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No Rooftop? No Problem!

Jeff Gilmore

There's no doubt about it, solar energy is still hot—PV systems continue to see substantial growth from year to year, with 7.7 gigawatts (GW)—that's 7,700,000 kW—of capacity projected to round out 2015, according to the Solar Energy Industry Association's "Solar Market Insight Report 2015, Q2." Compared to 2014 numbers, that's more than a 24% boost in installed capacity.

You, like many of our readers, may be proud to count your rooftop (or property) among the ever-growing number of on-site clean-energy generators. But if you are instead lamenting the lack of a well-oriented roof, have a tree-filled horizon, fighting a reluctant homeowner's association, or living in an apartment or condo—with no access for a personal PV system—don't let this dash your green dreams. According to the U.S. Department of Energy, almost half of U.S. homes and businesses are unable to accommodate a PV system. These impediments can be overcome, and community solar projects may be one solution for those without rooftop access or property for their own PV system.

Community solar is a growing segment of PV installations. These shared PV projects are often sited on public or jointly-owned property and offer their investor-owners a way to tap into the benefits of solar-produced electricity, even if they don't have rooftop space of their own. Almost half of the states now have some sort of community solar project in the works, and about a quarter have dedicated policies that encourage project implementation. Of the 68 megawatts (MW) of community solar installations, says SEIA, more than 33% of that total has come online since 2014.

There are several models of community solar projects, from utility-sponsored programs, where investors purchase a certain amount of solar-generated electricity for a set period (say, 20 years), to "special purpose entities," where individuals pool their financial resources to develop a shared PV project (for more info, see sharedrenewables.org).

Further encouraging the development of community solar farms is a recent ruling by the Internal Revenue Service that allowed an owner in a community-shared solar array to claim the 30% federal residential income tax credit (calculated on their portion of investment in the project). While tax accountants warn that this ruling may not apply to every situation, it is a bright development in the economic viability of similar projects.

No solar access? No problem. With a community solar array, you can still reap the benefits of solar energy. Check out the Interstate Renewable Energy Council's "Model Rules for Shared Renewable Energy Programs" to lay the groundwork for a local project (bit.ly/SharedSolar).

—Claire Anderson, for the *Home Power* crew

Think About It...

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—Alice Walker, author

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contents

24

Main Features

continued on page 6

On the Cover

The Fessenden/Adelman family at their Crested Butte, Colorado, home that utilizes passive solar design, solar thermal hydronics, and photovoltaic technologies to try to achieve net-zero energy use.

Photo by Lena Wilensky

34

44

Photos: Lena Wilensky; courtesy PowerSpout; SMA America


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Up Front

More Features

In Back

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Home Power (ISSN 1050-2416) is published bimonthly from offices in Phoenix, OR 97535. Periodicals postage paid at Ashland, OR, and at additional mailing offices. POSTMASTER: Send address corrections to Home Power, PO Box 520, Ashland, OR 97520.


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Home Power Managing Editor **Claire Anderson** lives in a passive solar, (almost) net-zero-energy home she and her husband designed. She and her family are developing their 4.6-acre homestead to incorporate more resilience in their energy, food, and water systems. Chickens were new additions this spring.

Brian Mehalic is a NABCEP-certified PV professional, with experience designing, installing, servicing, and inspecting all types and sizes of PV systems. He also is a curriculum developer and instructor for Solar Energy International and an independent contractor on a variety of PV projects.

Lena Wilensky was inspired to take leave from her high school teaching career to explore the world of renewable energy. She built her experience from Solar Energy International, taking classes and helping construct their PV Lab Yard, and now teaches PV Design and Installation classes around the country and online. She worked as an electrician in Crested Butte for several solar installers, and is thrilled to now own her own business.

Brad Berman is the editor of PluginCars.com and HybridCars.com. Brad writes about alternative energy cars for *The New York Times,* Reuters, and other publications. He is frequently quoted in national media outlets, such as *USA Today*, National Public Radio, and CNBC. Brad is the transportation editor at *Home Power* magazine.

Hugh Piggott lives off-grid on the northwest coast of Scotland. He builds small wind turbines, writes books about how to do so, and has taught construction courses around the world. Hugh also installs hydro and PV systems, and writes about off-grid renewable energy systems.

Home Power senior editor **Ian Woofenden** has lived off-grid in Washington's San Juan Islands for more than 30 years, and enjoys messing with solar, wind, wood, and people power technologies. In addition to his work with the magazine, he spreads RE knowledge via workshops in Costa Rica, lecturing, teaching, and consulting with homeowners.

Paul Cunningham moved off-grid in 1973 in New Brunswick, Canada. With his engineering background, he built several designs of water-powered generators to power his own home. This led to starting a business in 1980 selling plastic Pelton wheels and soon led to making complete machines. Today, the business has several employees and makes four types of hydro machines and several other products.

Justine Sanchez is *Home Power*'s principal technical editor. She's held NABCEP PV installer certification and is certified by IREC as a Master Trainer in Photovoltaics. An instructor with Solar Energy International since 1998, Justine leads PV Design courses. She previously worked with the National Renewable Energy Laboratory (NREL) in the Solar Radiation Resource Assessment Division. After leaving NREL, Justine installed PV systems with EV Solar Products in Chino Valley, Arizona.

Zeke Yewdall is the chief PV engineer for Mile Hi Solar in Loveland, Colorado, and has had the opportunity to inspect and upgrade many of the first systems installed during Colorado's rebate program, which began in 2005. He also has upgraded many older off-grid systems. He teaches PV design classes for Solar Energy International.

Thirty years ago, **Kathleen Jarschke-Schultze** answered a letter from a man named Bob-O who lived in the Salmon Mountains of California. She fell in love, and has been living off-grid with him ever since. *HP1* started a correspondence that led Kathleen and Bob-O to *Home Power* magazine in its formative years, and their histories have been intertwined ever since.

Michael Welch, a *Home Power* senior editor, is a renewable energy devotee who celebrated his 25th year of involvement with the magazine in 2015. He lives in an off-grid home in a redwood forest in Humboldt County, California, and works out of the solar-powered offices of Redwood Alliance in nearby Arcata. Since 1978, Michael has been a safe-energy, antinuclear activist, working on the permanent shutdown and decommissioning of the Humboldt Bay nuclear power plant.

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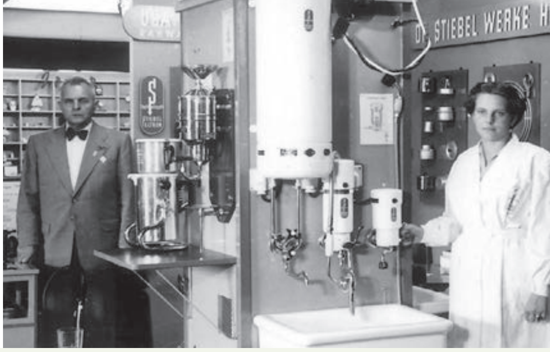

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Higher-Capacity 60-Cell PV Modules

Manufacturing advances allow 60-cell PV modules to reach 320 watts (historically, modules at that power required 72 cells). The lower module voltage offers more series-string options, while still maximizing array output per square foot.

Courtesy SolarWorld

SolarWorld Sunmodule Modules

SolarWorld (solarworld.com) released its Sunmodule Plus Mono module series, which increases power density using five bus bars (instead of the conventional three) that interconnect cells within the module. The additional bus bars decrease electron-hole pair-recombination within the PV cell by reducing the distance electrons need to travel. Thinner bus bars also create less "cell shadowing" overall. These factors boost module output of these 60-cell (p-type) modules by 5 watts over this module's predecessor. The series includes four modules with silver frames and white back-sheets, ranging from 285 to 300 watts. Maximum power voltage (Vmpp) and current (Impp) range from 31.3 to 31.6 V and 9.20 to 9.57 A, respectively.

LG Solar NeON 2 Modules

LG Solar (lg-solar.com) offers its NeON 2 modules featuring "cello technology," which utilizes a bus bar system of 12 thin circular-shaped wires—rather than three conventional (thicker) bus bars—which decrease electrical loss. The circular wires increase light absorption by scattering the light within the cell, rather than reflecting it out of the cell. These 60-cell modules also have a double-sided (n-type) cell structure to take more advantage of low-incident-angle light (i.e., in mornings and evenings). With black frames and a white back-sheet, four models range from 305 to 320 W. A 300 W model is available with a black back-sheet. Maximum power voltage (Vmpp) and current (Impp) range from 32.5 to 33.6 V and 9.26 to 9.53 A.

—Justine Sanchez

Courtesy LG Solar

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Hydro Measurements

Benjamin Root (2)

A comprehensive microhydro resource survey will include four measurements:

- Head (vertical drop)
- Flow
- Penstock length
- Transmission length

The last two measurements are fairly straightforward. Once you have established the location of the intake and the turbine, you can determine the best penstock route and then measure the distance, so you'll know how much pipe to buy. The transmission distance is similarly easy to determine once you know the locations of the turbine and the point of use for the energy.

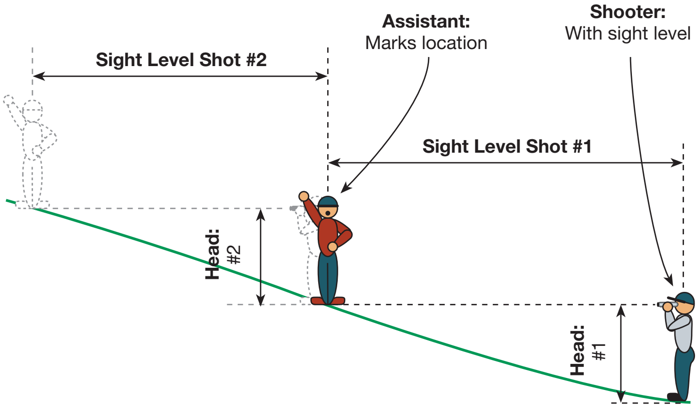
The first two measurements are not as easy, but they are critical to understanding the potential of your hydro site and how to develop it. Head and flow will determine what pipeline and turbine you choose, and will affect other hydro installation factors (see "Designing a Microhydro System" in this issue).

Measuring Head

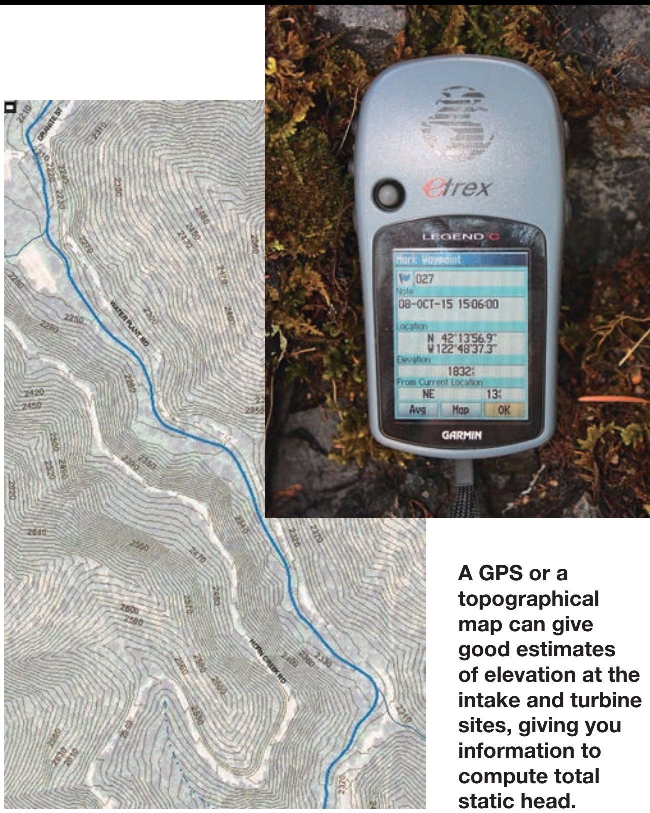
There are a number of ways to measure head. Which you choose will depend on your site and equipment.

If there is an **existing pipeline** on the site, such as a water supply pipe, it may be possible to use it to measure some or all of your head. Head, or vertical drop, is what determines pressure. Every 2.31 feet of vertical drop gives 1 pound per square inch (psi) of static water pressure. So a pressure gauge on an existing pipeline—with the water in the full pipe, but not flowing—can give you a very accurate head measurement for that portion of your site's vertical drop. Use a pressure gauge with good accuracy in the measurement range needed and make sure the pipe is full to the intake and there is no air in the line—an air vent just downstream of the intake can be useful in many systems.

Without a pipeline, using a level and a tape measure is common and accurate, if done carefully. A **sight level** is a simple and inexpensive tool that can be used with two people to measure sections, moving up the hill from the turbine site in stages. If the area is clear enough, it is helpful to have one person with brightly colored shoes going up the hill while a person below with a site level follows, shooting full-height levels (from the site-level person's eye to the bottoms of the brightly colored shoes), tallying each measurement.



Measuring head with a handheld sight level (see below) and a friend. Adding all of the legs determines the entire head.



A GPS or a topographical map can give good estimates of elevation at the intake and turbine sites, giving you information to compute total static head.

A **GPS** or altimeter can give a reasonable idea of different elevations if used properly. It's important to have an accurate device—there's a lot of variety in accuracy, and an error of 20% will give you an equivalent error in your power and energy predictions. If your altimeter is based on barometric pressure, do both measurements (proposed intake and powerhouse locations) on a stable weather day in a narrow period of time. Checking your device and method against a known elevation, and rechecking measurements will verify your data's accuracy.

Accurate **topographic maps** can give you solid information, especially for higher-head systems. Most of these maps don't show better than 20-foot elevation lines and, in lower-to-medium-head systems, this leaves a wide margin of error. But if you have a few hundred feet of head, that sort of inaccuracy may not be as important.

Using more than one method to confirm your head measurement often makes sense. Your whole system design will be affected by this measurement, so getting it right is worth the time and investment.

Measuring Flow

The smaller and more variable the stream, the more important it is to get good numbers. If you have lots of water, but are only going to use a small portion of it to generate electricity, it's less crucial that you accurately measure the total flow. How much water to take is not always an easy decision—finding a good balance between your energy desire and the ecosystem is wise.

If your stream's flow is variable, as most are, it's ideal to take measurements at various times of year. Measuring at the lowest and the highest flows is a bare minimum. Getting four seasonal or monthly measurements is ideal, so you can plan your system and energy production accordingly. You may find **flow records** of your stream from government agencies, past owners, or other sources, and these could be useful to confirm your own test results.

The **bucket method** can be used with most small streams, but you'll need another person to help. To capture all or most of the flow, set or dig in a container—from a small bucket to a 55-gallon drum—under a culvert or small waterfall in the stream. A stopwatch can track the time required for the container to fill. This method should be done multiple times to check accuracy.

The **float method** can be used to measure larger water courses that have a 10- to 20-foot segment of the stream that stays roughly the same in size and configuration. Measuring all dimensions of this segment carefully will give you a water volume in cubic inches or feet, which can be converted to gallons. Once you've calculated volume, time a float moving down this segment of the stream. With this time, you can estimate fairly accurately the flow, in gallons per minute.

The **weir method** employs a temporary dam with a measured notch opening, and a reference stake upstream of the weir. Once you see how many inches of water are flowing through the measured notch, flow tables can give you the actual stream flow. This method takes more preparation and gear, so may be your last choice, depending on the stream configuration.

With accurate head and flow numbers in hand, you'll have taken the first and most important steps in assessing your hydro site. Only then can you move forward with the design and installation of a home-scale hydro-electric system.

—Ian Woofenden

If you can get a container under the majority of the flow, the bucket method can be an easy way to measure it.

Benjamin Root (3)


Courtesy Pete Gruenderman

PV for Hot Water

PV has gotten cheap and is easy to install, providing opportunity to defect hot water heating from the electrical grid or from propane or heating oil. Electric resistance water heaters can be powered by direct current, straight from a PV array, with no batteries, no inverter, and no grid-tie. The PV is connected to the bottom element, with the top element still connected to the electric grid as a backup.

At one time, solar thermal was a tenth of the cost of PV. At about 50 cents per watt, solar thermal equipment is still cheaper than PV, but often not by enough to offset its higher installation and storage costs. A PV-based domestic hot water (DHW) system using a large electric water heater for storage, and a resistance element as the "heat exchanger" can be cheaper for homes with minimal hot water needs, and very much a DIY project. You can even use the water heater you already have. I use the 50-gallon unit that has been here since 2007.

Another benefit of using PV for DHW is that the distance from the array to storage isn't nearly as critical as it is with solar thermal. That's because electrical line loss can be lower than thermal loss and the cost of wire is so much less than plumbing plus insulation. With my PV array, the distance was 240 feet, but it cost just over $250 for the #8 cables to keep line loss under 2%.

For homes with more hot water needs, solar thermal may still be a less expensive option. A solar thermal system will collect more energy per collector area than a PV array. For modest hot water needs, such as for one or two people in a single-family home, using PV for hot water makes sense. Using PV for DHW also presents an opportunity for backup power, since the PV electricity could in a pinch be redirected to DC loads or to a battery-inverter system.

