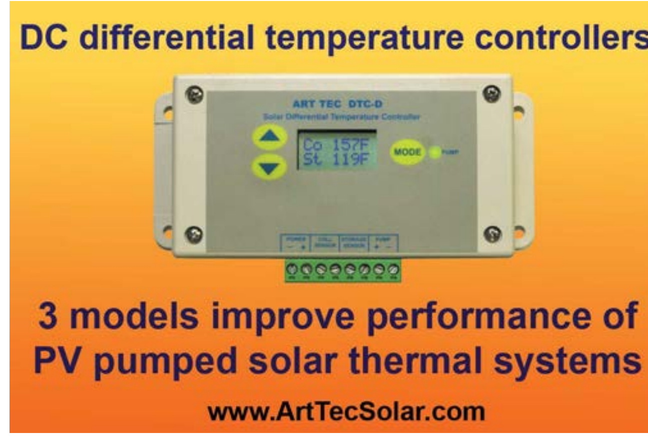
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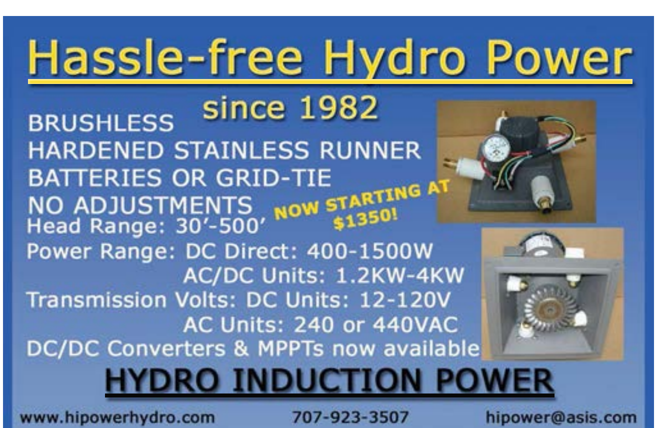
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Microhydro: Measure First to Reap the Bounty

Very few residential properties have a hydro resource to tap. But if you have it, hydro can be a cost-effective and reliable renewable electricity source with a modest investment.

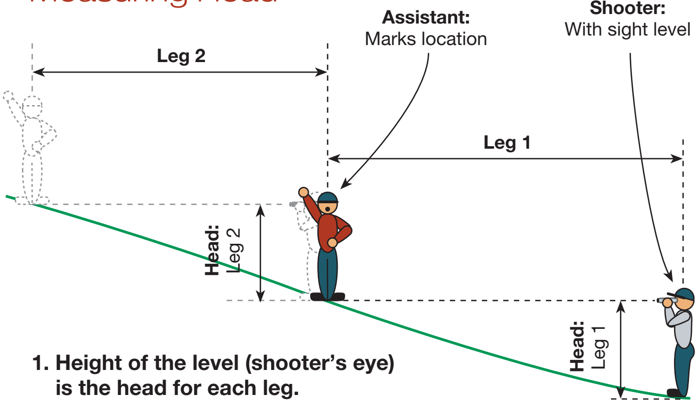
Hydropower comes from a combination of vertical drop (head) and water flow. It takes both in reasonable quantities to make meaningful amounts of energy. If your stream only has a little head, you'll need a lot of flow. If your stream only has a little flow, you'll need a lot of head.

Head

Head is the vertical drop from the intake, where water enters the pipeline (penstock) to where the water hits the "runner"—the wheel that converts the energy in the water jet into rotational force. Head is measured in feet, meters, or pounds per square inch (psi). Vertical drop and pressure are the same thing—every 2.31 feet of head results in 1 psi.

Smart hydro designers consider *all* possible head on a site, and choose what is needed and most economical to tap. Not taking advantage of available head will shortchange your available energy—double the system's head and you double your potential energy.

Measuring Head



1. Height of the level (shooter's eye) is the head for each leg.

2. Assistant marks spot on slope for the shooter's next position.

3. Repeat multiple legs from turbine location to intake location.

4. Multiply the height of the level times the number of legs to determine total head.

Flow

Flow is the amount of water that runs through the penstock and nozzle to hit the runner. It is typically measured in gallons per minute (gpm), or cubic feet per second in larger systems.

Measuring stream flow with a bucket and a stopwatch. If it's not possible to measure the full stream flow, measuring part of it gives you some data to work with. It may even be enough data, since typical systems only use a portion of the stream flow.

Ian Woofenden

The penstock need not follow the stream, but should be as short as reasonably possible, follow a route that is secure from physical damage and frost, and preferably runs continuously downhill. Pipe sizing is crucial to good hydro system design, to minimize friction loss. Undersizing the diameter of a penstock means losing some of the pressure to friction—and that means losing some of the power potential. Friction-loss tables and calculators can help make the right pipe size and type choices. Choosing the appropriate type and pressure rating of pipe is also important.

Math

A rough formula for estimating your site's hydro potential says that the flow (in gpm) times the head (in feet) divided by 12 (or thereabouts) will give you the potential power (in watts). For example, if your stream has a flow of 22 gpm and a head of 120 feet, it might provide about 220 watts, or about 5 kilowatt-hours per day (22 × 120 ÷ 12 × 24 hrs./day).

Once you've generated the electricity with a hydro turbine, you need to transmit it to where you want to use it. This may entail using low-voltage (12 to 48 V) lines if the distances are short, or using higher-voltage (120+ V) lines for longer distances. Exact system electrical details will depend on whether you are charging batteries on- or off-grid, or connecting directly to the utility grid.

Whatever you end up powering, the energy available comes back to how much head and flow you have. So *measure* both carefully, including seasonal flow variations. Without reliable measurements, any microhydro dreams you have may not come true. Get the numbers, see if you have the resource, and then work on making those dreams a reality.

—Ian Woofenden

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