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12 VOLT

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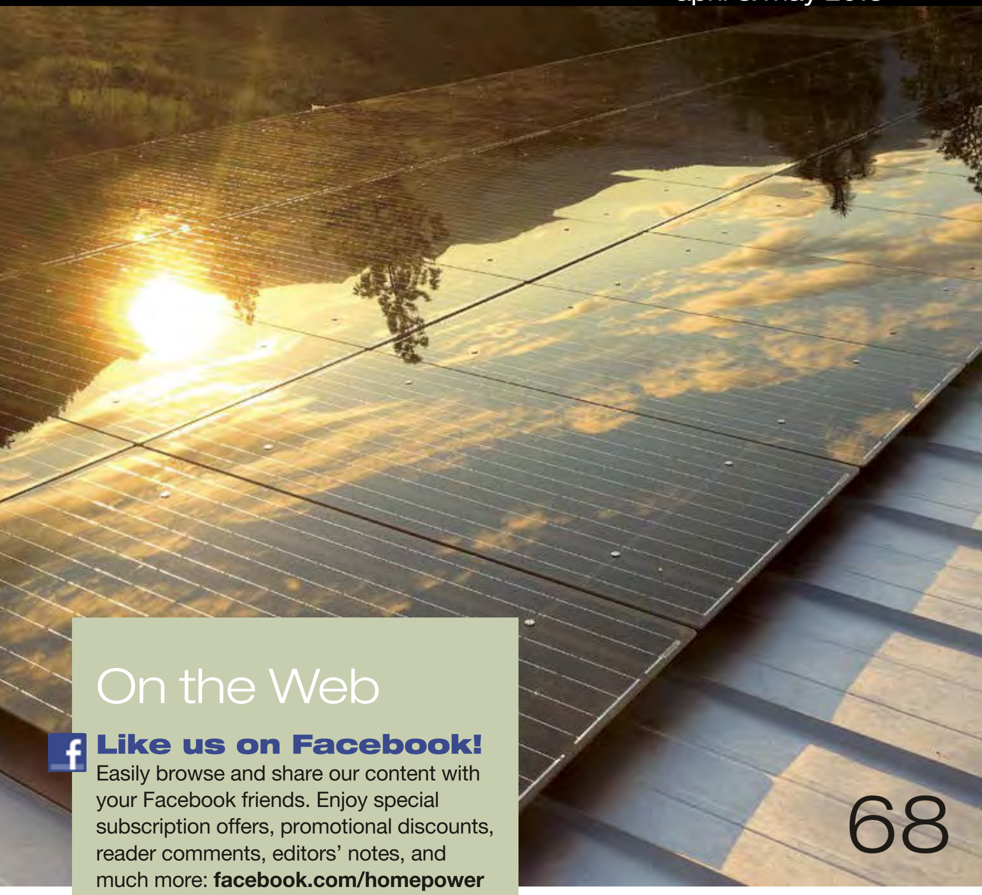

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On the Cover

Form meets function in this array of frameless PV modules.

Photo by Shawn Schreiner

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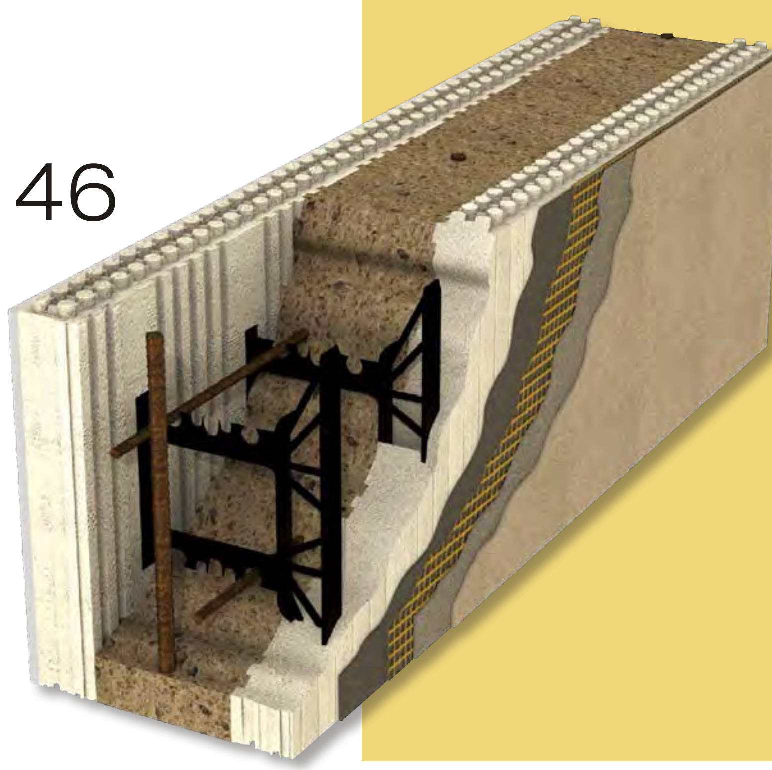

Photos, left to right: Shawn Schreiner, Logix, istockphoto.com/jfsower, istockphoto.com/caseyimage, Randy Richmond

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We All Start Somewhere

In 1995, I took a hiatus from my carpentry job in Oregon, packed up my Datsun 510 wagon, and headed to Colorado for a summer of training at Solar Energy International (SEI). I'd spent a couple of years reading whatever I could dig up on solar energy and figured it was time to dive in. That summer, and three people I met because of it, changed my life. And, as I would come to learn, they changed the lives of thousands of other people as well.

Courtesy Joe Schwartz

Johnny Weiss leads an SEI PV installation workshop at Uncle Bud's Hut, Colorado Rockies, summer 1995.

Johnny Weiss, a cofounder of SEI, taught some of the first days' coursework. Johnny also came from a construction background. He's smart, approachable, has a great sense of humor, and (what sealed the deal for me) could answer any question about solar energy I could think of.

After my "solar" summer in Colorado, I headed back to Oregon—and to pounding nails. But landing a job installing solar was where my head was at. So I contacted *Home Power*'s art director, Ben Root, who I'd met that same summer at SEI. Ben introduced me to Bob-O Schultze, an installer who was a close friend and neighbor of Ben's employers, Richard and Karen Perez, publishers of *Home Power*.

Like most RE installers who helped pioneer the industry, Bob-O had cut his teeth on renewable energy systems by living with them, in his case on a remote mining claim in Northern California's Salmon River country. When Richard decided to make publishing *Home Power* a full-time job, he passed on his installation business, Electron Connection, to Bob-O. My on-the-job training with Bob-O came both at the job sites and in the cab of his pickup, where we'd talk equipment, wire sizing, code—you name it—during the long drive to our next remote, off-grid installation.

On weekends, I'd drive the six miles up the rutted Yellow Dog Trail to Richard and Karen's homestead, where I worked on construction projects and upgrades to their off-grid PV and wind power systems. Richard is the first truly visionary person I've met. Physics, technology, and politics are his passions, and he has an unwavering belief that renewables will not only lessen our environmental impact on the planet, but also make people more independent and free.

The list of people who have been instrumental in moving renewable energy forward is long and growing. Mentors are everywhere and excited to share what they know. Johnny, Bob-O, and Richard are three people out of thousands who have devoted their lives to changing the way we make and use energy, and have changed countless people's lives in the process. I'm certainly one of them.

—Joe Schwartz, for the *Home Power* crew

Think About It...

"If you don't start somewhere, you're gonna go nowhere."

—Bob Marley


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The RE Right of Way on Public Lands

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When President Obama took office, there were no renewable energy projects allowed on public lands. But since 2009, the U.S. Department of the Interior (DOI) has approved 34 RE projects, including 18 utility-scale solar facilities, seven wind farms, and nine geothermal plants, with associated transmission corridors and infrastructure. While wind energy projects are authorized or under review in Oregon and Wyoming, the majority of the projects are on public desert lands in Arizona, California, Colorado, New Mexico, Nevada, and Utah. When built, these projects will total 10,400 MW of capacity. While that capacity could provide an estimated 3.4 million U.S. homes with renewable energy, not everyone is happy about it.

In its quest to have permitted 10,000 megawatts of renewable power on public lands by the end of 2012, the Obama Administration has been criticized for "fast-tracking" projects without adequately assessing the impacts on wildlife and Native American sacred lands, specifically across the Mojave and Colorado deserts. The Bureau of Land Management (BLM)—which oversees the approval and leasing process for public lands operating under the arm of the DOI—has been called out by environmental and community groups for making "hasty" and "short-sighted" decisions when granting the leases or right of ways for RE projects.

Concerns over planning missteps continue to escalate as the DOI moves forward with permitting for an additional 23 utility-scale projects on federal lands. In early February 2013, the department announced that it had identified 14 solar, six wind, and three geothermal projects that should be approved for construction over the next year or two.

Taking Issue

As the California Desert Program Manager with the nonprofit National Park Conservation Association (NPCA), David Lamfrom has been close to the planning process since stakeholder discussions began in 2008. His chief concern is the proximity of current and future projects to national parks, and "the loss of habitats and the fragmentation of habitats" caused by some of these projects, which could "threaten the existence of the diverse plant and animal life that lives in our national parks and preserves."

The National Park Service identified areas around 53 national park sites in the six-state region where significant impacts to resources would result from industrial solar development. The NPCA advocates that energy development should be focused on fallow agricultural or disturbed lands rather than on public lands with intact desert habitat.

Other environmental groups, big and small, have actively lobbied against RE projects on public lands and filed lawsuits against federal and state agencies—some of which are still pending. The general contention is that many of these projects pose significant harm to habitats and wildlife, including the federally protected endangered desert tortoise, golden eagle, California condor, and San Joaquin kit fox, as well as desert bighorn sheep and other species.

Tribal groups also sued federal and state agencies over the fast-track approval process for projects, which, they say, violated federal law by failing to engage in "government-to-government" consultation with tribes. More than 40 solar and wind energy projects are proposed within a 50-mile radius of the Colorado River Indian Tribes (CRIT) reservation,

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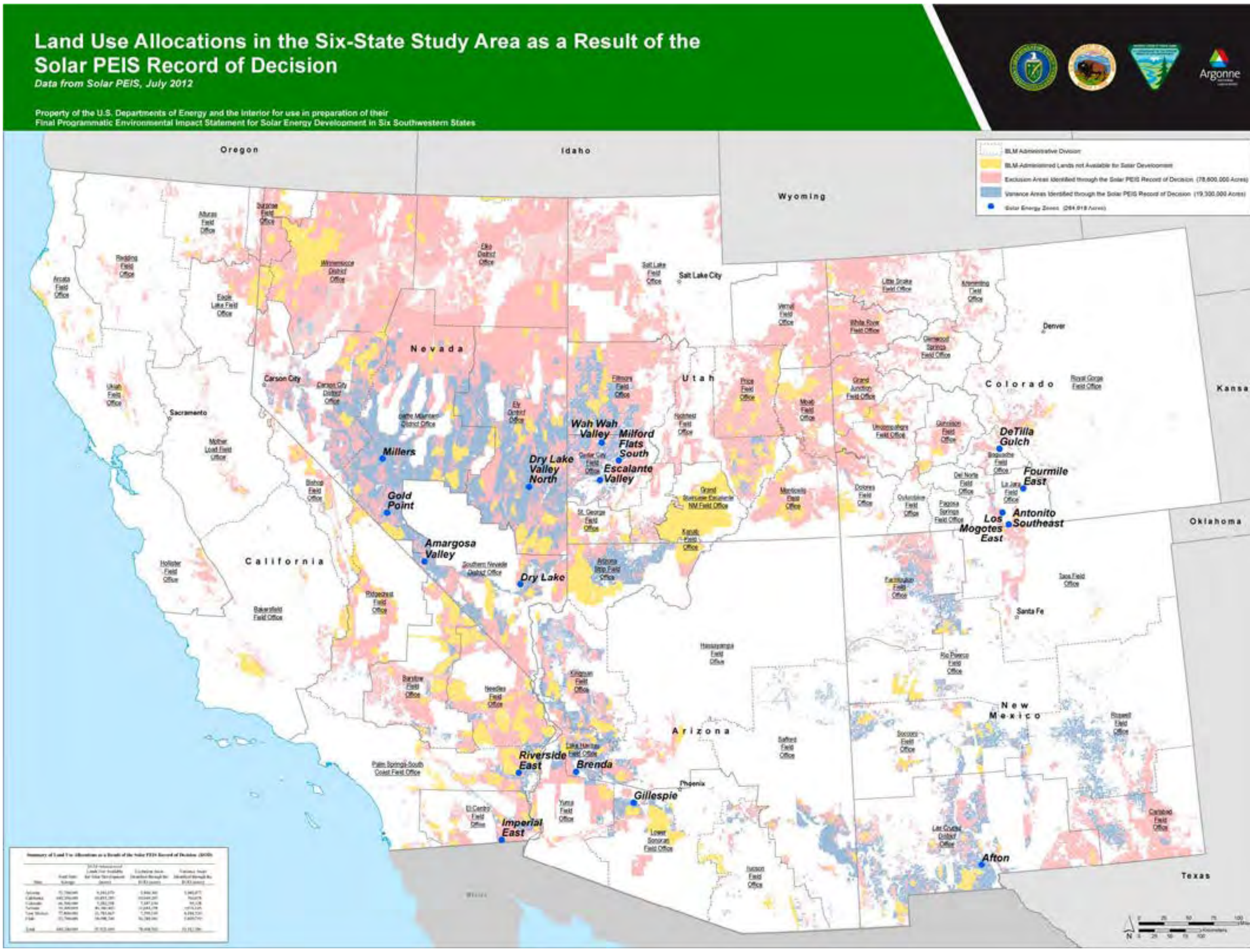

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which stretches along the Colorado River on the Arizona and California border. CRIT says that these projects will desecrate sacred places and viewsheds, impairing the tribes' ability to practice their traditional and religious beliefs.

"The tribe acknowledges the need for energy projects and supports renewable energy," says John Batisky, the Historic Preservation Officer for the Quechuan Tribe, "but there is some question as to whether the government is doing enough on the consumption side to encourage consumers to reduce their fossil-fuel use and encourage communities to develop smaller, distributed-generation RE systems."

Addressing Concerns

In October 2012, the BLM, along with the Energy Efficiency and Renewable Energy Program (overseen by the U.S. Department of Energy), adopted a plan that establishes a blueprint for how and where utility-scale solar projects will be permitted in Arizona, California, Colorado, Nevada, New Mexico, and Utah. Known as the Programmatic Environmental Impact Statement (PEIS) for Solar Energy Development (aka Solar PEIS), the plan identifies 18 solar energy zones (SEZs) on 287,550 acres of public land. The PEIS also keeps the door open for solar projects to be sited outside the SEZs, on an additional 19 million acres of variance lands where projects will be approved on a case-by-case basis.

Prior to finalizing the PEIS with stakeholders, the DOI approved 17 desert solar projects—several in areas that were later precluded from development in the final draft due to further analysis and stakeholder input. "The fact that the DOI has grandfathered in these projects completely undermines the planning process. These projects are moving forward without any regard for the stakeholders' input and the analysis that went into developing the PEIS," says Lisa Belinky, senior attorney with the Center for Biological Diversity.

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For more info

To view maps of BLM-administered lands open for solar development under the Solar PEIS, go to: **http://solareis.anl.gov/**

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"The plan creates a little more focus. Technically, from the DOI's interpretation, there is less land on the table because they've removed zones, but in reality, they've opened up 19 million acres in variance lands with virtually no analysis. That's a big step backward," says April Sall, conservation director for the Wildlands Conservancy, which, in 2000, raised $45 million to purchase 560,000 acres of the Mojave Desert and then deeded the land to the federal government to protect for perpetuity. A portion of those acres could end up in an RE development zone, depending on the outcome of another BLM PEIS currently being drafted.

According to Shannon Stewart, BLM senior National Environmental Policy Act specialist, applications for variance lands will need to meet higher standards of analysis than those for SEZs, with applicants required to do more upfront work and resource gathering. She also notes that any projects for variance lands must be approved by the BLM field manager on the ground and then go on for a second-level review in Washington—a measure that she says "will bring consistency" to the process.

Not Just High-Yield Sites

The Solar Energy Industries Association (SEIA), in conjunction with the Large-Scale Solar Association (LSA), were among groups that objected to a criterion that excludes solar development lands that receive less than 6.5 kWh per square meter of daily insolation. Although intended to support high-efficiency projects with greater production capacity (since a smaller physical footprint may also have fewer environmental impacts), the BLM has since conceded this point. Developers may be able to obtain special permission for projects on lands that don't meet the criterion.

"We hope that this decision results in a permitting process that brings more solar online to serve the American people," says Rhone Resch, president and CEO of SEIA. "The PEIS identifies a process that has the potential to accommodate well-sited solar power plants outside of designated solar energy zones and protects the rights of pending solar applications. The BLM must ensure pending projects do not get bogged down in more bureaucratic processes."

Meanwhile, in California, the California Desert Renewable Energy Conservation Plan provides stakeholders with another opportunity to be heard. The plan is a joint state and federal effort to identify areas within the state for RE development and areas for long-term conservation. As part of the process, the SEZs and variance areas outlined in the Solar PEIS will be updated with further analysis, and tribal groups will collaborate with state agencies on a cultural sensitivity map that identifies areas with minimum cultural and natural resource conflicts. The first draft is expected by June 2013.

Deserting the Desert for DG

The controversy over RE development in the desert piggybacks on the issue of RE project scale, namely utility-scale projects versus distributed generation.

A report by the National Renewable Energy Laboratory (NREL) points to the theoretical possibility of *urban* utility-scale and distributed generation systems being able to meet the annual U.S. electricity use. While the numbers give distributed generation advocates hope, the study looks only at the feasibility of the technology, and does not take into account political and economic factors. But, says Anthony Lopez, one of the study's authors, "once you take into account all the other factors, the story changes quite a bit. The study shows a very idealistic view of what could be."

NREL analyst Easan Drury says, "No matter what the many studies out there may say, the reality is that what can be built and what *will* be built to meet renewable portfolio standard requirements is going to be dictated entirely by economics."

Some utilities claim that the shift from centralized to decentralized power requires restructuring their business model, as well as implementing changes to deal with potential voltage and energy storage issues from a large-scale deployment of distributed generation systems.

"Large-scale RE projects are easy and keep things relatively status quo because they still rely on transmission, which is where the utilities make their money," says Belinky. "We should have spent the last two decades building the appropriate RE infrastructure and preparing the utilities to make the transition to distributed generation."

The Sierra Club and the Natural Resources Defense Council have come under fire for taking the middle ground, advocating for reduced barriers to distributed generation at the state levels, while supporting large-scale solar power as a necessary step in reducing climate change—what both groups have called the nation's most serious environmental problem.

"Sure, we want distributed generation, but we are a long way from the day when state-run utility commissions will do what it takes to encourage widespread use of distributed generation. If we want to shut down coal plants, we have to accept some big solar development today," says Sierra Club's Barbara Boyle, senior lead for energy issues.

"The reality is that there is no free lunch when it comes to energy," says Johanna Wald, senior attorney with the NRDC. "Any way we produce energy has impacts, some bigger than others."

—Kelly Davidson

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SOLECTRIA RENEWABLES

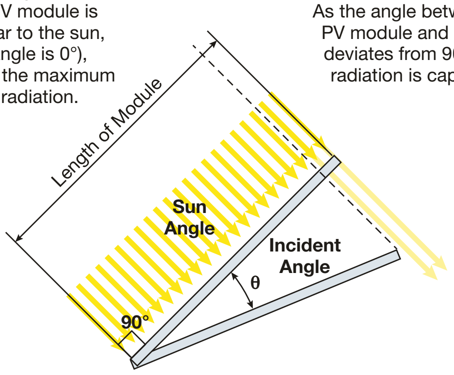
To Track or Not to Track?

This passive tracker uses the sun—and a liquid that condenses into a gas when heated—to position the modules instead of motors, gears, or electronics.

In the northern hemisphere, a fixed PV array is usually oriented south (180° azimuth), to capture as much sunshine as it can. But that results in less-than-optimal energy production because the PV modules' surfaces face the sun directly for only a short period each day (at solar noon). Additionally, because the sun is higher or lower in the sky each day depending upon the time of the year, tilt adjustments are necessary to optimize seasonal production.

The sun's intensity is at its maximum on a PV module when it is striking it perpendicularly—the incident angle is 0°. The larger the incident angle, the smaller amount of energy that hits the module. When the incident angle increases, reflection also increases and the amount of energy that can be gathered drops.

Insolation as a Function of Incident Angle



To maximize production, tracking systems keep PV modules facing the sun all day throughout the year. Trackers can be single- or dual-axis, and either passive or active. A single-axis tracker follows the daily movements of the sun from east to west (about 15° per hour). A dual-axis tracker also adjusts the array's zenith, changing its tilt to keep the modules truly perpendicular to the sun's rays all year long.

Passive tracking relies on the sun to heat a liquid in canisters affixed to the sides of the array. As the liquid in the unshaded canister heats up, it expands into a gas, which pushes the heavier liquid to the shaded canister, shifting the weight to that side of the array, which causes it to rotate. Zomeworks (zomeworks.com) pioneered the passive PV tracker.

Active tracking relies on hardware or software that tracks the sun's movements. Wattsun (wattsun.com) solar trackers use motors and gears activated by onboard photosensors that find the brightest spot in the sky. DH Solar (dhsolar.net) uses software to calculate the sun's track based on latitude, longitude, date, and time. Motors and gears still do the heavy work. Bob-O Schultze of Electron Connection says that "passive trackers point west each night and sleep in late, especially on winter mornings." Schultze has five active PV trackers at his home/office near the California-Oregon border.

Tracking increases production throughout the year. The amount of gain varies depending on the latitude, amount of unobstructed horizon, and local weather. Dual-axis trackers can provide up to 40% increased energy harvest compared to fixed arrays.

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This active tracker is pointed at the brightest spot in the sky, even though there is no direct sunlight yet. The bright spot is quite low on the horizon—hence the array's nearly perpendicular position to the ground.

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The downside of tracking is the higher cost of the tracker, plus the costs of concrete, labor, and burly structural components needed for the pole-mounted array. With active trackers, there's the potential for failure of motorized and electric components. Repairs and maintenance costs can offset any production gains, as can storm damage, which is more likely with a tracked system. While inverters and PV modules carry 10- and 25-year warranties, respectively, most tracker warranties range from two to 10 years.

When PV modules were more expensive, trackers were used to squeeze more energy production out of the modules. Now that modules are much less expensive, trackers may not make sense for some applications. You'll need to compare the cost and maintenance of tracker hardware to the cost of adding more modules to a fixed array to achieve the same energy output.

For commercial PV installations with an economy of scale that residential PV doesn't have, tracking often comes out ahead—especially single-axis. For grid-tied residential PV systems, the best choice is usually a fixed array. With inexpensive PV modules, the most cost-effective approach—assuming enough available space—is to install more modules.

For an additional cost, a rack system could be used that allows for seasonal tilt adjustment instead of tracking. According to the National Renewable Energy Laboratory's *Solar Radiation Data Manual*, changing the tilt angle of a fixed array four times (midway between the solstices and the equinoxes) per year can result in up to a 5% annual increase in energy production—but only at higher U.S. latitudes.

Both aesthetic and practical considerations can come into play. Modules mounted parallel to the roof can have somewhat less production than ones more optimally tilted toward the sun, but they are less aesthetically obtrusive. Then there is the matter of climbing on the roof several times a year to adjust the array's tilt. "Many folks with utility-tied batteryless systems request a seasonal adjustable rack," says David Duffield of DP&W Solar, a PV rack manufacturer, "but then they never change the angle—that's just human nature." Tilting the modules away from the roof plane also creates higher wind loading on the array, and the increased stress on the attachment points and the building needs to be taken into account.

If your PV system is off the grid, other considerations apply. Duffield, who lives off-grid, notes the benefits of adjusting the panels for increased winter production. When the number of daylight hours is shortest, more captured solar energy mean less use of the backup generator. The steeper winter angle also means less snow buildup on the modules.

"It's not the slam-dunk it was 10 years ago," says Michael Reed of Array Technologies, which makes both residential (Wattsun) and commercial PV trackers. Wattsun has sought to revive residential PV tracking by offering less expensive single-axis tracking. East-west tracking provides a larger increment in energy production than tracking the sun's annual changes in height. Downscaling from dual- to single-axis tracking reduces the tracking cost by about half while still providing a 30% increase in production over a fixed array.

—Andy Kerr

Renewable Energy Events

Courtesy SolarFest

Northwest & Alaska

- **April 20, Douglas County Earth Day & Energy Fair,** Roseburg, OR, bit.ly/DouglasFair
- **May 4, Lacey Alternative Energy Fair,** Lacey, WA, bit.ly/LaceyFair
- **July 27, NW SolarFest,** Shoreline, WA, shorelinesolar.org
- **July 26–28, SolWest Renewable Energy Fair,** John Day, OR, solwest.org
- **August 10, Alaska Renewable Energy Fair,** Anchorage, AK, realaska.org

Southwest

- **April 27–28, Solar Fiesta,** Santa Fe, NM, nmsea.org

Central

- **May 1, Milford Renewable Energy Fair,** Milford, UT, sutrec.org
- **September 14–15, Sustainable Living Fair,** Fort Collins, CO, sustainablelivingassociation.org

Courtesy SolarFest

Courtesy Dave Densley


Courtesy Illinois Renewable Energy & Sustainable Lifestyle Fair


Courtesy Southern Green Living Expo

Northeast

- **May 11–12, Solar & Wind Expo,** Central MD, thesolarandwindexpo.com
- **May 18, Living Green & Renewable Energy Fair,** Salem, MA, bit.ly/SalemMaFair
- **July 12–14, SolarFest,** Tinmouth, VT, solarfest.org

Midwest

- **June 7–9, Iowa RE Expo,** Cedar Rapids, IA, irenew.org
- **June 21–23, The Energy Fair (aka MREF),** Custer, WI, midwestrenew.org
- **June 7–9, Michigan Energy Fair,** Ludington, MI, glrea.org
- **August 17–18, Illinois RE & Sustainable Lifestyle Fair,** Oregon, IL, illinoisrenew.org
- **August 17, Polk County Energy Fair,** St. Croix Falls, WI, polkcountyenergyfair.com

Southeast

- **October 4–6, Southern Green Living Expo,** Asheville, NC, southerngreenlivingexpo.com

For the Pros

- **April 16–20, Solar 2013 (ASES),** Baltimore, MD, ases.org/solar2013
- **June 18–19, Small Wind Conference,** Stevens Point, WI, smallwindconference.com
- **July 8–11, Intersolar North America,** San Francisco, CA, intersolar.us
- **October 21–24, Solar Power International,** Chicago, IL, solarpowerinternational.com


Courtesy JRob Adams

Courtesy Jake Hardman

Courtesy KACO/Tigo Energy

KACO Blueplanet Inverters with Integrated Tigo MMUs

PV systems using Tigo Energy module maximizers preinstalled in "smart modules" can now include inverters that communicate directly with individual PV maximizers. KACO (kaco-newenergy.com) has released its 6400/7600M inverters integrated with the Tigo Maximizer Management Unit (MMU).

Systems using maximizers include module-level MPPT, module-level monitoring, and help keep any modules operating at lower output levels from adversely affecting others in the string. Integrating the MMU into the inverter reduces material costs and labor. The MMU "PV Safe" button is also integrated into the inverter, allowing deactivation of the high-voltage direct current—limiting exposure to the open-circuit voltage of a single module.

—Justine Sanchez

SMA Smartformer

Courtesy SMA

SMA America's (sma-america.com) Smartformer enables the 120 VAC Sunny Island battery-based inverter to output either 120 or 240 VAC. The Smartformer also allows 240 VAC output Sunny Boy batteryless inverters to work with a *single* Sunny Island inverter for AC-coupled systems. Features include an integrated manual bypass switch, which directly powers loads from an alternate AC power source (such as the grid or a generator), should the Sunny Island inverter need maintenance or repair. The Smartformer specifications list a maximum efficiency of 99% and California Energy Commission-rated efficiency of 98.8%. Although its operating temperature range is -13°F to 122°F, it must be mounted indoors or in a weatherproof enclosure.

—Justine Sanchez

Rock the Bike

Putting a New Spin on RE

Remember the freedom you felt as a kid riding your bike, with the wind blowing in your hair? Paul Freedman is helping people recapture that feeling and awaken what he calls "the spirit of the bike." And he's doing it by putting a fresh spin on renewable energy.

Courtesy San Francisco Bicycle Music Festival

Freedman has never owned a car. He relies on public transit and his bikes to get him near and far. "It's funny how when I ride my bike somewhere, like to a wedding recently, people always ask me if I need a ride home. It's hard for people to understand that my bike *is* my ride. It is my vehicle of choice," he says.

With a computer science degree from Harvard University, Freedman was on track to make his name in the tech industry. But after several Internet-related internships in the late 1990s, he decided to shift gears. He left behind his hometown roots in Boston to set up shop in San Francisco, where in 2003, he founded Rock the Bike (RtB).

A mobile, pedal-powered stage takes live music to the streets.