Pete Gruendeman • La Crosse, Wisconsin

Happy with Solar Electricity

The solar bug bit hard after a little practice with a PV electric fence charger, solar camp shower, solar oven, and home-built solar food dryer and beeswax melter. Interest increased with home study and two, one-week classes (Northwestern Michigan College NABCEP certificate of knowledge and Great Lakes Renewable Energy Association (GLREA) PV apprenticeship). Interest progressed into a grid-tied 3.3 kW, battery-based PV system, net-metered by Thumb Electric Cooperative (TEC) at my home. It is the first PV system connected to TEC, which was very cooperative and did the billing manually until the billing software

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was revised to handle it. The system has 16 Evergreen 205 W modules, a Xantrex 4548 inverter and charge controller, and eight golf-cart batteries.

The system design was one of the three projects submitted for the GLREA apprentice certification. For additional peace of mind, the design was later reviewed by the instructor of the NABCEP class. I took responsibility for purchasing materials, overseeing installation, and commissioning the system. The NABCEP instructor also took time from his busy schedule to visit the job site to consult my crew and me before installation, which started in October 2010. With full responsibility for the system, I personally quadruple-checked *all* connections. When energized, the inverter made a most beautiful humming sound that brought tears of joy to my eyes. Almost five years later, I still get emotional thinking about it.

I received a federal tax rebate the following spring. I perform battery maintenance quarterly. The system produces an average of 3,805 kWh per year. My rooster, Dutch, guards it closely.

Sonia Swartzendruber • Millington, Michigan


Courtesy Sonia Swartzendruber

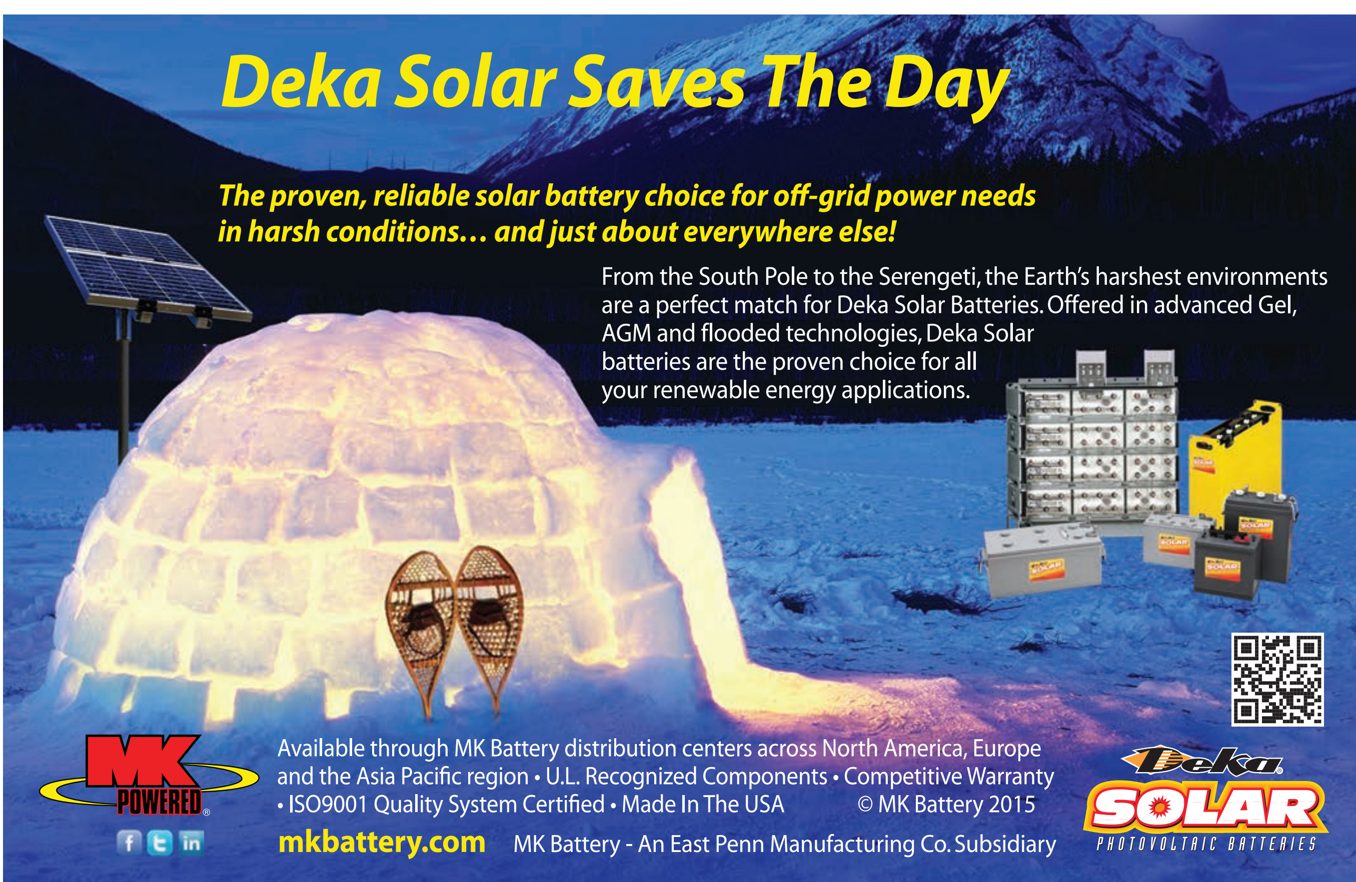
A Funny Solar Story

In 1999, our local utility was raising the rates through the roof. I had long dreamed of solar electricity and decided to go for it. Trouble was, I was renting the house I lived in and could not qualify for grid-tied incentives. So I went off-grid and built my system. I did tons of research—learning electrical codes, voltage drops, battery capacities, safe wiring, etc. And then I had to find the equipment.

Finally, the project was done. I hired a local electrician from a PV installation company to do my final inspection—I did not want to burn down the landlord's property. Up on the roof and smiling at my installation, he asked, "You got your information from *Home Power?*"

It was the first time I'd heard about the magazine, but that very night I subscribed. My first issue and each one since has shown me how to do complete systems. Oh, that I had known you in 1998! Thanks for a great publication!

Jim La Joie • via homepower.com



Michigan, Too

I read the "Florida Politics" letter by Glenn Hallick ("Mailbox" in *HP169*), and have to respond because the same thing is happening here in Michigan with Senate Bill 438. What is particularly disheartening is that our local utility only allows for 1% of peak demand for net-metering participation. Apparently, they're not satisfied with having 99%!

For the utilities to use the legal system in such a way is beyond pathetic. It's taking a step away from the environmental benefits of solar, negating the benefits of a grid resiliency through home solar (particularly in the summer), crushing the incentive for private individuals to spend money on solar, and affecting the jobs that make our local economy strong.

I wasn't sure how to rectify this issue other than to go off-grid—which we did. I now have a 7.8 kW PV array, 24 Surrette S550 batteries, and a 15 kW Generac generator. But I would much rather see the legal system used appropriately rather than as a tool to stop healthy and constructive progress.

Jack Fernard • Kzoo, MI

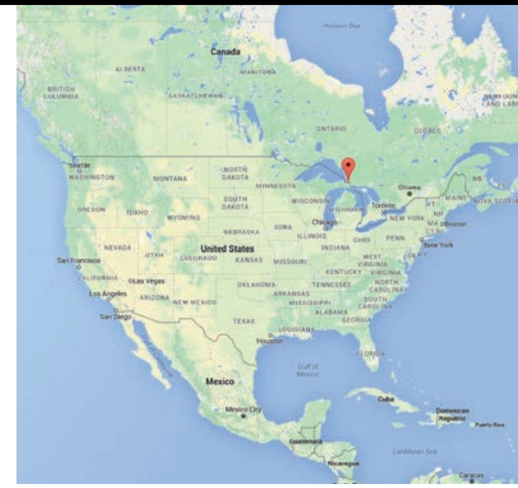
Seeking Off-Grid Homes to Visit

Great job on *Home Power!* The more people who can visualize a life with the least amount of energy consumption, the brighter the future. Green energy is the way to go. I am a certified electrician living in Sault Ste Marie, Ontario, Canada. I grew up in small communities such as Marathon and Manitouwadge, Ontario.

For many years, I have dreamed of building an off-grid house. I would like to spend the next couple of years visiting people who are living off the grid. This would be a great way to educate myself, and also inspire my wife and kids to see my dream.

If you are willing to have strangers visit you, please let me know by email. I would be happy to hear from *Home Power* readers in my region who are willing to share their experiences.

Mike St Jean • Sault Ste Marie, Ontario, Canada • mikestjean1@hotmail.com



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Sizing PV for a UPS

In third-world countries, there is frequently unscheduled load shedding by utilities. In some areas, service is on for one hour and off for two to three hours. As a result, batteries used for uninterruptible power supplies (UPSs) get drained quickly and ruined. I want to install a solar-electric module to fully charge the battery, at least during the daytime hours. Can you tell me how to calculate PV module size to match a battery's amp-hour capacity?

Kalim Khan • New York, New York

Many smaller UPSs are designed to run loads for only a few minutes—giving you enough time to shut down your electronics without them crashing from the utility outage. Check with the UPS manufacturer to see if there are maximum run-times for the inverter. Also, it is important to find out the maximum DC voltages the equipment can handle—it could be that the higher voltages from some 12 V solar modules could temporarily push the UPS battery voltage higher than its electronics can withstand. An appropriate solar charge controller will be needed in any case.

There are two sizing approaches to your situation: Either size the solar-electric module to refill the battery in one day or to offset (in real-time) the energy being taken from the battery.

Let's say you want to refill a depleted battery in one day of full winter sun. You need to know how much that takes, in watt-hours. A larger-than-typical UPS battery would be 20 amp-hours at 12 V, which would be 20 × 12 = 240 watt-hours. But you can probably access only 80% of that, so it would take 192 watt-hours from a solar-electric module to refill that emptied UPS battery.

You also need to know how much sun your site gets. If you live in India, your July resource might be an average of 5 daily peak sun-hours, so you'd need a 55 W PV module to serve this need:

192 Wh ÷ 5.0 sun-hours ÷ 0.7 system efficiency = 55 W

One or two of these Kyocera Solar 140 W PV modules could provide enough energy to keep a UPS battery from becoming overdischarged.

Of course, this is only an example for how to calculate the array sizing for refilling an empty battery. There are other important factors, such as a battery's depth of discharge, which shouldn't go too low, since that can shorten battery life.

If you wanted to keep up with usage while the sun is out (as your original question suggested), you need to know how much energy the UPS is drawing from the battery. Let's say, for example, you are using a laptop and used a watt-meter to measure a 70 W draw.

The conversion efficiency within the UPS is probably close to 80%.

70 W ÷ 0.8 UPS efficiency ÷ 0.7 system efficiency = 125 W

So you'd need a 125 W solar-electric module to run the laptop while the sun is at its fullest, around solar noon. But earlier or later in the day, the PV module won't get full sun; so you might want to consider doubling the module size.

I'd be tempted to employ a bigger battery and more solar production. Two 125 W PV modules would give plenty of off-peak energy for the example laptop or other things you might want to do. Don't forget to include a name-brand charge controller to prevent the battery from being overcharged.

For a good book that covers all the basics, including system sizing, I recommend *Solar Basics* by Neil Kaminar. You can find the solar resource for many places throughout the world on this Web site: bit.ly/NASAsolardata

Michael Welch • *Home Power* senior editor

Tall Towers vs. Efficiency

I've heard over and over that tall towers are very important for wind energy generation. But, how important? Is there no wind to be captured on short towers? Is there a dramatic difference between a tower just above the treetops and a tower way above the treetops? How do I decide tower height, balancing the cost of a taller tower with the increased production?

Also, sometimes I wonder if some wind experts get fixated on tall towers and don't pay enough attention to other important factors. How do I decide whether to spend my money on a more efficient machine or a taller tower? Thanks for any light you can shed on these issues.

Marvin Chessly • Memphis, Tennessee

Wind energy is generated by sustained wind power over a period of time. Wind power depends on the machine's efficiency, but variations in efficiency can be 20% or more. Wind power depends on the machine's rotor radius, squared—doubling the blade length will quadruple the power capture. But most importantly, wind power depends on the cube of the wind speed—doubling the wind speed will give eight times the power.

High above everything, the wind blows strong and straight. Closer to the treetops, it is slowed by friction and diverted into turbulent eddies. Below the level of treetops and roofs, there's a zone of high turbulence, with very little potential for energy capture. Gusts may come, zooming around and knocking over the garbage cans, and brief peaks of power might be experienced and captured, but only by

continued on page 22

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continued from page 20

a wind turbine that could respond quickly enough, and none of these exist. These types of winds yield no sustained power, and generate no real energy at this lower level.

Wind turbine experts often recite the 30/500 rule: "Put your turbine at least 30 feet above any obstacle within 500 feet." How much difference does it make? When you apply the cube law, the result is that there's twice as much energy 30 feet above the treetops than there is 10 feet above the treetops.

Turbine Height (feet)	Wind Speed (meters/second)	Energy (kWh/year)
60 ft.	3.7 m/s (8.3 mph)	700 kWh
70 ft.	4.1 m/s (9.6 mph)	1,000 kWh
90 ft.	5.3 m/s (11.9 mph)	2,100 kWh

A vertical-axis wind turbine mounted on a short tower and located within the trees is a recipe for wind energy system disappointment.

Courtesy Hugh Piggott

In most situations, small-scale wind energy is not a particularly viable technology, although wind power is fun for many, and it can also work fairly well at certain exceptional sites, or on very tall towers, where the wind speed is suitable. But all too often we see completely unrealistic installations on rooftops or among tall trees. Anyone who studies the energy production of such installations will conclude that wind turbines are a complete waste of time. And this is a shame because it tarnishes the reputation of renewable energy in general.

Hugh Piggott • Scoraig, Scotland

Module Degradation

We had a grid-tied solar-electric system installed on our house in 2006—10 Sanyo HIT modules. In 2013, a metal roof was installed for the rainwater catchment system. The PV modules were removed by my original installer and I noticed degradation along the conductor ribbons of bottom corner cells in seven of the modules. Damage varies from module to module, but does not yet extend beyond the bottom corner cell or two. We have not done a performance test because I am awaiting the feed-in tariff results from the utility to determine if the damage is sizable enough to have noticeably decreased production. My concern is continued degradation of the modules as they age.

My installer and I are considering what action to take. The module manufacturing quality warranty expired after five years, and I don't think the output warranty can be applied in this situation. I do not blame my installer's handling for the seal failure. I believe it was as a result of the manufacturer using sealing systems that were not robust, hence them only giving a five-year manufacturing warranty. We have not yet found a way to reestablish a watertight, weather-resistant seal. Has anyone developed an effective resealing process, or should I resign myself to replacing the defective modules?

Jack Herndon • via homepower.com

"Delamination" is apparent in the PV cells of several modules in this array, which was installed in 2006.

Courtesy Jack Herndon

This looks like a defect in the lamination process of the module, possibly chemical incompatibility between excess solder flux or the antireflective coating and the lamination, resulting in degradation of the EVA (ethylene vinyl acetate, part of the lamination). It does not appear, from the photo, to extend to the edge of the module, so resealing the module may not do much for an internal air bubble. Eventually, corrosion may form inside the air bubble, and the module could stop performing. Until then, there is not much that can be done. Finding a method of resealing it that is UV-resistant—so it won't yellow over time—is also difficult. (See http://bit.ly/ModDelam for more info.)

Remember that if you do anything to the module, you also void the 20- or 25-year power production warranty, which is still valid, and which would apply if corrosion does start forming in the lamination and causes the module to stop working. Documenting the issue with the manufacturer, and if possible, taking images with an infrared camera to see if heat is starting to form in the bus bar is probably the best course of action.

Until the last decade or so, it was uncommon for modules to have any sort of manufacturing warranty—the power production warranty was the only one, under the assumption that as long as the modules are producing the rated amount of power, they're still good. Many manufacturers' warranties still exclude things such as rust, scratches, discoloration, etc., that do not affect the module's output. Manufacturers have typically been hesitant to replace modules with various issues (like "snail trails" and discoloration) that have not conclusively been linked to power reduction. And, in some cases, instead of replacing a module that is not producing well, they will just pay the value of the power that it will not produce up to the end of the warranty period.

Fortunately, with a defect like this, corrosion usually causes a severe power decline (often an open circuit)—and that is easy to prove, unlike some of the other module degradation issues that may require more expensive tests to prove that the power has actually declined below the amount covered by the warranty.

Zeke Yewdall • Mile Hi Solar

Seeking Hydro Manufacturer & Installer

I live in Lewis County, Washington, and have completed all the feasibility work for a hydro system on my property. I'm ready to find a manufacturer/installer in my area—where do I start?

Dean Scott • via homepower.com

Finding a hydro turbine manufacturer and finding an installer are usually two different tasks. Though some of the smaller manufacturers get involved in local or even distant installations at times, they are not usually installation contractors, and are primarily focused on turbine design and manufacture. Fortunately, the small turbine manufacturers are small companies dedicated to customer service, so they tend to be very helpful with homeowners and contractors installing their products.

Check out *Home Power* advertisers for manufacturers of small hydro turbines. What turbine you choose will depend on the size of the resource and your energy needs, the specifics of head and flow at your site, as well as other factors such as price, availability, and location. See the hydro design article in this issue for more information.