Courtesy Rock the Bike

The Berkeley-based company started out with a focus on the everyday rider, selling bike gear and gadgets that Freedman designed and built in his workshop. The success of his signature product—a fluorescent stick bike light called the Down Low Glow—gave the company the financial footing to expand into pedal-powered products with the 2007 purchase of his friend's bike blender business.

"I saw pedal power as an opportunity to showcase bikes while educating people about climate change and the importance of our energy-use decisions, but I never anticipated that it would become the focus of the business the way it has," Freedman says.

The "Fender Blender"—a bike that powers a blender solely with pedal power—was RtB's gateway into pedal power. With its ability to churn out smoothies and cocktails, the Fender Blender quickly became a top seller (and rental) for schools, farmers' markets, festivals, and parties. Among Rock the Bike's repeat clients is Kaiser Permanente, who rents the bike blenders to feature at health fairs. Freedman adapted the design to accommodate an ice cream maker and a spin-art station—offerings that help his message appeal to younger crowds.

"The trick is reaching kids at the right age, that sweet age when they're receptive," Freedman says. "I hope our products can help kids have an 'aha' moment—I want them

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Kids line up for pedal-powered ice cream and smoothies.

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to think about their energy use and think about the role bikes can play in reducing pollution."

Pedal power isn't new, of course, but Freedman, whose friends describe him as a "mad scientist inventor," has taken the idea beyond the novelty of the Fender Blender to power concerts and events. To decrease the use of diesel generators, extension cords, and batteries at concerts and events, Freedman developed a batteryless system of audio and LED lighting equipment that is powered 100% by stationary bike generators (which use a small electrical generator built into the wheel's hub). Since towing large, professional equipment around by bike would be impractical, Freedman designed and built his own setup, with modified speakers that provide high sound quality sufficient for audiences up to 1,000 people and bands with up to eight members.

RtB sells the equipment and also provides full-service pedal-powered event services. When logistically possible, his team transports all the gear to and from the event on bikes towing RtB's custom cargo trailers called Table Trailers. For out-of-area events, they rent a truck or use a freight company if necessary. Once on site, the team transforms their cargo bikes into stationary generators that can power loudspeakers, mixers, monitors, 2,000-watt subwoofers, and LED stage lights. Freedman and his "roadies" serve as pedal coaches who motivate the audience to pedal, and while the crowd does most of the pedaling, the RtB crew jumps in to boost power as needed. When music is at full volume for RtB's largest festival stage, the typical power consumption is between 800 and 1,200 W. "The burden is on us as the event producers to provide enough bikes so that pedaling feels only like climbing a small hill," Freedman says.

The brain of RtB's pedal power system is the Pedal Power Utility Box, which serves as the hub for up to 20 pedalers and the Pedalometer, an LED display tube that shows pedalers how hard they must pedal to produce the power needed. The box includes large capacitors for two to four minutes' worth of concert sound, and a sine wave inverter for lights, music, and anything else that can plug into its standard 110 or 220 VAC outlets.

"Our goal is to get people excited about pedaling and make them think about their energy choices by reaching them through their muscles, by making them feel what it takes to make the energy needed for their everyday lives," Freedman says.

Over the past six years, RtB's gear has powered events large and small, from San Francisco to Barcelona—including the stage in Energy Park at the Oregon Country Fair and the annual San Francisco Bicycle Music Festival, which the company cofounded in 2007 as a platform for promoting its pedal power message.

A longtime admirer of street musicians and performers, Freedman succeeded in his mission to turn bikes into moving stages. The festival plays at multiple stops throughout the city, with a caravan of bikes transporting all of the equipment from each stop. Artists and bands perform while rolling down the city streets with microphones and amplifiers mounted on the backs of cargo bikes and bike trailers. The sound is wirelessly routed to "party" bikes interspersed throughout the crowd.

Freedman says the company sells about 35 pedal-powered units a month—all shipped from its Berkeley workshop. The event and rental side of the business continues to pick up speed, attracting big-name clients like Facebook, who recently hired RtB to power music and bike blender stations for the grand opening of the company's commuter bike shop at its Menlo Park, California, headquarters.

Freedman is committed to inspiring people to ride their bikes. "I want people to get on one of our bikes, pedal and keep pedaling until something whimsical, musical, delicious happens," he says. "I want them to get excited about pedaling, and be inspired to ride their bikes more and drive their cars less."

Freedman designs and builds all the products in his workshop, outsourcing only what is necessary to other area businesses. As much as possible, he uses components that are manufactured in the United States. To make pedal power more affordable and keep the company's shipping impact down, Freedman developed a custom conversion kit (starting at about $600, depending on the intended use) that will turn virtually any bike into a pedal-powered generator. The kit features a custom wheel equipped with a hub generator that can be installed by the customer with a few tools.

—Kelly Davidson

Learn More

Visit **rockthebike.com**. To see RtB in motion, go to: **bit.ly/RocktheBike.**


Nature provides us with the gift of energy through the sun, but unfortunately, nature's wrath may not be all that friendly to your PV system under stressful conditions. Snow, wind, extreme heat or cold, and seismic activities can wreak havoc on underengineered, underdesigned and insufficiently tested racking structures. Only UNIRAC solar structures have been engineered and third-party tested to withstand the harshest of elements and events for a long and enduring service life. Complies with IBC, IRC, ASCE-7-05, ADM, AISI, AISC, NEC and UL. For the highest level of engineering and construction with the lowest cost of ownership in the business, Unirac is the 24/365 solution for performance in and out of the sun. Visit unirac.com for more information.
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Positive Recovery

Courtesy Paradise Energy Solutions

James and Elizabeth Williams lost nearly everything—their house, garage, shed, and household possessions—in a June 2011 tornado that tore through western Massachusetts. But in the process, they "found" renewable energy.

Although they were already aware of the power of PV—a neighbor had installed a solar-electric system—it was meeting Olan Martin of Paradise Energy Solutions at the Big Home Show that springboarded the Williamses' solar project—a batteryless grid-tied PV system. A combination of state and federal incentives helped make the system affordable. Incentives included a federal tax credit of 30% of the system cost and a state tax credit of $1,000. They also received a MassCEC grant of $2,000, plus a storm damage adder of $5,000. After rebates, the cost for their 5.25 kW system was $11,200. The Williamses also participated in the Massachusetts solar carve-out program by selling their solar renewable energy credits (SRECs). The system is expected to produce six SRECs annually, at an estimated value of $200 to $300 per SREC.

With the retail cost of electric energy from their utility between $0.15 and $0.17 per kWh—among the highest in the country—the couple's PV system will offer them significant savings. The system is expected to produce approximately 6,000 kWh per year, paying off their investment in less than five years, and their electricity bill is estimated to be reduced by about 70%.

The system is secured to the roof of their new garage using Unirac rails with Quick Mount PV mounts. The 250-watt Mage PV modules are each coupled with Enphase 215 W microinverters, giving module-level monitoring. The two strings of AC modules run to a combiner box in the garage and feed the service panel in the house. As of January 15, 2013, the system has produced just over 2,000 kWh—right on target with expectations.

—Andrew Kurtz

Overview

Project: Williams residence

System type: Batteryless grid-tied PV

Installer: Paradise Energy Solutions

Date commissioned: September 5, 2012

Location: Monson, Massachusetts

Latitude: 41.9°N

Average daily peak sun-hours: 4.4

System capacity: 5.25 kW STC

Average annual production: 6,000 AC kWh

Average annual utility bill offset: 87%

Equipment Specifications

PV modules: 21 Mage PowerTEC 250 W

Inverters: 21 Enphase M215 microinverters

Array installation: Roof-mounted on Unirac rails with Quick Mount PV mounts at 180° azimuth, 38° tilt angle

Array Wire Management

In the early days of PV systems, modules had junction boxes to which conduit was attached. Module wiring was added by the installer and run in that conduit, which kept wires organized and protected. To reduce installation time, junction boxes have been replaced with pre-attached wire leads. The leads from one module plug into the connectors of the adjacent module. That change has brought with it the challenge of protecting and managing the wires dangling between the modules, as well as the exposed home-run wiring behind the array.

While the *NEC* does allow these conductors to be exposed, it is required that they be supported and secured for aesthetic and safety reasons. If the insulation on dangling wires comes into contact with sharp or abrasive edges of metallic racking or asphalt shingles, for example, it can become damaged over time.

Wire Tying Solutions

Historically, wire ties have been used to keep conductors from laying on the roof, and organized and neatly secured to the rack. UV-resistant ties are durable and long-lasting, especially if kept out of direct sunlight. Even so, the ravages of weather and time will eventually take their toll on plastic UV-resistant wire ties, and they will need replacement.

Other bundling and securing solutions include metallic clamps with EDPM rubber collars; stainless steel cable clips, such as those from Wiley Electronics; and SunBundler vinyl-coated stainless steel cable ties from Heyco. Some rack manufacturers offer solutions with integrated wire management. Manufacturers offering integrated wire management for their pitched roof racking products include Legrand, Lumos Solar (see "Design with PV in Mind" on page 68), and SnapNrack.

Courtesy Heyco

Heyco's SunBundler.

Animal Guards

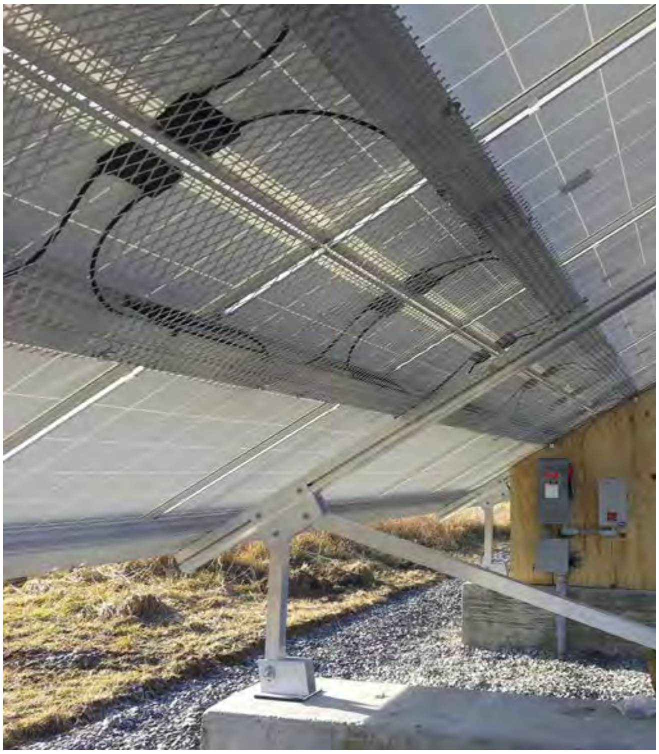
Array wire management also should consider the potential for critters, such as squirrels that like to chew on these wires. Installers facing this problem have innovated with homebrew solutions to block critters but not airflow (such as wire mesh screens secured between the array edge and the roof), and a few companies now have developed products to address this issue as well, such as Heyco's Sunscreen and Spiffy Solar's galvanized steel screen and Spiffy clips.

Wiley Electronics' stainless steel ACME cable clip.

Courtesy Wiley Electronics

Wire mesh secured around the bottom of this array keeps out critters while maintaining airflow underneath the modules.

Topher Donahue


Courtesy Positive Energy NY LLC

An aluminum screen secured to the racking system helps ensure that the conductors on this ground-mounted array are no longer "readily accessible," satisfying *NEC* 690.31(A).

While careful wire management can take some time, it is an important step in the installation process. Modern PV arrays can operate at up to 600 VDC and care must be taken to protect conductors from becoming damaged, since compromised conductors have the potential to create a ground fault, which can lead to rooftop fires.

While this article has focused on rooftop wire management, it is also important to understand the *NEC* 690.31(A) requirement for removing access to "PV circuits operating at maximum system voltages over 30 volts installed in readily accessible locations," such as those on the back of ground-mounted (and shorter pole-mounted) arrays that either animals or humans can reach. This requirement is generally met by installing a fence around the back of the array or by routing wires through a wire chase attaching to the rack itself.

—Justine Sanchez

Courtesy Rebecca Brewer (2)

Energy Independence When It Counts!

On Halloween 2011, 4 inches of wet snow fell in much of Pennsylvania and New Jersey, resulting in downed trees and wires, with a power outage that lasted four days. That was the last straw for our all-electric, well- and septic-dependent household. We decided to pursue energy independence.

We contacted Penn Renewables to help us navigate the array of options available. We thought we would want solar electricity, but were uncertain about a wind-electricity option.

Penn Renewables set up an anemometer to measure wind on our site for a month before we settled on the final design. The wind results were borderline, as we had suspected. Paul Stepanoff, our engineer, suggested that we might want battery backup to seamlessly support critical circuits when we lose utility power. Further, he suggested that a wind turbine could be helpful during times when the sun wasn't shining to keep the batteries charged. We liked the idea of a backup energy source, but we had a lot of questions about wind power. Is it efficient? Is it noisy? It has a lot of moving parts—is it hard to install and maintain?

Paul showed us the wind turbine buyer's guide in *HP143*, where installers rated different wind turbines. For our zoning constraints and planned contribution to our system, the Xzeres 110 (2.5 kW peak rating) was the best balance between power, noise, and cost. This turbine was as quiet as low-rpm, three-bladed turbines can be, with good ratings from installers.

With a large, all-electric house that supports a well pump and geothermal heat pumps, we would need our systems to generate approximately 25,000 kWh per year. We selected Sanyo 220-watt modules, referring to the PV module guide in *Home Power*. By looking at our required circuits, we decided on four AGM 8A8D batteries for our battery backup, including an eight-position rack for future expansion. Since our backup needs were moderate, the engineer suggested splitting the system to cut costs. Two-thirds of the array is wired to the battery backup Xantrex inverters and the rest goes to the batteryless Power One inverter.

The PV system was commissioned in April 2012. A month later, we had our first 3,200 kWh on the meters! The wind system took a bit longer because we were the first in our township to install a turbine and needed a variance. Our installers were invaluable in helping educate the zoning board and our neighbors on the intended installation. The turbine was installed and operational by mid-September.

On Halloween 2012, a year to the day from our decision to implement this project, Hurricane Sandy ravaged New York, New Jersey, and Pennsylvania. We were without grid power for nearly six days—and without sun, as the nearly 1,000-mile-wide storm passed through our area. But, boy, did we have wind! The wind turbine kept our batteries charged every day of the storm. We only drained our batteries once during the six days, when we left the aquarium equipment on overnight when the wind died down. The solar output was very low during this period and would not have kept the batteries charged.

continued on page 34

continued from page 32

While our neighbors were adding gasoline to their noisy generators and having to find an open gas station (a challenge when there is no power) to refuel the generator every four or five hours, we had clean, quiet RE that required us to do nothing. The inverters in a battery system do all the switching automatically, so there was seamless startup when the grid power returned.

We learned an important lesson during Hurricane Sandy: System redundancy with various sources of renewable energy is important. Although the wind turbine seemed like a marginal portion of our system, it proved to be worth its weight in gold during this event. We are also looking at other options, like installing additional batteries for flexibility in our usage during outages. Practical experience of having a prolonged power outage taught us about our usage and battery management. Both our turbine and solar-electric array made it through the high winds unscathed.

Rebecca Brewer & Keith Snedeker • Perkasie, Pennsylvania

Clean Energy Bias?

In “How Clean Is Your Electricity?” (*HP152*), Andy Kerr gives several sources of electrical generation negative nicknames. He uses the terms “miner-killing and mountaintop-removing coal; aquifer-polluting and fracked ‘natural’ gas; radiation-producing nuclear; war-causing oil; or fish-killing dams,” but he describes wind power as “wind power.” He does state that wind power “can be bad for birds if poorly sited.” I suppose it can be bad for birds, since it can kill them. Most people consider death very bad. Why the bias? Why not describe wind power as bird-killing wind power or describe dams as merely dams that can be bad for fish if poorly sited?

This appears to be just another example of promoting your political agenda. I know that my solar panels were not manufactured with 100% renewable energy. I do not know which of the dirty energy sources the manufacturer used, but it was one of the ones listed. I know the solar panels were transported by diesel trucks using “war-causing oil.” I suspect they were stored in a warehouse receiving electricity from “miner-killing and mountaintop-removing coal.” I know the installer receives his electricity in part from

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“radiation-producing nuclear,” so should I call my solar panels “war-causing, miner-killing, mountaintop-removing, and radiation-producing solar panels”? I would be justified, since my solar panels have embodied energy that comes from all of those sources.

I do not believe that the article used the best approach. I believe we should leave negative nicknames out of any discussions, especially when you treat “fish-killing dams” differently than “bird-killing wind power.” Describe the positive and negative attributes of both sources of electricity and convince me that dams are worse than wind power through the strength of your arguments. Although this article did not talk about politics specifically, the bias did bring back memories of past issues. I canceled my subscription to *Home Power* once, because I was tired of the political agenda being pushed. I returned several years ago because it appeared to me the rhetoric was toned down and *Home Power* is far and away the best source of information on renewable energy. You have an excellent informational magazine. My wife teaches high school English and journalism. Two of her friends are school librarians. I would love to donate my old magazines to the school library and to my wife's classes so she could use them in her classroom, but I do not want to expose young people to a political agenda that I oppose.

I believe that there are a lot of conservative people in America like me. I care about renewable energy and the environment, but it is not anywhere near the top of my voting priorities. I have changed the way I use energy and I talk to my friends about the value of energy conservation and renewable energy, but I do not talk to them about your magazine and that makes it more difficult to educate them. If you want to change society, do it with persuasion, not force. If you can't persuade enough people you are right, then any political victories will be quickly reversed. Win the battle of renewable energy one household at a time. It might take longer, but each victory will last because it will be voluntary. I do not know how many people you win over because of the political leanings of your magazine and how many you lose, but there are hundreds of young people each year that could be exposed in a positive manner to your magazine and I am sorry they are not.

Joey Dobbins • via email

Thanks for the feedback. I agree that some of the wording choices in the article you mention could have been toned down.

Home Power's *editors, authors, and readers have very diverse viewpoints and we strive to present objective, technical information in a way that will be well-received by all of our readers. Your points are a compelling reminder of the need to do so.*

Joe Schwartz •
Home Power *executive editor & CEO*

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Water Heater Safety Issue

I noticed in *HP152* there is possibly some misinformation. On page 74, there is an image of a gas-fired water heater being wrapped with a fiberglass blanket. This is generally considered unsafe, and I don't see the safety issue being clarified in the hot water efficiency article. I usually recommend any combustion appliance be 3 feet from any combustible materials.

The problem with the blanket is that they often slide down and sometimes reduce the combustion air. The real danger is if the home's performance is compromised—for example, in an airtight home with poor chimney draft and a couple running exhaust fans, such as a dryer and oven vent fan. While the situation is unlikely, getting flame rollback onto the fiberglass blanket wouldn't be desired. This is not to say they shouldn't be installed on gas water heaters, but caution should always be advised.

Also along the same lines is fitting pipe insulation to pipes in close proximity to the water heater flue. I often see heat-damaged foam pipe insulation there as well. Perhaps some caution is warranted with showing the image on page 73 as well. The article had plenty of useful information, but for someone who has no previous knowledge about these systems, it could be a potential hazard to apply the information as presented. It might be good to further graphically show what a heat trap or loop is also.

James Meehan • via email

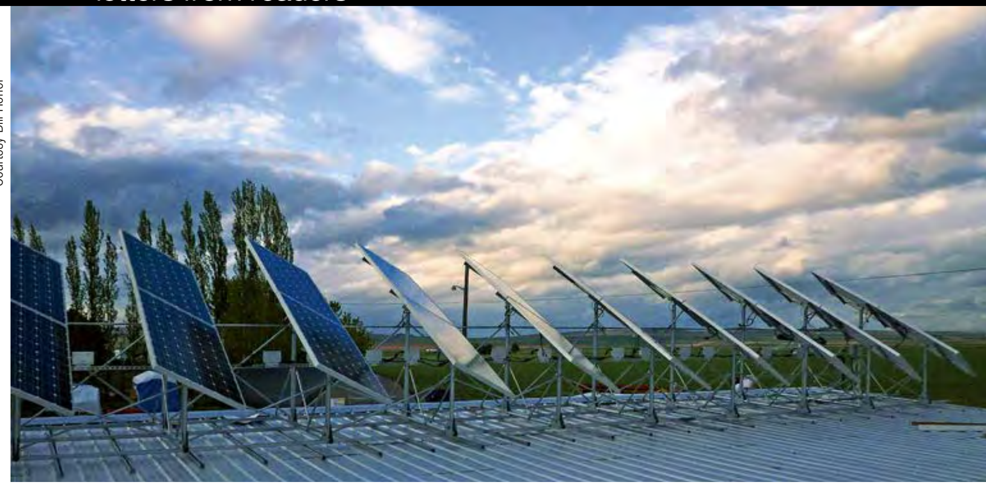
Elephant Energy

I loved "Elephant Energy—Helps Light the Night" in *HP153*. Wow—so much poverty in this world! We have no idea how people live; it seems that Africans consume 1/100th of the energy I consume! Seeing the picture on page 26, I thought to myself, "…the only trash they produce is the one they just received in this packaging (solar light). I produce 10 pounds of trash a day!"

I wish there would be more people around the world finding creative ways to help these precious people. Please keep sharing stories where renewables can help them. (I think there are *many* ideas!).

Hannes Fischer • via email

Courtesy Elephant Energy


Courtesy Bill Hoffer

Passivhaus

Thank you for the article on "Passivhaus in Chapel Hill" (*HP152*) showing how amazing new technologies and building materials can be incorporated into elegant design. The article also provides some history on Passive House design, which I read with interest.

I think some of the credit should also go to some Canadians working on this idea in the 1970s. According to *Canadian Geographic* magazine, one of the first passive houses was built in Saskatchewan in 1977. The Saskatchewan Conservation House had three elements—super-insulation, extreme airtightness, and a heat-recovery ventilator.

Thanks for a great magazine. One day I hope to build my own version of the Passivhaus in northern Alberta!

Kate Morrison • via email

Errata

We regret that Bill Hoffer's articles in *HP153* referring to the Cloudview installation and commissioning omitted mentioning the contractors responsible for the system's design and installation: Designer and installer: Bruce Gage, co-owner, Eco Depot (ecodepotinc.com); electrical contractor: Tieson Lodahl, master electrician; and Epic Electrical Enterprise, both from Spokane, Washington. Additionally, the APS microinverters used in this installation are produced in the United States by Blue Frog Solar (bluefrogsolar.com).

write to:

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

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

Portable Solar Generator

Hurricane Sandy has motivated me to buy a generator, but I don't want to add another gasoline engine to my "fleet." Instead, I'd like to develop a small PV system to provide some backup energy.

Here's what I was thinking: A 12-volt system with a 100 amp-hour battery should yield 1,200 watt-hours of energy, excluding inefficiencies. If I charge that battery with a 400-watt solar-electric array, it would take three hours of sunshine (under perfect conditions) to charge the battery. Is my math correct?

Dan Kostenbader • via email

Your basic math is sound. We just need to get some facts about solar-electric modules and batteries to get the full picture. Then we can fine-tune your calculations to make them realistic and useful.

Solar-electric modules are rated under specific conditions—we could call them "perfect" conditions. Technically, it's 1,000 watts per square meter of sunlight at 77°F. However, reality is much different, since modules rarely receive the full amount of sunshine for long, and most modules operate at temperatures greater than 77°F most of the time, which reduces their output. (PV modules perform better at low temperatures.) It's fairly common to apply a factor on calculations to accommodate for the difference between "perfect" and reality for an off-grid, battery-based system, and to account for other system inefficiencies. System designers usually choose an efficiency factor/rating between 0.6 and 0.7. (Batteryless grid-tied systems are more efficient.)

Simple PV Sizing Worksheet

1: CALCULATE DAILY LOAD

Description	Qty.	×	Watts	×	Hours	=	Load (Wh / Day)
DC lamps	4		15		5		300
DC fan	1		30		5		150
DC TV	1		50		3		150
					Total		600

2: CALCULATE TOTAL BATTERY STORAGE NEEDED

Load (Wh / Day)	×	Days Storage	÷	Depth of Discharge	=	Total Capacity Needed (Wh)
600		3		50%		3,600

3: CALCULATE INDIVIDUAL BATTERY STORAGE

Battery Voltage	×	Battery Ah Rating	=	Capacity (Wh)
12		100		1,200

4: CALCULATE QUANTITY OF 12 VOLT BATTERIES NEEDED

Capacity Needed (Wh)	÷	Battery Capacity (Wh)	=	Total Number Batteries
3,600		1,200		3

5: CALCULATE TOTAL ARRAY SIZE

Total Load (Wh / Day)	÷	Insolation (Sun Hrs. / Day)	=	Power Needed (W)	÷	Efficiency /Rating Factor	=	Array Size (W)
600		5		120		65%		185

6: CALCULATE QUANTITY OF PV MODULES NEEDED

Array Size (W)	÷	Module Size (W)	=	Quantity Modules
185		60		3

This sizing method assumes an MPPT charge controller is used.

For your "hours of sunshine," be careful. There's a technical term—a peak sun-hour—that is a measure of solar energy (1,000 watts per square meter, for an hour). Sun-hours at various sites around the country have been measured; you can find tables that tell you how many peak sun-hours a location near you gets. To help understand the concept of peak sun-hours, you could imagine that from noon to 1 p.m. on a sunny day, an array might receive 1 peak sun-hour. In the morning, when the sun is rising and at an oblique angle to the array, it might take three or more hours of partial sun to equal 1 peak sun-hour. Peak sun-hours take into account the local weather, but not your site's specific shading, which is another factor you'll need to consider.

The other key modification to make to your math is based on battery needs. While it's possible to discharge flooded lead-acid batteries as deeply as 80% once in a while (*if* they can be recharged quickly), it's better to not discharge below 50%. A battery bank's size is often calculated on a 50% discharge—this means you need twice as much total battery capacity as you want to use. Some designers are even more conservative, and some batteries have different characteristics that might affect the calculation.

The key factor that you didn't mention is your *load*—how many watt-hours do you need in your solar-electric backup system, and for how many days? Most RE system designers typically start with this figure, designing the system around your electrical energy needs. Let's take the numbers you did supply to make a more realistic formula (see table).

Battery sizing will be more complex because you'll have to decide how many days without sun you want to provide for. And you will want some surplus generation—it's better to have too much than too little—though the exact ratio between generating capacity and battery capacity could be debated among designers until the cows come home. It is also important to realize other equipment will be required to make the system work, such as a charge controller to regulate battery charging and an inverter if you want to power any AC loads with this system, along with the other required balance-of-system (BOS) components (i.e. disconnects, overcurrent protection, battery box, etc.).

Ian Woofenden • *Home Power* senior editor

Hydronic Heating

I very much enjoyed John Siegenthaler's article, "Renewable Hydronic Heating" (*HP152*), and wondered if he might comment on lightweight systems that use aluminum as a heat conductor as opposed to those that use concrete as a thermal mass. I was recently made aware of this type of system and the benefits to the overall flooring process when looking at building a home over a basement foundation. Details of the system can be found at warmboard.com. I hope to hear another opinion on this.

Rick Wimberly • via email

I'm glad you enjoyed the article. There are several radiant panel systems that use aluminum plates or claddings as "wicks" to pull heat away from the tubes and spread it across the panel surface. The product you mentioned—Warmboard—is designed as a complete subfloor/radiant panel system. It is about 1.125 inches thick and, as such, can serve as a structural subfloor and replace conventional plywood or OSB subfloors.

The key to success with any of these products is to keep the water temperature required as low as possible. As I suggest in the article, design the distribution system so that it can supply the maximum required heating load without exceeding a supply water temperature of 120°F—even lower if possible. The lower the water temperature, the higher the efficiency of heat sources such as solar collectors, heat pumps, and condensing boilers.

Warmboard uses 12-inch tube spacing; other aluminum plate systems use 8-inch tubing spacing. They should not be covered with more than R-1 from flooring materials, and should have at least R-19 underside insulation. This type of system would provide about 19 Btu/hr./ft.^{2} of output, when operated with a supply temperature of 120°F.

I would also highly recommend the use of PEX-AL-PEX tubing (versus standard PEX) for any system involving aluminum heat dissipation plates or claddings. PEX-AL-PEX with aluminum is less likely to make any expansion noise as the system warms up.

John Siegenthaler • Appropriate Designs

Courtesy Warmboard

This system from Warmboard uses aluminum cladding to distribute heat.

Adding Backup

My home has a grid-tied batteryless solar-electric array. Can I have it retrofitted with batteries? If so, how is this done and how expensive is it?

Jim Giambrone • via email

Adding batteries to a grid-tied system is possible, but can be expensive. You may not really need it unless you have prolonged or frequent utility outages or have a critical need for energy, such as for medical equipment. Most people do not find it worth the added cost and decreased system efficiency. Generally, PV systems with battery backup cost 1.5 to two times as much as a batteryless grid-tied PV system. Their reduced efficiency (about 10% less) translates to fewer kWh sold to the utility.

You also will need to either replace the inverter with a more expensive one that not only inverts, but also controls grid charging to maintain the batteries, or you could add a battery-based inverter and related equipment that can work with your existing grid-tied inverter on the AC side of the system. You will need a safe battery box and a separate subpanel for backup loads.

If you replace your inverter, you will also need to reconfigure the PV modules for a voltage that is matched to a battery charge controller (another additional component), and you may need to rewire them with larger-gauge wire to avoid wiring energy loss, since system voltages will likely be lower. Chances are, you will need to add to or subtract from the total number of PV modules so that the reconfigured array ends up at the right voltage.

Finally, this is not the kind of project that most grid-tied PV installers have experience with. You will need to find an installer who is expert in battery-based systems.

Please let us know how this project proceeds—be sure to take lots of photos and document the transition for possible future publication.

Michael Welch • *Home Power* senior editor

Solar Energy Wasted

A recent *New York Times* article, "Solar Companies Seek Ways to Build an Oasis of Electricity," started by saying, "When Hurricane Sandy wiped out the power in areas like coastal Long Island and the Jersey Shore, what should have been beacons of hope—hundreds of solar panels glinting from residential rooftops—became symbols of frustration."

I read in the article a sense of missed opportunity. I've had a grid-tied system for a few years now. I understand that with my current configuration, the essential strategy was to ensure my system *wouldn't* energize what would be expected to be powerless grid lines to protect utility repair personnel from electrical shock.

However, in situations where restoration of power from the grid may take days or weeks, wouldn't it be useful for the homeowner, as well as the solar-electricity industry, to have an isolation cut-out device between the grid and the service entrance that would prevent electricity from the PV array from being sent to the grid, but provide electricity to the house and neighboring houses?

Wouldn't it have been great to read that homes with PV systems were supplying enough electricity to provide a refuge for neighbors who would have been shivering in the dark? Instead, I read about solar energy going to waste.

Michael Welch (2)

Watt for watt, grid-tied inverter systems are less expensive and take up less space than battery-based inverter systems. However, they won't supply power if the grid goes down.

With all of the gadgets and systems mushrooming in the industry, can't someone come up with an option that would allow for emergency electricity while protecting the power line workers?

Julius Hayden • Covington, Georgia

There actually is such an option—a grid-tied system with battery backup—but it is significantly more costly, requires more and slightly different equipment, and requires batteries. In *HP110*, you can find an article on such a system that provides electricity for my office. (Additional articles about grid-tied systems with battery backup can be found in *HP139*.)

However, the problem is not so much the danger of sending energy back onto the grid when it is down, since there are standard and inexpensive ways of dealing with that. The problem is that a solar-electric array puts out a fixed amount of energy and cannot make up for surges and other quickly changing energy requirements of a home. Plus, sunshine is variable, only available during the day and when there are few or no clouds. That is where either the grid or batteries enter to buffer surges and changes in the solar resource and in usage.

With more components, battery-based inverter systems are more complex and expensive than comparable grid-tied systems.

A good example of the problem is a fridge—something that folks really would like to have energy for during a blackout. That fridge might only take a couple of amps to run, but when its compressor motor tries to start, it might draw 10 to 15 amps for a brief period. And when a cloud skitters over the PV array, without batteries, the fridge—and everything else—would go out.

A battery backup system is more costly—1.5 to two times the cost of a batteryless system—and about 10% less efficient. We usually recommend that people consider batteries only if their homes experience frequent and/or prolonged outages. Of course, with storms occurring with greater frequency due to climate change, more people may be willing to spend the extra money for battery backup.

Michael Welch • *Home Power* senior editor

write to:

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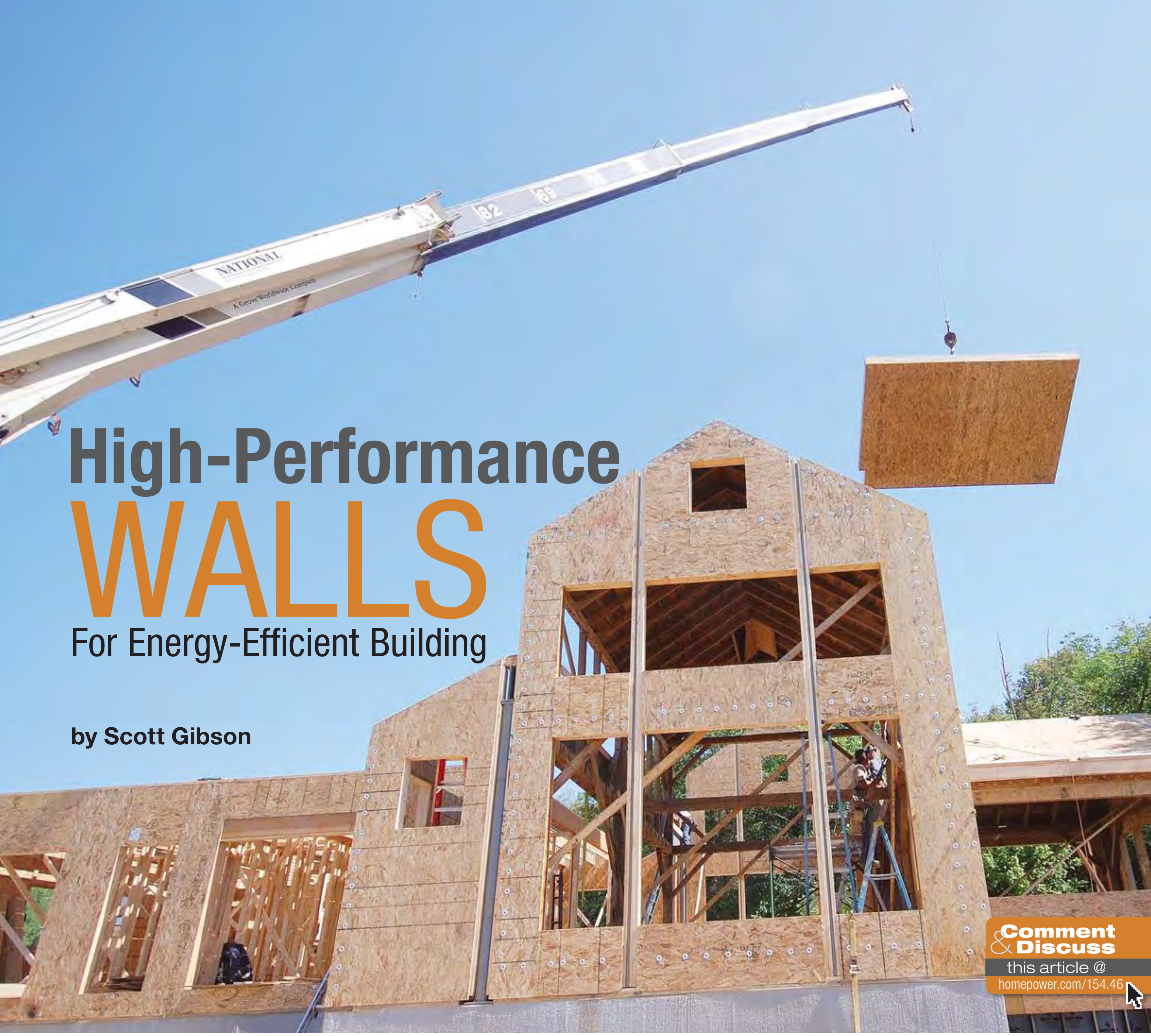
Published letters are edited for content and length. Due to mail volume, we regret that unpublished letters may not receive a reply.



High-Performance WALLS
For Energy-Efficient Building

by Scott Gibson

The walls of this home, which are constructed with structural insulated panels (SIPs), combine the framing, insulation, and sheathing into one unit, providing faster assembly and a thermally efficient envelope.

Not long ago, 2-by-4 walls insulated with R-13 fiberglass were standard in North American homes, even in regions where winter temperatures fall well below freezing. But residential construction has taken tremendous strides forward. Researchers are helping builders understand much more clearly how heat and moisture move through walls, roofs, and floors. Now, there are a variety of options for building more efficient, comfortable, and durable houses. Tougher building codes promoting energy efficiency and a clamor for lower energy costs have helped advance the technologies, too.

This article will explain some wall-building technologies and techniques in a range of high- and low-tech options. These wall systems come with different price tags and require different construction techniques, some more specialized than others. But all of them are aimed at providing better thermal barriers, fewer air leaks, and lower costs for heating and cooling than conventional stick-frame construction.

One caveat: As houses get tighter, whole-house mechanical ventilation gets more important. If you're planning a super-insulated house with very low air leakage, make room in your budget for a heat recovery ventilator or its equivalent.

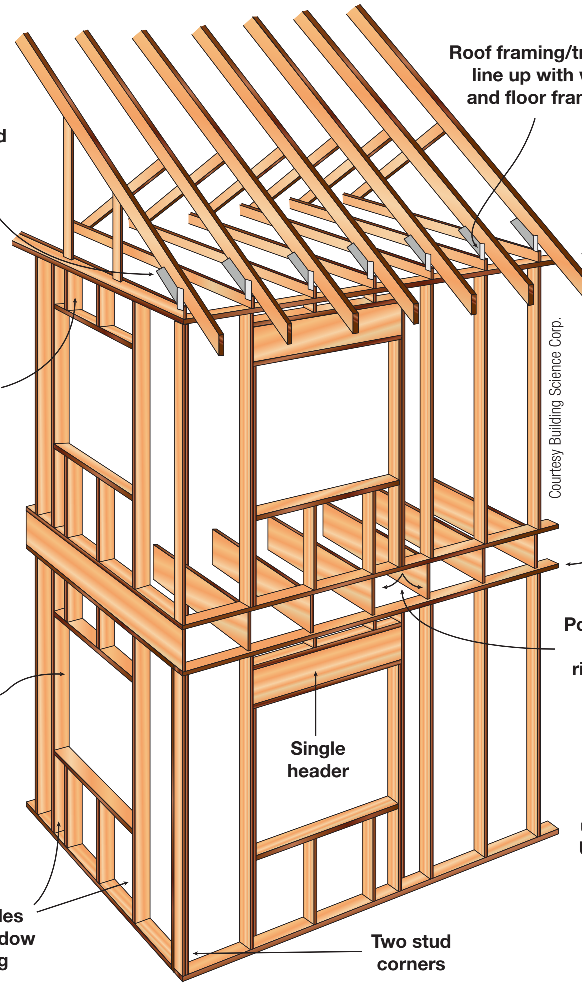
Advanced Framing

Less Lumber, More Insulation

Advanced framing (aka optimum value engineering) boils down to less wood and more insulation. This method of framing structurally sound houses with less lumber—saving time and materials—grew out of a partnership between the U.S. Department of Housing and Urban Development and the National Association of Home Builders Research Foundation in the 1970s. Walls built with fewer sticks of wood allow more space for insulation and help reduce thermal bridging—the movement of heat through relatively dense framing members.

Advanced framing technique relies on standard building materials and is relatively easy to adopt, yet yields big returns—30% fewer pieces of lumber and 60% more room for insulation compared to conventional 2-by-4 walls on 16-inch centers. Some of advanced framing's major differences over conventional wood-framed construction:

- 2-by-6 studs, on 24-inch centers.
- Single top plates and in-line or stack framing—joists are located directly over studs, and studs are located directly over each other on adjacent floors.
- Eliminating door and window headers without loads and using single headers for load-bearing openings.
- Two-stud corners.
- Fewer studs around door and window openings.
- Raised-heel roof trusses, allowing more insulation where the roof intersects with the walls.



Courtesy Building Science Corp.

Some builders haven't liked some elements of advanced framing. Two-stud outside corners made hanging drywall seem problematic, although drywall clips proved an easy fix. Eliminating one of the top plates on the wall also required that studs be 1 1/2 inches longer to maintain the same ceiling height.

There also was a perception that a house framed this way wouldn't be strong enough. Builders who learned traditional framing techniques could see the value of using 2-by-6 studs (more room for insulation) but might balk at the 24-inch on-center (o.c.) spacing and fall back on 16-inch o.c. framing.

But once convinced to try, builders could see the improvements in building performance and ease of assembly, as well as lower labor and material costs. The Building Science Corp. estimates that advanced framing saves 13% in space-conditioning costs compared to conventional construction.


Courtesy What's Working

Traditional framing often results in thermal bridging and excess wood use.

Raised heel roof trusses allow more attic insulation in the space between the wall top plate and roof.


Ben Root

I-Joist Walls

Repurposing Floor Joists for Superinsulated Houses

Walls framed conventionally with dimensional lumber have two big energy-efficiency problems: there's not enough room for insulation, and there's a good deal of thermal bridging—heat transfer through the framing. But modern techniques are addressing those issues.

The Passivhaus concept. Katrin Klingenberg found a way around both of those issues and designed a house in Urbana, Illinois, to the performance standards of Germany's Passivhaus Institute. Instead of framing with dimensional lumber, she used 12-inch-deep I-joists for the walls and wrapped the outside with a 2-inch layer of rigid foam insulation. Wall cavities were filled with blown-in fiberglass for about R-60. Walls were balloon-framed, meaning the I-joists run uninterrupted from the foundation to the top plate, eliminating heat loss through a rim joist between floors.

I-joists are usually used in floor framing, not walls. But their thin webs of oriented strand board reduce thermal bridging, and their depth provides lots of room for insulation. I-joists, however, aren't as stiff as dimensional lumber, and using them for wall framing requires a slightly different technique. Both sides of the I-joist, for example, need structural sheathing to prevent their flanges from bending or flexing.

Courtesy Katrin Klingenberg (2)

Klingenberg's I-joist solution, before and after wrapping with rigid foam insulation. Furring strips screwed to the I-joist flanges through the foam provided a vented rain screen and a place to attach the siding.

Klingenberg, the executive director of the Passive House Institute US, no longer uses I-joists as weight-bearing components in walls. Instead, she builds structural 2-by-4 walls, sheaths them with OSB, and bolts I-joists to the outside. "It's easier to get inspectors to sign off this way," she says.

Larsen trusses. I-joist walls are similar to Larsen trusses, developed by Edmonton, Alberta, builder John Larsen in the early 1980s. Like the newer I-joist technique, Larsen trusses do not carry any of the roof loads. They can be made on site with 2-by-2s that are connected by small gussets of 3/8-inch plywood. When completed, the truss looks something like a ladder. Trusses are attached to the outside of sheathing that covers a 2-by-4 or 2-by-6 wall, and then sheathed on the outside before the siding is applied. Wall R-values can easily top 40.

Larsen says the trusses arose as a faster alternative to a double stud-wall design. Houses built with Larsen trusses are not only well-insulated but also can be very tight; one 4,500-square-foot house had an air-leakage rate of only 0.80 ACH at 50 pascals—almost "tight" enough to meet very stringent Passivhaus standards. An air barrier applied over the sheathing is less likely to have penetrations in it. Also, dense-pack cellulose at that thickness, while not technically an air barrier, is a lot more effective compared to something like fiberglass batts.

One advantage of this method is that trusses can be built on site from relatively low-cost materials. Blown-in fiberglass or cellulose costs less than sprayed polyurethane foam, but at 10 inches or 12 inches thick makes high R-values and low thermal bridging. On the down side, these extra-thick walls require special detailing for doors and windows.

Courtesy SIP School

SIPs are custom-fabricated in a factory and then shipped via truck to the building site. There, panels are typically set in place by a boom truck.

Structural Insulated Panels

Fast Assembly, Tight Construction

Structural insulated panels (SIPs) are sandwiches of insulating foam faced on both sides with a thin skin, often oriented strand board. They combine the framing, insulation, and sheathing in a single package. SIP houses can be built much faster than conventionally framed homes.

Panels can be up to 8 feet wide by 24 feet tall, with standard thicknesses ranging from 4 1/2 to 12 1/4 inches, according to the Structural Insulated Panel Association. Small panels can be moved around and set by hand. Large wall panels and roof panels require a crane to help set them in place.

Panels arrive on the job site ready to assemble, allowing faster construction times than are possible with conventional framing.

Courtesy Structural Insulated Panel Association

R-values vary considerably, depending on how thick the panel is and what type of foam is used. For example, a 4 1/2-inch EPS panel has an R-value of 14, while a 10 1/4-inch XPS panel has an R-value of 48. Today, the most common core by far is expanded polystyrene (EPS). Less frequently, panels are made with extruded polystyrene (XPS) or urethane foam. Both of those alternatives have higher R-values than EPS, but they also have a few drawbacks, such as higher cost; a higher melting point, which makes field alterations with heated cutting tools more difficult; and, in the case of XPS, limitations in panel thickness.

For those who are concerned about using plastic foam, Agriboard Industries makes a panel with a core of compressed wheat straw. Tests at the Oak Ridge National Laboratory found the R-value of a 7 7/8-inch-thick panel was 16.47, although the manufacturer has claimed higher effective R-values because of the wall's mass (see the discussion on thermal mass and R-values in the "Insulated Concrete Forms" section).

SIP manufacturers can take construction drawings and turn them into precut panels with door and window openings already cut. There is a learning curve to assembly, but seasoned carpentry crews should be able to pick up what they need to know fairly quickly, and some manufacturers offer job site assistance.

Speed of assembly, low rates of air infiltration, and dramatically reduced thermal bridging all are energy-saving advantages with SIPs. Although material costs are higher than for conventional frame construction, costs usually even out when lower labor costs for SIP assembly and less job site waste are taken into account. In addition, improved energy performance may allow the installation of smaller, less-expensive heating and cooling equipment.

Straw Bales

Simple Techniques & Materials

Scott Price, CelebrateBig.com (3)

Applying the protective stucco outer coat. The wire mesh keeps the stucco from breaking away from the wall. Inset: A bale knife can be used to trim straw bales for windows and doors, or to aesthetically round wall corners.

Straw bale construction in the United States dates to the late 19th century in a part of Nebraska where trees were few and far between. Some of those straw bale houses are still standing.

Advocates point to a long list of advantages of straw bale construction, including durability, fire- and insect-resistance, the renewable nature of the building material, low material cost, high R-values, and relative ease of construction, making houses well suited for owner-builders on a tight budget.

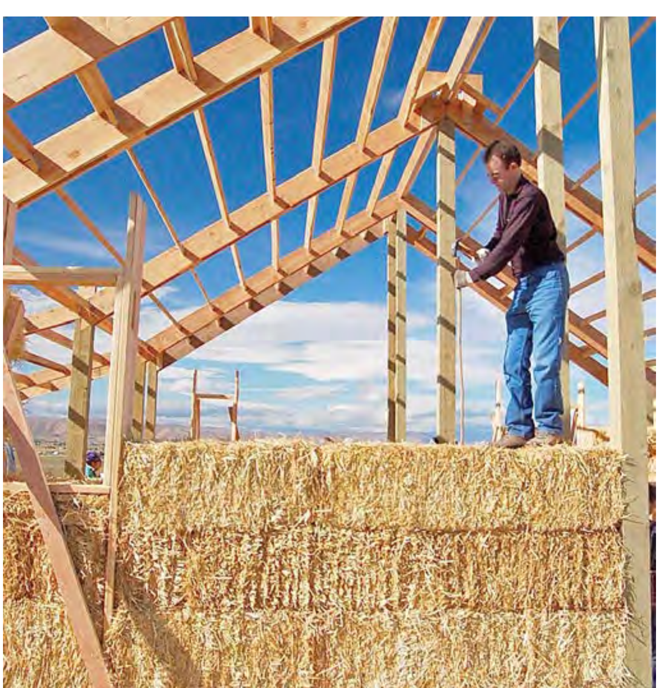
Straw (not to be confused with hay) is an abundant resource—it is what's left after the harvest of grain crops such as rice, wheat, oats, barley, or rye. Bales can be two-string, which weigh about 50 pounds each and are up to 40 inches long, and three-string, which may weigh 100 pounds and measure up to 47 inches long. Straw bale houses can be planned around these dimensions to make construction simpler, just as a conventionally framed house can be planned around the 4-foot increments that panel products come in. According to one online calculator, it takes 240 bales to make a 30-by-40-foot one-story house (see ironstraw.org).

Bale walls can be load-bearing ("Nebraska style"), or used as infill for a timber- or stick-frame that carries roof loads. Bales are stacked flat or on edge between framing members (for infill construction) atop a conventional concrete stem wall, and then finished with earthen or lime plaster, or cement stucco, to protect the building from the elements. Window and door openings are created with wood frames. For load-bearing walls, bales are typically compressed under a top plate to distribute the weight and help prevent uneven settling. In the original Nebraska straw bale homes, roof loads were evenly distributed around the perimeter of the building with hip roofs, and window sizes were limited. Infill designs are well-suited to complex house shapes. Straw is resistant to rot when protected from rain and snow, and is fire-resistant because its density limits combustion air (likened to trying to burn a telephone book).

Given their thickness, straw bale walls should have higher R-values and less thermal bridging than wood-framed walls insulated with fiberglass or cellulose. In tests at the Oak Ridge National Laboratory, a 19-inch-thick straw bale wall had an R-value of 27.5, or 1.45 per inch. By comparison, a 2-by-6 wall insulated with standard fiberglass batts (and no exterior insulation) would have an R-value of roughly 20 at the center of the wall (less when thermal bridging is taken into account for a whole-wall measurement).

Straw bale construction is not covered in the International Residential Code, meaning that prospective builders need approval from local code officials.

Lengths of rebar help keep bales aligned. These bales are infill walls, with the load-bearing structure already in place.



Double-Stud Wall Construction

Standard Building Techniques & Materials

Building a double-stud wall is an easily understood approach to achieving an energy-efficient envelope, using the same techniques and materials that go into a conventionally built house. Two parallel-framed walls are framed from dimensional lumber—one load-bearing and the other a nonweight-bearing partition. The walls are separated by a gap and studs in the two walls can be staggered—or not. Then the wall is filled with insulation, which could be cellulose, fiberglass batts, or something else, which can result in R-40 or above.

This strategy is simple and effective, and used on many high-performance houses, including a Habitat for Humanity house in Wheat Ridge, Colorado, that was designed by Habitat and the National Renewable Energy Laboratory. These designers had two goals: create a net zero-energy home, with the house producing as much energy as it used each year, and have Habitat volunteers build it, not professionals.

The designers spaced the two 2-by-4 walls 3 1/2 inches apart. Fiberglass batts were installed vertically in both stud walls, with a third layer of batts placed horizontally in the space between the two walls. Even though fiberglass batts can be one of the least-effective types of insulation when poorly installed in a conventionally framed house, they proved highly effective here.

Other builders might construct the outer, load-bearing wall from 2-by-6s, for example, to give even more room for insulation. The gap between the two walls eliminates the path for thermal bridging, so double-stud walls don't need a layer of rigid foam insulation over the sheathing, which simplifies construction considerably while holding costs down.

A trade-off is that some floor space is lost to the second framed wall. In houses with very small footprints, this could be an issue. And, since the framing is duplicated, it doubles the amount of time it takes to frame the house. Applying advanced framing techniques reduces the amount of lumber and construction time. Finally, because of the extra wall depth, detailing doors and windows is a little more complicated. Windows set to the outside of the wall require extra-deep jamb extensions, and some builders flare window openings so walls don't look too thick, which is also an extra step.

Door and window framing in a double-stud wall is more complex compared to standard framing.

NREL (2)

Ben Root

Two approaches to double-stud walls: Separated by a gap that will be filled with insulation, both staggered studs (right) and aligned studs (left) help minimize thermal bridging.

Insulated Concrete Forms

Combining Insulation & Structure

Insulated concrete forms (ICFs) are made from a variety of materials, including rigid plastic foam, composites of wood chips with cement, and recycled polystyrene with cement. But they all work in basically the same way: Units are assembled to form walls, reinforced with steel, and filled with concrete. Forms are later covered with finish materials—stucco or conventional siding on the outside; drywall or plaster on the inside.

ICFs are most often used to build foundation walls, but they also can be used above grade, and some brands are marketed with this in mind. Building with ICFs is more expensive than conventional wood-framed walls, but manufacturers list a number of advantages, including lower rates of air infiltration, high strength, excellent sound deadening and wind resistance, and high thermal mass. EPS Industry Alliance, a trade group for the ICF industry, says using ICFs add between 0.5% and 4% to construction costs, when the house is built by experienced contractors. Higher costs are somewhat offset by the ability to use smaller heating and cooling equipment. Relative costs are affected by a number of variables, including local labor rates, the design of the house, and the type of ICF the builder or designer has chosen.

ICFs come as blocks, panels, or planks. The shape of interior cavities varies, too, so the concrete might be a flat wall of uniform thickness; a waffle grid; or a "screen grid" layout, with both horizontal and vertical columns of concrete. Crews accustomed to conventional wood-frame construction should expect a learning curve when they start building with ICFs. Detailing for windows and doors, stacking walls so they're plumb and straight, bracing walls adequately for placing concrete, consolidating the concrete to eliminate voids, and running interior wiring all are a little different and take time and practice to master. Durisol, a Canadian ICF manufacturer, recommends builders take a one-day training session, and also offers on-site training.

Weighing the Benefits of Thermal Mass

R-value claims for ICF buildings can be confusing, mainly because the thermal effects of the wall's concrete core vary depending on climate. In the case of Rastra, for example, tests at the Oak Ridge National Laboratory have found the "steady state" R-value of a 10-inch-thick wall is between 7.7 and 8.2. But Rastra says its walls behave as if they had higher R-values because of the mass of the concrete—what it calls the "thermal mass multiplier." This, the company says, varies by climate zone—a 10-inch panel (which contains 6 1/2 inches of composite material) has a claimed R-23.8 in climate zone 2, a mild part of the country, which includes the Gulf Coast and southern Arizona, but only R-11 in Alaska.

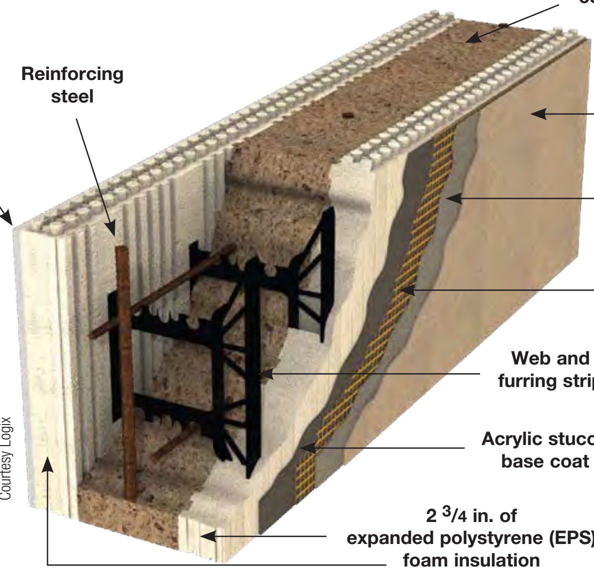
In writing about "mass-enhanced R-value," *Environmental Building News* says that it is "only significant when the outdoor temperatures cycle above and below the indoor temperatures within a 24-hour period. Thus, high-mass walls are most beneficial in moderate climates that have high diurnal (daily) temperature swings around the desired indoor set point."

In very cold climates, where outdoor temperatures stay below the indoor temperature (the "set point") for days, weeks, or even months, the mass of the concrete wall doesn't provide a thermal benefit. Where the mass of the concrete does help is in regions where there's a big swing in daily outdoor temperature, or during the spring and fall "shoulder seasons" in colder climates.

Durisol ICFs, ready to receive concrete.

Courtesy Durisol Building Systems

Anatomy of an ICF Wall



Courtesy Logix

Houses made with ICFs don't have as much potential for air leakage as conventional wood-framed houses, and may use less energy for heating and cooling, depending on where you build. In one side-by-side test in Knoxville, Tennessee, the Oak Ridge National Laboratory found that an ICF house used 7.5% less energy than the otherwise identical wood-framed house.

Cement-polystyrene composites. Rastra is a well-known brand of this type, with a composition of 15% cement and 85% recycled expanded polystyrene, a composite the manufacturer calls Thastyron. Blocks, which can be cut with ordinary woodworking tools, are up to 10 feet long, 15 or 30 inches high, and available in thicknesses of 8 1/2, 10, 12, and 14 inches. A 10-inch-thick by 10-foot-long panel 15 inches high weighs 158 pounds—light enough to be handled without a mechanical lift or crane.

Because it's relatively soft, Rastra panels also can be shaped to make curves or gently rounded shapes. According to the company's website, building with Rastra adds about $5 per square foot to construction costs over a conventional home built with wood.

Courtesy Rastra

Larger Rastra ICF panels require heavy equipment to lift.

Insulation Particulars

The type of cavity insulation has an impact on performance. Equally important is whether a layer of rigid foam insulation is placed over the sheathing. Although it complicates construction, this extra layer of insulation reduces thermal bridging and boosts the home's overall energy efficiency significantly. The thickness of the foam layer should be carefully calculated to prevent condensation inside walls. Details vary by climate, but the foam must be thick enough to prevent the accumulation of moisture on the back of the sheathing in cold weather. Because the rigid foam will prevent the wall assembly from drying to the exterior, a vapor retarder, such as polyethylene sheeting, should not be used on the interior.