Finding an experienced hydro installer is harder than finding a good turbine, since there are so few people and companies who do this work. I'd start by looking for renewable energy (primarily solar) installers in your region and inquiring with them about their hydro installation experience. If you don't find someone locally, you can either bring someone in from outside the area, or you can educate yourself and get involved in the installation directly, perhaps in collaboration with a solar electrician.

It's ideal to find an installer who has done numerous hydro systems and also understands the electrical/electronic side of things. But often for hydro systems, you'll need to lean on expertise from more than one person or company, since the folks who understand the electronics don't always have experience with the plumbing and its design principles, and vice versa.

See our many hydro articles in our online article archives for more information on system specification, design, and installation.

Ian Woofenden • Home Power senior editor

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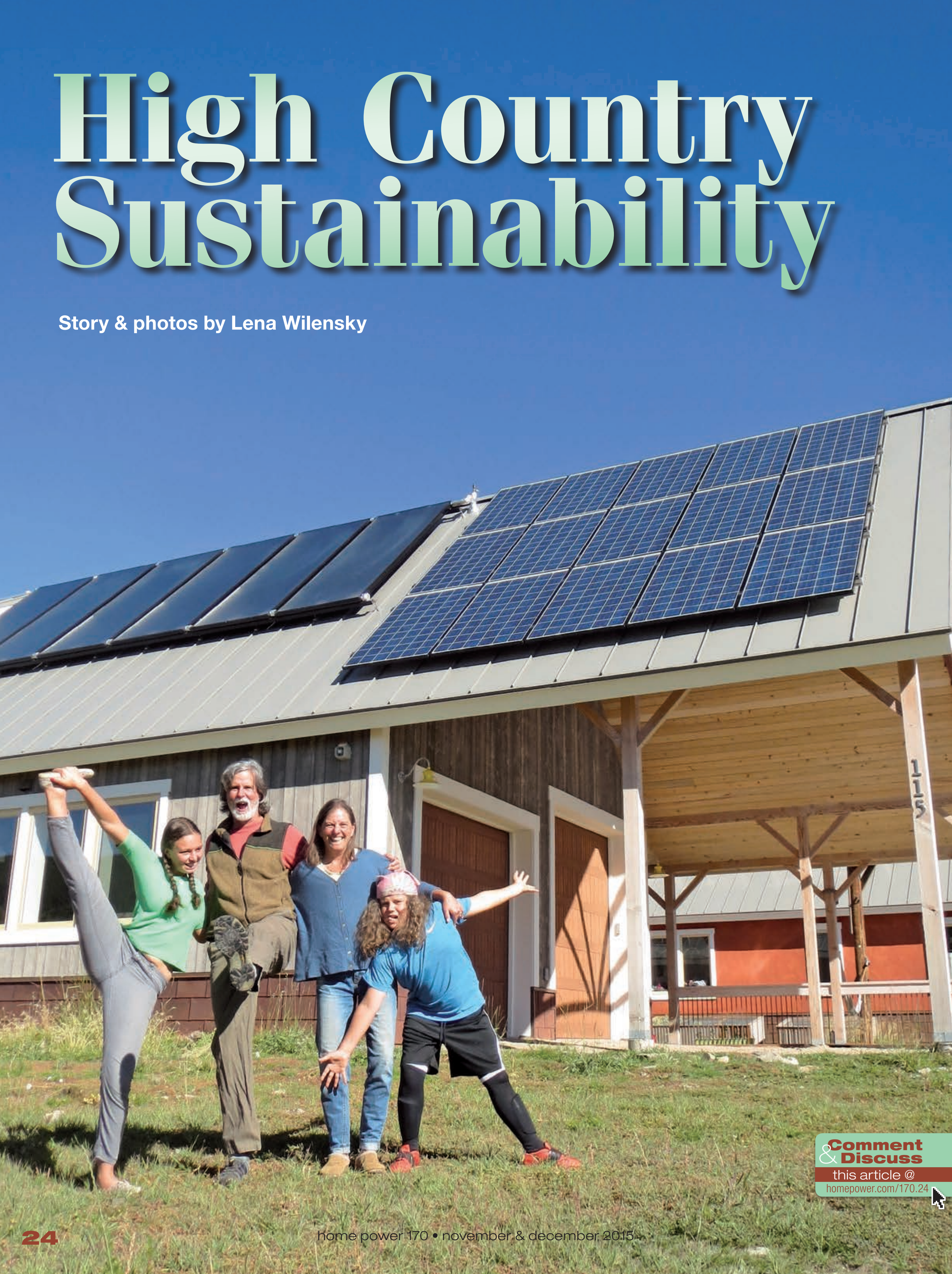
High Country Sustainability

Story & photos by Lena Wilensky



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Creating sustainability in a mountain home at 9,000 feet can be a challenge, but Robb Fessenden, a sustainable building contractor, welcomed the chance. After years of building green homes in a harsh climate (more than 11,000 annual heating degree days) for others, he had the opportunity to build one for his family. He wanted to use many tried-and-true green building techniques, and also try out some ideas he had not had a chance to perform in the field. He wanted to use renewable energy as much as possible to heat, cool, and run his home, whether by outright replacement of fossil fuel usage or offsetting usage through feeding renewable energy back into the grid. To reduce heating and cooling loads from the start, a passive solar design had to be a part of that goal.

Creative Design

In 2007, Robb and his wife Karen Adelman bought 1.67 acres, just a short bike ride from Crested Butte, Colorado. They chose the site for its mountain and river views, sun exposure, and proximity to town and schools. While the lack of trees on most of the lot made good solar access and views of the surrounding mountains, it also meant that the cold winter winds whipped across the land when storms rolled through. They figured they could design a home that would be warm, as well as provide some sheltered outdoor space and take advantage of the mountain views.

There were some 20-foot-tall Engelmann spruce and aspens on the northwest side of the property that provided some buffer from the sound of the state highway and the cold winds. Robb and Karen planted more trees—spruce, aspen, and some bristlecone pine—to increase the wind shelter and create more privacy.

A balanced design was necessary to take advantage of northern views without excessive heat loss from too many north-facing windows.

A greenhouse integrated into the southern wing collects solar energy passively, while the garage roof provides space that's ideal for active solar collection.

The greenhouse and its tall wall of windows help capture solar gain and contribute to the home's heating in winter.

Even year-round vegetable production in the greenhouse doesn't cause excessive humidity in the living area.

The home's design—a U-shape, with a central courtyard—provides more shelter from the wind while gathering sunshine. There are cold frames for growing vegetables, and tables and chairs for al fresco dining. The southernmost wing (about 1,200 square feet) faces the road with a large covered area for winter parking or for Robb's crew to work in summer. It's a shop/garage, greenhouse, mechanical room, and has lots of storage. The cover also provides ample roof space for PV modules. The north wing, also about 1,200 square feet, houses the living room, a master bedroom, and two bedrooms for their two children. To increase the southern exposure on that wing and capture more passive heat, the southern wall was raised enough to provide loft space with 9-foot-tall ceilings where their kids sleep, as well as a small study/music room above the living room.

One of the biggest design challenges was capturing the views, which are mostly to the north, while preserving the home's efficiency. They found a compromise by placing north-facing windows only where the views were the best and using triple-pane low-e windows (R-5; Eagle brand from Anderson). The triple-pane windows have two low-e (272) coatings and U-values between 0.20 and 0.27. The south-facing windows have 180/i89 glass to maintain decent U-values but allow increased solar gain. The dining room bump-out, in which two of the three exterior walls are primarily glazing, brought concerns of excessive heat loss. A glass door and insulated "plug" for the pass-through opening above the kitchen counter can isolate the space from the rest of the house, helping minimize heat loss.

The U-shaped floor plan creates an east-facing courtyard that provides a wind break and heat trap for an extended outdoor living season.

Straw-bale walls help improve thermal performance naturally.

Building Envelope

To minimize heat movement through the building envelope, Robb paid special attention to limiting thermal bridging. The roof insulation is 4 inches of rigid foam over the roof decking. Some of the walls are double 2-by-4s and infilled with straw bales—18 inches thick, plus 1 inch of plaster. The other walls are custom-built, 6-inch-thick structural insulated panels. No studs or other framing members bridge the interior and exterior spaces. The "blanket" of insulation continues into the monolithic slab foundation as well, with insulated concrete forms around the perimeter and 2 inches of rigid foam insulation underneath the entire south wing's slab. The north wing has a crawl space, where the exterior is insulated concrete forms and the floor has cotton batt insulation.

To store the heat from all the Colorado sunshine, mass is used on the surfaces the sun hits. Overall, the house has about 35,000 pounds of clay and sand—mostly in the interior walls and floor. The floor near the southern windows is primarily concrete tile (made by Robb), and the adjacent window sills are adobe—both effective mass to absorb heat during the day and slowly release it at night. Both the garage and greenhouse have concrete floors, and the greenhouse also has a dark clay plaster covering the area the sun hits throughout the year.

Mechanical Systems

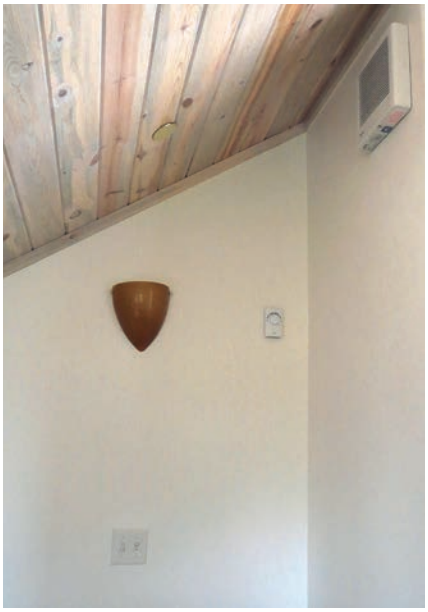
Part of the challenge of making a solar-heated home comfortable is distributing the heat. Since the hottest places in the home were likely going to be the loft spaces with southern glazing, Robb installed vent fans, ducted through the interior walls, to circulate warmed air to colder parts of the house—mainly the office room just south of the kitchen (in the apex of the U, where there isn't much passive heat gain).

With a tight building envelope, a source of fresh air is critical to avoid moisture issues and indoor air quality problems. But pulling cold fresh air in means venting heated air out—a huge loss of energy unless a heat recovery ventilator (HRV) is exchanging the heat between the air streams. One unit serves the north wing and kitchen (most of the living space) to ensure fresh air circulates, while another serves the greenhouse to combat moisture buildup. A humidistat in the home activates the greenhouse HRV only when the humidity rises above 45% in the house.

Despite the passive solar gain, supplemental heating is needed during the winter. The living area, greenhouse, and garage all have in-floor hydronic radiant heat, which is divided into zones for more efficient temperature control. The radiant system is fuelled by a Triangle Solo natural gas boiler and a closed-loop glycol solar thermal system, which also heats the domestic hot water. To increase the performance and efficiency of the in-floor heat, each zone, or loop, is controlled by a high-tech manifold that can vary flow rates in each loop independently. The tubes were installed in 1.5 inches of gypsum concrete, and areas which do not receive direct sunlight were covered with the rough sawn wood flooring.

To reduce heat loss, the dining room bump-out can be isolated from the rest of the house by a door and pass-through barrier.

Natural and locally sourced materials reduce the home's embodied energy, while defining an aesthetic style.



Circulation fans move stratified hot air from loft ceiling areas.

High-efficiency kitchen appliances reduce the load on energy systems.

Tapping Into Active Solar Heating

Six 4-by-10-foot Heliodyne flat-plate collectors on the south wing's roof provide domestic hot water and preheating for the radiant floor system. A 550-gallon insulated stainless steel tank stores the heated water, and the boiler provides backup, usually at night or in the early morning. If the storage tank is hotter than the DHW tank, it sends water to the DHW heat exchanger. The solar thermal system is designed to lower the radiant heating load, and they are getting "free" DHW heating from the system when the storage tank has built up excess heat, which is most of the year.

The modern backup boiler is an integral part of the thermal system, and varies its output based on the return water temperature. It pairs well with a solar thermal system, since the collectors can often produce those lower temperatures on its own, and just use small amounts of "boost" from the smart boiler that can regulate fuel usage and flow rates. The closed-loop glycol-based system was designed to meet about 40% of the building's heating load in winter. While it was tempting to install a larger solar thermal system, which would have offset more natural gas use, there's a balance to strike. The most heating is needed during the coldest winter days—during summer, that number of collectors would be overkill and would put the system at risk of overheating.

The domestic hot water (DHW) is mainly heated by the solar thermal system. The DHW is stored in its own 50-gallon tank, with one heat exchanger coil plumbed from the solar storage tank, and another coil internal in the tank for backup heating from the boiler.

More Solar Power for Electricity

Besides solar water heating, the Fessendens installed a 3.75 kW grid-tied batteryless PV system, with the goal of offsetting 100% of their annual electricity use. The PV system shares the south wing roof with the solar thermal collectors, but is mounted on the garage carport. My company, Nunatak Alternative Energy Solutions, designed and installed the system.

SHW/Radiant Heating System Costs

Item	Cost
Six 4 x 10 ft. Heliodyne flat-plate collectors	$8,000
Tank: 550 gal., stainless, custom	4,500
Labor	4,200
Misc. pipe, fittings, insulation, etc.	2,775
Heat exchangers for solar tank	1,400
Mounts for standing-seam roof	1,300
Heat exchanger for heating system - external plate	700
Grundfos stainless circulation pump	600
iSolar BX controller	425
Propylene glycol antifreeze, (High-temp Solar-Gard) 14 gal.	350
Tekmar mixing control	300
Grundfos solar loop pump	100
Total	$24,650
Federal Tax Credit	-7,395
Grand Total	$17,255

Various floorings cover the 3,600 square feet of hydronically heated slab.

Six 4-by-10-foot flat-plate solar collectors provide domestic hot water and offset a significant percentage of space-heating loads.

Solar Radiant Floor & DHW Tech Specs

Overview

System type: Closed-loop glycol solar hot water

Installer: Jim Lohr, Advanced Mechanical

Production: 12.75 million Btu per month average

Climate: 11,000 heating degree days

Hot water produced annually: 97% (DHW)

Solar Equipment

Collectors: Six Heliodyne 4-by-10-ft. flat-plate collectors

Collector installation: Roof, south-facing, 45°

Heat-transfer fluid: Solar-Gard high-temp glycol

Circulation pumps, solar loop: Grundfos UPS 1558FC

Circulation pump, DHW loop: Grundfos UP15-29SF

Pump controller: Caleffi iSolar-BX

Storage

Solar storage tanks: AMPeirce Welding custom stainless atmospheric, 550 gal.

DHW tank: DHW tank, HeatFlo HF50, 50 gal.

Heat exchanger, solar loop: Triangle-Tube heat exchanger model TTP3-20;

Heat exchanger, DHW loop: Cooper coil in solar storage tank

Backup DHW: (see DHW tank above)

System Performance Metering

Thermometer: Pasco temperature gauges

Flow meter: Caleffi 132662A flow meter

Pressure: Generic

Radiant Floor System

Floor tubing: Wirsbo HePEX, ½ in.

Boiler or water heater: Triangle Solo 110 NG

Amount of tubing: 4,500 ft. (*3,600 ft.^{2} of conditioned ground space)

Number of zones: 12

Circulation pump: Grundfos ALPHA ECM "smart pump"

Pump controller: Internal in smart pump

Zone valves/heat distribution manifold: Watts Canada Zzone, #81005799

Tempering valve: Internal to "smart" boiler; does this internally; set to 117°F

Other Equipment

Overtemperature dump valve: Dump loop in garage floor

Valve controller: Dump loop controlled by Honeywell Aquastat

Fifteen REC Solar 250-watt PV modules provide about 5.88 megawatt-hours of energy per year.

Above: Each PV module has a SolarEdge DC optimizer to allow module-level maximum power point tracking and monitoring.

A SolarEdge 5 kW batteryless grid-tied inverter allows for another 1.25 kW of future expansion.

As with most new construction, arriving at an appropriate system size to zero out the homeowners' electricity usage was tough. We projected their electric bills by comparing homes in the valley with similar electric loads and then assessed the roof space to see how many modules would fit. Fifteen 250 W modules fit well, providing an annual energy production of about 5,880 kWh.

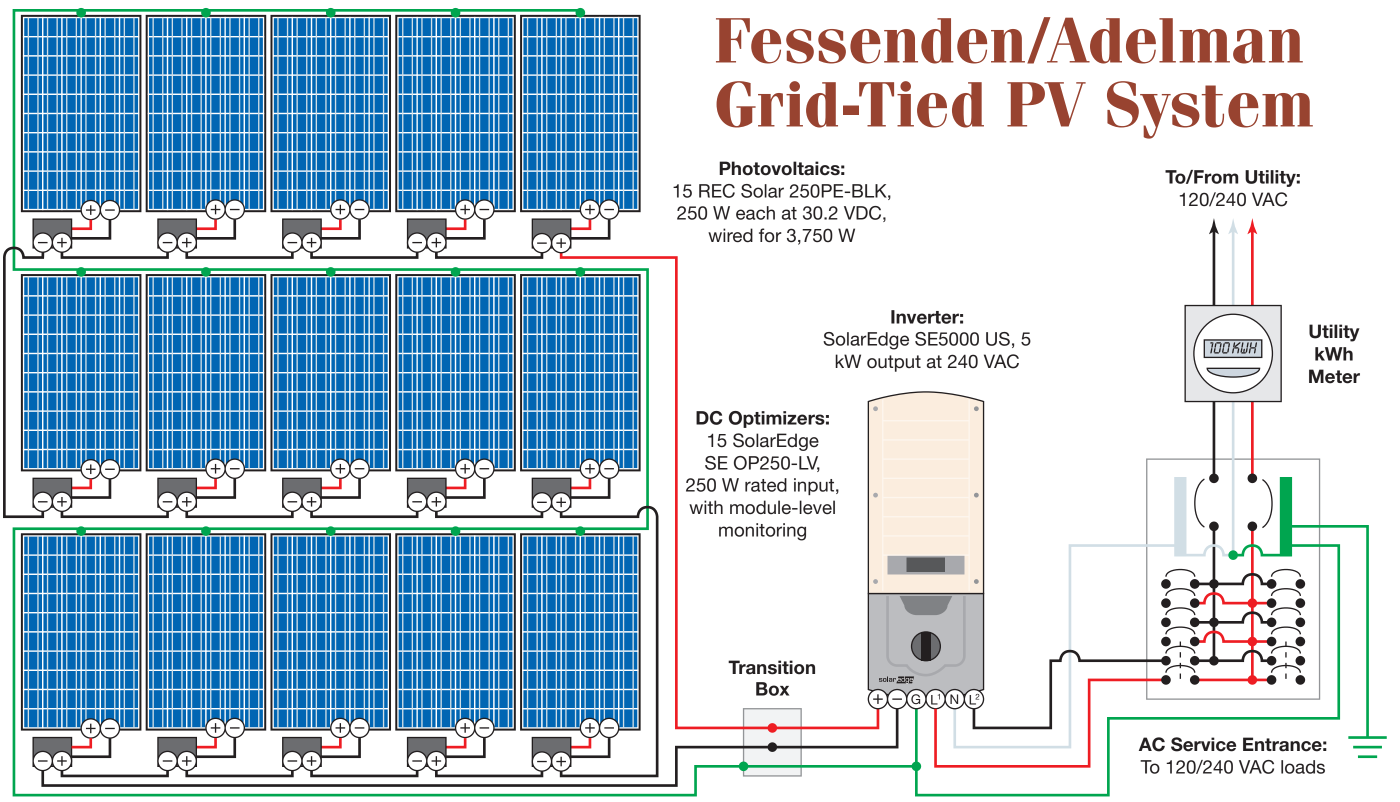
Robb was interested in monitoring his PV system's energy production, so we specified a SolarEdge string inverter, which uses DC optimizers to maximize each module's production. Every module is directly wired to its own optimizer, which tracks the individual module's maximum power point for the best possible energy production at that moment. The optimizer has a consistent voltage output of 60 V maximum, no matter the temperature, so string sizing is easy—there's no worry of exceeding the inverter's maximum voltage or dropping out of the lower part of the inverter's voltage window if temperatures get high or module voltage sags as modules age. Like microinverters, these optimizers also have a safe shutdown mode, dropping to 1 volt output if there is no connection to an operating inverter. SolarEdge also boasts a Web-based portal that monitors individual module performance. It will be easy to spot any performance problems to avoid energy output loss.

Roof clamps were used to attach the rails to the standing seam metal roofing without penetrating the roof. The rack is a top-down rail system, engineered to withstand the high snow loads in the region (100 pounds per square foot).

Performance

Robb and his family have been living in their home for a little more than a year now, and report that the house has been very comfortable to live and work in. With the thermostats set at 50°F in the garage and 40°F in the greenhouse, the heat never turns on in that wing. The combination of solar gain and storage mass works well. In the greenhouse, greens and tomatoes grew during the winter, even with multiple -20°F days. With the door shut to the main house, the greenhouse can reach temperatures

Fessenden/Adelman Grid-Tied PV System



PV System Tech Specs

Overview

System type: Batteryless, grid-tied solar-electric

Installer: Nunatak Alternative Energy Solutions

Date commissioned: May 2013

Location: Crested Butte, Colorado

Latitude: 38.85°

Solar resource: 5.5 average daily peak sun-hours

ASHRAE lowest expected ambient temperature: -23.8°F

Average high summer temperature: 82.4°F

Average monthly production: 490 AC kWh

Utility electricity offset annually: 90%

PV System Components

Modules: 15 REC Solar 250PE-BLK, 3,750 W STC, 30.2 Vmp, 8.3 Imp, 37.4 Voc, 8.86 Isc

Array: 15-module series string, 3,750 W STC total

Array installation: TRA Mage mounts installed on south-facing roof, 45° tilt

DC optimizers: 15 SE OP250-LV-MC4SM-2NA, 250 W rated input, 55 VDC max. input, 60 VDC rated max. output

Inverter: SolarEdge SE5000A-US, 5,000 kW rated output, 500 VDC maximum input (*nominal DC input to inverter from optimizers is 350 VDC), 240 VAC output

PV System Costs

Item	Cost
15 REC Solar 250PE BLK modules, 250 W	$4,043
Labor	4,000
SolarEdge 5 kW inverter with 15, 250 W optimizers	2,682
TRA Mage mounts for standing-seam metal roof	1,738
Shipping	768
Miscellaneous electrical	718
Taxes	151*
Permits & licensing	300
Total	$14,400
Federal Tax Credit	-4,320
Grand Total	$10,080

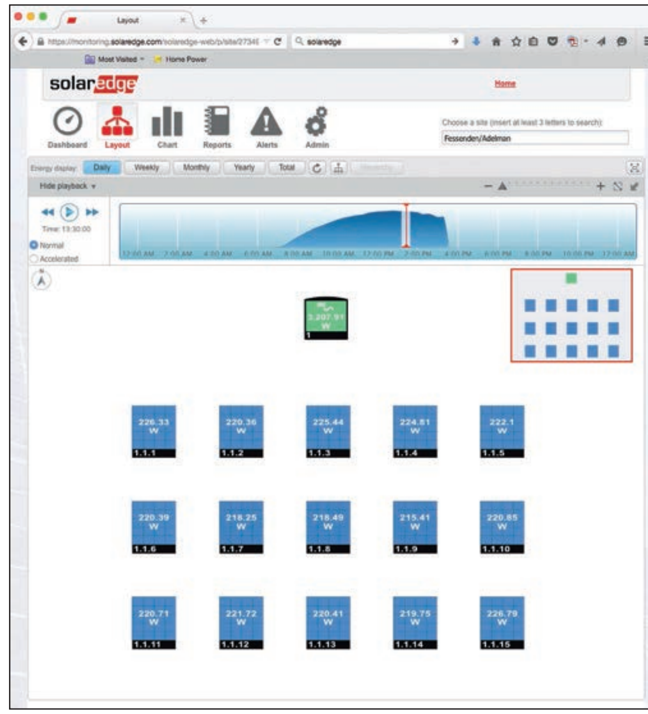
*Colorado has a sales-tax exemption for RE equipment. Only local tax applied.

greater than 100°F, but simply opening the door keeps the temperature around 75°F; plus, it serves as another heat source for the house. In the summer, the overhang helps shade the windows and simply opening the exterior windows keeps temperatures comfortable. Summer overheating in the lofts is not an issue, as the eaves block the higher-angled sun.

The greenhouse provides just enough moisture to keep the living space comfortable, and the humidity is below levels that would create any mold or mildew issues. The humidistat in the house is set at 45%, and even with the greenhouse door open during the day it was a struggle to get the humidity up to even 30% in the house, reports Robb.

The solar thermal system has also been performing well. Their highest monthly gas bill was about $65, with the annual total around $500. Crested Butte is ranked as one of the coldest towns in the continental United States, with an average temperature of only 33.8°F.

The PV system was commissioned while the house was still under construction. Robb built the south wing first (the garage/shop, greenhouse, and mechanical room), which provided a staging area to work on the rest of the home. His strategy worked well, as the PV system had generated a credit by the time they moved in the following year. The PV system had been outproducing PVWatts estimates during some of the fall and winter months, but an incredibly wet and cloudy spring—the wettest in 100 years—caused production to lag. Their utility electric meter is slowly creeping forward to zero—it was installed at 0 kWh, and then moved backwards during construction, and Robb thinks that they could probably be at net-zero for electricity if they were a little more mindful about their usage, such as forgoing the electric dryer and hanging clothes outside to dry.



SolarEdge provides Web-based monitoring that's user-friendly, and displays production and power data at the module level. It shows real-time data for energy production, and you can view charts to see module or inverter voltage, power, and current.

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- Sun Xtender batteries are sealed maintenance free batteries having no free electrolyte. Therefore, they can be shipped via common ground or air freight Hazmat Exempt.
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DESIGNING A MICROHYDRO SYSTEM

by Ian Woofenden & Paul Cunningham

The energy in falling water can be a reliable and economical source of electricity for homes and businesses. This natural and recurring energy is a form of solar energy, since it's the sun that drives the hydrological cycle, evaporating water, which condenses in the clouds and rains back down on us. While much of the potential energy is lost as the rain falls miles from the clouds to the land, there is still plenty to use as it makes its way down the mountains and hills to the oceans.

Ian Woofenden

Energy Systems & Design

Basic Principles

Hydropower is a combination of vertical drop ("head") and flow. There must be energy in the water that powers a hydro machine. The water has to be flowing downhill or at least moving—there is no energy in still water. These two parts of hydropower equally influence how much energy we can get.

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To make significant energy:

- If the water source doesn't have much head, it will need a lot of flow
- If the source doesn't have much flow, it will need a lot of head

Unlike wind and solar energy, water power is limited by the source. You can always add more solar-electric modules or wind generators if you have a good site for these technologies. But at a hydro site, once you are using most of the available flow and head, you cannot add more collectors to reap more energy. Solar and wind systems are limited primarily by space available for the collectors, and the homeowner's budget. While budget is always an issue, home hydro projects are most often limited by the actual resource (head and flow) on site.

For a typical small system, a useful formula for estimating available power is:

Head (in feet) × flow (in gallons per minute) ÷ 10 = power (watts).

This formula assumes an output efficiency of 53%, which is typical for small systems. For example, a system with 120 feet of head and 55 gpm of flow could yield about 660 watts of output. Multiplying by 24 hours means 15.8 kilowatt-hours (kWh) per day of potential production. This amount of electricity can provide an energy-efficient home with plenty of modern conveniences.

Sizing a system requires knowing how much energy you are using now and how much you'll use in the future. Load analysis is a key part of any renewable energy system design process, and a hydro system is no exception. Calculating your current energy use, making a detailed load list of planned future energy use, and accurately determining the number of kWh needed per day will help you make a good plan for your hydro system.

Once you have a good load estimate, work a little harder to see if you can reduce it through conservation and efficiency measures. While some hydro systems produce a surplus of energy, it still makes sense to whittle your usage before you start. That may allow you to pare down all the system components—pipeline, turbine, transmission, storage, and electronics—which will shrink the purchase and maintenance costs. There's usually no better money and time spent on an energy system than figuring out how to use less energy.

It's also worth considering whether your hydro system will power your home completely, or if it will be supplemented by the utility grid, another renewable source, or even an engine-generator. Many hydro sites are limited—there is only so much water, and that might disappear in the summer or other dry times. Then, solar energy can be useful, since the dry periods usually coincide with the sunny times. If you're off-grid, this makes for a rain-or-shine system. If you're on-grid, you don't need to make all your own energy, and this could affect your design choices as well.

This 1,200-watt HiPower induction turbine is mounted in a plastic barrel bottom. If there's a water resource at your site, hydro can be one of the most inexpensive and reliable renewable energy options.

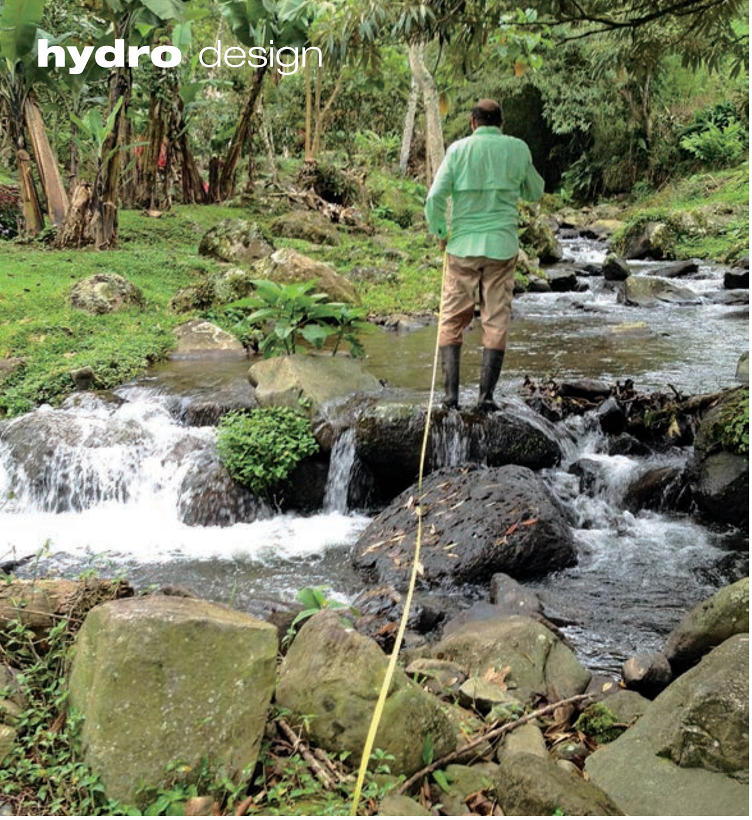
Courtesy Hydro Induction Power

There are as many possible intake designs as there are varieties in flow rate, stream topography, streambed geology, and debris loads.

Courtesy HydroScreen

When planning your intake, consider seasonal variation in flow and debris, both for the protection of the turbine, runner, and penstock, and for the intake itself.

Ian Woofenden (2)



Ian Woofenden (2)

The penstock may or may not follow the path of the stream. Measuring vertical drop is an independent process necessitating a sight level, or accurate GPS or topo map.

Flow can be measured by the time it takes to fill a container of known volume. Some streams require calculating flow based on the stream's cross-sectional area and speed of current.

Measuring

Once you've completed your load analysis and efficiency upgrades, assess your site. This involves four basic measurements:

- Head
- Flow
- Pipeline length
- Transmission length

Measuring head can be done with a site level and two people, with an accurate GPS, with detailed topographic maps, or with an existing pipeline.

Measuring flow can be done with a stopwatch and a bucket, with a weir and measuring stake, or by calculating the volume of a stretch of the stream that is similar and timing a float going through it. (See "Methods" for more details on measuring head and flow.)

web extras

For more information on measuring head and flow, see "Methods" on page 14, or **homepower.com/170.14**

Measuring pipeline length involves determining the best route for your penstock (pipeline), and taking a linear measurement so you know how much pipe and how many fittings to buy. This line will not necessarily follow the stream; in fact, make sure the pipeline is protected from flooding.

Measuring transmission distance, which is the route length from your proposed turbine site to where you need the electricity. Siting your powerhouse may be affected by where you need the electricity, but the available hydro resource and maximizing production need to be weighed in the decision-making.

If your transmission line needs to go a long distance, you can do what the utilities do—generate at higher voltage, which reduces the amperage to allow smaller-gauge wire. The high-voltage power is converted to battery or utility voltage with either transformers or electronic converters. Installing an appropriately sized wire run and protecting it from damage is crucial for a long-lasting installation.

Configuring

Hydro systems can be divided into "high-head" and "low-head" systems. This rather arbitrary division could be at about 6 to 10 feet of head. All high-head systems route the water through a pipeline to the turbine. Low-head systems may do this as well, but more commonly use a flume or direct diversion to the turbine. And because there is so little head (sometimes as little as a few feet), these turbines need more water (sometimes the whole water course) to generate significant energy.

Intake to Power Plant

A hydro "intake" is the part of the system that takes the water out of the stream and gets it into a pipeline or flume. A wide variety of intake configurations are possible in hydro systems, though an ideal system has several characteristics:

- Stable area of stream
- Simple diversion of water
- Pipeline leaves intake and runs downhill
- Pipeline stays away from stream to avoid damage during flooding

Your stream's head and flow characteristics are crucial in determining where to place the intake and turbine. Mapping your property and noting the head and flow in various sections will make these decisions easier. On small properties, the intake may be located where the stream crosses into the property; and the turbine where the stream exits the property. In other situations, you may be able to choose the most promising section of the stream—usually the section with the greatest head over the shortest distance.

For systems using a pipeline ("low-head" systems may use a flume instead, with the turbine located at the diversion), an intake filter/screen is required to keep debris out of the turbine. Ideally, this is a self-cleaning screen with continuous flow over it. The other common method is to use a screened box, set at the beginning of a pipeline, in a deep-enough pool. This screen must have openings small enough to keep out particles that might obstruct a turbine nozzle or become lodged in the turbine wheel.

Though it is possible to set up a pipeline that involves some changes in elevation, or even a siphon, it is ideal to have your penstock run continuously downhill. This will avoid air pockets in the high spots and silt settling in the low spots, which will necessitate air vents and flushing drains.