R-Values of Common Insulating Materials

Material	R-Value per In.	DIY Install?	$ per Board Ft.*
Closed-cell polyurethane foam	6.5	No	$1.03
Rigid polyisocyanurate	6.0	Yes	1.20
Rigid extruded polystyrene (XPS)	5.0	Yes	1.15
Rigid expanded polystyrene (EPS)	4.0	Yes	0.85
Blown cellulose (wall)	3.8 – 3.9	No	0.58
Blown fiberglass (wall)	3.7 – 4.3	No	0.55
Open-cell polyurethane foam	3.6	No	0.60 – 0.70
Sheep wool batts	3.5	Yes	0.70
Cotton batts	3.4	Yes	0.17
Fiberglass batts	3.2 – 4.3	Yes	0.15
Loose-fill cellulose (attic)	3.2 – 3.8	Yes	0.14
Loose-fill rock wool (attic)	3.0 – 3.3	Yes	0.25
Loose-fill fiberglass (attic)	2.2 – 2.7	Yes	0.20
Straw bale	1.5	Yes	Regional

Sources: U.S. Department of Energy, zerobydegrees.com, coloradoenergy.org, Green Building Advisor.
*Board ft. = 1 in. thick by 1 ft. square. Installed prices vary widely by region.

Wood chip-cement composites. Durisol and Faswall are two brands of ICFs made with cement-bonded wood fiber. Among the advantages cited by Durisol are no plastics, no volatile organic compounds, no off-gassing, and the capacity to absorb water vapor, which helps maintain healthy indoor humidity levels. Durisol walls won't burn or melt and have a four-hour minimum fire rating.

Faswall blocks are made from 85% mineralized wood chips and 15% cement. Reported R-values for 12-inch Faswall blocks range from R-21 with a mineral wool insert to R-26 with polyisocyanurate insulation. Durisol blocks come in several thicknesses. With an insert of mineral fiber insulation, the company claims R-14 for a 10-inch wall, up to 21 for a 12-inch wall, and up to 28 for a 14-inch wall. The company says the block material has an R-value of 1.75 per inch, as measured by the National Research Council of Canada. A mineral fiber insulation insert adds another R-4.2 per inch. With these known values, whole-wall R-values can be estimated.

Foam ICFs. Several kinds of foam are used to make most concrete forms, including EPS (the most popular), XPS, and expanded polyurethane. A typical EPS form consists of two parallel sheets of foam separated by plastic or metal webbing. Blocks are stacked together to form walls. Builders add steel rebar and then pour concrete into the forms. Foam ICFs are available in fully assembled blocks or as ready-to-assemble components that are shipped flat.

The R-value of the blocks depends on foam type and foam thickness. EPS, for example, is about R-4 per inch, while XPS is rated about R-5 per inch. Polyurethane foam used in ICFs is about R-6 per inch. The concrete inside an ICF wall contributes virtually nothing to its insulating qualities. Forms are available in a variety of widths to produce concrete cores from 4 inches to 24 inches or more. Thicker walls are stronger because of the increased concrete content, but are not necessarily better thermal insulators.

Courtesy Quad-Lock

ICFs consist of two outer layers of rigid foam insulation separated by metal or plastic webbing. After reinforcing steel is added, the forms are filled with concrete.

Like many other wall systems, ICFs rest on continuous poured-concrete footings.

Courtesy Benchmark Foam

ICF construction has some advantages—high strength and low rates of air infiltration are two important ones—but overall wall R-values aren't as high as with some of the alternatives. In fact, the material used to make some types of ICFs—polystyrene beads and cement or wood chips and cement—have lower per-inch R-values than rigid foam, sprayed-in foam, or even dense-pack cellulose. That makes it difficult to get the R-values that high-performance buildings often specify—R-40 in the walls and R-60 or more in the ceiling. As a result, builders might consider ICFs for the foundation but choose another option for above-grade walls, such as wood-frame construction with both cavity insulation and a layer of rigid insulation over the sheathing. ICFs made with EPS foam are relatively effective thermal insulators, but it would still take 10 inches of foam— 5 inches on each side of the concrete core—to equal R-40.

Whole-Wall R-Values & Thermal Bridging

Conventional wood-framed houses insulated with R-19 fiberglass batts won't have R-19 walls. Why not? Because the studs and rafters that form the skeleton of the house have an R-value of about 1 per inch—less than one-third that of a fiberglass batt. When framing and insulation are considered together for "whole-wall" R-values, numbers will be lower than for the insulation alone. This effect, called thermal bridging, can be significant. The Oak Ridge National Laboratory (ORNL), for example, pegs the R-value of a 2-by-6 wall on 24-inch centers with R-19 batts at R-13.7. ORNL maintains an interactive calculator on its website where you can plug in various values to see how a given wall would perform (bit.ly/WallCalc).

Another issue is the installation itself. Fiberglass must be installed between studs and cut to fit around window openings and wiring. This process can never be perfect and often leaves gaps where there is no insulation at all. Even very small gaps reduce the effectiveness of the insulation significantly, and perfect installation by insulation subcontractors is rare. That's one reason that high-performance houses often have *blown-in* polyurethane foam, cellulose, or fiberglass, which fills stud and rafter bays more effectively.

Whole-Wall R-Values

Wall Construction	R-Value
I-joist, 12 in., blown-in fiberglass + 2 in. rigid XPS foam sheathing	60.00
Double 2-by-4 stud-wall, high-density fiberglass batts	47.00
SIPs, 12 1/4 in. (EPS core)	42.00
SIPs, 10 1/4 in. (EPS core)	35.00
2-by-6 wall with high-density fiberglass batt (5.5 in.) & 2 in. XPS rigid foam	32.88
SIPs, 8.25 in. (EPS core)	28.00
Straw bale, 19 in.	27.50
9.5 in. ICF, 4 in. concrete, 5.5 in. EPS foam	24.30
2 by 6 wall with high-density fiberglass batts (5.5 in.)	22.88
Durisol 12 in. block with mineral fiber insulation & 5.5 in. concrete core	21.00
Conventional 2-by-4 wall, with high-density fiberglass batts (3.5 in.)	16.88
SIPs, 7 7/8 in., Agriboard	16.47
SIPs, 4.5 in. (EPS core)	14.00
Rastra, 10 in.	7.70 – 8.20

Wall R-values are at center of stud cavity and include gypsum board, 1/2 in. plywood sheathing and wood bevel siding.
No adjustment for thermal bridging.
R-values for ICF walls (Durisol and Rastra) do not include any adjustment for thermal mass.

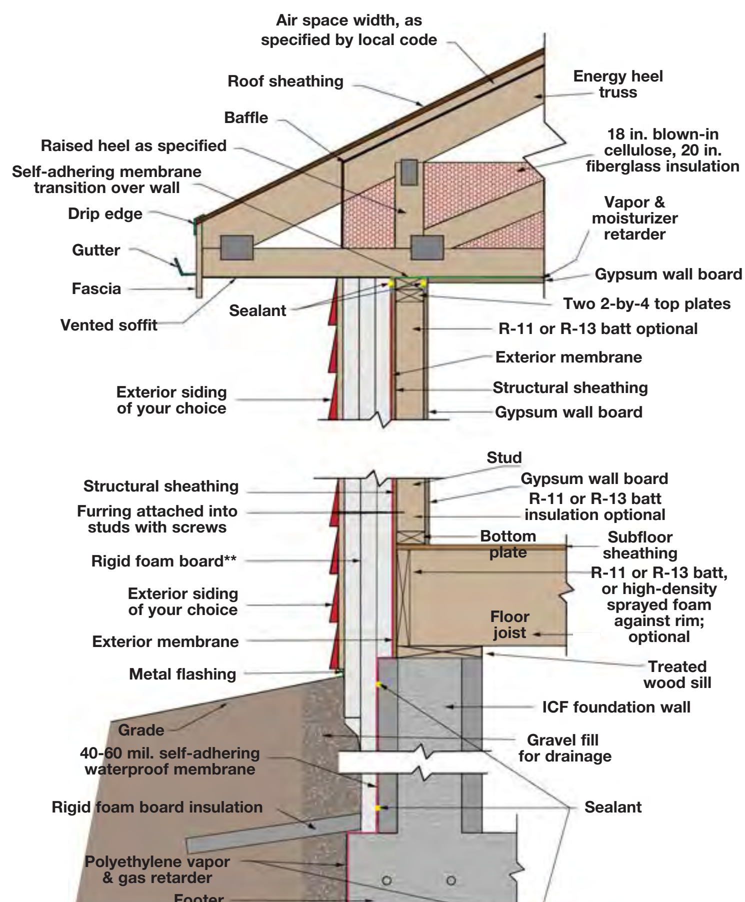
Insulation

On the Outside

One of the most radical high-performance wall systems is the "pressure equalized rain screen insulated structure technique" (PERSIST), developed by the National Research Council of Canada in the 1960s. Walls are framed with 2-by-4s without any roof overhangs, sheathed with plywood or OSB, and covered with a peel-and-stick membrane, such as Grace Ice & Water Shield (a rubberized asphalt adhesive backed by a layer of high-density cross-laminated polyethylene). Then the building is wrapped in one or more layers of rigid foam insulation, which in very cold regions could be as much as 8 inches thick. Using XPS foam at that thickness would mean walls of R-40. The membrane provides an effective air and vapor barrier and, because it's installed on the warm side of the insulation, does not foster condensation inside the walls.

Builders apply strapping over the foam on the walls and attach the siding to the strapping. This creates what's called a "rain screen." Any water that is forced through the siding (in a driving rain, for example) drains away, and the back of the

REMOTE Construction with Outside Insulation



**Thickness of exterior rigid foam depends on climate. 2/3 of total wall R-value is recommended for Interior Alaska.

Courtesy Cold Climate Housing Research Center siding dries more effectively, which extends siding life. On the roof, sleepers—2-by-4s on the flat—are installed over the rafters, followed by a second layer of sheathing. Rakes and eaves are applied.

Houses built this way are extremely resistant to air leaks, with greatly reduced thermal bridging, and the insulation-free stud cavities are excellent places to run wiring or plumbing without interrupting the air barrier. On the down side, all that membrane and the layers of rigid foam are expensive—and there's extra time involved in detailing the doors, windows, and roof overhangs.

Choosing a Wall System

When you're choosing a high-efficiency wall system, you may want to also consider:

Total cost: This includes both the cost of the materials and the labor (time) to install it. Some systems, like structural insulated panels or insulated concrete forms, incorporate both structure and insulation. With other systems, you'll have to factor in the additional cost of adding insulation after the structure is built.

Ease of construction: Are you planning on doing the construction yourself, or hiring it out? If you're hiring a pro, who has experience with your chosen wall type? Will you need to rent or buy specialized equipment (concrete mixer, hoist, etc.) to assemble the wall structure or install insulation? If you or your builder are not familiar with a particular building technology, plan on a longer construction schedule.

Materials: Are the wall system's components made with renewable, recycled, or nonrenewable materials? Are the materials inert once installed or will they off-gas, potentially compromising indoor air quality? What is the embodied energy—the energy required to fabricate and transport—of each of the materials?

Think beyond R-values: Although the thermal performance of a wall is certainly important and higher R-values usually mean less energy consumption, don't forget about air sealing, a crucial element not only for energy efficiency but also for the durability of the building. Houses should be tested with a blower door during construction so air leaks can be corrected.

Durability: Are the materials you chose insect- and pest-resistant? Will the insulation degrade over time, losing some of its value?

Resistance to thermal bridging & air infiltration: Does the complete wall system limit thermal bridging and air infiltration?

Quality of construction: Even the best materials won't make up for sloppy building practices. It takes time, care, and expertise to detail buildings so they're comfortable, durable, and energy efficient. If you don't know what you're doing, hire someone who does.

Courtesy Karl Kassel, Arctic Sun/Reina

The REMOTE building technique being applied. Note the waterproof barrier under the layers of rigid foam.

The PERSIST is effective in all climate zones, not just the far north. A similar approach called residential exterior membrane outside-insulation technique (REMOTE) uses almost the same wall system but a more conventional unconditioned attic. As explained by the Cold Climate Housing Research Center (CCHRC) in Fairbanks, Alaska, REMOTE eliminates the need to build a second roof. It also calls for the addition of cavity insulation in the framed wall, with one-third of total wall insulation on the warm side of the membrane and two-thirds on the outside. (Note that this ratio of inside to outside insulation would be dictated by climate to keep the dew point to the exterior of the vapor barrier).

Given the design, air leakage rates can be very low. A blower-door test of a REMOTE house by the CCHRC showed air tightness at 0.4 ACH50 (air changes per hour at 50 pascals of pressure, a standard industry measure). This is an extremely low number, and about one-fifth the leakage of a conventionally built comparison house. In the CCHRC house, building costs were about $0.85 more per square foot of heated space than a conventionally built house, including labor. Keep in mind that cost differences depend on a variety of factors, and that this side-by-side comparison took place more than 10 years ago, so costs are out of date.

Access

Scott Gibson (scottgibson51@gmail.com) co-authored *Green from the Ground Up* and *Toward a Zero Energy Home* (The Taunton Press). He is a contributing writer at *Fine Homebuilding* magazine, and at GreenBuildingAdvisor.com. Scott and his wife live in southern Maine.

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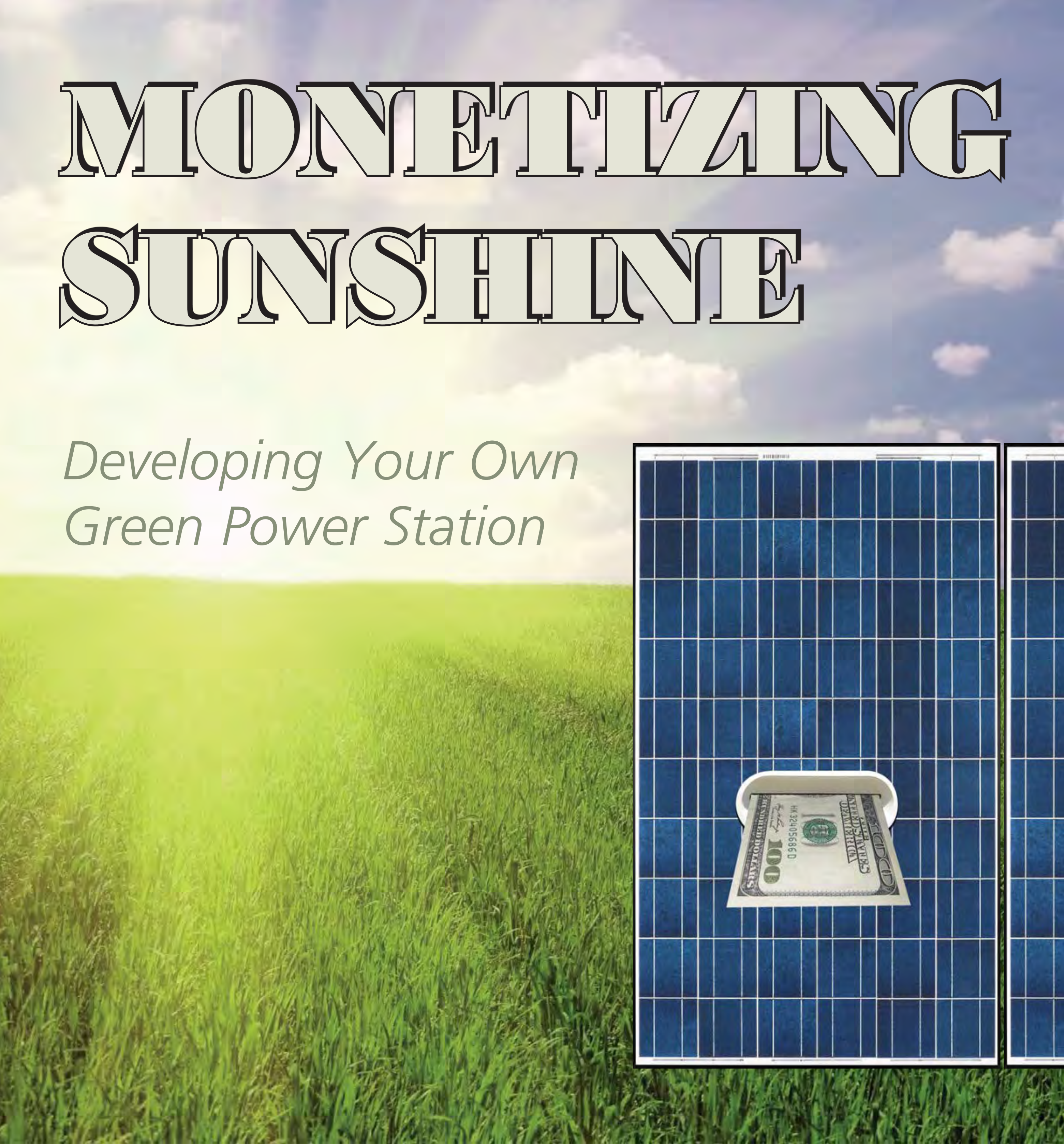
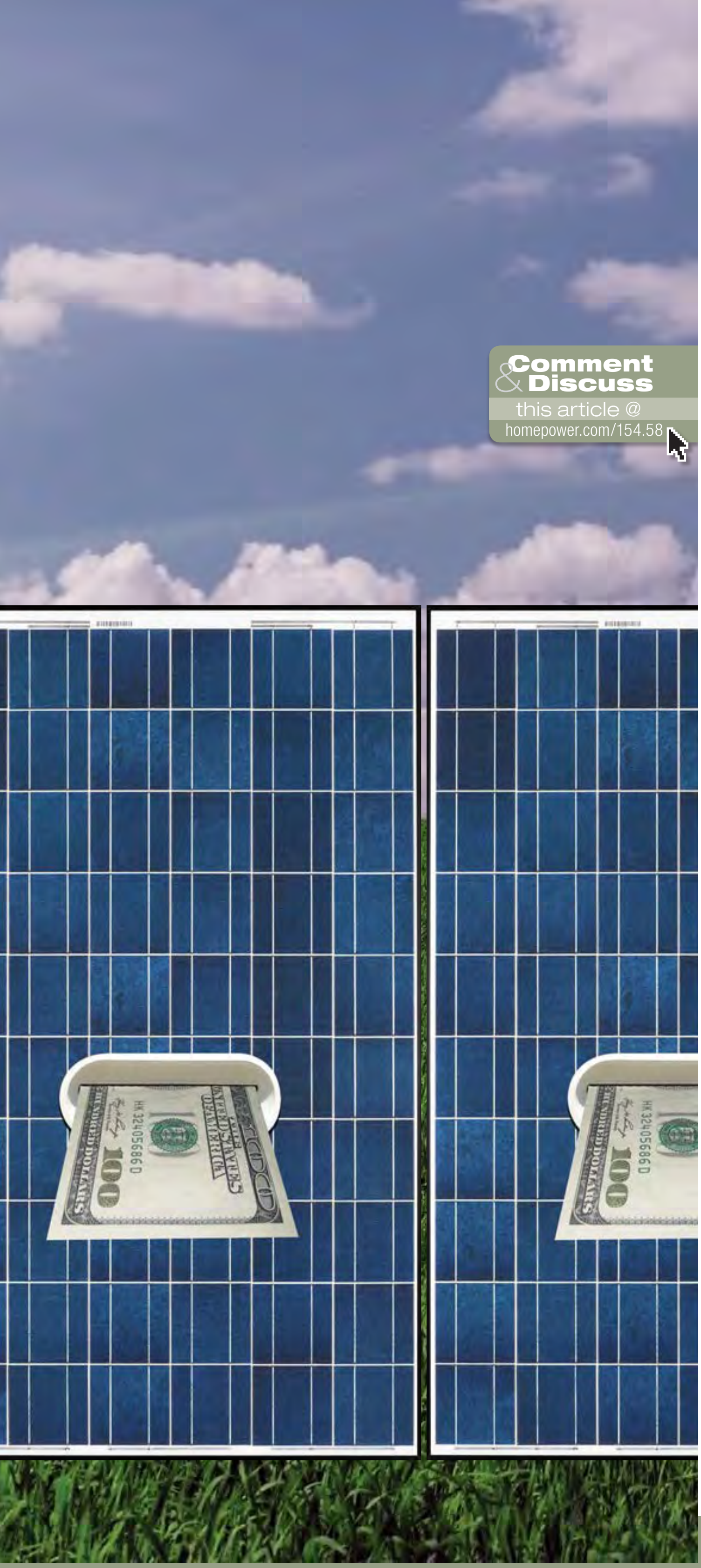


by Andy Kerr

Back in the day, folks installed PV systems usually for one of two reasons—they were living remotely or because they wanted clean energy. Today, if your house or business is already connected to the grid, there's another reason to have a PV system installed—it can be a rational financial investment with very competitive returns, and part of a diversified investment strategy.



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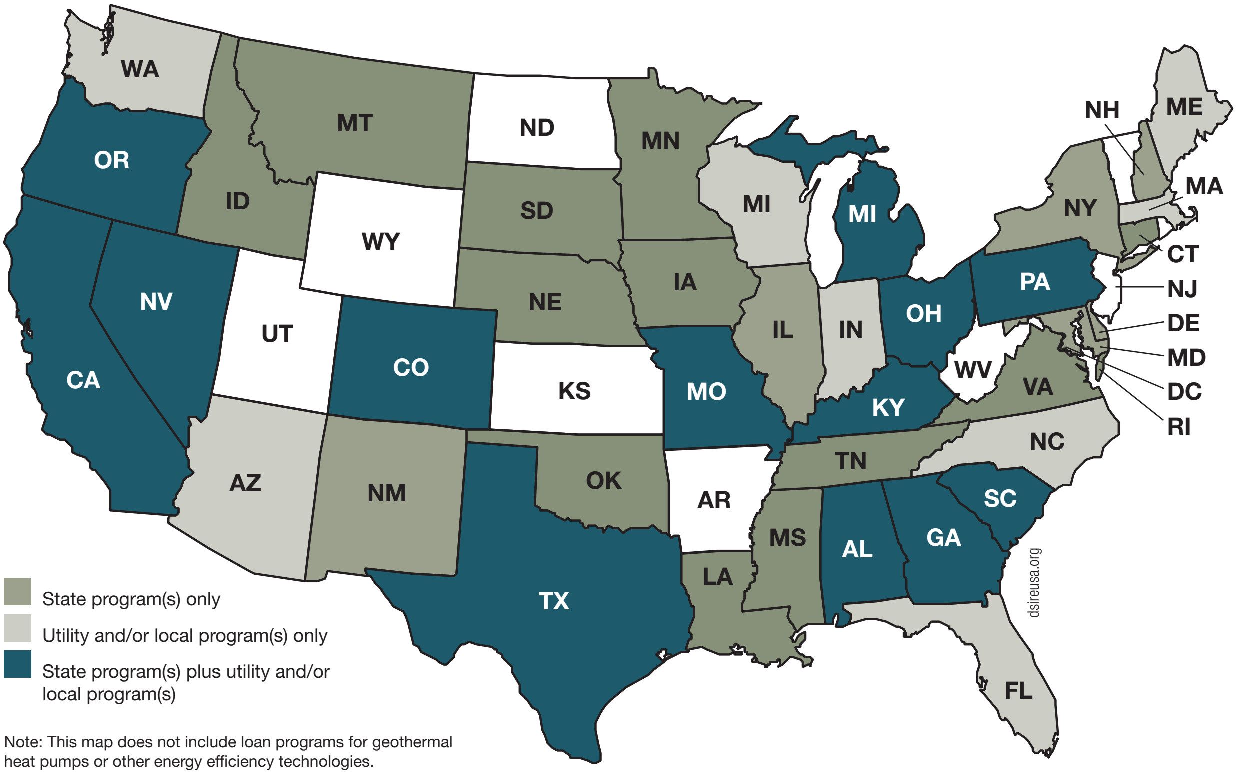
Every jurisdiction has different energy prices and specific incentive options, but let's take Washington, DC, as an example: Here, investing $25,000 in a rooftop PV system that will likely last well beyond 25 years can result in a 14% return on investment. With savings accounts paying less than 1% interest and certificates of deposit not much better, and with the volatile stock and bond markets, where else can you make a very safe 14% return?

The opportunities in your state may be even better—or much worse. If you have low electricity rates and few local solar incentives, a PV system may not be a rational economic investment. You won't really know until you do "due diligence," which is a fancy way of saying do your homework before investing.

If you are intrigued about developing a small PV "business" on your roof that generates some income, hedges against increasing electricity rates, and adds value to a home or business, you need to survey the opportunities and put together a workable business plan. The plan's success relies on the details. First, specify the most cost-effective system. Second, take advantage of available incentives. Third, if you need to, borrow money as inexpensively as possible.

gigaom.com

Loan Programs for Renewables
(41 states offer loan programs)



Driving Down Costs

Get several bids from various installers, and make sure you understand what you are getting for the price. One installer's system sizing approach may differ widely from another's, and the lowest bid may not be the most cost-effective when you factor in installation and the system's production, efficiency, and reliability. Developing a spreadsheet to compare these factors can help you make an informed decision (see "One Roof, Many Options" in this issue). You may also be able to tap into a local PV buying cooperative to take advantage of volume pricing.

Once you have the estimate you want (the gross system cost), determine the net system cost by subtracting available incentives. You may be eligible for federal, state, local, utility, and private incentives. Beyond the federal tax credit, the other incentives vary by location, so you'll have to research your own circumstance. Search the Database for State Incentives for Renewables and Efficiency (dsireusa.org) to determine what available incentives are offered in your area and apply to your specific situation (i.e., residential, small business, etc.). DSIRE catalogs incentives by tax (personal, corporate, sales, and property), rebates, grants, loans, industry support, bonds, and performance-based incentives.

If you have federal tax liability, 30% of the system cost can be taken as a tax credit on a federal income tax return. A credit is a dollar-for-dollar reduction in the tax you owe, and is better than a tax deduction, which reduces the amount of income that you have to pay tax on. If not used up in the first year, the federal tax credit can be applied in succeeding years if your system is installed before the end of 2016. If you or your business doesn't have enough tax liability to offset the tax credits, you may be able to sell your tax credits to some entity that does—known as a "pass-through." Your PV installer or your banker may be able to help you in this regard.

How Do I Pay for Thee? Let Me Count the Ways

To capitalize your PV system investment, you are going to borrow money from someone. Even if you pay cash, you are borrowing money from yourself—money that if invested elsewhere could generate some rate of return. Whether it makes the best sense for you to borrow money—from yourself or from another source—depends upon several factors. The first is whether you have the money to lend yourself. The second is whether another source will lend you money. If they do, what is their interest rate? How does this rate compare to your other investments? For example, say

One installer's system sizing approach may differ widely from another's, and the lowest bid may not be the most cost-effective when you factor in installation and the system's production, efficiency, and reliability.

solpowerpeople.com

The PACE Option

Property Assessed Clean Energy (PACE) programs can offer a no-upfront-cost option for financing PV systems. PACE financing allows those without conventional access to capital to invest in their own PV systems. In these programs, the cost of the efficiency improvement (in this case, adding a PV system), is covered by a loan through the city or county. The loan is amortized over 15 to 20 years, with the annual repayment added to your property tax. While your property tax bills will increase, your energy bills will decrease. If you sell your property, the property tax assessment transfers to the new property owner.

Residential PACE programs got off to a great start in several states, but they've since been stymied by the Federal Housing Finance Agency, which asserts that the PACE loans, which take precedence over pre-existing first mortgages, subordinate Fannie Mae and Freddie Mac interests in the property, transferring financial risk to those agencies without "adequate consumer protections."

A few states have enacted legislation to address the problem. Congressional legislation to address the problem died at the end of the 112th (2011-2012) Congress and is expected to be introduced into the 113th Congress (2013-2014). It would "prevent Fannie Mae, Freddie Mac, and other federal residential and commercial mortgage lending regulators from adopting policies that contravene established state and local property assessed clean energy laws." Until Congress acts, however, most PACE financing is on hold.

you can borrow money at 5% and are making 4% on your investments. At first blush, using your own money might seem the best plan. However, do you have excess investment capital to loan to yourself for this project? More importantly, don't forget taxes, or legitimate deductions that reduce taxes. Your tax advisor should be able to give you advice on what will best serve your financial situation.

Vendor financing is often available from loan institutions that partner with your installer. You should also check with your local banks to see if they offer "green" or "energy" loans for renewable energy projects. If you have good credit, these loans can be unsecured. Credit unions may offer more competitive rates than banks.

If you have enough equity in your home, consider taking out a second mortgage. Finance institutions, likely including the one that services your first mortgage, offer either a home equity loan (HEL), usually for a specific improvement or purchase, or a home equity line of credit (HELOC), which is usually for larger expenses, like college tuition or medical bills.

While purchasing a PV system can be the most straightforward option, it may not be the most beneficial in maximizing your return on investment. Leasing programs may make the most of your money instead.


powerhome.ca

With a solar lease, someone else owns the PV system on your roof and you lease it, keeping the electricity to use or sell.

Government-backed loans, which have some of the lowest interest rates, may be available if you live in the right area. They usually have a lower interest rate than you can get elsewhere. For example, if you live in Mississippi, you may be able to get a seven-year loan with an interest rate that's 3% *below* the prime rate. At this writing, the prime rate was 3.25%—that means you could borrow money for seven years at 0.25% interest.

Another option might be **peer-to-peer lending,** an alternative to traditional bank financing. There are online websites that connect borrowers and lenders (in this case, microinvestors). The borrower makes the pitch and the seller decides to fund it—or not. This is often used in cases where traditional credit is not available.