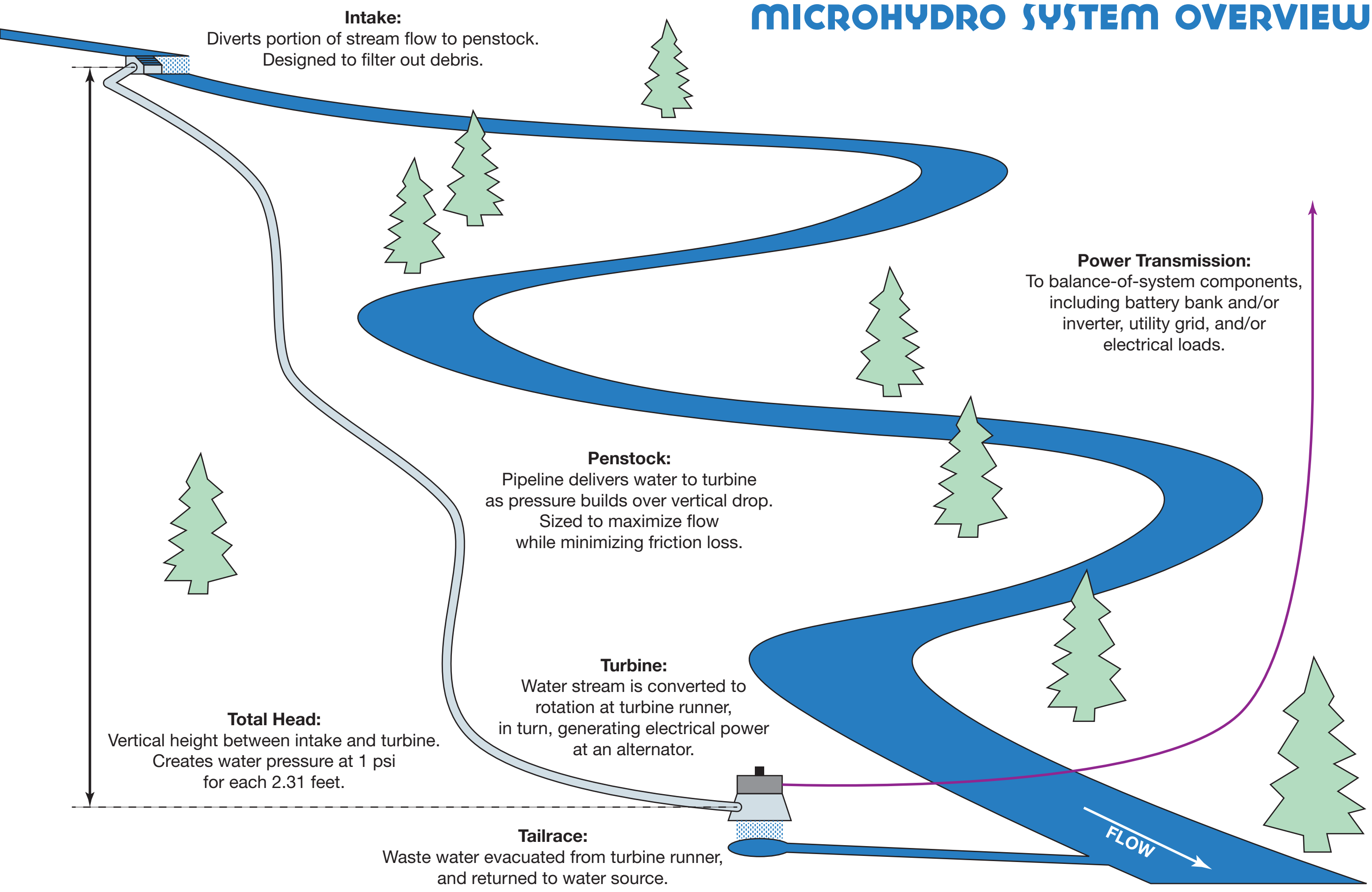
The placement of the hydro turbine is usually close to the watercourse (often the lowest spot on the property), to gain as much head as possible. The water can find its way to the brook at the outlet easily—much less difficult than getting the water into the pipeline at the top end.

Depending on the turbine size and local conditions, you'll need to physically protect the equipment. This could be as small as a covered box or as large as a framed, stand-up powerhouse. This will not only protect the gear from the elements, animals, and humans, but will also dampen the turbine's sound.

web extras

See "Microhydro Intake Design" by Jerry Ostermeier at **homepower.com/124.68** and "Hydro Design Considerations" by Ian Woofenden at **homepower.com/132.78**

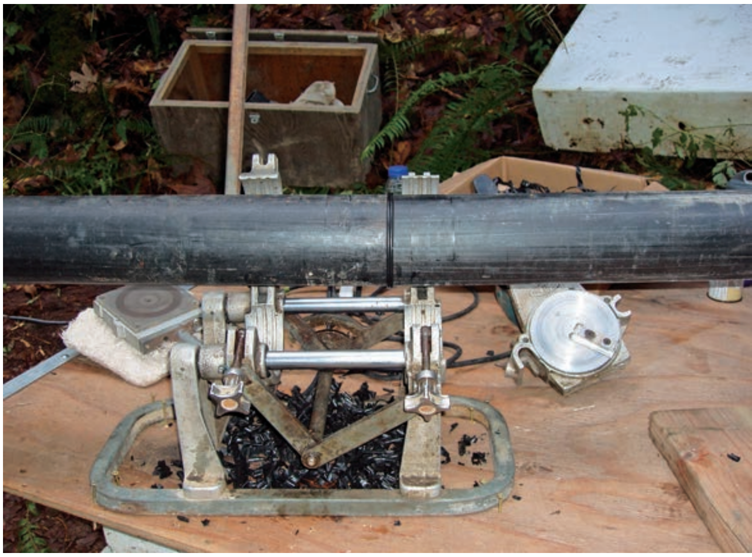
Microhydro System Overview



Penstock Choice & Specification

"Penstock" is just a fancy word for a hydro pipeline. A range of pipe sizes and types can be used for hydro system penstocks. Usually PVC or polyethylene is used. If it's a site with very high head, steel pipe may be needed to withstand the high pressure. Poly pipe is flexible, so it will conform better to variable terrain. It can be welded so that no fittings are required. You may have to bury the line because of freeze risks, or physical protection and stability issues.

The pipeline has to be large enough in diameter to carry the water with acceptable friction loss, and strong enough to handle the pressure. For the upper, low-pressure sections, pipe with a lower pressure rating can be used. There is no advantage to using progressively smaller pipe sizes—this does not increase the pressure, it actually reduces it by increasing friction loss; use one size throughout.



Ian Woofenden

High-density polyethylene pipe for penstocks can be welded, reducing the cost and friction loss of using couplers or other connectors.

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Left: A low-head system may use a flume for a penstock, especially in a location where all of the drop occurs in a short horizontal distance.

web extras

See "Pipeline: Hydro-Electric Penstock Design" by Jerry Ostermeier at **homepower.com/125.56**

Courtesy Christopher Freitas

Left: A thrust block at the bottom of the penstock keeps the heavy water-filled pipe from sliding downhill.

Right: At the end of the line—a Pelton runner turbine is tilted up to show the "tailrace," where waste water falls away from the spinning runner to prevent interference with incoming water. Commonly, water is returned to the stream.

Ian Woofenden

Turbines & Generators

The turbine runner and generator type will be determined by your site conditions. The two main categories of runners are impulse and reaction.

- Impulse types squirt water through a nozzle that's directed at the turbine wheel—in decreasing order of head, they are Pelton, turgo, and crossflow machines.
- Reaction runners are submerged in the flow of water through the turbine, and include Francis and propeller turbines, and also centrifugal pumps, which are often used as turbines.

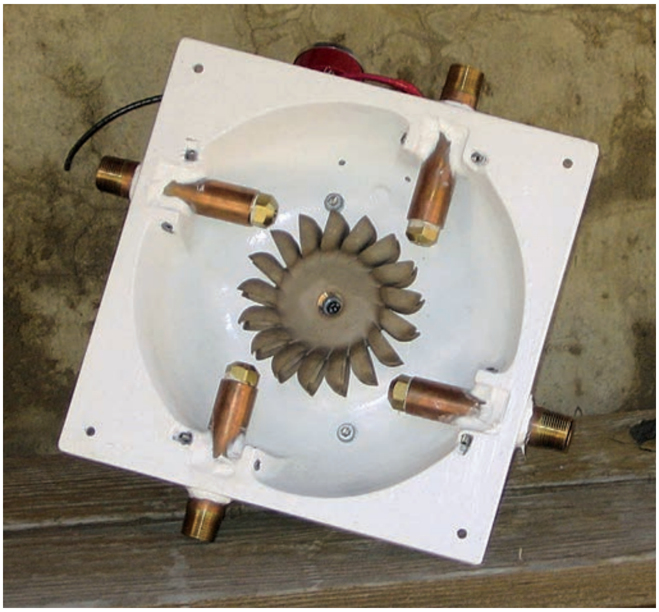
The electrical generators (alternators) used in smaller microhydro systems are usually brushless permanent-magnet. They are more efficient (more power from the same water) and simpler; some are even tunable by adjusting the gap between the magnet and windings so that the output can be maximized.

web extras

See "Hydro-Electric Turbine Buyer's Guide" by Ken Gardner & Ian Woofenden at **homepower.com/136.100**

A reaction turbine like this PowerSpout LH places the runner within a falling column of water, perfect for low-head applications.

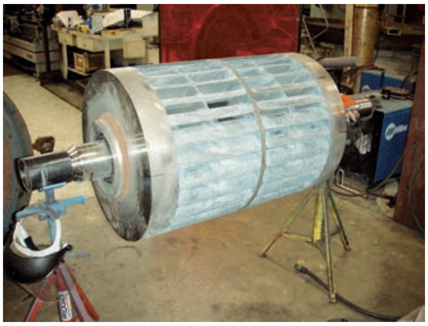
Courtesy PowerSpout



Courtesy Harris Hydro

Left: A four-nozzle Harris Hydro turbine, with Pelton runner.

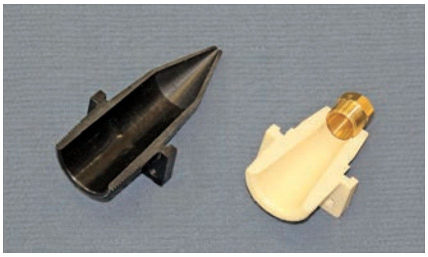
Above: Reaction runners come in various styles like this propeller type. Below: This impulse machine is a crossflow runner.



Ian Woofenden (2)

Right: The ES&D Water Buddy impulse turbine is designed for low-flow applications, and has a 2-inch-diameter runner and 200-watt maximum power output.

Below: In an impulse turbine, water pressure is converted to high velocity in the nozzle to spin the runner in a free airspace.



Courtesy Energy Systems & Design (2)

Manifolds & Streamlining

Some details can keep your hydro machine from generating at its full potential. One of the most common but elusive of these is the transition from the penstock (pipeline) to the hydro turbine—plumbing that is called a "manifold," and delivers the water from the penstock to multiple nozzles. In household plumbing, peak efficiency is not usually the focus—the goal is that water is delivered to its destination (sink, shower, etc.). Unfortunately, many turbines have been connected similarly, with lots of turns and fittings; the consequence is that far less energy is generated. If you've already taken the time to install a pipeline of sufficient size to supply water to your machine, streamlining the transition makes sense.

For one-nozzle turbines, bring the main pipeline as close to the machine as is practical, and then do not use anything smaller than the nozzle connection, and do not make sharp bends in the final leg.

For situations where the pipeline divides to feed multiple nozzles, keep the pipe and fittings as large as you can until they meet the nozzles. This keeps the water velocity, and losses, low. As the plumbing approaches the nozzle, size reduction is necessary—the main pipeline is almost always larger than the nozzle connection. Any time a size transition is made, choose reducing fittings that make the change as smooth as possible. At this point, the fittings' shape becomes more important.

The final short run of plumbing that connects to the nozzle should be at least twice as large as the nozzle diameter. This means that the water's velocity in the plumbing will be 25% of the water's velocity passing through the nozzle. The friction may still be quite high, but that's why this section should be short. Avoid sharp bends—using flexible line allows gradual bends and easy nozzle alignment. This also lets the nozzle assembly be removed easily when you need to change nozzles or clear debris from them.

The difference that good plumbing practices makes may be dramatic. Some installations are so poorly done that no power is produced—fittings with tight corners can greatly reduce flow. It's much better to make a gentle, tapered transition to minimize turbulence.

Key guidelines for manifold design include:

- Streamline
- Keep velocity low and diameters large
- Make gradual transitions
- Use sweeping bends in smaller lines

Energy Systems & Design

Smooth sweeps reduce friction losses in this four-nozzle turbine manifold.

On or Off-Grid?

Off-Grid. Powering an off-grid house's lights, refrigerator, well pump, and washing machine can be done with as few as 300 watts continuous output (7.2 kWh per day)—if the right appliances are chosen and usage is conservative.

There are only two options for an off-grid hydro system. If your system's peak capacity is more than a few kW, consider a batteryless AC-direct system where the turbine's generator operates at the correct speed to give the proper frequency to the output (60 Hertz in North America and 50 Hz many other places). This system needs to generate enough to cover the peak load at all times so that the power will be available as appliances are switched on and off. If the turbine stops for any reason, there is no backup in these systems. These systems use a controller to divert unused energy to a dump load, keeping the turbine fully loaded at all times.

The other option is a battery-based system. Only the average load needs to be generated, since the batteries carry the loads when the energy use is greater than what is generated. A battery system can operate at a much lower power level than an AC-direct system. Energy from other

Unloaded, hydro turbines can be damaged by overspinning. Off-grid hydro systems may use battery-based inverters and diversion-capable charge controllers to shunt extra energy to dump loads—usually air or water resistance heaters.

Courtesy PowerSpout

Courtesy Hydro Induction Power

Left: AC-direct hydro units like this HiPower unit often employ induction alternators to match AC waveform with the grid.

Ian Woofenden

Right: Off-grid AC-direct hydro systems require specific electronic controls to variable dump loads to ensure that all of the generated electricity has a place to go.

sources like solar and wind can also charge the same battery bank. Note also that the batteries in a hydro system generally have a much longer life than those in solar or wind systems—since the hydro system is generating continuously, batteries are less likely to sit in a discharged state.

On-Grid. Without batteries, there will only be backup when the grid goes down if it is an AC system, configured to switch to stand-alone use in an outage. A battery bank and associated equipment can carry you through an outage when you might otherwise be in the dark, with your frozen food thawing, but there will be costs—up front and in lifetime system efficiency.

An AC-direct induction system is also an option for grid-tied sites. Power is generated by the turbine at the correct frequency and voltage and fed into the grid. This system may require gear for under- and overvoltage and frequency protection, and an automatic shutdown device—in case the grid has troubles.

Another option is to send high-voltage DC hydro power through a grid-tied inverter. Since these are already approved for grid connection, it may be easier than trying to get an AC-direct machine approved by your local authority. Another advantage of using an inverter is that it will likely have maximum power point tracking technology, which means that the output of the system will be optimized automatically.

Balance of System (BOS)

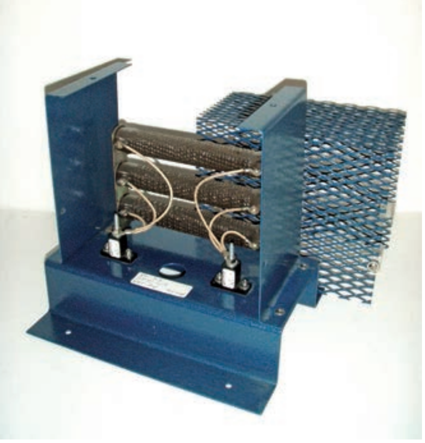
An **AC-direct system** requires an electronic governor, which monitors the turbine's output and maintains the system's frequency and voltage by sending extra energy to secondary loads, such as air or water resistance heaters. Since these systems require generating enough power to meet the peak load, surplus energy usually amounts to several kWh per day—considerable energy that can be used for water- or space-heating.

Battery-based systems also require a few accessories to operate properly. If there is a long transmission distance, a high-voltage generator may be needed. At the point of use, transformers or converters can be used to step down the power to battery voltage. A charge controller monitors the battery voltage and sends surplus energy to a diversion load, such as a space- or water-heater, as the batteries fill. This load must be equal to or greater than the maximum power that the machine will generate. Many inverters have auxiliary outputs that can be used for this.

Very small systems for off-grid cabins and camps can use 12-volt battery banks, but for higher-power sites, usually 24 or 48 V is chosen. At these higher battery voltages, the inverters tend to be more efficient and more powerful, and the cabling and breakers can be smaller, reducing cost.

web extras

See "The Electric Side of Hydro Power" by Jerry Ostermeier & Joe Schwartz at **homepower.com/126.68**



Courtesy Alternative Power & Machine

An Alternative Power & Machine air resistance heater (dump load) with protective cover.