The options available to you may not be available to others, and vice-versa. Find out what is available to you and then compare the options. This should all be part of your business plan.

Lease or Purchase?

While purchasing a PV system can be the most straightforward option, it may not be the most beneficial in maximizing your return on investment. Leasing programs may make the most of your money instead.

According to the U.S. Environmental Protection Agency, a solar power purchase agreement (SPPA) is a financial arrangement in which a third-party developer owns, operates, and maintains a PV system, but you site the system on your property and purchase its electrical output from the developer for a predetermined period. The benefit? You receive stable, and often less expensive electricity, as well as hold on to your money, while the investor reaps the financial benefit of tax credits and income generated from the sale of electricity to the host customer. SPPAs are best for people who don't have the money or don't want to use their own money to invest in a PV system and/or don't have the tax liability to absorb available tax credits.

With a solar lease, someone else owns the PV system on your roof and you lease it, keeping the electricity to use or sell. A solar lease differs from a solar power purchase agreement (PPA) in that you are leasing the equipment, whereas with a PPA, you're simply paying for the energy the equipment produces.

Income Streams

A primary "income" stream is avoided electricity costs, since electricity you produce and consume on site is electricity you don't have to buy from the utility. Depending upon the jurisdiction, your income stream could be structured in various ways.

Net metering is the most common program that's available in most states. The utility grid takes all of your excess energy production, and credits this at retail electricity rates. When you consume more electricity than your PV system produces, you "buy back" those kilowatt-hours using the credit. One electric meter monitors the inputs and draws.

Feed-in tariff (FIT) programs pay a high price for your PV-produced electricity over a set number of years, as specified in a contract. Your PV system's production is monitored separately from your household's electricity consumption. FITs can convince a lender to finance your PV system by showing a guaranteed income stream. If you participate in a FIT, however, you may not be eligible for other subsidies and incentives.

Solar renewable energy credits (SRECs) provide income by selling the environmental attributes (including avoided carbon emissions) associated with that electricity, not by selling the actual solar-produced electricity. SRECs, in the states that allow them, also show a guaranteed income stream to a lenders. See "SRECs Can Turn PV Generation into Profits" on opposite page.

Your utility may offer **time of use (TOU) metering** that prices your electricity differently at different times of the day. When electricity demand is high, rates are higher;

continued on page 66

SRECs CAN TURN PV GENERATION INTO PROFITS

In most states, grid-tied PV systems have had only one income stream—the money saved by not having to purchase electricity from the utility. By monetizing the "green" (environmental) attributes of small PV systems, solar renewable energy credits (SRECs) are making PV production in some states far more profitable by providing an additional income stream.

What is an SREC?

SRECs (pronounced "ess-reks") are "tradable commodities that represent the green attributes associated with energy generated from [sunlight]" according to SRECTrade, a pioneering company in SREC transactions. One SREC represents the environmental benefits of one megawatt-hour (MWh or 1,000 kWh) of PV-produced electricity.

SRECs are the most common, cost-efficient way for electricity suppliers to meet a state's renewable portfolio standard (RPS)—especially an RPS with a "solar carve-out" requiring that a percentage of the renewable electricity be met using solar. Rather than build their own solar-electric generation plants, utilities often buy SRECs through aggregators or brokers that trade on behalf of small and large PV system owners. The utility meets the requirements by purchasing the green attributes of a third-party's PV system.

The party that buys the SRECs from the PV system owner has the right to claim in marketing materials or for meeting regulatory policy goals that they are producing clean power, and the PV system owner can no longer make those claims. This promotes the spread of solar energy by making it more profitable, while preventing two parties from making green claims for the same energy produced.

If a regulated energy supplier fails to meet their state-mandated RPS, they are subject to solar alternative compliance payments (SACPs), which are set at a fixed rate—unlike SREC prices, which vary based on supply and demand. A utility is better off buying SRECs when the price is less than the SACPs, which are scheduled to begin high and ramp lower each year.

Where Can I Find SRECs?

Only eight states have true SREC markets (see map). To create local jobs and economic activity, almost all these states now require that the SRECs to meet that state's regulatory requirements be produced in that state.

California created its own unique system that allows the use of tradable RECs (tRECS) for RPS compliance. Unfortunately, tRECs are just for electric utilities and large suppliers; small producers need not apply.

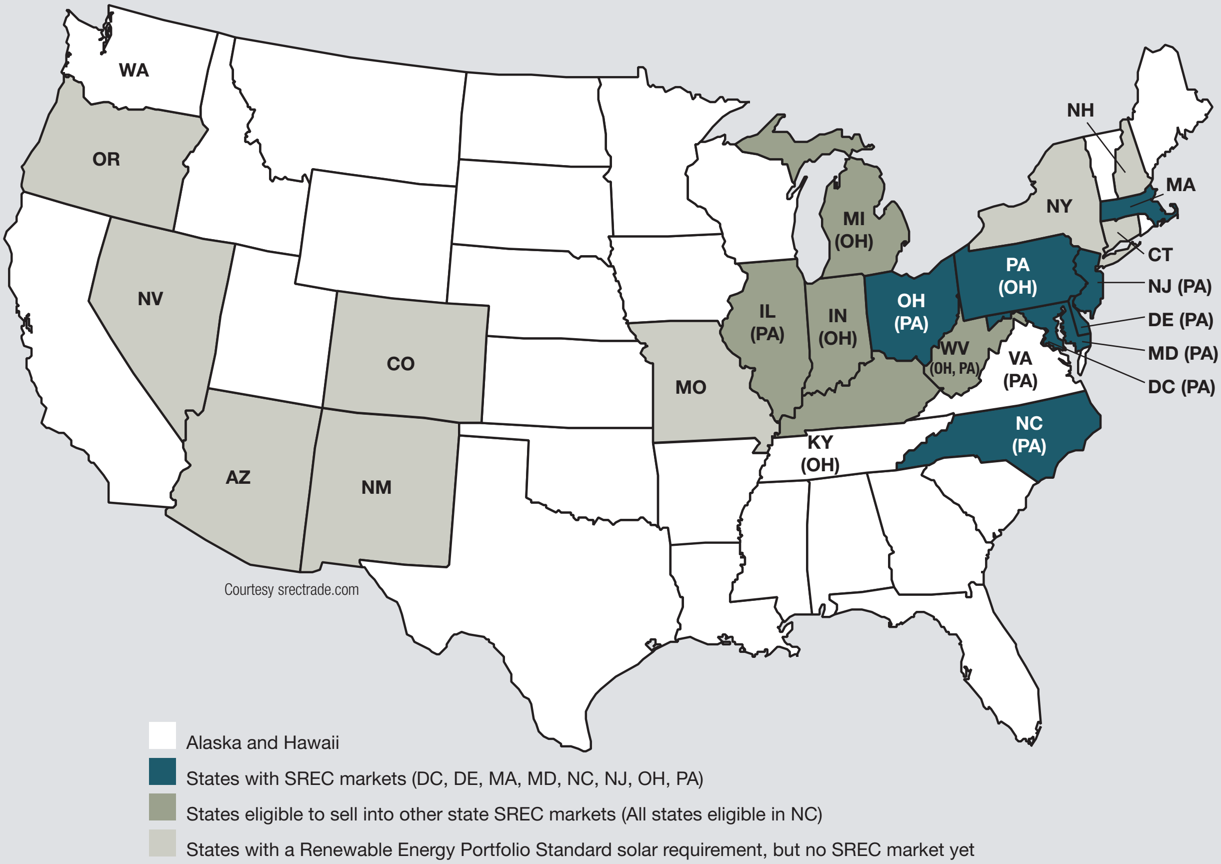
A number of other states have solar RPS requirements but do not yet have SREC markets. SREC markets must be created by regulatory action in addition to establishing an RPS; some states have yet to act. If a utility has to meet an RPS standard with a solar carve-out, it will soon realize that a tradable SREC market can be the most efficient way to meet the regulatory requirement.

RECs & Voluntary Markets

In states where there are no RPS requirements, voluntary programs sell renewable energy credits (RECs), also known as green tags. Through these programs, energy customers can choose to pay a little extra to offset their fossil-fuel grid electricity use with an equivalent amount of renewable electricity produced from a wind farm, PV array, or other renewable source ("renewable" is defined by a state regulatory authority and can sometimes include sources such as natural gas fuel cells and biomass burning, which aren't actually "renewable"). However, trading demand for voluntary RECs is pretty low, thereby keeping the selling price low and doing little to provide much financial motivation for new RE installations. SRECs fetch much better prices than voluntary RECs because of the penalties incurred by a utility for not meeting an government-mandated RPS standard.

One SREC represents the environmental benefits of one megawatt-hour (MWh or 1,000 kWh) of PV-produced electricity. SRECs are the most common, cost-efficient way for electricity suppliers to meet a state's renewable portfolio standard (RPS).

Solar Renewable Energy Credits (SRECs)



Make $$ Selling SRECs

In late 2012, an SREC sold for $75 ($0.075 per kWh) in New Jersey. Further south in Washington, DC, an SREC was trading for $340 ($0.34 per kWh). Why the disparity? Simple—supply and demand. SREC demand varies in each state where they are traded, with regulatory policy being the primary driver.

SRECs only thrive in RPS markets where policies require significant solar carve-outs. New Jersey's RPS requires that energy providers supply 20.4% of their electricity with renewable energy by 2021, with a 4.1% solar carve-out by 2028 (with accountable benchmarks that must be met each year).

As RPS or solar carve-out percentages increase, SREC demand grows. As the solar carve-out gets closer to being met, SREC demand falls, assuming the same supply. SREC supply is determined by the available qualified generation, which is determined primarily by the price of PV modules and other hardware costs, the cost of capital, and other incentives (tax credits, etc.) available to the prospective PV system developer.

In addition to prohibiting out-of-state system eligibility in its SREC market, the District of Columbia increased its RPS solar carve-out to 2.5% by 2023 from 1%, thereby increasing demand for SRECs. With demand for solar energy now greater and the potential supply limited geographically to the 68.3 square miles of the federal district, SREC prices in DC are likely to increase—at least until supply catches up with demand. Those high prices are causing more people to invest in PV systems, but as a lot more do, it will tend to reduce prices as the supply of SRECs increase.

SREC markets exist only in those states that have made regulations to create them. In DC, a 5 kW grid-tied PV system could produce about 6 MWh per year, equivalent to 6 SRECs per year. If sold in early 2013, the owner could receive a total of $2,040 ($340/SREC) if sold on the spot market. In New Jersey, it would fetch for $450 ($75/SREC).

The party that buys the SRECs from the PV system owner has the right to claim in marketing materials or for meeting regulatory policy goals that they are producing clean power, and the PV system owner can no longer make those claims.

New Jersey End-of-Year SREC Prices

Year	Amount
2006	$245
2007	250
2008	650
2009	670
2010	650
2011	288
2012	75

Source: New Jersey Clean Energy Program

Like commodities, SRECs go up and down in value. In August 2011, the New Jersey SREC price plummeted from $640 to $300, due to 49% more PV being installed in the first quarter of 2011 than in the same quarter of 2010. In June 2011, 520 PV projects came online, totaling more than 40 MW of capacity. In early 2013, NJ SRECs are trading for $90. The market is flooded because declining module prices, along with continued federal tax subsidies, make investing in PV systems attractive financially—for many, the SREC price is icing on a cake that is tasty enough. More people and companies are going solar and able to supply SRECs while the demand for SRECs remains stable.

Trading SRECs

Typically, homeowners must rely on third-party aggregators or a brokerage firm to sell their SRECs. "The way the market is designed makes it virtually impossible for a homeowner to sell directly to a primary energy supplier. These entities, mainly large utilities, must meet quotas for several thousand SRECs per year. They simply do not have the resources to work up deals with individual homeowners who want to sell three or four SRECs at a time," says Brad Bowery, CEO of SRECTrade, a San Francisco-based SREC brokerage.

An aggregator/broker's goal is to bring buyers and sellers together to transact SRECs. They act as an intermediary between small generators (homeowners and small businesses) and big energy suppliers, bundling small transactions into high-volume transactions that can be processed more efficiently.

Since the market is still relatively new, there is no universal model—each aggregator/broker (often one and the same) seems to have their own way of doing business. Most operate in SREC markets in multiple states. Some will only do spot trades or over-the-counter transactions, usually for a set fee—about $2.50 per trade. Others require contracts. Some do a mix of both. Many aggregators act as brokers, trading the SRECs on their client's behalf. In this scenario, the aggregator's interests are usually closely aligned with those of their clients, since the aggregator usually earns a commission as a percentage of the traded price—the higher the price, the higher the commission.

Other aggregators purchase SRECs from homeowners and then resell them in a bundle to energy suppliers at marked-up prices. The aggregator is motivated to buy as low as possible from homeowners and sell as high as possible to energy suppliers. This model is often packaged as an annuity with fixed payments or as one upfront payment for a specific term, from three to 20 years. While this approach may hedge against the potential decline in SREC prices and eliminate the market risk of fluctuating SREC prices, a homeowner may end up selling at the wrong time for too little.

"Transparency is probably the most important factor when shopping for a brokerage firm or an aggregator," says Michael Flett, president of Flett Exchange. "Do not sell your SRECs to someone if they aren't willing to substantiate their pricing. Ideally, you want to work with someone that makes their pricing public. You want to understand the basis for their price and whether the price reflects fair market value."

Flett Exchange operates a stock exchange with a 24/7 marketplace where homeowners can watch the bids from energy suppliers and choose to sell their SRECs when the price is right. When a hands-off approach is preferred, Flett, like most other brokerage firms, will manage a homeowner's SRECs—for a higher fee. Alternatively, SRECTrade sells SRECs online via monthly auctions in which homeowners set a price floor and are matched with buyers that will meet or exceed the homeowner's minimum price. Rounding out the

Metering

Until recently, most states that have SREC trading allowed owners of small PV systems (less than 10 kW) to estimate their system's performance using the National Renewable Energy Laboratory's PVWatts2 program, rather than install utility-grade meters. But some states are adopting stricter regulations. In May 2012, New Jersey required all systems to install revenue-grade meters—in addition to the home's standard electric meter—to qualify to sell SRECs. As of November 2012, SRECs in New Jersey are only issued based upon revenue-grade meter readings.

The way the market is designed makes it virtually impossible for a homeowner to sell directly to a primary energy supplier. These entities, mainly large utilities, must meet quotas for several thousand SRECs per year. They simply do not have the resources to work up deals with individual homeowners.

Taxable or Not?

Many experts argue that the income from SREC sales is income and needs to be reported as such on your taxes. If you report it as income, you should be able to deduct the cost of your PV system from your taxable income. Others argue you don't need to report it as income until you've sold enough SRECs to offset the cost of your PV system. Consult a tax professional for advice, as the IRS has issued no guidance and qualified tax professionals won't give generic advice to the public.

mix are the more traditional aggregators like Washington, DC-based Sol Systems, which offer homeowners options based on their desired level of risk.

"It's the age-old risk/reward paradigm. How much risk are you willing to take? Most homeowners do not have the time track to the SREC markets, and they do not understand why prices go up and why prices go down," says Williams Graves, an associate at Sol Systems. "Managing your own SRECs trades take time and commitment, and homeowners should be realistic about what they can take on."

If you want to spend your time first learning and then keeping up with the SREC market and you like trading (similar to stocks and commodities), the DIY approach of spot (aka over-the-counter) trading offers the greatest flexibility and the greatest potential reward, but with the highest risk. Remember, buyer's bids reflect supply and demand in the market—SRECs could be worth less in the future than they are today. If you go this route, you will need to register your SRECs with the appropriate authority (it varies by state).

The SREC market is an emerging one, and no specific resources, such as books, are available to study. Scour the websites of the SREC trading companies and employ your search engine of choice.

continued from page 62

when overall grid demand is low, rates are lower. In many locations, high TOU rates are designed to reduce peak demand caused by air conditioning. They may also coincide with times of high production from your PV system, earning you net-billing credit or, in some cases, FIT payments, at higher rates.

Taxes, Insurance & Such

Most property insurance covers residential PV systems without additional charge, since they are typically permanently affixed to your dwelling or business. Check with your insurance agent to be sure.

And don't forget taxes—the plan is for your PV system to make income for you, either by selling the energy or offsetting the energy you would otherwise have to buy. While income is taxable, there may be some offsetting business deductions, such as depreciation, that reduce your tax liability. Depreciation means that you can deduct the cost of acquiring your PV system. What you can deduct, you don't have to pay income tax on.

Many jurisdictions exempt PV systems from property taxes. Check with your local assessor's office.

Run Some Numbers

After you determine the system cost and available incentives, refine your plan and prepare a benefit-cost analysis. Profit only occurs if benefits exceed costs. As you develop a spreadsheet, decide if you are going to determine *accounting profit*—which tallies the benefits and subtracts the costs—or *economic profit*, which factors in opportunity costs, such as if you could make more by spending your money and time doing something else. If you are investing in PV solely as a commercial enterprise, you should be concerned more with economic profit.

This article has concentrated on the financial benefits to individuals (investors) of developing PV systems. There are also benefits to society in terms of a cleaner and healthier environment. Those benefits accrue to society as a whole, rather than individual PV investors. The good news is that these societal benefits don't have to directly accrue to the individual to make investing in a PV system a rational act for an individual investor. Investing in a PV system can mean not only doing well for one's self, but doing good for society and the Earth.

Access

Andy Kerr (andykerr@andykerr.net) writes and consults on nature conservation and renewable energy issues through The Larch Company (andykerr.net). He's developed four residential photovoltaic installations and five solar hot water installations.

Related *Home Power* articles:
"Grid-Tied Solar in Small Town, USA" in *HP101*
"Mixing Business & Pleasure" in *HP101*
"Making PV Pay—It's Just Good Business Sense" in *HP117*
"Building a Solar Business" in *HP135*

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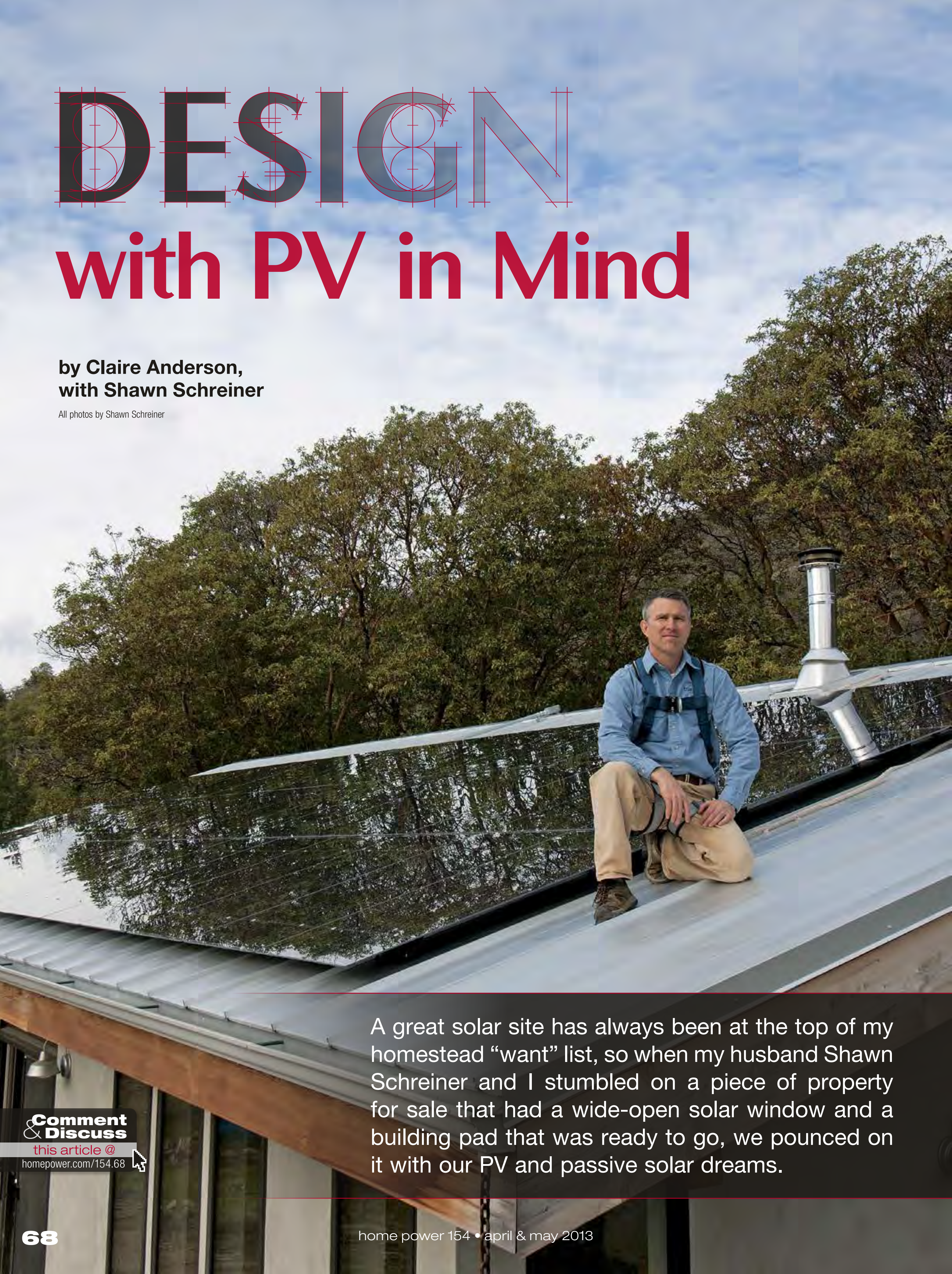
DESIGN with PV in Mind

by Claire Anderson, with Shawn Schreiner

All photos by Shawn Schreiner



A great solar site has always been at the top of my homestead "want" list, so when my husband Shawn Schreiner and I stumbled on a piece of property for sale that had a wide-open solar window and a building pad that was ready to go, we pounced on it with our PV and passive solar dreams.

Comment & Discuss this article @ homepower.com/154.68

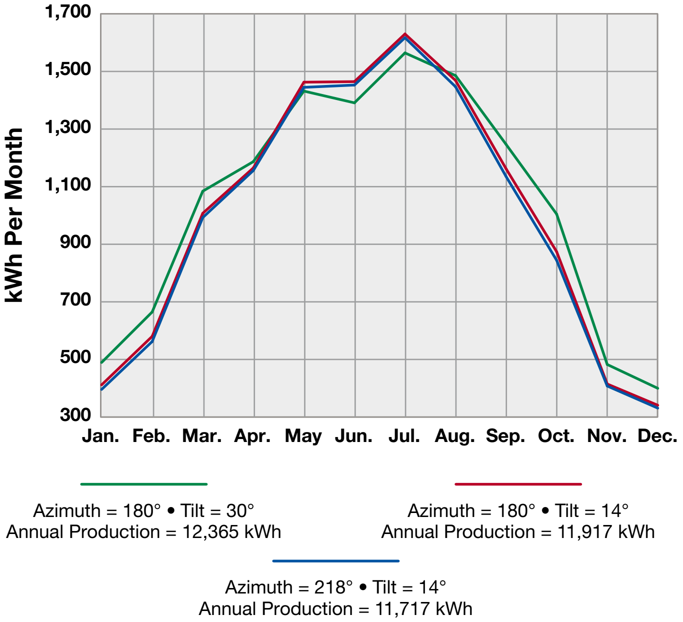
Both Shawn and I spent months scouring the Web for passive solar home plans that provided a small, efficient footprint and that would be relatively easy to build ourselves. We initially fell in love with a modern, simple design that would have suited our passive solar plans well, but scrapped it due to its north-facing roof.

So we went back to the drawing board—Shawn spent lots of time drawing in SketchUp, free modeling software that proved very handy, since we could observe how the various designs worked with solar gain. Besides having a passive solar home, we knew we wanted to use renewable fuels exclusively, so designing a large, uninterrupted south-facing roof space for a PV array and, potentially, solar hot water collectors, was essential.

The design we finally arrived at was a modified, "modernized" ranch—two long rectangles joined at a common wall. A south-facing roof measuring 60 feet by 20.6 feet would give us more than 1,200 square feet for PV modules and solar hot water collectors. With only one penetration for a stove pipe in the uppermost part of the roof, we had lots of room for renewable energy collection.

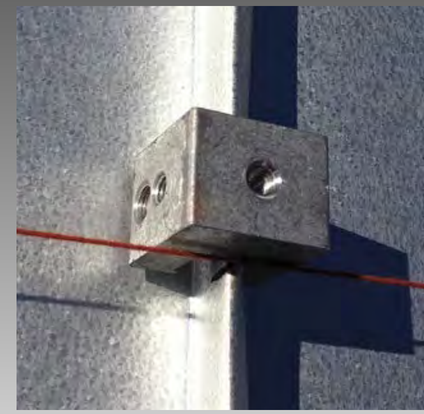
The building pad wasn't facing true south and redoing it wasn't an option—we needed to work with what was there. At a 218° azimuth, the house favors the south-southwest. We also deviated from the "default" roof pitch (equal to the location's latitude: 42°) specified by PVWatts, and the "optimal" orientation specified for our location, which is 7:12 or 30°. Instead, we went with a 3:12 (14°) pitch for ease of building and aesthetics. How much would this compromise solar generation? Surprisingly, not very much—compared to an "optimal" orientation and tilt, our potential solar production would only take a 5% efficiency hit (see graph).

ARRAY ORIENTATION & PERFORMANCE



Data calculations courtesy PVWatts: 9.72 kW array; default derate of 0.77

A good view of the home and site, showing its unobstructed southern exposure and a nearly complete PV array.



Above: S-5! clamps were used to attach the rails to the standing-seam metal roof.

Left: The beautifully reflective Lumos Solar modules at sunset. At bottom right is the proprietary spacing tool that helps ensure proper module layout.

Load Goals

Our main goal was to use renewable energy systems for our homestead, which includes a small, separate office building and a 576-square-foot cabin, and make as much electricity as we use each year. Except for space heating, which would typically be served by our wood heater, all of our loads would be electric.

Although I hand-calculated the potential heating contributions from our passive-solar design, the figures were untested until the house was built and occupied. We sized a wood heater to provide backup heating, but building codes required an auxiliary system, so we opted for an in-floor hydronic system, fueled by an electric water heater. Our original plans called for using solar thermal collectors for both domestic hot water and hydronic heating. However, winters in southern Oregon are often overcast—when we'd need space heating the most. The sunny summers would've guaranteed plentiful production from a SHW system, but with a system also sized for space heating, we would have had to make sure our overheating protection was robust and design in some sort of diversion load.

Given the falling price of PV modules and Shawn's ability to install the system himself (he's a solar installer with True South Solar, based in Ashland, Oregon), we felt it made more sense to design a solar-electric system to meet our homestead loads. Like an SHW system, a grid-tied PV system would produce energy year-round and have its highs and lows. However, the big difference would be that we could use all of the energy it produced. How? With a net-metering agreement with the utility that would credit any surplus energy our system generated, "banking" it for our future use. In summer, when we could hang our clothes on the clothesline and use our solar oven more, our system would almost always be generating more electricity than our homestead uses, and we could draw upon this surplus in the cloudier winter months.

KNOWING OUR LOADS

Our homestead encompasses much more than our house. Here's a list of electric loads that we currently have:

- Four-burner cooktop
- Wall oven
- Refrigerators (2), plus small refrigerator in travel trailer
- Chest freezer
- Dishwasher
- Electric range
- Point-of-use 5-gallon water heater
- 50-gallon water heaters (2; one is lightly used for backup clothes washing); 30-gallon water heater (cabin)
- 40-gallon water heater (for hydronic heating)
- Space heaters (used occasionally for zone heating)
- Vertical-axis washing machine
- Horizontal-axis washing machine
- Electric clothes dryer
- Lighting
- Well pump
- Three computers, two printers (one inkjet; one laser), two LCD monitors
- Ceiling fans
- Ventilation fans
- Aboveground pool pump & salt-water ionizer (seasonal)

Design Marries Substance & Style

We lived in the house for almost a full year before installing the PV system, so we were able to use our past electricity bills to help arrive at a system size. In many cases, we had duplicate loads, since the workshop, which includes an electric range, space heater, and water heaters, was often occupied. The spa tub (admittedly, an energy hog) also ran during this assessment time, as did the radiant floor system. (The spa tub is no longer in use, and we use the radiant floor system only as a backup to the wood heater, which is a backup to the passive solar.) With the extra loads, that year, our monthly consumption for the homestead averaged about 1,350 kWh—or about 45 kWh a day. Ouch! With an average of 4.7 daily sun-hours and a 77% system efficiency, we'd need a 13.4 kW system to zero-out the homestead!

However, we knew we could—and would—do better in decreasing our electricity use. Some of that "extra" electricity use during the year had been running some big tools during the home's construction, such as compressors, saws, drills, heaters, dehumidifiers, and the like. Some of that usage was due to the inefficient spa's draw, and some due to testing (and initially "charging") the radiant floor system. We guesstimated that a system that was under 10 kW would do the trick—and then some.