Installation Considerations

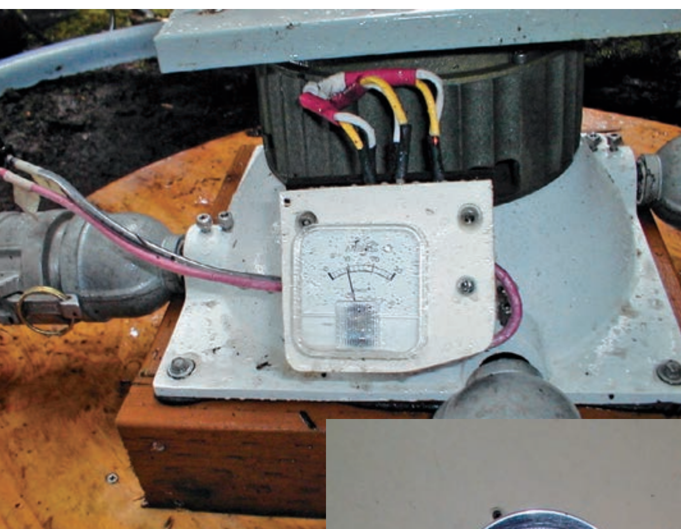
In a freezing climate, the entire plumbing for the machine may have to be buried or placed underground. The hydro machine can even be installed in a below-ground chamber with the pipelines (in and out) entering and leaving below ground level. Sections of pipe that must be above ground can be insulated. Even a shallow burial for the pipeline is better than nothing and can work well if the water keeps flowing.

Just like the pipeline, the transmission lines have to be adequately sized to keep resistance loss at an acceptable level. These can be run overhead, or be buried in conduit.

The battery bank and inverter should not be in the powerhouse with the turbine. It can put the inverter at risk to be in an unheated and often damp location. The batteries should not be in the living space, although keeping them warm also helps improve their capacity. Using a garage or other outbuilding is one solution for providing a protected space for batteries.

Ian Woofenden

Hydro is a scalable technology, dependent only on the size of the resource: Coauthor Ian Woofenden sits on a couple of large Pelton runners at Canyon Industries, while holding a small one in his hands.



Ian Woofenden (2)

Energy Systems & Design

Various types of analog and digital metering can tell you a lot about how your hydro system is functioning—if you know how to interpret the readings.

Monitoring, Maintenance & Operation

All systems should have a meter that shows the turbine's output, preferably located at the point of use. If the output falls a bit with no other discernible cause, it could mean failing bearings, and you want to be aware of this. This could also be an indicator that a nozzle is clogged, the source water level is low, or there is some other kind of obstruction.

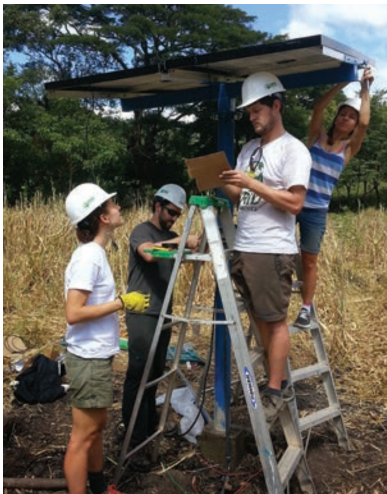
A pressure gauge just upstream of the turbine and its shutoff valve is a crucial diagnostic and performance tool. Static pressure (no water moving) will tell you the total head in feet—just multiply the PSI reading by 2.31. Dynamic pressure (water flowing) will show the normal operating head for the set of nozzles currently in use. Deviation from normal dynamic pressure can indicate a blocked nozzle (pressure indicating higher than normal) or that your pipe is not completely full (pressure indicating lower than normal).

Regular inspection and maintenance are key to long-term performance of microhydro-electric systems. Solid design and installation can avoid otherwise unnecessary maintenance, such as cleaning the intake screen daily because of a poorly designed system. A well-designed system may need weekly or monthly system checks, and seasonal nozzle-changing.

Although careful design is needed to produce the best performance, home hydro systems are usually not too complicated to be implemented and maintained. People who have hydro systems are very happy that they can use this source of energy, borrowed while on its way from the sky to the ocean.

web extras

See "Microhydro Myths & Misconceptions" by Benjamin Root, at **homepower.com/146.76**



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- Polly Shaw, Volunteer

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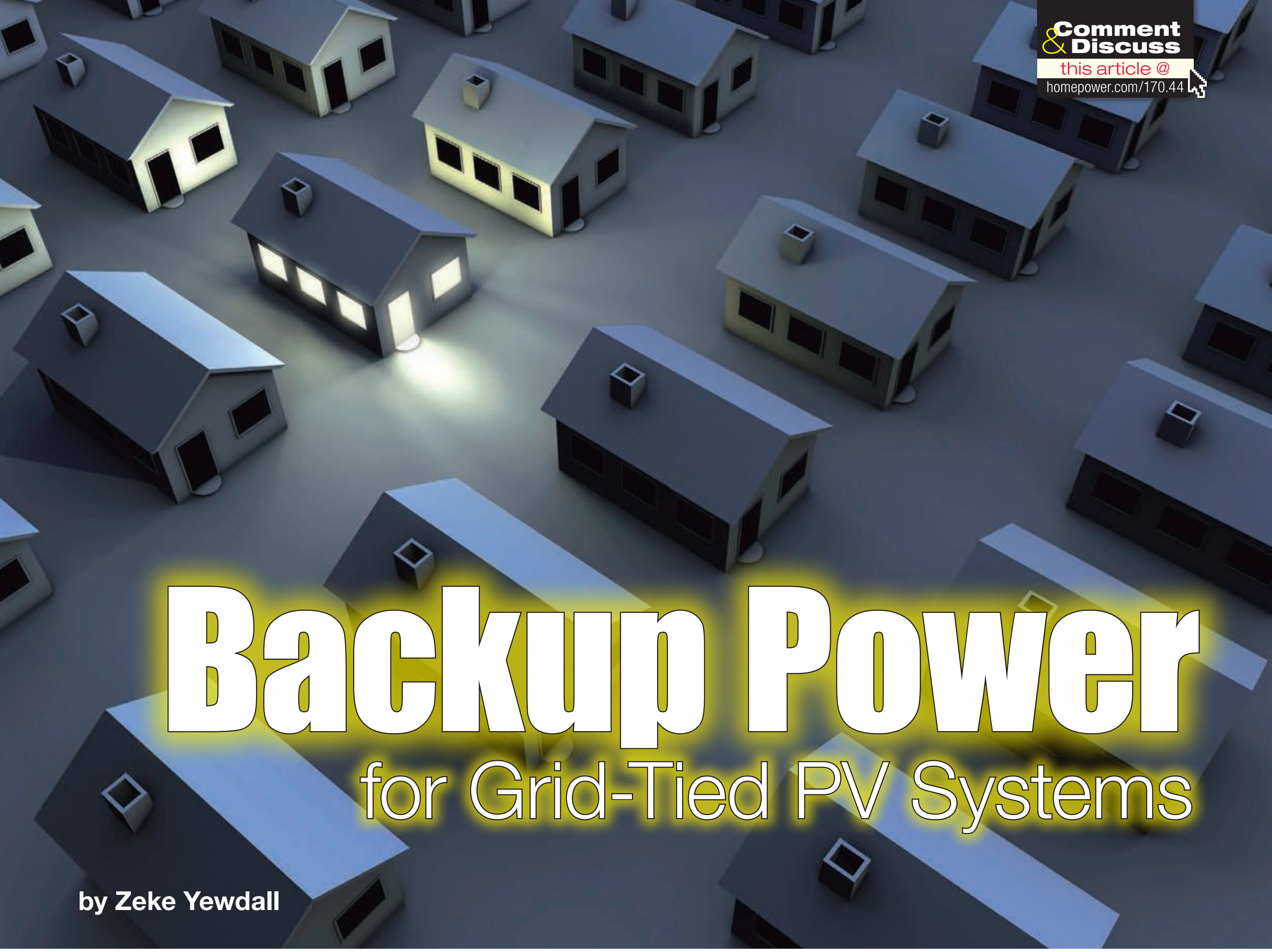

Backup Power
for Grid-Tied PV Systems

by Zeke Yewdall

©istockphoto.com/JochenK

A grid-tied PV system is great at reducing your electricity bills with clean on-site energy generation. But when the grid goes down, a standard grid-tied inverter also shuts off, leaving you without power, even with a PV-covered rooftop. If you want backup power, there are several options—it just depends on your needs.

Identify Your Needs & Loads

What kind of power outages are common where you live? Are they short power blips that occur several times a day for a second or two, and make all of the clocks reset, or do the outages last a few minutes to a few hours? How often do they occur? Perhaps there are days- or weeks-long outages that occur only every few years during major storms.

What do you need backup power for? Do you want power to back up all of your household loads, or just enough to charge a few cell phones and keep the fridge cold? If you buy a generator for backup power, it may not cost much more to back up the entire house than a smaller selection of loads. For example, the installed cost of a 15-kilowatt (kW) generator is not too much more than for a 5 kW generator—perhaps $8,500 versus $6,500. What does cost more is fuel for a larger generator. Another option is to install a backup battery bank. Having whole-house battery backup can be very expensive compared to having a smaller battery bank to back up a subpanel of "critical loads," which are commonly lighting, refrigeration, well pumps, and communications devices (cellphones, computers, and modems).

Before you invest in an electrical backup system, consider non-electric options. It is usually much cheaper to switch to propane or natural gas for heat-related appliances (stoves, space heaters, water heaters, etc.) than backing up the electric ones with a large battery bank. For example, backing up a 1,500-watt electric space heater to run for a three-day power outage during an ice storm will cost upwards of $20,000 in battery storage alone. An efficient wood or propane heater would cost just a fraction of that.

Courtesy Tripp-Lite

Left: An uninterruptible power supply (UPS) provides fast, automatic backup, but is usually for smaller loads (like computers) and short periods of time.

Right: SMA America Sunny Boy batteryless inverters with secure power supply (SPS) can provide up to 1.5 kW, but only during sunny conditions.

Courtesy SMA America

An **uninterruptible power supply (UPS)** can be an option for smaller equipment for short power outages. These self-contained plug-in units usually store 15 minutes to an hour of energy for a computer or other small electronics, and switch on automatically—quickly enough to keep computers running so you don't lose data. If typical outages in your area are short blips that cause all of your computers and modems to reset, then a UPS can be an inexpensive solution. Price: $50 to $500.

Secure Power Supply (SPS). During a utility outage, SMA America's line of SPS transformerless inverters provide up to 1,500 W of 120 VAC (without requiring a battery bank), dependent upon how much the PV array is putting out at the time. With its dedicated outlet, you can charge cellphones, run other small electronics, and possibly have enough power for a refrigerator.

There are two main disadvantages. The first is that operation requires flipping a switch, then plugging the desired load into a special outlet. The second is that, during the night, there's no backup power. On the plus side, this feature only requires a little extra wiring. The major advantage is that there are no batteries to pay for, maintain, and eventually replace. This inverter is available in seven different capacities, ranging from 3 to 7.7 kW. The additional cost for labor and the SPS outlet ranges from $100 to $300.

Generator—Autostart or Portable. A fossil-fuel-powered generator can be a good fit in many cases. Generators are well-suited for powering large loads, and can be less expensive than a large battery bank. The drawback is engine maintenance, dealing with generator emissions, noise, and fuel cost. Fuel availability can also be an issue—when a major storm strikes, it may be difficult to get fuel.

Generators can range from a small portable generator used with an extension cord to power a few electrical loads to a large, automatically starting generator with an automatic transfer switch. With this approach, your PV system is still not being tapped during an outage, so all of that potential energy is being wasted.

Portable engine-generators can cost as little as $200 for a 1,000-watt unit; higher-power (10,000 W) and higher-quality ones start around $2,000. The cheaper ones are suitable for expected use of a few *hours* a year; choose a higher-quality one if you expect to be using it for a few *days* a year or

A small gasoline generator may be an easy and inexpensive backup power option, but it doesn't take advantage of an existing PV array's output.

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Left: A larger generator may be a permanently installed unit, with natural gas or propane fuel piped to it. Autostart is an option, but won't activate online fast enough to keep computers up.

©istockphoto.com/ dsmoulton

Below: This unique DC-coupled system splits the PV array to feed a battery backup system and a grid-tied-only system. An OutBack battery-based inverter (upper left box) is connected to four 12 V AGM batteries (lower left box) that provide 5 kWh of storage; a Xantrex grid-tied-only inverter is mounted to the right. This solution can be less costly than having battery backup for the entire array.

Zeke Yewdall

more. Portable generators exhaust carbon monoxide and other harmful pollutants, and can be very dangerous if run indoors—even in an open garage, which is a temptation if it's still raining or snowing outside. They should also never be connected to the home's permanent electrical system unless proper transfer switches are used, since they might shock or even electrocute utility workers trying to repair power lines.

Just as with inverters, generators come in many different power sizes. Portable generators start as small as 600 W, which can run a small fridge, a computer, and some electronic devices, and go up to around 15 kW, which could run most appliances in an entire house, including air conditioning and well pumps, if a suitable transfer switch is used. A small one might run for 8 hours on just 1 gallon of gasoline, while a 15 kW unit might use 15 to 20 gallons of gasoline for that 8 hours. Permanent residential backup generators range from around 6 kW to more than 20 kW.

Permanently mounted generators that hook up to propane or natural gas lines for fuel and have automatic transfer switches can range from about $6,500 installed cost (for a 5,000 W unit) to $10,000 or more for higher-quality ones in the 15 to 25 kW range. Quality does not vary as widely here as for portable units, but still remember that the cheapest ones are only designed to provide backup power for a few hours a few times a year—not to run several hours a day for many days straight.

Battery Backup. A grid-tied PV system with battery backup can operate as an off-grid PV system. The inverter rapidly responds to power outages, switching quickly enough that computers don't go offline, so most people won't even notice the grid is out. The transfer time is much faster than an auto-start generator, which will take several seconds to start and come up to power delivery speed.

Options for Adding Backup to Your PV System

Installation	Plug-In UPS	Sunny Boy Inverter w/ SPS	Battery-Based PV System	Portable Generator	Permanent Generator	Battery-Based PV w/ Generator
Cost range	$150 – $500	$100 – $300*	$3,000 – $100,000	$500 – $6,000	$5,000 – $20,000	$10,000 – $100,000
Ease of installation	Easy	Moderate	Moderate to difficult	Easy to moderate	Moderate to difficult	Difficult
System Operation						
Uses solar during outage	No	Yes, daylight	Yes	No	No	Yes
Quiet	Yes	Yes	Yes	No	No	Yes, except with generator
Requires fuel storage	No	No	No	Yes	Maybe, depends on fuel type	Maybe, depends on fuel type
Ongoing fuel costs	No	No	No	Yes	Yes	Yes (for generator fuel)
Maintenance	Replace batteries every 5 years	None	Depends on battery type	Engine maintenance	Engine maintenance	Engine maintenance; battery depends on type
Outage Duration						
Automatic transfer	Yes	No	Yes	No	Yes, slow	Yes
Short outages	Good	Poor	Good	Poor	Poor	Good
Hours-long outages	Poor	Good, daylight	Good	Good	Good	Good
Weeks-long outages	Poor	Good, daylight	Good	Good	Good	Good
Load Applications						
Whole-house	No	No	If large enough	If large enough	Yes	If large enough
Lights & refrigerator	If large enough (Output limited to 1,500 W; 120 VAC)	Possibly; daylight only	Yes	Yes	Yes	Yes
Computer backup	Yes	No	Yes	Maybe	Yes	Yes
Personal electronics	Yes	Yes, daylight	Yes	Yes	Yes	Yes
Heating systems	No	No	If non-electric	Maybe	Yes	If non-electric

***Additional cost of labor (wiring) and outlet; assumes SPS-enabled inverter already installed**

In this type of system, when operating in backup mode, there are no fuel costs—so long as the array receives enough sun to recharge the batteries each day, it can operate indefinitely. Of course, when outages occur during winter storms, large loads and many sunless days can deplete your battery bank.

The primary limitation of this approach is the size of the battery bank and inverter. If you have large loads, you need lots of batteries and more inverter capacity, which can greatly increase the system cost.

There are two options for adding batteries to an already-existing grid-tied PV system that don't necessitate rewiring the array. In either case, you'll have to add a battery-based inverter and connect the existing PV array to the new system components.

High-voltage MPPT charge controllers allow PV arrays originally wired for grid-tie-only to be integrated with a battery-based system by reducing array voltage to match battery voltage.

Courtesy Morningstar and Schneider Electric

This classic AC-coupled system consists of 10 kW in the two gray SMA America Sunny Boy inverters; 8 kW in the Sunny Island inverters (yellow); and 10 kW of sealed AGM batteries (not shown) for storage.

The first option is to use a DC-coupled system, which uses a high voltage charge controller to convert the high-voltage DC generated by most grid-tied PV arrays down to the lower voltage (24 or 48 V) common for battery-based inverters. The second option is to use an AC-coupled system that uses the battery-based inverter's output to provide the AC needed to keep the grid-tied inverter operating. The grid-tied inverter gets connected to the backed-up critical load panel. An AC-coupled system needs a way to keep batteries from becoming overcharged during a utility outage, since there isn't a charge controller to regulate energy coming from the PV array. The method depends upon the chosen equipment—see "Adding Battery Backup to Your PV System with AC Coupling" in *HP168*.