The PV system's design would have been straightforward, except for one thing—my knowledge of a sleek, sexy new PV module that was just being introduced. I had seen Lumos Solar's glossy frameless modules at a solar conference earlier that year and I was smitten. The marriage of form and function—"art" that made electricity!—was just too tempting for me. I also thought it would be a great opportunity for my solar-installer husband to showcase a product that was a little different from other modules on the market. The company he works for could potentially use our home to show the frameless module option to clients.

MICROCLIMATES MATTER

While online solar energy estimators like PVWatts can give you an idea of how a PV system will perform in your location, it's important to pay attention to microclimates, which can have a marked effect on how much sun your array can collect. In our area, elevation changes and local weather patterns can greatly influence solar collection.

Thankfully, our property sits high enough to escape the fog that tends to settle on the valley floor in the winter. We also sit on an exposed knoll in one of the sunniest areas in the valley. From our house, if you travel about 13 miles in any direction (sometimes less), the sunshine can quickly give way to overcast skies. The local topography also impacts solar gain—mountains surrounding us decrease our overall solar window, since they block the early morning sun and make the evening sun disappear earlier than if our property sat at a higher elevation, though early or late-day sunlight does not count for much because of the angle of incidence.

WORKING WITH FRAMELESS MODULES

As a solar-electric installer, I had my reservations about using a system that was such a departure from what I knew, but Claire was persistent—and I eventually agreed. At the time, 180 W was the biggest module Lumos Solar offered with a black back-sheet. The company I work for was installing mostly 235 W modules and 180s seemed a little behind the times. However, we had plentiful roof space, so power density was not a huge concern.

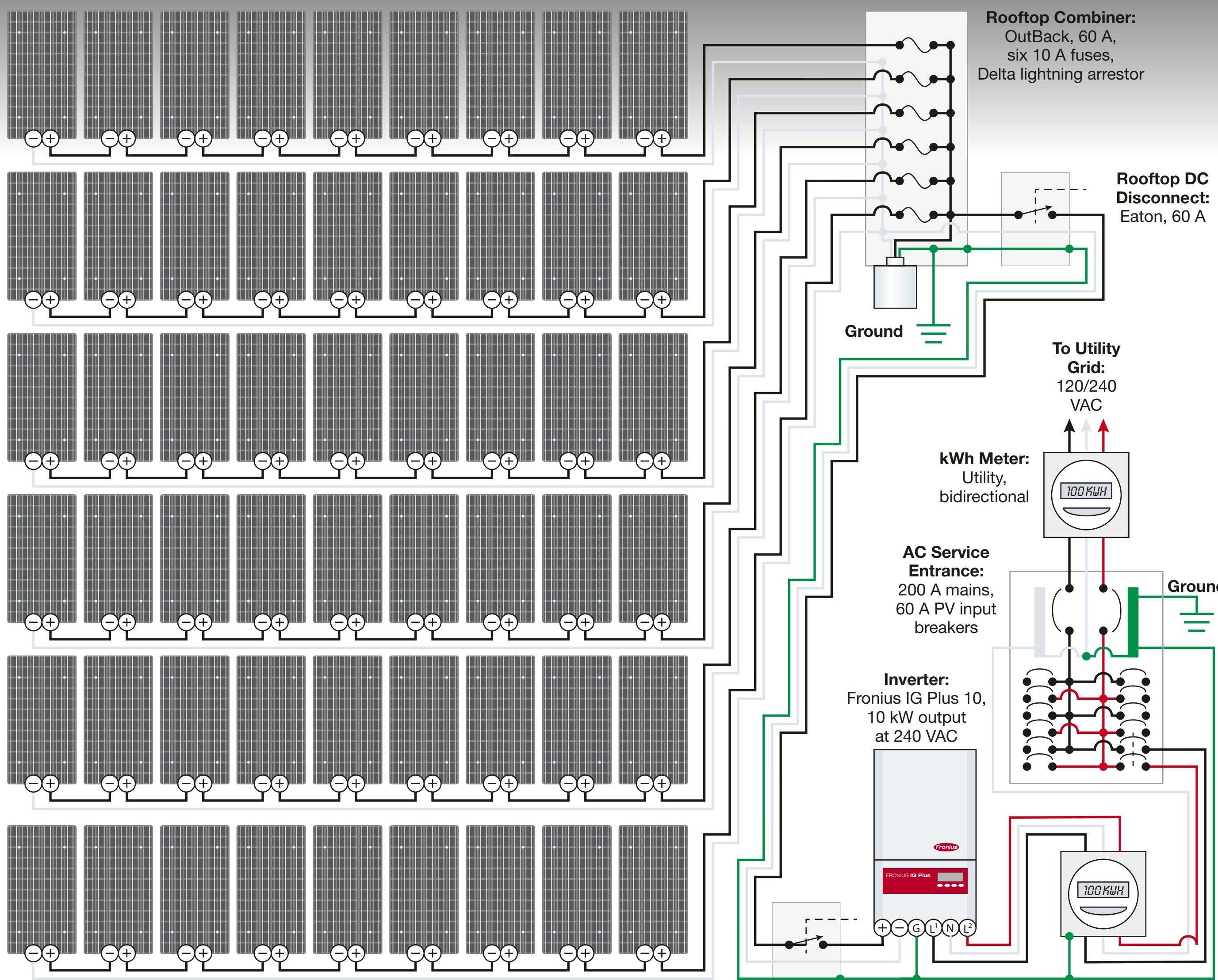
I settled on six strings of nine modules each, which required a fair bit of wire management. But the Lumos LSX rails have a spacious channel that accommodates everything nicely. I brought all the home-runs into an OutBack combiner mounted to the fascia on the north side of the roof, through a 60 A Eaton DC disconnect, and down to the power wall. That kept the south roof—with that amazing-looking frameless array—uncluttered.

The Lumos LSX modules and racks are an integrated system. Through four mounting holes, the modules are attached by bolts onto nuts constrained in the proprietary racks. It takes some getting used to—more time is spent perfecting the layout than with traditional systems, but there is a payoff—once racks and mounting nuts are all tuned, mounting the modules is very quick. I was nervous about the modules staying put as I worked, but the rubber strips on the rails eliminated sliding. The frameless modules are heavy, and no frame means no edge to grip. But it also means no metal parts to bond. In a 54-module system, that's a significant time-saver, not to mention fewer potential points of failure. I used bonding jumpers at the rail splice locations and tinned #6 solid from rail to rail. The tinned wire is extra protection against dissimilar material interaction over the metal roofing.

Although I spent a frustrating couple of hours getting to know the system, we quickly learned to get along famously. I racked most of the 54 modules unassisted in just over a day. I can't imagine doing that with traditional modules and rails.

—Shawn Schreiner

Wire management channels in the rails (right) keep wires neatly organized and protected (above).



Note: All numbers are rated, manufacturers' specifications, or nominal unless otherwise specified. Frameless modules do not require grounding. Rail grounding not shown.

ANDERSON / SCHREINER GRID-TIED PV SYSTEM

Overview

Project name: Anderson-Schreiner residence

System type: Batteryless, grid-tied solar-electric

Installer: True South Solar

Date Commissioned: December 2011

Location: Medford, Oregon

Latitude: 42.2°

Solar resource: 4.7 average daily peak sun-hours

ASHRAE lowest expected ambient temperature: 17.6°F

Average high temperature: 96.8°F

Average monthly production: 1,065 AC kWh

Utility electricity offset annually: 100%

PV System Components

Modules: 54 Lumos LSX180 frameless monocrystalline, with black back-sheet, 180 W STC, 35.3 Vmp, 4.96 A Imp, 44.5 Voc, 5.34 A Isc

Array: Six nine-module series strings, 9,720 W STC total, 317.7 Vmp, 29.8 A Imp, 400.5 Voc, 32.0 A Isc

Array combiner box: OutBack with six 10 A fuses

Array installation: Lumos mounts installed on standing seam metal roof with S-5! clamps; 218° azimuth, 14° tilt

Inverter: Fronius IG Plus 10.0-1 UNI, 10 kW rated output, 600 VDC maximum input, 230 – 500 VDC MPPT operating range, 240 VAC output

System performance metering: TED 5000

The DC disconnect (left) and the combiner, with its six fuses (right), are mounted on the north roof's fascia.

The power wall on the north side of the house with (L to R): AC disconnect, production meter, inverter, and household mains panel.

The modules didn't have the power density of some other brands, but we had a big roof and could fit more modules to meet our design goals. However, there was a learning curve involved in the installation process (see "Working with Frameless Modules" sidebar).

HOW DO WE COMPARE? LET ME COUNT THE kWh

Like other U.S. households, we use a mix of energy to meet our household needs. In our case, we use solar (active and passive), utility electricity (a mix of coal, hydro, and renewables), and wood. Most American homes use utility electricity and natural gas. According to 2009 U.S. Energy Information Administration data, annual energy consumption was 34.9 million Btu (10,225 kWh) per household member. That's 28 kWh per person, per day.

So how do we compare when you consider *total* household energy consumption? Besides our family of four, we often have one or more friends staying on site, and they add to the overall energy load. Unlike many homes, which are empty during daylight hours when people are at school or work, our household is occupied by three or four people during the day. Even so, our average daily *energy* use (electricity plus wood heat) per person has been reduced to about 16.9 kWh—a little more than half that of an "average" American household member.

System Performance

The PV system officially went online on December 13, 2011. As of January 22, 2013 (406 days later), the Fronius inverter showed 14,177 kWh production—a daily average of 35 kWh. PVWatts uses a system efficiency of 77% as the default, when our real-world efficiency is better than that. If you plug in the derate values of the actual components we used (0.97 for power tolerance for Lumos LSXs, 0.955 for the Fronius inverter's efficiency) and assume 100% availability, the DC-to-AC derate value goes to 83%, and 34.7 kWh per day predicted—very close to our daily average.

Since June, our monthly electricity bills have been $10.12—the "basic charge" for having a utility meter. As of December 13, 2013, we had used most of our accumulated surplus electricity, but several exceptionally sunny, cold days in January were replenishing our bank of energy again.

Access

Home Power managing editor Claire Anderson (claire.anderson@homepower.com) is keeping a watchful eye on her homestead's electricity use and PV system's production with a TED 5000 energy monitor.

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- Expertise
- Excellence
- Locally Owned & Operated
- Licensed/Bonded in CA & OR

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Lithium-Ion Batteries

for Electric Vehicles

Story & photos by Randy Richmond

Comment & Discuss this article @ homepower.com/154.76

In 2007, I converted a GMC Sonoma from its original gasoline propulsion to pure electric, using flooded lead-acid (FLA) batteries (see "Born to be Wired" in *HP122*). The type of FLA batteries most commonly used for EV conversions, golf cart batteries, have three 2 V cells and a capacity ranging from about 200 to 260 amp-hours (Ah). Moving the truck's 3,200 pounds required a higher voltage than the 96 or 120 volts commonly used for lighter-weight vehicles, so I used 24 batteries for 144 V and an energy capacity (at 100% discharge) of about 37 kilowatt-hours (kWh).

However, the battery weight (approximately 1,800 pounds) brought the vehicle very close to its maximum gross weight of 5,000 pounds. I expected my batteries to have a five-year life, but in the third year, they started to show signs of failure.

Eighteen of the original FLA batteries in a custom-built box in the truck bed. The six other batteries were housed under the truck's hood.

The short life boiled down to maintenance. I knew that the best practice for FLA batteries is to re-water them monthly if they are being cycled frequently (as they usually are in an EV). The charging process causes evaporation through electrolysis. I was usually good at watering the batteries, but on a few occasions, I postponed it, only to find that enough of the electrolyte had evaporated to expose the top of the lead plates to air. Exposed lead oxidizes, making it harder for the plates to interact with electrolyte and, thus, reduces their capacity.

This undoubtedly contributed to a shorter life, but the nail in their coffin occurred when I was unexpectedly called away for several weeks during the summer. In my original design, a daily timer was set on the battery charger to ensure the batteries were fully charged before I left on my morning commute. Without daily driving, the charger was excessively charging the batteries. This boiled off a significant portion of the electrolyte and overheated the batteries, causing them to swell.

I didn't realize this until I tried to drive my vehicle and heard a "bang" in the battery box, and the vehicle lost power. Several of the batteries in the middle of the pack (those that got the hottest) had swollen—one had swollen enough to cause an internal short circuit, which ignited the gasses at the top of the battery. I replaced the worst of the batteries, hoping that the remaining ones still had some life. But after testing, I found that all of the remaining batteries had a significant reduction in capacity—the only solution was to replace them all.

Battery Shopping

Because I wanted my next battery pack to give me better service, I started investigating lithium iron phosphate (LFP) batteries, which had dropped in price significantly—from $75,000 for a 31 kWh pack in 2006 to $12,000 in 2010 (since then, prices have remained fairly constant). A comparable FLA bank was more affordable (about $5,000), but I was convinced that Li-ion batteries would improve vehicle performance (power, acceleration, range, and energy economy) and render a long-term payoff.

Switching to LFPs shaved almost 1,000 pounds from the vehicle, more than doubled the vehicle's range, gained back the vehicle's original acceleration, and nearly halved its energy use per mile. To see why I experienced such a dramatic improvement, we need to compare the batteries themselves.

The FLA reference battery is a standard 225 Ah, 6-volt golf cart battery (e.g., Trojan T105). The LFP reference batteries are high-capacity (180 to 200 Ah), 3.2 volt prismatic batteries. There are a variety of manufacturers and distributors for this type of battery, the most popular and available being the CALB SE180AHA, the Sinopoly LPF200AHA, and the FluxPower BATVXLFP200AH. In comparing, keep in mind that a golf-cart battery has three cells for about 6 V, whereas the LFP prismatics come as single cells (packs of 4 cells for 12 V are also available). The comparison table values based on watt-hours (Wh) provide an apples-to-apples comparison because they relate to stored energy. Except where noted, the table characteristics come from manufacturers' specification sheets. The LFP column is the average of the specifications for the three popular LFP models, whose values differ by 10% or less.

Electrical, Physical & Environmental Comparison

	Flooded Lead-Acid (FLA)	LFP (LiFePO4) Lithium-Ion
Reference battery	Trojan Golf Cart	180–200 Ah Prismatics
Nominal cell volts	2.0	3.2
Cell capacity (Ah at 20 hr. rate)	225	190
Cell volume (in.^{3})	268	265
Cell weight (lbs.)	20.7	13.1
Cell energy capacity (Wh)	450	608
Volume per Wh (in.^{3})	0.596	0.402
Weight per Wh (lbs.)	0.046	0.021
Recommended discharge amps	45	57
Max. continuous discharge amps	500*	570
Peak discharge amps	not specified	950 (10 sec. max.)
Recommended charge amps	23	57
Max. charge amps	Not specified	570
Max. float volts per cell (77°F)	2.20	Check with manufacturer
Max. charge volts per cell (77°F)	2.45	3.6 – 3.9
Max. equalize volts per cell (77°F)	2.58	Not applicable
Max. volts per cell (77°F)	2.70	3.6 – 3.9
Min. discharge voltage per cell	1.75	2.5 – 2.8
Impedance (mOhm) per 3.2 V	2.2*	0.6*
Usable charge temperature range	24.8°F – 125.6°F	32°F – 113°F
Usable discharge temperature range	-4°F – 113°F	-4°F – 131°F
Temperature effect (capacity @ temp)	50% @ -0.4°F 100% @ 80.6°F	92% @ -4°F 100% @ 77°F
Self discharge (per month @ 77°F)	4%	1 – 3%*

*Obtained from actual measurements or discussions with manufacturer—not from the product specification sheets

Of the many advantages of LFP over FLA, the most important may be the difference between their cycle life versus depth of discharge. The LFPs can be discharged more deeply, which means more usable energy. A typical FLA golf-cart battery has a life of about 1,000 cycles when discharged to 50% of its capacity each cycle. An FLA's life cycle drops rapidly when the depth of discharge is increased above 50%. LFP batteries have a life of about 3,000 cycles when discharged by 70% each cycle (about 2,000 cycles when discharged by 80%). This factor plays significantly into the total payback of these batteries.

Compared to flooded lead-acid batteries, lithium iron phosphate batteries pack in more energy per physical size and weight.

Usable Energy Comparison

	Flooded Lead-Acid (FLA)	LFP (LiFePO4) Lithium-Ion
Reference battery	Trojan Golf Cart	180–200 Ah Prismatic
Recommended maximum depth of discharge	50%	70%
Cycle life	1,000	3,000 (2,000 @ 80%)
Usable energy capacity (Wh)	675 (3 cells)	426 (1 cell)
Volume (in.^{3} per usable Wh)	1.19	0.570
Weight (lbs. per usable Wh)	0.092	0.030

The Sinopoly batteries, with the battery management boards, newly installed in the truck.

Other LFPs vs. FLA Advantages

Lighter weight. For about the same usable energy capacity, LFPs are about one-third the weight. The reduction of weight contributed significantly to my vehicle's increased acceleration and range, and decreased the amount of energy used per mile.

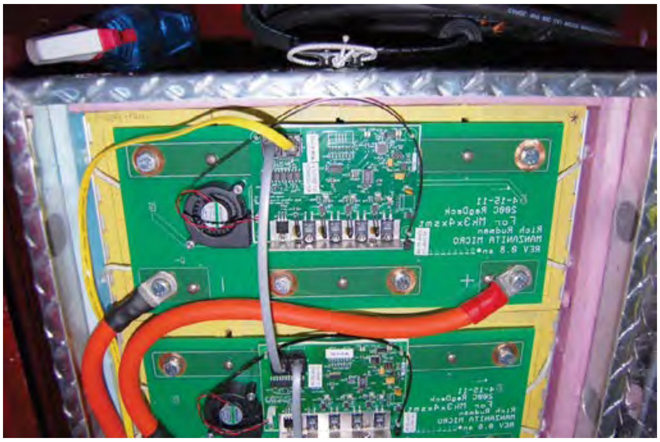
Less space. LFPs are about half of the volume of FLAs—I was able to consolidate all of my batteries in the bed of the pickup (instead of putting some under the hood), while retaining the pre-upgrade cargo space. This left more room under the hood for future enhancements, such as regenerative braking.

Improved capacity at low-temperatures. In cold (say, -4°F), the capacity of FLAs drops to about 50%. LFP capacity only drops by about 8% at that temperature. Although winters where I live aren't that cold, I still had to reduce my winter driving range expectations by about 25% with FLAs—with LFPs my range reduction is less than 10%.

Steady discharge voltage & low impedance. An FLA's discharge voltage tapers significantly as its state-of-charge decreases, whereas an LFP's remains fairly constant until the battery is close to empty. Also, with one-quarter of the internal resistance (impedance) of FLAs, LFPs supply more power to the motor and lose less to heat. The steady discharge voltage and the lower impedance, along with the weight reduction, also improved the vehicle's acceleration and range.

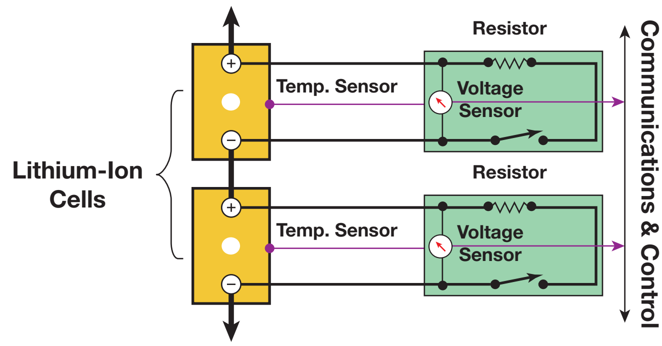
Higher charge & discharge current. LFPs can be safely charged and discharged at a much higher current than FLAs. A suitably large charger is capable of charging a nearly empty pack within about one-third of an hour (based on a 3C charge rate). To keep costs down, I kept my 30 A Manzanita Micro PFC-30 charger.

The on-board 30-amp charger.



A battery management system protects its cell by shunting current around it when it is full.

Battery Management System (BMS)



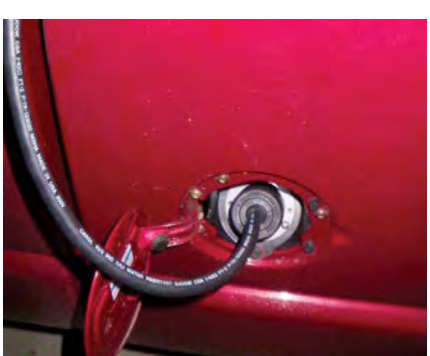
The higher discharge capability allowed me to increase the battery amp setting on my Zilla controller, adding a few more horsepower to improve acceleration.

Less self-discharge. When not being charged, FLAs can lose 4% to 15% of their energy per month (depending on temperature), compared to 1% to 3% for LFPs. I can now let my EV sit for long periods without having to worry about recharging the batteries.

In addition to these measurable ones, there are some less tangible advantages that also make a big difference:

No idle memory. Although a phenomenon that is not well-documented, experienced EVers know that FLAs temporarily lose capacity when left idle. Prior to the battery upgrade, if the EV was idle for several days, the apparent capacity on the first drive/charge cycle was reduced by up to 25%. LFPs don't experience this.

No maintenance. LFP batteries need no regular maintenance, eliminating the risk of damage that can result to FLAs if they are not watered—the reason that I got only 60% of the useful life out of my original batteries. There are "zero-maintenance" sealed lead-acid batteries, but these have a lower cycle life and a higher cost than vented FLAs, and they can still lose capacity if left in even a partially discharged state.



The AC input for the battery charger is accessed through the old fuel filler door.

Longer life. While this can vary widely depending on factors such as daily depth of discharge and LA battery type (marine, golf-cart, AGM, industrial, etc.) regularly used and properly maintained EV-type FLAs have a typical life of about five years; LFP batteries have a typical life of 10 years. With only 12 years of data on LFP technology, their true longevity is uncertain.

The Main Disadvantage

While Li-ion batteries offer many benefits for EV applications, the main disadvantage (other than cost) compared to FLAs is the need for a battery management system (BMS), particularly while being charged. The job of a BMS is to monitor the voltage and temperature of each cell to protect them from excessive charging and discharging. While any battery system, whether it be FLA or Li-ion, can be improved with a BMS, they are not typically used with FLA cells because, as long as all the batteries in a pack are of the same manufacturer, model, and age (ideally from the same manufactured batch) and have been treated equally, the individual cells tend to behave the same while being charged. However, LFP cells, even of the same manufactured batch, can vary in capacity, leading to dangerously elevated voltages on the full cells as the others are still being charged.

FLA cells tend to be fairly tolerant of brief periods of high charge voltage (it is recommended to periodically elevate charge voltage, known as an equalization charge, which gasses the electrolyte vigorously in an effort to remove water/acid stratification and bring weaker cells up to full). With Li-ion batteries, even a fraction of an hour at elevated voltage can cause damage. Highly overcharged cells will swell and create internal gas pockets that prevent electrolyte contact with the electrodes. This usually permanently damages the cell (cells can be damaged and not show swelling). In extreme cases, the swelling can cause a cell case to rupture, releasing volatile organic solvent gases, which can be caustic and flammable. It should be noted that LA batteries have their share of dangers, including explosions, and a very hazardous electrolyte.

The truck's in-cab battery monitors show battery state-of charge (top), and BMS cell voltage and temperature (bottom).

A BMS protects individual cells from over-voltage by shunting current around the full cells when they reach their "full" voltage, which allows the other cells to continue to charge. A good BMS can also detect when a cell is beginning to overheat (another sign of pending danger to cells) and shut off charging to the pack to protect all of the cells.

Battery Lifetime Price Comparison

Characteristic	Flooded Lead-Acid (FLA)	LFP (LiFePO4) Lithium-Ion*
Reference battery	Trojan Golf Cart	180–200 Ah Prismatic
Average price	$160	$270
Average price per Ah	$0.64	$1.40
Average price per Wh	$0.12	$0.44

Recommended Discharge Depth	Flooded Lead-Acid (FLA) 50%	LFP (LiFePO4) Lithium-Ion 70%	LFP (LiFePO4) Lithium-Ion 80%
Cycle life*	1,000	3,000	2,000
Usable energy capacity (kWh)	0.675	0.426	0.486
Lifetime kWh (cycles × usable capacity)	675	1,278	972
Average BMS price per cell	None	$35	$35
Lifetime price per kWh	$0.24	$0.24	$0.31

*190 Ah rating. **The long cycle life of LFPs potentially prevents using their full mileage capability within their lifetime.

A BMS can also help during discharge by signaling for disconnection of the load when individual cells drop below their minimum voltage. Cells discharged too deeply can be permanently damaged or, at minimum, have their capacity or cycle life permanently reduced.

All factory EVs, such as the Leaf and the Volt, have a BMS that performs these functions. Some also manage air or liquid cooling of cells, both during charge and discharge, to prevent thermal runaway (a condition where one overheated cell causes its neighbors to begin generating heat), and to help maintain peak battery efficiency. Typical EV conversions using prismatic, hard-cased LFP cells usually don't need active cooling for the cells because the cases have separators and air gaps built into them. This helps spread out the heat, and LFP chemistry (unlike some lithium-oxide-based chemistries) does not contain much internal oxygen, which can be a catalyst to thermal runaway.

The bottom line is that the risk of damage or danger is far too high to use Li-ion batteries without a battery management system. My upgraded conversion uses a relatively high-end BMS manufactured by Manzanita Micro (about $35 per cell). An optional display shows the state of each cell—both its voltage and temperature—in real time. Being a data-geek, I like to keep an eye on the whole system.

Is the Investment Worth It?

When I decided to go with LFP batteries, I dug into EV discussion forum (evdl.org) archives, and researched large-format Li-ion vendors. I settled on a set of 48, 200 Ah, 3.2 V cells manufactured by Winston (formerly Thundersky, now Sinopoly) of China, and sold by Manzanita Micro, for $15,000 (with BMS).

The price comparison table compares the cost of a properly maintained FLA system and an LFP system using two reference batteries that are the most economical options available in both categories. It shows the lifetime price per kWh for the two battery types. Note that the up-front price per unit of storage (Wh) of LFPs is nearly four times higher than FLAs. But the LFP lifetime energy capacity (usable energy multiplied by cycle life) is much higher than the FLA. Thus, even with the additional cost of a BMS (ranging from $15 to $50 per cell) the total lifetime price per kWh for LFPs is very close when using a 70% depth of discharge, and somewhat worse than FLA when using an 80% depth of discharge.

The long cycle life of LFPs potentially prevents the ability to use the full mileage capability of those batteries within the 10-year expected battery longevity. With my vehicle's 400 Wh per mile, this can yield 153,000 miles. With an average annual driving distance of 7,500 miles, that's about 20 years. However, the true longevity of LFPs is unknown since this type of battery was first put into use only 12 years ago.

The real comparison comes by looking at your particular vehicle's performance, local energy costs, and the distances you intend to travel. The good lifetime price per kWh of LFPs, combined with the reduced energy cost per mile, is where the rubber meets the road. The cost comparisons table shows the projected total cost of my two battery systems (pre- and post-upgrade), plus the electrical energy used to charge them over a 10-year period, with my particular EV, using my electrical rate of $0.09 per kWh, an average commute of 25 miles, and my average annual driving distance of 7,500 miles. Even without using the full kWh lifetime capacity of my LFP batteries, the 10-year total cost is nearly $3,800 less, or 82% of the cost of FLAs.

I've been driving my LFP-upgraded GMC Sonoma EV conversion for about a year and have put about 7,500 miles and 200 cycles on the LFP batteries. Compared to using FLAs, LFPs give about twice the range (with very little range reduction in cold weather), much better acceleration, and zero maintenance. Compared to FLAs, they only use about half the energy per mile, and this is with LFPs that have 77% of my original FLAs' energy storage capacity (200 Ah vs. 260 Ah). The advantages gained were well worth the higher up front cost. What next? The new batteries are now capable of supplying more power than my 9-inch DC motor can consistently take, so I am preparing my EV for a higher-power AC motor, which will be more efficient and provide regenerative braking, promising to extend the EV's range even farther.

Randy shows off his Li-ion-powered truck.

Vehicle Performance

Number of batteries	24	48
Battery voltage	6.0	3.2
Capacity (Ah)	260	200
Cost	$3,300 (in 2006) $5,500 (2011 price)	$15,000 (w/BMS; in 2011)
Usable energy storage (kWh)	19 (50% of 37 kWh)	25 (80% of 31 kWh)
Battery weight (lbs.)	1,730	775
Vehicle weight (with batteries)	5,000 lbs.	4,045 lbs.
Typical driving range (miles)	25	60
Max. driving range (miles)	40	75
Acceleration, 0–60 mph (sec.)	35	21
Energy per mile (approx. kWh)	0.75	0.40

10-Year Projected Costs

Characteristics	Pre- Upgrade	Post- Upgrade
Battery Type	FLA[a]	LFP
Energy use per mile (kWh)	0.75	0.40
Energy price (per kWh)	$0.09	$0.09
Price per mile	$0.07	$0.04
Avg. miles per charge cycle	25	25[c]
Battery life cycles	1,000[b]	3,000[c]
Battery lifetime mileage	25,000	75,000
Avg. annual miles driven	7,500[d]	7,500[d]
Battery longevity (Yrs.)	3.3[e]	10.0
Battery system price	$5,500	$15,000
Battery cost per year	$1,650	$1,500
Energy cost per year	$506	$270
Total cost over 10 years	$21,560	$17,700

"Notes: a) The author's pre-upgrade FLA batteries were Trojan T-145s, slightly larger and more expensive than the T-105s commonly used in EVs and shown in the other comparison tables. b) Had the original FLA batteries been properly maintained, this is the cycle life that could have been expected. c) 25 miles represents about 36% of the LFP battery capacity, which will probably yield a battery cycle life much greater than 3,000. d) 7,500 miles per year is significantly less than the national U.S. average, but EVs are used for commuting, not long-distance driving. Thus, they typically experience much lower annual driving distances. Due to circumstances, I was driving considerably less than 7,500 miles per year before the battery upgrade. e) Although a well-maintained FLA battery should be capable of lasting five years, in this case, the battery's 1,000-cycle life is reached within 3.3 years. The author's FLA batteries died at three years, but that was due to neglect, not because the cycle life had been reached.

Access

After earning his electrical engineering degree, Randy Richmond (Randy@RightHandEng.com) went to work for the telecom industry. In 1999, Randy founded RightHand Engineering LLC, which makes products for monitoring RE systems. He is a professional engineer and offers design, test, educational, and consulting services for Li-ion-based power systems.

Large-Format LFP Manufacturers:

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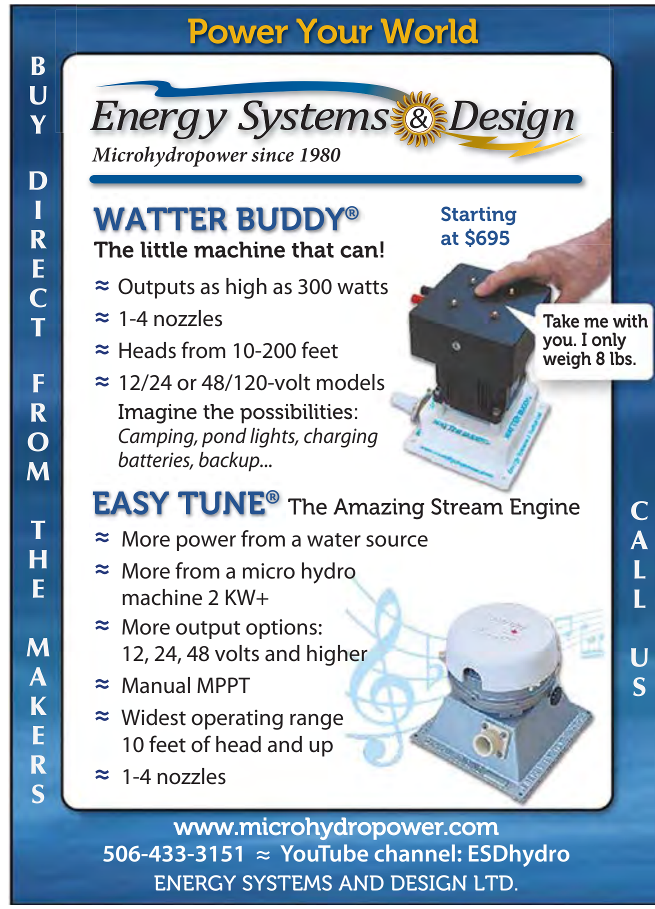
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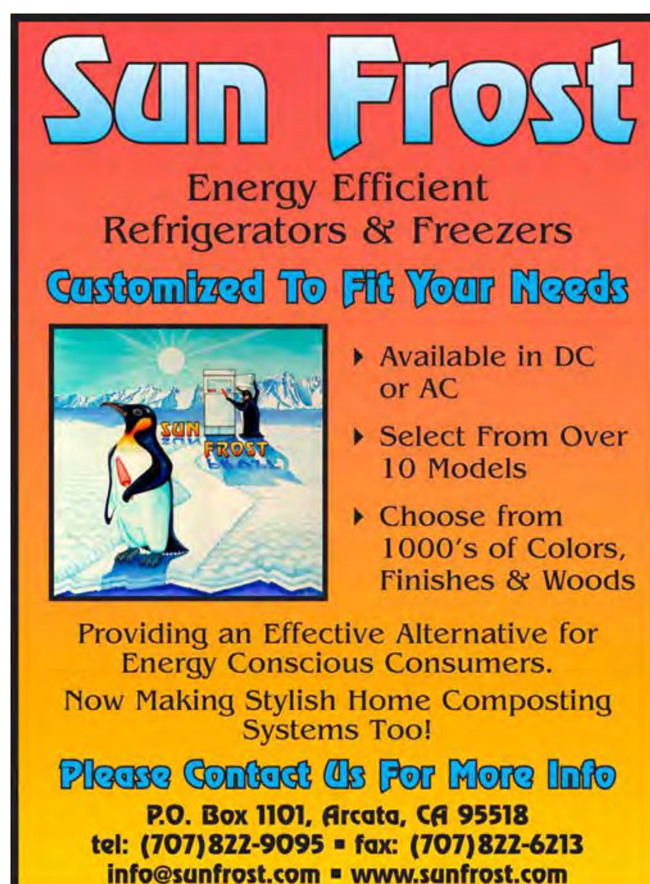
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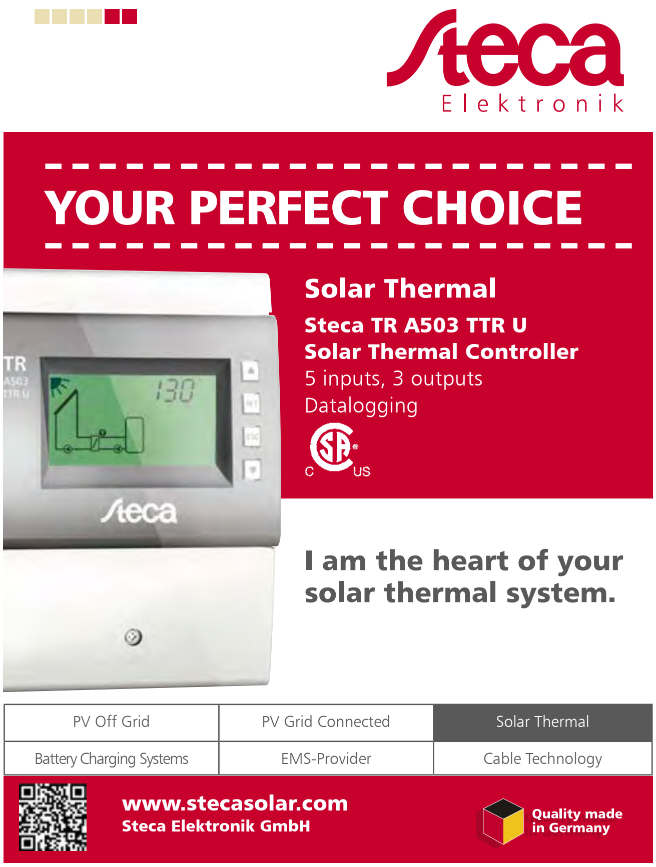
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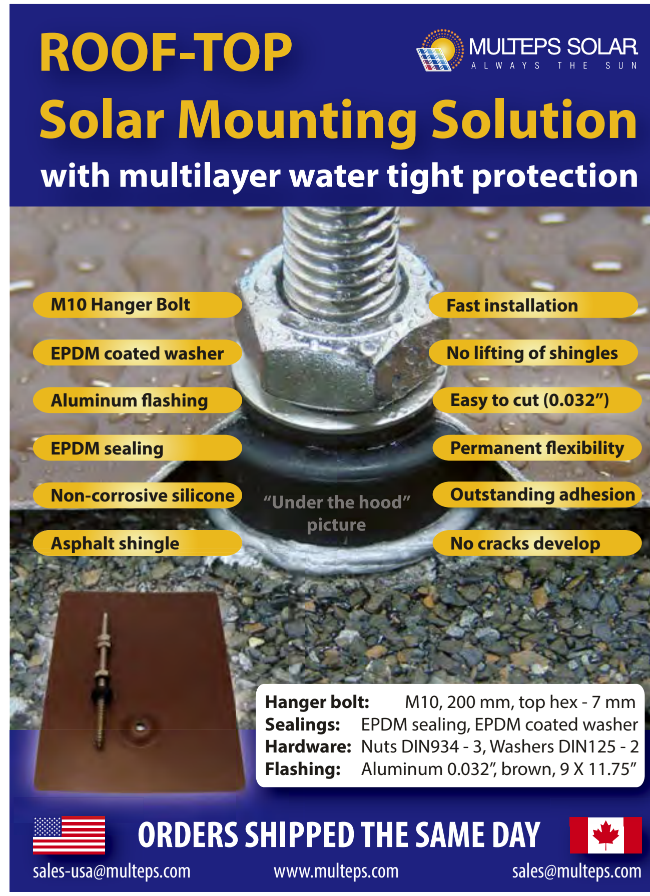
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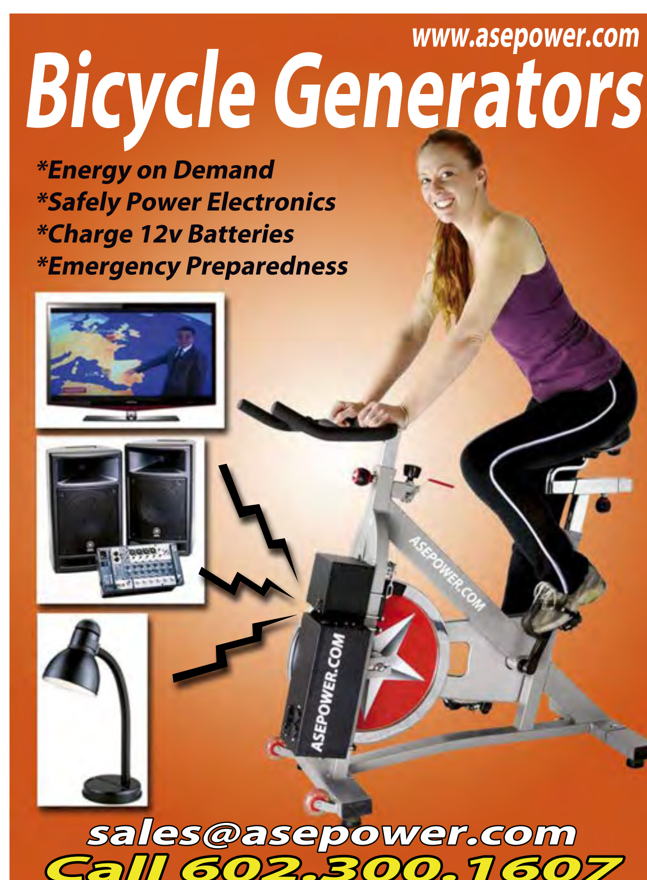
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Passive strategies can help your home keep its cool during the hot summer months and cut down on air conditioning use.

Traditional architecture in hot, humid climates makes use of deep porches and tall windows to help a home stay cool.

Cooling Your Home *Efficiently*

with Claire Anderson

In hot, arid climates, shaded windows and ample thermal mass work in concert to slow heat transfer into a home and keep interior spaces comfortable.

In the days before mechanical cooling systems, architecture responded to the climate. In the humid Southeast, where cooling needs predominated, houses had big porches, deep eaves, high ceilings, and plenty of well-placed windows to encourage cross-ventilation. In the desert Southwest, the thermal mass of earthen berms and adobe blocks helped slow heat transfer through the walls to keep interiors cool. But mechanical systems that could operate independently of the weather—keeping a home's interior at a steady temperature—changed our architecture, and many of the features that were once relied on for achieving comfort without energy input were shunted to the wayside.

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Fifty years later, we're beyond the age of cheap energy and we're again turning to traditional passive cooling strategies. Unlike mechanical air conditioning, passive cooling approaches take their cues from the area's climate—see the "Find Your Passive Cooling Path" sidebar. What's appropriate in Santa Fe, New Mexico, won't likely be effective in Savannah, Georgia.

Preventing heat from entering your home's roof, walls, and windows should be your first priority. Combat this by using reflective surfaces, high insulation levels, heat-blocking window films or shades, and appropriately sized roof overhangs. Shading with vegetation and structures, and if you're building new, properly orienting your home, are also important.

Kelvin Hughes

Properly sized overhangs on this passive solar home help shade the upper story windows in the summer, keeping heat at bay. A pergola structure and awnings shade the windows and doors on the first floor.

Reflect It

According to the U.S. Department of Energy (DOE), dull, dark-colored exteriors can absorb 70% to 90% of the sun's radiant energy. And your home's roof could capture about 30% of this undesirable heat gain, depending on its pitch and orientation. Dark-colored roofs can reach temperatures of 150° or more in the summer.

White or light-colored roofing materials ("cool roofs") reflect sunlight, staying 50°F cooler than their darker counterparts, and reduce the amount of heat absorbed and passed through to the attic or to living spaces below. Three terms come into play with a cool roof material:

- **Solar reflectance (SR)** is the fraction of sunlight reflected by a surface. Measured on a scale from 0 to 1, an SR of 0.45, for example, would represent a roofing material that reflects 45% of the sun's light. The SR of a dark roofing material is usually between 0.05 and 0.20, while a light-colored roofing material may have an SR between 0.55 and 0.90.

- **Thermal emittance (TE)** measures how efficient a surface is at emitting thermal radiation. Like SR, it also uses a 0 to 1 scale. Nonmetallic surfaces typically are more efficient emitters, with TEs between 0.80 and 0.95. So even though a bare metal surface may reflect as much sunlight as a white surface, it will stay warmer in the sun because it has a lower TE.

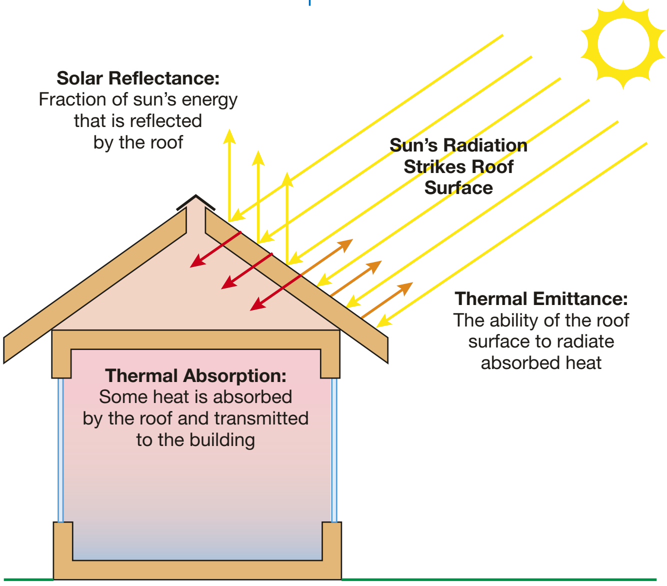
- **Solar reflectance index (SRI)** is a metric derived from SR and TE values. SRI uses a scale from 0 to 100; the higher the SRI, the cooler the roof will be in the sun.

The Cool Roof Rating Council (CRRC) tests roof products, assigning them a performance label that shows the measured SR and TE values. However, just because a product is listed in the CRRC directory does not make it a "cool" roof. A roof can qualify as "cool" by meeting or exceeding the minimum SRI requirement *or* by meeting or exceeding the minimum SR and TE values. Soiling and weathering affect a roof's surface properties over time, so values are also given for "three-year weathered conditions" to account for this.

While white roofs tend to be good reflectors, colored roofing materials can also be manufactured to reflect sunlight. Known as "cool dark-colored surfaces," these materials might reflect 40% of the incoming sunlight as compared to a conventional dark-colored surface, which might only reflect 20% of incoming sunlight.

Cool roofs are strongly recommended for climate zones 1 through 3 in the United States (see map and other information

Roof Surface Properties



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Dark asphalt shingles (top) can absorb as much as 90% of solar radiation, while some light-colored metal roofs (bottom) can *reflect* up to 90%.

Minimum Values for Cool Roofs

Roof Type	SR (3-year, aged)	AND	TE (new or aged)	OR	SRI (3-year, aged)
California Energy Commission					
Low-slope (2:12 pitch or less)	0.55		0.75		64
Steep slope	0.20		0.75		16
Energy Star					
Low-slope (2:12 pitch or less)	0.50		*not considered		0.50
Steep slope	0.15		*not considered		0.15
U.S. Green Building Council: LEED					
Low-slope (2:12 pitch or less)	NA		NA		78
Steep slope	NA		NA		29

in the DOE's Guidelines for Selecting Cool Roofs at bit.ly/CoolRoofGuide), where they can help achieve the greatest savings in cooling costs, although some microclimates may also call for cool roofs. (Be aware that in colder, heating-dominated climates installing a cool roof may *increase* energy costs.)

If you live in a cooling-dominated zone and are building new or replacing a roof, choose a roofing material with high reflectivity, like white and light-colored metal roofs or ceramic tiles. Most asphalt and fiberglass composite shingles, even light-colored ones, still absorb quite a bit of solar radiation. With these materials, installing radiant barriers directly underneath the roofing material or in your attic can minimize heat gain through your roof and ceiling.

Some places—for instance, South Carolina—have legislation that requires installing cool roofs on residences. The CRRC maintains a list of state codes, standards, and voluntary programs, organized by state (see Access).

Seal & Insulate

No matter what climate you live in, weather-stripping and caulking leaky windows and cracks to prevent air infiltration is a good idea. Next, check insulation levels—the more insulation your home has, the better. Insulation is relatively inexpensive, durable, and works year-round. The 2012 *International Energy Conservation Code* (*IECC*) has boosted its minimum insulation requirements for all but the mildest climates (see "2012 *IECC Minimum Insulation Levels*" table). If you have a limited budget for improvements, most experts recommend adding insulation to a home's attic first, since it is a major contributor to a home's heat gain.

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Attic insulation can often be the most economical thermal improvement, as it works in every season.

2009 & 2012 IECC Minimum Insulation Levels

Climate Zone	Ceiling R-Value		Wood Frame R-Value		Basement R-Value		Crawl Space R-Value	
	2009	2012	2009	2012	2009	2012	2009	2012
1	30	30	13	13	0	0	0	0
2	30	38	13	13	0	0	0	0
3	30	38	13	20 or 13 + 5[1]	5/13[2]	5/13	5/13	5/13
4 (except marine)	38	49	13	20 or 13 + 5	10/13	10/13	10/13	10/13
5 & 4 marine	38	49	20 or 13 + 5	20 + 5 or 13 + 5	10/13	15/19	10/13	15/19
6	49	49	20 or 13 + 5	20 + 5 or 13 + 5	15/19	15/19	10/13	15/19
7 & 8	49	49	21	20 + 5 or 13 + 5	15/19	15/19	10/13	15/19

Source: Energy Efficient Codes Coalition (2012 changes shown in darkened cells)

1. Commonly available insulation in 2-by-6 cavity (R-20) or in 2-by-4 cavity with sheathing (R-13 + x)

2. R-5 continuous insulation or R-13 for framed cavity insulation

Plan Ahead for Passive Cooling

If you are planning to build a new home, you can take tips from some of the historic homes in your region. In the South, wide porches, tall windows, and high ceilings all play a role in helping keep a home and its occupants cool(er). In the Southwest, thermal mass in the envelope (adobe brick walls) provides a buffer against the intense summer sun. In more temperate climates, a mix of these strategies married with a high-performance envelope can result in a home that needs very little, if any, mechanical cooling.

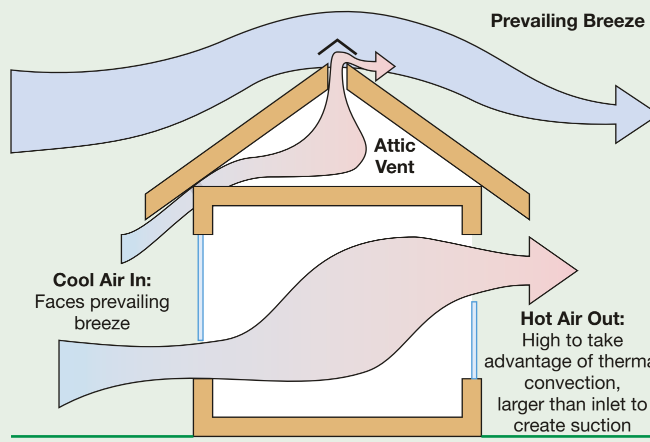
In most regions of the United States, "ranch-style" homes that orient their long axis east to west can be most successful when it comes to passive cooling and heating. This design minimizes the home's direct gain from the summer sun while maximizing its winter solar exposure.

Once the home's external shape has been determined, consider thermal zoning—placing living spaces based on the building's natural susceptibility to heat gain. In extremely hot climates, cluster main living spaces along the cooler north and east sides. Place buffer zones, such as garages or porches, on your home's west side to protect interior living spaces from gaining too much heat.

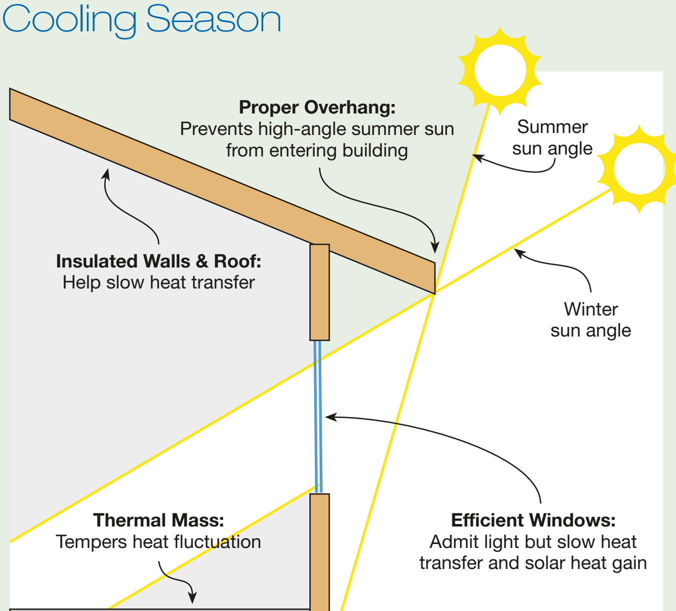
Carefully consider window placement and window type. Identifying the dominant summer wind direction at your site can be critical in your passive cooling plans, since you can tailor your window schedule to your site's specifics and use the prevailing breezes to your advantage. For example, casement, jalousie, and awning windows can act as air scoops, channeling breezes into a home. Windows placed on opposite sides of the house aid in cross-ventilation, routing air through the home instead of letting it stagnate.

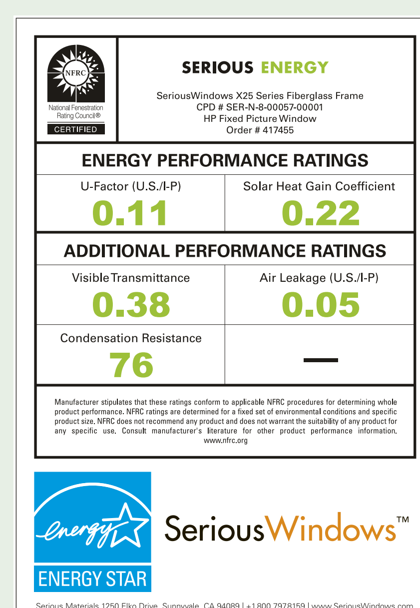
Depending on the climate, it's possible to do away with whole-house mechanical cooling. That's the strategy behind Passivhaus, but you don't necessarily have to build to these standards to be successful. The author's home in southern Oregon, where summertime maximum temperatures regularly climb into the 90s (and even top 100°F), was purposefully designed without a central cooling system. It has a reflective metal roof; 12 inches of ceiling insulation; and high-performance windows that were placed to capture prevailing winds. Thermal mass in the concrete floor and, to a lesser degree, in earthen plaster-coated walls, act in concert to create an envelope that is more resistant to thermal fluctuations. The active systems include ceiling fans in each room and nightly heat "flushing," which is accomplished by opening most of the windows in the house, including three clerestory windows that sit at the top of the north wall and a series of low awnings on the south wall. When the temperature outside starts to drop, windows are opened to let in the cool night breezes When temperatures start to climb in the morning, windows are shut, capturing the "coolth"—for free.

Design to Catch Prevailing Winds



Design to Prevent Solar Gain During Cooling Season





Windows with low values for U-factor, solar heat gain coefficient, and air leakage have better heat-stopping capabilities for cooling-dominated climates.

Create Shade

According to the National Renewable Energy Laboratory, shading your home can decrease indoor temperatures by at least 20°F. Shading may be accomplished naturally (shrubs, vines, and trees) or with built structures.

Trees and other plants placed around the house can provide seasonal shade and help lower the localized air temperature, since the leaves absorb heat and remove it through transpiration. But plan your planting wisely—placing vegetation against a wall stifles airflow, making your house even warmer, and also can damage siding. For cooling purposes, shrubs and small trees can work well to shade east- and west-facing windows. If your goal is also to capture passive solar gain in the winter, keep trees out of your solar window to the south. Even bare branches can create significant shade, reducing your solar gain in the wintertime. Deciduous vines, planted close to but not up against your home, may be a better choice, as their seasonal leaf loss, die-back, and much finer branches may not block passive solar gain during the winter.

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Retractable awnings can provide adjustable shading (and rain protection) with the changes in the weather and seasons.

Deciduous vines on a trellis can provide seasonal shading, while allowing light through in the winter.

Courtesy: passivehouse.us

Exterior shades and (to a lesser degree) interior shades can also help prevent overheating, although exterior shades are generally superior because they block sunlight *before* it enters a home. Another option that fits both summer passive cooling and winter passive heating goals is adjustable overhangs, such as retractable awnings. Rolling panels and shutters attached to the wall on either side of a window can also filter out some of the sun's energy, although they'll also restrict views. Other shading options include roll-up shades, which are best mounted on the home's exterior to prevent heat buildup inside the building.

Creating a cooling checklist—which lists each strategy and the estimated expense of implementing it—can help you identify the most cost-effective strategies for your home. Even if you can't retire your air conditioner for good, incorporating some of these methods can still save you energy and money—and make it easier to keep your cool.

Access

Home Power managing editor Claire Anderson (claire.anderson@homepower.com) keeps her cool in her passive and active solar home in southern Oregon.

Portions of this article were adapted from "Be Cool" (*HP108*).

Resources:

CRRC • coolroofs.org • Cool roofs

NCDC • ncdc.noaa.gov • Climate data

When Passive Strategies Aren't Enough

More Efficient Active Systems

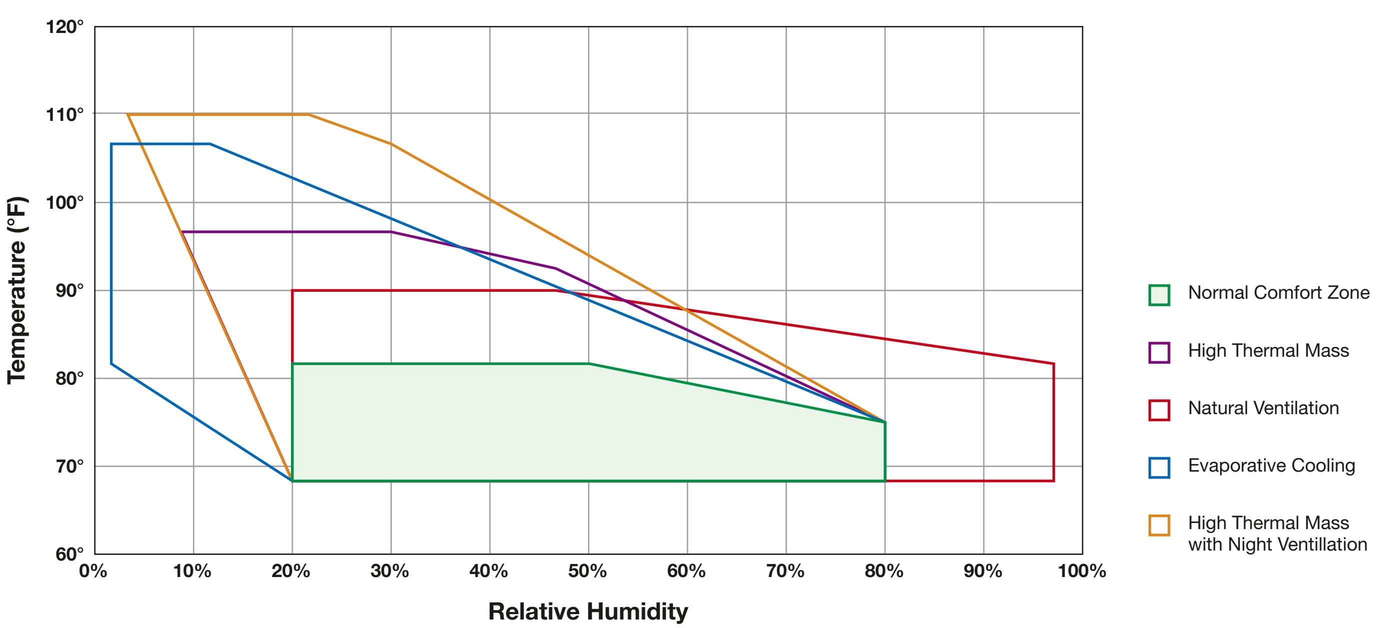
Comment & Discuss this article @ homepower.com/154.90

by Kathy Kelley

Passive strategies may not always be enough to beat the heat, depending on your home's age, construction, and location. And even though newer central air units are more efficient than their older counterparts, overall, central air conditioning systems use a lot of energy.