This large AC-coupled battery backup system includes 26 kW of PV power connected to five Sunny Boy inverters (not shown) and four Sunny Island inverters (shown below).

The additional cost for a battery backup PV system (compared to a grid-tied-only PV system) can range from $3,000 to tens of thousands, depending on how many loads need to be backed up, and for how long. For a two-day-long outage without sun, a backup system with 4.5 kW of 240 VAC inverter capacity and 15 kWh of storage capacity using sealed AGM batteries—which could back up a fridge, well pump, computer and modem, and a number of LED lights, as well as some miscellaneous small appliances—would cost from $10,000 to $14,000.

Battery Backup, Plus Generator. Adding a generator along with a bank of batteries provides another backup method, and reduces the size of the battery bank and inverter capacity needed. This can be especially helpful during sunless periods by keeping the batteries from being overly discharged. Fuel usage during long outages is less than with a generator-only system—even if there is no sun, the generator only has to run a few hours a day to recharge batteries, rather than running 24 hours a day to serve loads. Typically, there is at least some solar input contributing to battery charging.

Below: This combo DC- and AC-coupled system has 5.4 kW that are DC-coupled through an OutBack Radian inverter; 6 kW are channeled through an AC-coupled inverter (not shown). MidNite charge controllers serve the DC-coupled system, while Morningstar controllers operate a diversion load for the AC-coupled system (protecting batteries from overcharge). Surrette flooded lead-acid batteries provide about 34 kWh of energy storage.

Zeke Yewdall (3)

Battery Options

What type of batteries to choose is a big question. Most battery-backup PV systems use a battery bank that is 12 V or, more commonly, 24 or 48 V. The bank is made up of smaller individual batteries, wired together in series-parallel to achieve the desired voltage and storage capacity.

The amount of energy storage you need depends on the total of the loads and how long they will be run. While many off-grid houses have small battery banks—5 to 20 kWh of storage—that won't go far with the loads of average grid-connected houses. They may take 50 to 100 kWh or more of storage, which can be very expensive. A detailed loads analysis will help determine the size of battery bank needed.

Several types of batteries are available. Most backup systems use sealed absorbed glass mat (AGM) lead-acid batteries, which last about eight to 10 years in backup applications. These are widely available, don't require any maintenance, and, paired with modern equipment, don't lose very much energy in standby mode. Nickel-iron batteries promise long life (40+ years), but at a high initial cost, a higher self-discharge rate, and occasional maintenance (i.e., water replacement). Flooded lead-acid batteries are the least expensive, but require regular watering, and usually last eight to 10 years. More expensive lithium batteries are fairly new, but should last 10 to 20 years with no maintenance.

The efficiency of various battery types also varies. With lithium, you lose less than 10% of the energy charging and discharging them. With others, notably flooded lead-acid and nickel-iron, you might only get 75% to 80% of the energy back if they are heavily used.

Upper right: Sealed absorbed glass mat (AGM) batteries like these Full River 2 V (1,150 Ah each, for 55 kWh of storage at 48 V) are maintenance-free.

Right: Nickel iron batteries are an old technology experiencing a renaissance. Their lower efficiency and higher upfront cost are offset by their longevity, making them possible candidates for backup systems.

Zeke Yewdall (3)

Left: This 3,280 Ah battery bank of 32 Surrette flooded lead-acid batteries provides about 158 kWh of storage at 48 V—whole-house backup for a large on-grid home.

What's It Worth?

A common method of assessing the economic advantages of a batteryless grid-tied PV system is to figure the time that it takes to recuperate initial costs. Computing payback for a backup power system can be a little more complex. Adding backup capability to your grid-tied system will cost more (sometimes a lot more) than a batteryless system and, since it uses the same PV array, it won't generate any more energy. What it does generate is reliability and resilience. If you are running a business, you may be able to come up with a value for lost sales, lost data, or lost perishable merchandise. But valuing reliability at a residence can be more difficult. Spoiled food in the fridge might have a value, but what is the exact monetary value of having lighting at night or the security of communications?

web extras

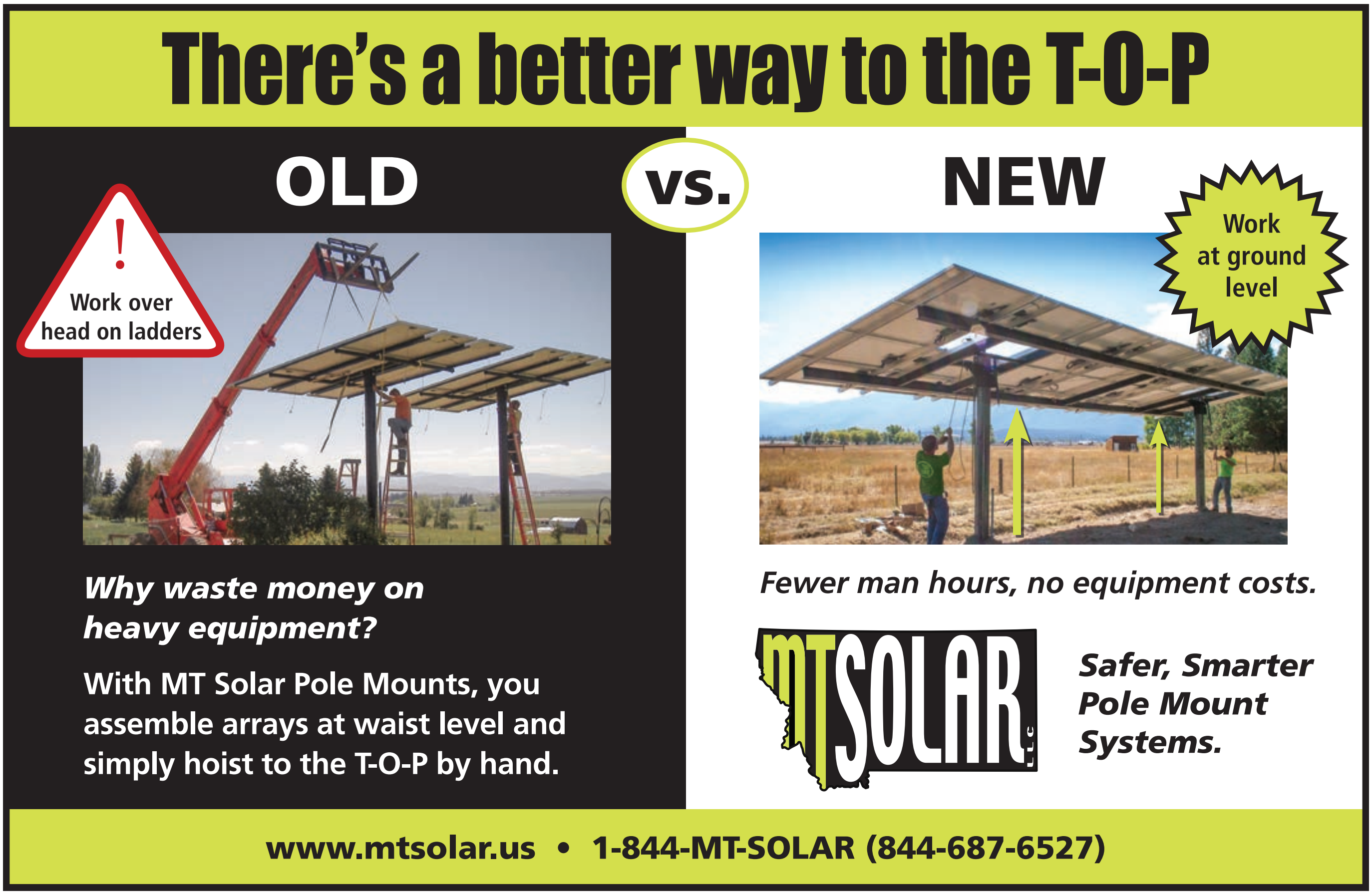
"AC Coupling" by Zeke Yewdall • **homepower.com/162.24**

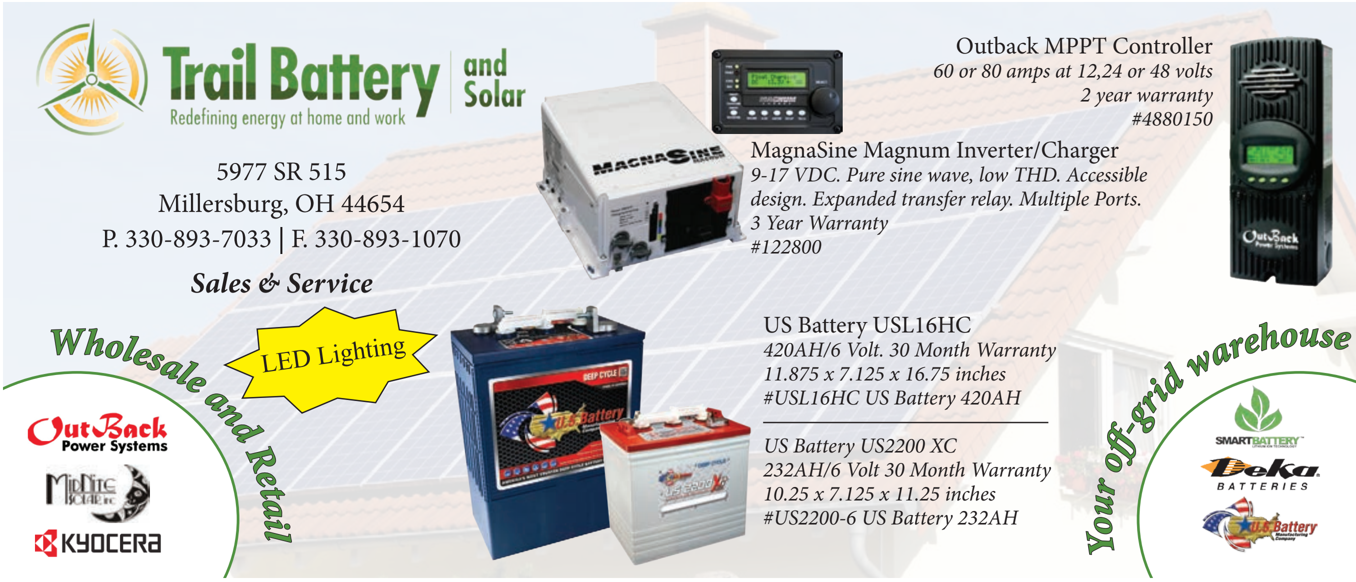
"Adding Battery Backup to Your PV System with AC Coupling" by Justine Sanchez & Jasun Mills • **homepower.com/168.38**

"Sizing a Grid-Tied PV System...with Battery Backup" by Flint Richter • **homepower.com/139.60**

Zeke Yewdall

A simple DC-coupled battery backup system can be straightforward to install, and most economical if battery backup is installed as part of the original PV installation. Here, a Xantrex 6 kW inverter is powered by a 4 kW PV array. Eight sealed AGM batteries in the cabinet provide about 10 kWh.





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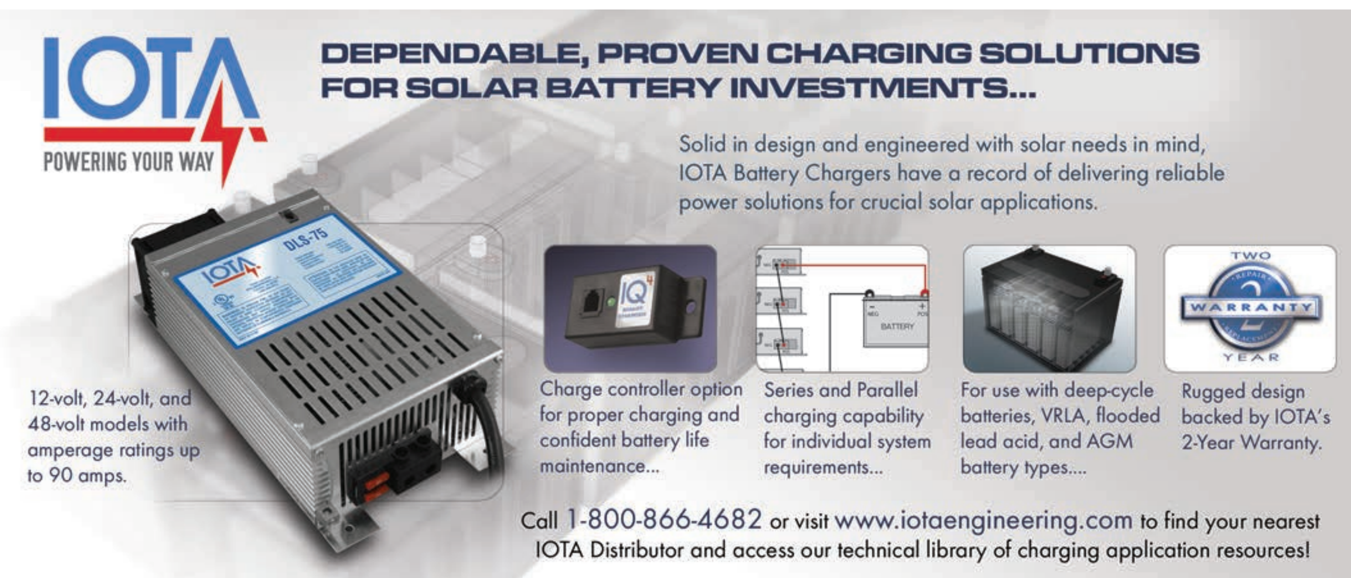

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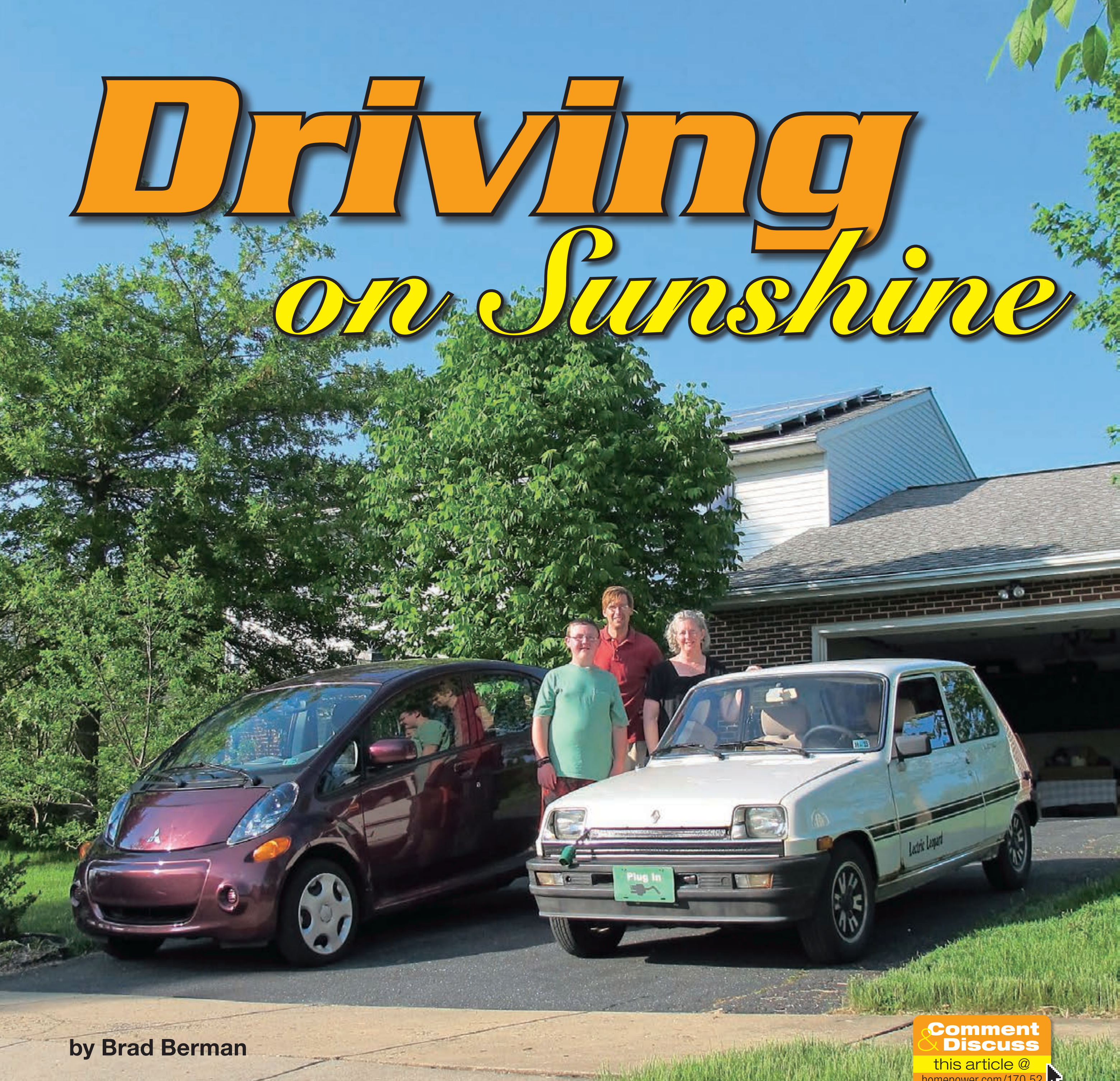

by Brad Berman

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The Gallagher family with their two solar-powered EVs—one a modern Mitsubishi i-MiE and one a factory-converted Renault LeCar.