In 2005, the Energy Information Administration reported that air conditioning accounted for 8% of residential energy use, consuming 0.88 quadrillion Btu per year. Air conditioner use in the United States results in an average of about 100 million tons of carbon dioxide emissions from power plants every year. Here are some ways you may be able to avoid central air entirely.

Comfort Range by Cooling Method



Minisplit Systems

Although minisplit systems are often chosen by homeowners who have no existing ducts in their homes, their high energy efficiency makes them an excellent candidate for any home. Minisplits got their name because they have two components: an exterior compressor/condenser, and one or more interior units installed on a wall or ceiling.

Minisplit systems use air-source heat pump technology to provide cooling or heating. Refrigerant is pumped through tubing from the outdoor condenser and compressor to the indoor unit(s). In cooling mode, indoor air to be cooled is drawn across the unit's interior evaporator coil and distributed via a fan. Humidity is removed from the room's interior via a drain in the indoor unit.

Compressors of various sizes are available; the most powerful systems can support up to four indoor units and are capable of cooling an entire house (depending on size). Minisplit systems are energy efficient because they take advantage of zone cooling. Each interior unit is individually controlled to turn off cooling to a room or rooms when unneeded. Most, if not all, minisplit systems have a built-in timer so you can program when they turn on and off without being at the control.

Small and fairly unobtrusive minisplit indoor units require no ducts.

Courtesy Jim Riggins (2)

The minisplit exterior unit dumps the heat pulled out of the interior. In winter, the unit can run in reverse to produce heat.

Comparing Efficiency

Whether you're talking about central air, window air-conditioning units, or a minisplit system, there are two standards that measure cooling efficiency. The seasonal energy efficiency ratio (SEER) indicates the relative amount of energy needed to provide a specific cooling output. The energy efficiency ratio (EER) is defined as "the steady-state rate of heat energy removal in Btu (e.g., cooling capacity) by the equipment, divided by the steady-state rate of energy input to the equipment in watts." The higher the ratio, the less the unit will cost to operate.

Bob Lange, owner of Guardian Heating and Cooling in Chicago, believes the EER ratings are a better indicator of cooling efficiency. "The SEER number is the best-case scenario, tested at low humidity," he says.

If you attempt to compare SEER and EER, the Energy Star program suggests that an SEER of 14.5 for a central air system is roughly equivalent to an EER of 12 for a minisplit system.

The installed cost of a minisplit is more than the cost of a window unit (or units) but lower than central air (considering ductwork). Lange, whose company installs both central air conditioning and minisplit systems, has seen nothing but positive responses from his minisplit customers. "Usually I get very few calls from customers saying how satisfied they are with their [central] air conditioning, but just about every person who has a minisplit installed calls to say how much they enjoy it."

Central air conditioning ducts may leak conditioned air—an efficiency problem not possible with minisplits. The U.S. Department of Energy reports that duct losses can account for more than 30% of energy consumption for central A/C, especially if the ducts run through an unconditioned space such as an attic.

Solar Attic & Whole-House Fans

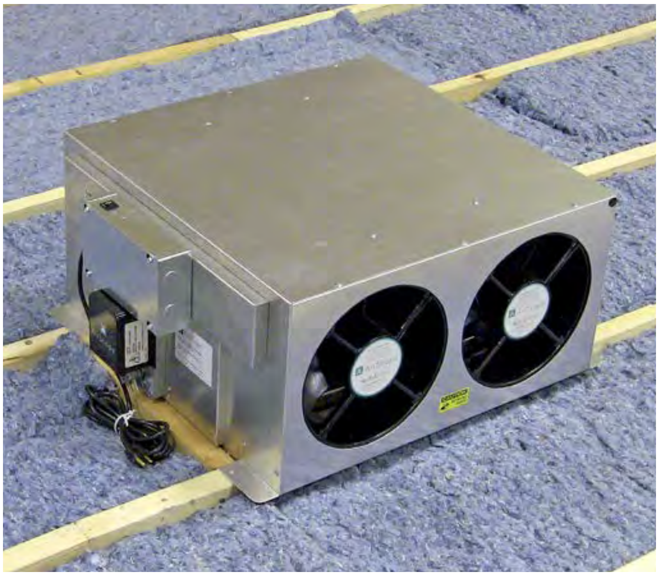
Many people confuse attic fans with whole-house fans, primarily because both are usually installed in the attic. Attic fans are designed to cool and ventilate the attic only. They help regulate the temperature of your roof, thereby extending the life of your roofing. They also reduce the amount of heat that radiates from the attic to the living space. If you already have central air, a solar attic fan is an excellent option for reducing your energy costs and your carbon footprint.

Whole-house fans are oversized exhaust fans that pull in cool air (from open windows) while expelling hot air. As the name implies, they're used to cool the entire house when the outside air temperature is lower than inside.

For houses with air conditioning, a strategy is to use whole-house fans to eliminate air conditioning use at night. On average, a whole-house fan uses 90% less energy than an air conditioner. Depending on your climate and your home's thermal mass, it may be possible to precool the entire house sufficiently overnight to avoid air conditioning entirely.

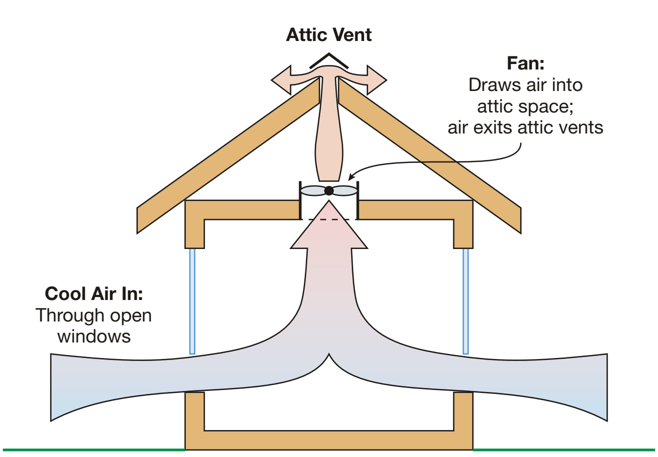
Attics are the preferred locations for whole-house fans for several reasons. Attics are vented and usually have space for equipment. They also provide a space for hot air to collect. The fan itself is installed in a centrally located hallway ceiling that opens into the attic floor. For houses without attics, homeowners may choose alternate fan locations, exhausting to a garage or crawl space. Most whole-house fans are designed to sit on top of the ceiling joists. Typically, cutting joists is unnecessary—the area directly below the whole-house fan is framed to form a channel for the air and support for the grille or backdraft damper. These self-closing dampers close by gravity and open when the fan's moving air pushes against them.

While backdraft dampers offer basic protection against debris (and rodents) from entering the house, they have no insulating qualities. These fans can be manually insulated in winter. A more expensive alternative is a whole-house fan with insulated doors. These use electric motors to open and close the doors.


Courtesy AirScape Fans

A whole-house fan exhausts hot air out through the attic space, or directly to the outside. Cooler air is drawn into the home through open windows.

Whole-House Fan Operation



Some whole-house fans use a remote fan connected to the plenum box with flexible ducts, which is a great acoustical attenuator. Pulling air through a duct consumes extra electricity, a consideration when you're weighing energy use. However, with careful selection of motors, duct size, and fan blades, this energy cost can be minimized.

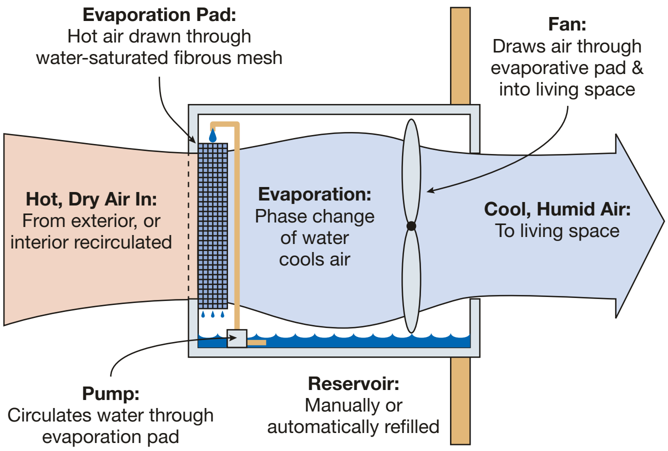
There are many factors that affect human comfort, from temperature and humidity to individual sensitivity. Based upon user feedback collected by Neil Smith, mechanical engineer and owner of AirScape Fans, a fan that delivers a minimum airflow per bedroom of 500 to 700 cubic feet per minute (CFM) is generally recognized as sufficient.

Computer software can predict energy performance quite well, including how whole-house fans will cool a house. For more information, see "Cheaper, Efficient Cooling with Whole House Fans" in *HP140*. For more about attic ventilation and attic fans, see bit.ly/AtticFans.

Evaporative (Swamp) Coolers

Probably the oldest form of air cooling, the technique of evaporative cooling dates back to ancient Egypt. People would hang wet mats in their doorways, hoping to make the most of a cool breeze. The richest Egyptians would have slaves fan large clay pots of water to keep the air moist while they slept. Evaporative cooling was also widely practiced in the Americas from colonial times on as people hung wet sheets on their sleeping porches on hot nights.

Evaporative Cooling



Evaporative coolers work well in hot, dry climates.

Courtesy Rollswell Electric Appliances & Equipment Co. Ltd.

Today, evaporative coolers work on the same principle. Outside air is drawn over water-saturated pads by a fan. The water evaporates, cooling the air by 15° to 40°F. Larger units can direct the cooled air through the home's ductwork for effective whole-house cooling. To allow the warm air to escape, you'll need to have at least one window open on the opposite side of the house.

Evaporative coolers are ideal for hot, dry climates. They cost about half as much to install as central air conditioners and use about one-quarter as much energy—for the fan and a small pump that keeps the pads saturated with water. The moistened pads filter the air to help keep dust and pollen out of the home. The disadvantages are that they require annual maintenance (changing pads), and are only suitable for arid climates.

Evaporative coolers may be installed with or without ductwork. Ducted systems can cool an entire house. If installed without ducts, evaporative coolers are usually placed in a central location as window units. Portable coolers aren't as effective as whole-house units. But they can cool a room by 5°F to 15°F, and may be used to cut back on air conditioning use at certain times of the year.

Evaporative coolers are rated in cubic feet per minute (CFM). It's easy to determine what CFM rating you need. First, calculate the square footage of the area you need to cool. Multiply this number by the height of your ceiling, then divide by two. The result is the CFM you'll need for a complete exchange of air every one to three minutes.

Access

Kathy Kelley writes about energy and environmental topics for the U.S. Navy. She is a regular contributor to *Currents*, the Navy's energy and environmental magazine. Last summer, her family installed a minisplit system in their home.

Labeling Requirements

by Brian Mehalic

The 2011 version of the *National Electrical Code (NEC)* expanded the labeling requirements for all types of PV systems. These requirements, in addition to those already in the *Code*, help to ensure quality workmanship; prevent confusion between AC and DC conductors; facilitate PV system service and maintenance; and help protect emergency responders. Additionally, the 2012 *International Fire Code* (*IFC*) has labeling requirements that mirror or, in some cases, expand on those of the *NEC.*

The various requirements are noted throughout the *NEC,* appearing in Articles 690 and 705, as well as in articles that are not specific to PV systems. For example, Section 110.22, "Identification of Disconnecting Means," requires that a disconnect be "legibly marked to indicate its purpose unless arranged so that the purpose is evident." This will be augmented by PV-specific requirements for marking. However, Articles 690 and 705 do not allow unmarked equipment even if its purpose is obvious.

The Labels

Labels and markings must be suitable for the location in which they will be installed. Section 110.21 states that "markings that indicate voltage, current, wattage, or other ratings shall be provided as specified elsewhere in this *Code*. The marking shall be of sufficient durability to withstand the environment involved." While requirements for materials may be based on the requirements of the authority having jurisdiction (AHJ), in general there are three choices: preprinted or customized stickers, engraved plastic, and engraved metal.

Depending on the location and the AHJ, a particular job may require more than one type. For instance, stickers may not be adequate for locations that receive direct sun, but their lower cost may make them preferable for interior applications (such as conduit inside an attic). Additionally, engraved signage and labels can still be read even if they are painted over; however, they do have longer lead times for their fabrication and higher cost, and care must be taken when choosing an adhesive for attaching them.

Circuit Routing

As with other changes made to protect firefighters working on buildings with PV systems, Section 690.4(F) requires marking the location of PV source and output circuits that are embedded in built-up, laminate, or membrane roofing in areas not covered by PV modules or system equipment. There are several products on the market to help accomplish this, the goal of which is to minimize or eliminate the chance of a firefighter accidentally cutting through energized PV circuits.

"Markings that indicate voltage, current, wattage, or other ratings shall be provided as specified elsewhere in this *Code*. The marking shall be of sufficient durability to withstand the environment involved."

Multiple Inverters & Power Sources

A new addition in 2011 that explicitly allows multiple inverters on a single building or structure, Section 690.4(H) also requires a directory to be installed—as per Section 705.10—when the inverters are not adjacent to each other. While not defined, a directory is a map and description of the equipment's location. Together, these sections require that the locations of all service disconnecting means, interconnected power production sources (PV systems), and accompanying AC and DC disconnects be identified via a directory at each of the noted locations. This can result in a lot of directories when equipment is spread out. An exception states that directories are not required when the equipment is all grouped at the main service disconnect. This directory requirement is also stated in Section 690.56(B).

GFDI Labeling

Most grid-connected PV systems are required to have ground-fault protection per Section 690.5. One of the section's requirements is to install, in a visible location near the ground-fault indicator, a label stating:

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

If a battery bank is part of the system, this label must be installed in a visible location at the battery bank. This label indicates to service personnel that voltage potential between conductors and grounded surfaces may differ from normal conditions after a ground fault has occurred.

Single 120 VAC Supply

In stand-alone systems, a 120 VAC inverter commonly provides power to service equipment that is designed for connection to 120/240 VAC, split-phase utility power. Section 690.10(C) allows this, which is accomplished by using a suitable jumper to connect both bus bars in the service equipment to the same single 120 VAC phase from the inverter. To reduce wire expense, multiwire branch circuits—where a single neutral conductor is used with two "hot" conductors on separate phases—are commonly installed in new construction. The neutral conductor never carries the sum of the current from the two circuits since they are out of phase with each other. However, if the two hot conductors are on the same phase—for example, being supplied by a 120 VAC inverter—then the currents will be additive on the neutral conductor, possibly overloading it. Because of this, the following label must be applied to the AC service equipment:

WARNING:
SINGLE 120-VOLT SUPPLY. DO NOT CONNECT MULTIWIRE BRANCH CIRCUITS.

Disconnecting Means

Section 690.14 contains two provisions for marking disconnecting means. Section 690.14(C)(2) states that PV system disconnecting means must be permanently marked as such. Section 690.14(D), which allows utility-interactive inverters in locations that are not readily accessible, refers again to 705.10, and requires directories at the locations of all service disconnecting means, interconnected power production sources, and accompanying AC and DC disconnects. Similar requirements are found in *IFC* 605.11.1.1 and 605.11.1.4.

New to the 2011 *NEC* is the requirement that disconnecting means be within sight (visible at 50 feet or less) of all fuses that cannot be isolated from energized circuits. This applies to source-circuit fuses in combiner boxes as well as fusing in larger inverters with re- or subcombiners. When the disconnecting means are more than six feet from the associated fuses (even if they are still visible), a directory indicating the location of the disconnecting means must be installed at the fuse location.

Per Section 690.16(B), disconnecting means that are not load-break-rated, such as module quick connects (leads) and touch-safe fuse holders in combiner boxes, must be marked "Do not open under load." Typically, these components will already be marked by the manufacturer. However, this label warning is a reminder to those working on the system that the absence of current must be verified, to avoid a potentially dangerous arc.

Section 690.17 requires the following label be applied to any disconnecting means where both the line and load side terminals may be energized when the switch is off.

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

In particular, this applies to the DC side of PV systems. When the DC disconnect is off, the line-side terminals can still be energized by the PV array, and the load-side terminals can still be energized by the inverter's capacitors. (This is also the reason why manufacturers typically require a five-minute waiting period after all power sources have been shut off before removing the inverter cover.) For the majority of disconnect switches, which are similar to the disconnect on the AC side of a grid-connected system, this is not a normal condition. Rather, when the AC disconnect is off, it is still energized on the line side via the utility, but the load side of the switch is not energized since the inverter is required to shut down after a loss of grid power.

"When the DC disconnect is off, the line-side terminals can still be energized by the PV array, and the load-side terminals can still be energized by the inverter's capacitors."

Chapter IV: Wiring Methods

New to the 2011 *NEC* are marking/labeling requirements in 690.31(E) for any exposed raceways or cable trays, pull box covers and junction boxes, and conduit bodies (with unused openings) inside a building that contain "Photovoltaic Power Source" conductors. They must be labeled as such, using a "permanently affixed label or other approved permanent marking." This Section further states that the labels must be visible after installation; spaced not more than every 10 feet; suitable for the environment; and, when there is a separation, such as a conduit running through a wall, must appear on both sides of the wall. The 2012 *IFC* Sections 605.11.1.1, .2, and .4 extend these requirements, with similar language and intentions, to the outside of the building. They add the requirement that the labels be reflective, with a white-on-red background; the letters be all capitals, with a minimum height of 3/8 inch; and that the labels be placed within 1 foot of all turns or bends.

690.35 Ungrounded Systems

Ungrounded PV arrays are becoming more common for a variety of reasons, including their enhanced ground-fault protection. Because neither the positive or negative conductors are connected to ground, the only potential should be between positive and negative, not between either current-carrying conductor and ground. The following label is required at "each junction box, combiner box, disconnect, and device where energized, ungrounded conductors may be exposed during service."

WARNING:
ELECTRIC SHOCK HAZARD.
THE DC CONDUCTORS OF THIS
PHOTOVOLTAIC SYSTEM ARE UNGROUNDED
AND MAY BE ENERGIZED.

Chapter VI. Marking

NEC Sections 690.51 and 52 apply to the rated and operating characteristics of PV modules and AC modules, and should be marked on the products by the manufacturer as part of the NRTL testing and listing requirements. Section 690.53 requires the DC PV power source disconnecting means be marked by the system installer with:

1. The rated maximum power point current (module Imp × number of PV source circuits in parallel).
2. The rated maximum power-point voltage (module Vmp × number of PV modules in a source circuit).
3. The maximum system voltage, calculated per Section 690.7.
4. The short-circuit current, with an informational note referring to Section 690.8(A) for calculating maximum circuit current (module Isc × 1.25 × number of PV source circuits in parallel). Note that this terminology is slightly confusing, but calculating the value as Isc × 1.25 ensures that, even during high irradiance, current will not exceed the value on this label.
5. The maximum rated output current of the charge controller (if installed) per its specifications.

This label will be specific to the installation, as the values will vary based on the array configuration and size, the modules used, and the location (and corresponding low temperature value). Note that the Section 690.17 label is also required on this disconnect.

Section 690.54 requires that all points of interconnection between grid-connected systems and the utility be marked at the disconnecting means with:

1. The rated AC output current (per the inverter specifications).
2. The nominal AC operating voltage.

When energy storage is part of the PV system, Section 690.55 requires that the maximum voltage, the equalization voltage, and the polarity of the DC system grounded conductor (positive grounded, negative grounded, or ungrounded) be labeled, though the location of this label is not specified. Additionally, if it is a stand-alone system, then Section 690.56(A) requires a plaque or directory that states that the building has a stand-alone power system, and notes the location of its disconnecting means. This must be located on the building's exterior, in a readily visible location that is acceptable to the AHJ and, possibly, to the fire marshal or fire chief.

"Ungrounded PV arrays are becoming more common for a variety of reasons, including their enhanced ground-fault protection."

Article 705

Dealing with all types of power production systems interconnected to the grid, Article 705 has additional labeling requirements, as well as restating some of the PV system-specific requirements of Article 690. As mentioned, Section 705.10 requires directories at each service equipment location, as well as at the locations of all interconnected power production sources.

For load-side interconnections as permitted in Section 705.12(D), the location of all breakers supplying power to a load center or panel board must be marked—this applies to the main service disconnecting means as well as all back-fed PV system (inverter output circuit) breakers. Additionally, when the 120% allowance—permitted in Section 705.12(D)(2)—is being utilized and the sum of the breakers supplying power to the bus bar exceed the bus bar rating, the back-fed PV breakers must be located opposite of the main service breaker, and be marked:

WARNING:
INVERTER OUTPUT CONNECTION.
DO NOT RELOCATE THIS
OVERCURRENT DEVICE.

Access

Brian Mehalic (brian@solarenergy.org) is a NABCEP-certified PV installer and ISPQ-certified PV instructor. He has experience designing, installing, servicing, and inspecting both PV and solar thermal systems. He is a curriculum developer and instructor for Solar Energy International and a project engineer with O2 Energies.

A Real Gem

On Christmas Eve, I got a pre-holiday gift when the first seed catalog of the season arrived in our mailbox. I read each seed description carefully, marking the most favored varieties with a red pen and a dog-eared page. Later, I will hone those choices into a reasonable and affordable list.

I only grow open-pollinated seeds, and I try to save the seeds of the plants that do well in our microclimate. Every year I try out new varieties, trying to find the perfect vegetables that do well in the heat and in our dry, clay soil. Many plants do not grow so well here—that means I have space to try new seeds every year.

Finding a Gem

Early last spring, a photo of Glass Gem corn circulated on the Internet. It was pretty, multicolored, flint corn with an intriguing luster to its kernels. I tried to find seeds to buy, but the corn's photo and story had gone viral by then, and there were no seeds available. According to nativeseeds.org:

> *Like many heirloom treasures, Glass Gem corn has a name, a place, and a story. Its origin traces back to Carl Barnes, a part-Cherokee farmer living in Oklahoma. Barnes had an uncanny knack for corn breeding. More specifically, he*

excelled at selecting and saving seed from those cobs that exhibited vivid, translucent colors. Exactly how long Barnes worked on Glass Gem—how many successive seasons he carefully chose, saved, and replanted these special seeds—is unknown. But after many years, his painstaking efforts created a wondrous corn cultivar that has now captivated thousands of people around the world.

Approaching the end of his life, Barnes bestowed his precious seed collection to Greg Schoen, his corn-breeding protégé. The weighty responsibility of protecting these seeds was not lost on Schoen. While in the process of moving in 2010, he sought out a place to store a sampling of the collection to ensure its safekeeping. Schoen passed on several unique corn varieties to fellow seedsman Bill McDorman, who was owner at the time of Seeds Trust, a small family seed company then located in central Arizona. Curious about the oddly named Glass Gems, he planted a handful of seeds in his garden. The spectacular plants that emerged took him by surprise.

The story of Barnes, Schoen, and their remarkable corn is not unusual. For millennia, people have elegantly interacted with the plants that sustain them through careful selection and seed saving. This process, repeated year after year, changes and adapts the plants to take on any number of desirable characteristics, from enhanced color and flavor to disease resistance and hardiness.

I Get Some Seed

What history, what dedication, what an adventure in gardening! I was resigned to waiting to get my hands on this wonderful corn. I thought that maybe, by next year, the seed would be more plentiful.

One day, I followed an obscure thread on a gardening blog and ended up at Native Seeds/SEARCH—a nonprofit organization dedicated to promoting seed conservation (nativeseeds.org). They had Glass Gem Indian corn seed available. Not wanting to be greedy, I ordered a single packet of seeds immediately. Two days later, the still wildly popular seeds were no longer available on the website, but mine were on their way.

I was already growing a crop of Golden Bantam sweet corn in the lower garden. My husband Bob-O added manure and tilled a new corn patch 200 yards farther up the canyon. Corn is cross-pollinated by wind, not bees. I was kind of worried about the new bed's location, as the packet description said the corn "does not like heat or wind." That new bed gets summer sun, all day long, and gets the down-canyon wind that drives our wind turbine, spring through fall. But, a lot of times, gardening is about taking chances.

The seed packet did not have any information printed about the number of days to maturity, but my research about flint corn and popcorn told me 80 days to maturity seemed a good guess. I like to soak my corn seed until it sprouts, then I plant it in a seedling tray for three days. When the little corn plant is green and about 2 inches tall, I replant it into the ground. This sounds like a bunch of work, but I wanted to do everything I could to ensure the corn's survival. Runs of hoses, with a water dripper placed every 12 inches, supply water to the plants. I lay these hoses on top of the rows, turn them on for 30 minutes, then go back and plant a corn plant in every wet spot.

Kathleen Jarschke-Schultze

My Glass Gem corn did surprisingly well. The corn grew about seven feet tall. Some stalks had as many as five ears sticking out like oat spears. There was a rainbow of colors—reds, oranges, purples, and even greens—although all of the ears from a particular plant had the same color scheme. For instance, if a plant had ears of white pearlescent kernels dotted with pink and blue accents (I dubbed this "wedding corn") then every ear from that plant would be wedding corn.

I harvested the ears and, as they dried, played with them. I grouped the ears by color. I spread them in a graduated color rainbow of corn. I made small groups containing one of each color scheme. It was so beautiful that I wanted to wear it like jewelry.

I grew this corn for seed. As soon as I planted the seed, I asked my gardening friends if they wanted some of my harvest. By the time I shucked the corn, I had quite a long list of seed beneficiaries. I felt very good about growing and sharing an extraordinary heirloom like this corn. I think the way to keep this variety going is to plant the seeds from the ears we like most.

I believe the Native American saying—We are Corn People. There is something that stirs your heart deeply when you are in a tall patch of beautiful corn. From the time the honey bees find the newly opened pollen tassels to stripping the last ear from its dried husk, the corn patch is inspiring. Every ear of this corn that I husked was a gorgeous gift, and for that I am grateful.

Access

Kathleen Jarschke-Schultze (kathleen.jarschke-schultze@homepower.com) is considering growing ancient grains at her off-grid home in northernmost California.

Solar
Hands-on workshops
Installer workshops
NABCEP CECs

Wind
Onsite demos
Workshops
Exhibitors

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Live building demos
Expert workshops
Exhibitors

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Common Electrical Terms

If you're new to the world of renewable energy—like PV, wind, or hydro—some of the industry terminology and jargon may feel beyond your reach. But never fear, just keep reading *Home Power* and soon the basic concepts will become clear. In the meantime, here are some brief explanations of basic terms you will often see describing electricity, including from renewable sources.

Alternating current (AC) is a flow of electrical current, which repeatedly reverses direction in an electrical circuit. It is the type of electrical current provided by utility companies, and results from the rotating magnetic fields in alternators.

Amperage (current, A) is the rate of the flow of electrons through a conductor—the amount of electrical charge that passes a particular point in a circuit. Current is measured in amps—1 amp = 6.24×10^{18} electrons per second.

An **amp-hour** (Ah) is 1 amp of current flowing for 1 hour. Amp-hours are the most common unit of measurement for a battery's capacity.

Direct current (DC) is the one-way flow of current—electrons move in the same direction. PV modules produce DC current, which can be stored in batteries.

Energy is the amount of power either consumed or produced during a quantity of time. It is commonly measured in watt-hours (Wh) or kilowatt-hours (kWh).

Hertz count the number of alternating cycles per second (frequency) when describing alternating current (AC). North American AC electrical systems are 60 Hertz, meaning they have 60 cycles per second.

Kilowatt-hour (kWh) is a unit of measurement for energy. One kWh is the equivalent of using 1,000 watts of power (or 1 kilowatt) for 1 hour, or 100 watts for 10 hours.

Ohm is the unit of measurement of resistance to the flow of electrons in an electrical circuit or wire. Resistance is often discussed during wire sizing, and is determined by factors such as conductor gauge (size of the wire's cross section), length, and temperature.

Ohm's law defines the relationship between voltage (V), current (A), and resistance (Ω, or Ohms), $V = A \times \Omega$. The same formula rearranged can calculate any of the values, so long as the other two are known: $A = V \div \Omega$; and $\Omega = V \div A$.

Parallel connections are electrical connections made with the same polarity (positive to positive; negative to negative). For example, a PV array with PV modules wired "in parallel" results in current being additive while voltage remains the same. (See "Series" for comparison.)

Polarity is either positive or negative, and determines the direction of electron flow in a circuit. A point in a circuit with negative polarity has more electrons than a point with positive polarity, causing those electrons to flow toward the positive side of the circuit.

Power (watts or W; kilowatts or kW) is the instantaneous rate at which electricity is transferred by an electric circuit. Power is calculated using the power formula, $P = V \times A$.

Series connections are electrical connections made one after the other. Commonly, those made between the positive wire of one PV module or battery and the negative wire of another. In a PV system wired "in series," voltage is additive, while current remains the same. (See "Parallel" for comparison.)

Voltage (V) is the unit of electrical pressure—the potential for pushing current through an electrical circuit.

Simple Electrical Relationships