"Fueling with Sunshine" (*HP165*) outlined using solar energy to charge an electric car—providing guidelines for sizing a PV system for an electric vehicle (EV) and choosing a home charging system. While talking about the technology and process is important, it doesn't capture the deep satisfaction experienced by homeowners who power both their home and car with renewable solar energy.

I reached out to three PV-EV pioneers in different regions of the United States to gain a better understanding of what motivated them to combine solar energy and battery-powered cars:

- What came first, the PV system or the EV?
- Are they worth the money and effort?
- What kind of mindset is needed before taking the leap?

While these represent some of the most passionate PV-powered EV drivers, their stories give a sense of the decision process that goes with installing solar on their home after driving an electric car, or buying an EV after installing PV modules.

Incremental Adoption in Pennsylvania

"Energy is something that we can't take for granted," says Dan Gallagher, a software business analyst in Ephrata, Pennsylvania. "We should use it sparingly." Gallagher says that compared to the average Earthling, he consumes more than his "fair" share of energy, but "compared to the average person of my socioeconomic class in the United States, I'm probably one of the more energy-miserly ones."

A common thread that unites these three solar-EV profiles is an acute awareness of energy use and its impact on the environment. But like other EV drivers with PV systems, Gallagher also sees his home energy conservation and renewable energy use as an enjoyable pursuit.

Before putting PV modules on his house, he audited his electricity use. That led to replacing old appliances with more efficient ones; using LED lighting; and getting rid of his swimming pool, which used a lot of electricity with its pump and filtration system. In 2010, he added a 6.72-kilowatt PV array to his house, which offset about 90% of its electricity use.

Going solar whetted Gallagher's appetite for more energy-saving measures. He replaced his propane-fired furnace and standard air-source heat pump with a geothermal heating and cooling system, and then bought his first electric car, a 1980 Renault LeCar conversion. (The electrified version of the Renault is the "'Lectric Leopard," one of several models that U.S. Electricar converted after purchasing fleets of new cars and trucks from manufacturers, sans their gasoline-related components.) When he doesn't ride his bicycle, Gallagher still uses the Leopard for his daily 20-mile round-trip commute. (The car has a range of about 50 miles, according to Gallagher.) His wife uses another electric car—a Mitsubishi i-MiEV with about 62 miles of driving range—as her daily ride. With the two cars being recharged daily, and a geothermal pump in place, the PV system now offsets about 70% of their household electricity use.

"Despite the fact that I spent money on solar and geothermal and EVs, I'm still kind of a fiscally conservative person," Gallagher says.

Dual chargers keep the family's EVs ready to go.

Who: Gallagher family

Where: Ephrata, Pennsylvania

PV system: 6.72 kW batteryless grid-tied

Average daily sun-hours: 4.42

Average annual production: ~8,200 kWh

Drives: 1980 U.S. Electricar 'Lectric Leopard; 2012 Misubishi iMiEV

Range*: 50 hwy; 60 city, 62 hwy

*Range is reduced in hilly & mountainous regions

After taking the federal tax credit and a state incentive, the grid-tied batteryless PV system cost about $20,000. He spent another $15,000 on the geothermal system. The Leopard cost $7,000, and Gallagher invested another $7,000 to upgrade its lead-acid batteries to more a more capable lithium-ion pack. He loves the DIY aspect of the unique little EV, which required about 50 hours to upgrade, including redoing the electrical wiring.

He sees the economic benefits of his electric cars as a "wash," acknowledging that it's cheaper to buy and live with an "old beater car" for as long as possible. "The problem is that gasoline is so cheap in this country," he says, and believes most people don't understand the concept of total cost of ownership or how many kilowatt-hours of energy they use. "So, when it comes to the EVs, I just tell them that they are so much fun, so quiet, cheap to drive, and convenient."

Gallagher views solar electricity benefits similarly—valuable and enjoyable technology that pays broad personal and societal benefits that extend beyond the financial benefits. "I could have put the money in the stock market, but that's far riskier," he says. Instead, he comes out ahead with his PV system, which saves about a $1,000 a year on electricity bills.

Gallagher has earned a reputation as a local informational resource for electric cars, grid-tied PV systems, and geothermal systems—especially how they work together. One of his coworkers bought a Chevy Volt, and last year his sister bought a PV system. "People are thinking about what I did and making changes," he says. "That's worth a lot to me as someone who wants to change people's perceptions and start a grassroots movement to do things better."

The Gallaghers' son Henry (right) and a friend put a shine on the 'Lectric Leopard.

Courtesy Dan Gallagher (3)

EVs Get the Green Light

Compared to Gallagher's incremental approach, Dickson Pratt had a more holistic transition to pairing a PV system with an EV. He saw PV charging and an electric car as two parts of the same system. "In fact, I budgeted the PV system as part of the car's cost," he says. "In essence, the solar panels are 'part' of the car."

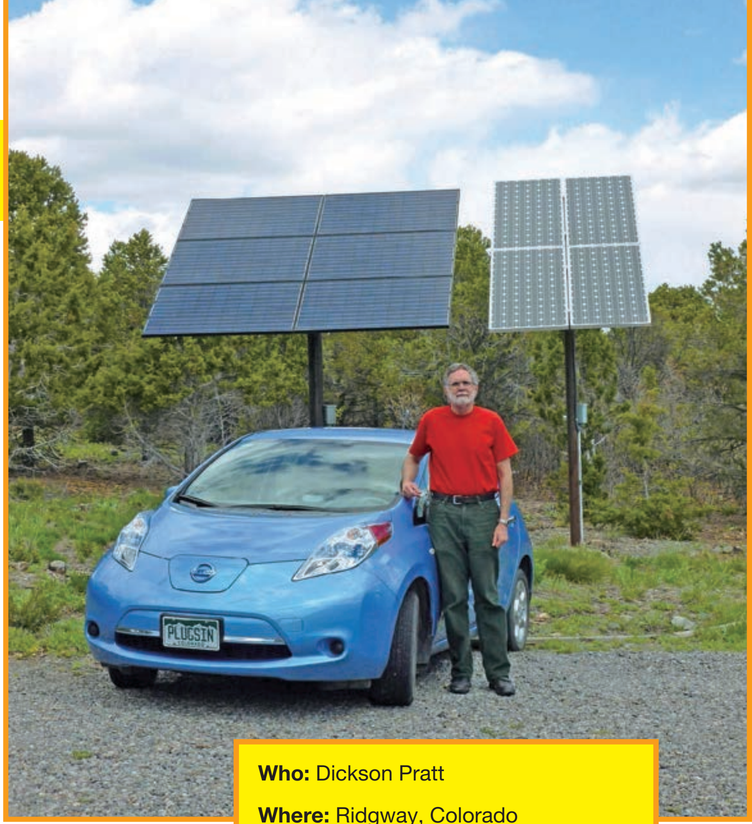
EVs are simpler than cars with internal combustion engines. There's no spark plugs, radiator, pistons, or exhaust system, so there's less to maintain and repair. And the fuel costs—already about one-third of the cost compared to gasoline-fueled cars—shrinks even more when the EV is charged with a PV system. In fact, Pratt says that the main per-mile cost of his car is tire wear.

"When I first moved to the boondocks in 1999, I was keenly aware that remote rural living was very energy-inefficient because of all the driving involved," says the Ridgway, Colorado, resident. A trip to the grocery store is about 65 miles round-trip with 2,500 feet of elevation change. He knew that he'd be racking up the miles, but his goal was to reduce his fossil fuel use as much as possible.

As early as 2008—more than two years before the first Nissan Leaf hit the market—Pratt was already anticipating the arrival of mass-manufactured electric cars. He installed a 700-watt grid-tied batteryless PV system to "get a sense of what it would take to offset my household usage." He used online tools to get a benchmark on his electricity use and discovered that, paired with his home's passive solar exposure, a thermostat set to energy-saving levels, and a shift to LED lights, the 700 W system was offsetting about 60% of his home's electricity use. From there, it wasn't difficult to calculate how much to expand the PV system to accommodate an EV.

In December 2011, he bought a 2012 Nissan Leaf, the only electric car available in Pratt's region. "It was the Leaf or nothing, unless you're talking about a plug-in hybrid like the Chevrolet Volt," he says. "But I wanted to go with a pure electric car. To me, that's a big deal."

Despite his insistence on a pure battery-electric car, rather than a hybrid for himself, Pratt nonetheless recommends a Volt for people who live in remote areas, given the range of about 80 miles from Nissan's electric car. "Otherwise, prepare to be committed to needing to charge at both ends of the commute," he warns. For Dickson, managing the Leaf's range and planning the trip is a fun challenge.



Dickson Pratt with his Nissan Leaf and two PV arrays that provide more than 100% of his annual electricity needs.

Courtesy Dickson Pratt (2)

Who: Dickson Pratt

Where: Ridgway, Colorado

PV system: 2.170 kW batteryless grid-tied

Average daily sun-hours: 5.68

Average annual production: 3,217 kWh

Drives: 2012 Nissan Leaf SV

Range*: 73 city/hwy

*Range is reduced in hilly & mountainous regions

A window sticker exemplifies the pride felt by many solar-powered drivers.

In 2012, he added 1,470 W of PV modules to bring the system to nearly 2.2 kW. "I figured that would give me pretty close to what's needed to run the house, plus the fuel costs for the car," he says. The total investment in his PV system, after incentives, was about $11,000.

Pratt says that for the first two years, his system has produced slightly more than needed for his house and at-home car-charging. That was the case even though he started putting more miles on the Leaf when public EV charging stations finally appeared in his corner of Colorado. "I was able to do quite a bit of charging away from home," he says.

He's now waiting for the Tesla Model 3 and its 200-mile range, expected in 2017. With Tesla's national network of quick-charging stations, Pratt could manage a 600-mile trip to visit friends in Denver, and even the 2,200-mile journey to family in Oregon. Some of Tesla's charge stations are equipped with PV systems and battery storage.

According to Pratt, the payback period on his PV system may be a couple of decades, but having a PV-powered EV changes the equation. First of all, charging an EV with solar electricity is an answer to the same "long tail[pipe]" argument that Gallagher mentions. Although his region's utility electricity is generated with coal, his car is charged with PV energy, not fossil fuel. "It also changes the psychology," he said. "If I want to take a trip to town, I don't have to pay for gas. And there are no exhaust emissions coming from my car's tailpipe."

TOU Makes Quicker Payback

The Gordi family next to their 6 kW PV carport.

Toufigh Gordi, who grew up in Sweden, is a consulting pharmaceutical scientist in San Carlos, at the northern end of California's Silicon Valley. The region is a hotspot for both EVs and PV systems. He viewed the installation of a PV array at his family's three-bedroom, 2,000-square-foot home and their adoption of electric cars as part of a comprehensive energy-saving plan.

To make sure he understood the energy impacts of home car-charging, Gordi bought a Nissan Leaf before installing any solar electricity. By the time he invested in a solar-electric system, he already had the energy data for the Leaf and for the Ford Focus Electric that would soon follow. (The Ford has now been replaced by a used Tesla Model S85.) "We put up 30 modules," he says. "It's almost 6 kilowatts."

Gordi also converted the home's lighting to LEDs, and switched to more efficient electrical appliances, including changing his stove from gas to electric. "I told the solar installer that I did not want to burn fuels," he says. "I'm very concerned about what we are doing to the climate, so I'm trying to be as carbon-neutral as I can be."

Despite his enthusiasm for fossil-fuel-free technologies, his wife remained skeptical about whether or not the grid-tied batteryless system would be a wise economic investment. Ultimately, she was won over when the bill for their first year's use of electricity arrived. They owed a total of $4.86 for the entire year, which included electricity use for charging the two EVs. In the following year, the bill was $5.24.

According to Gordi, one reason that their utility bills are so low is the time-of-use (TOU) EV rate plan offered by Pacific Gas & Electric, the local utility. "Our PV system produces electricity during the day—during peak utility-use hours—so this electricity earns a billing credit at the higher retail on-peak rate," says Gordi. "Our main electricity usage is for recharging the cars, and both of them recharge between midnight and morning, when TOU rates are low." He also sets timers on appliances, such as the dishwasher, so that they run during off-peak hours.

The Gordi array is installed on a carport, since the home's roof was too shaded. The net cost, after tax incentives, was about $20,000. He calculates an annual savings of about $2,100, which will pay back his loan in less than 10 years. Instead of taking a separate loan to buy the system, he pulled the money from a home equity line of credit.

"If we can borrow from the bank, and pay off the PV system in about 10 years, and then get free electricity and free fuel for the cars, then why not do that?" he says. "Instead of paying $200 a month to PG&E, we're paying $200 to the bank." When their house was recently appraised for refinancing, the appraiser boosted its value by $70,000 after learning that the PV system is reducing their home electricity costs to $5 a year.

Toufigh with the original Leaf and the newer Tesla S.

Courtesy Toufigh Gordi (2)

Who: Gordi family

Where: San Carlos, California

PV system: 6 kW batteryless grid-tied

Average daily sun-hours: 5.35

Average annual production: ~10,000 kWh

Drives: 2011 Nissan Leaf; Tesla S85

Range*: 80 city, 70 hwy; 230+ city, 230 hwy

*Range is reduced in hilly & mountainous regions

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Batteries & Energy Storage for PV Systems

by Brian Mehalic

Interest in energy storage, either as part of a PV system or as its own system, has been dramatically increasing for a variety of reasons. Many of these systems utilize multimode inverters capable of both interacting with a primary power source—such as the utility grid—and operating in stand-alone mode, using stored energy from batteries.

Energy storage and batteries are essentially synonymous, though there is a wide—and ever-increasing—range of energy storage options, including non-chemical technologies like flywheels. Batteries are addressed in numerous locations in the *National Electrical Code (NEC)*, but primarily in Article 480 and Part VIII of Article 690, both titled "Storage Batteries."

Although Article 480 has significant changes and additions in the 2014 *Code* cycle, it is still relatively brief. A new Informational Note refers to seven different Institute of Electrical and Electronics Engineers (IEEE) standards that are "frequently referenced" for battery system design and installation, including vented flooded lead-acid (FLA), valve-regulated lead-acid (VRLA), and nickel-cadmium batteries. Notably absent are references to lithium-ion batteries, which are increasing in popularity and availability. Some of the requirements, such as vents for vented and sealed battery cells (Section 480.10) and electrical insulation requirements for batteries under 250 volts (480.7), mostly fall on the manufacturer. For example, lead-acid batteries typically are built with "covers sealed to containers of nonconductive, heat-resistant material" and include flame arrestor or pressure relief vents as required by these sections. It is up to the system designer or installer to verify that this is the case for the particular batteries being used.

Battery Connections

Battery connection corrosion can increase resistance, which affects battery performance and can result in unsafe heat buildup at the points of connection. Many lead-acid batteries have lead terminals, though other materials are also used, and there are a variety of connection methods between batteries. Section 480.3(A) requires using antioxidant when connecting dissimilar metals, and refers to the battery manufacturer installation manual for guidance.

Frequently, installers use flexible, fine-strand cable for battery interconnections due to the ease of routing the typically large-gauge conductors between battery terminals. Available fine-stranded conductors (which are often listed to several of these types) include MTW and THW, RHW, THHW. See Table 310.104(A) for more details—welding cable, frequently used in the past, is not acceptable. It is critical to use terminals and connectors that are designed for use with flexible, fine-stranded conductors; otherwise, the cables may be damaged, or settling and loosening of crimped or pressure connections may occur—possibly leading to high resistance and increased operating temperatures. Pre-manufactured battery interconnects and battery-to-inverter cables are available; just make sure you specify the correct gauge.

Access, Workspace & Ventilation

Article 480 also addresses battery access and workspace requirements. If a battery requires testing, inspection, and cleaning, the terminals must be readily accessible. For batteries with transparent housing (aka "jars"), at least one side must be visible for inspection of the internal components and electrolyte [480.8(C)].

A room full of batteries can be hazardous—as such, Section 480.9(E) requires that doors to designated battery rooms must open outwards (in the direction of egress from the battery location), and use listed panic hardware—a lever that opens a door by pushing (or leaning) on it. Additionally, illumination must be provided for battery workspaces unless the area is lit from an adjacent light source (the type and amount of illumination is not specified).

Batteries that release gas while charging, such as FLA type, must have appropriate battery compartment ventilation to avoid flammable hydrogen gas buildup. The Informational Note in Section 480.9(A) refers to the National Fire Protection Association publication, *NFPA 1 Fire Code*, for ventilation requirements for various battery technologies; additional information can be found in the *NFPA 111 Standard on Stored Electrical Energy Emergency and Standby Power Systems*. For example, two air changes per hour are recommended for FLA batteries, so as to keep the concentration of hydrogen below the maximum recommended level of 2% of the total air volume in the battery compartment.

continued on page 58


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continued from page 56

Additional Battery Storage Requirements

The following requirements from Article 690 apply only to storage batteries in PV systems and, for example, would not apply to a batteries that are connected to a multimode inverter without PV.

Batteries in dwellings (defined in Article 100 as "…living facilities for one or more persons, including permanent provisions for living, sleeping, cooking, and sanitation") are limited to 50 volts nominal per Section 690.71(B)(1), unless there are no live parts that are accessible during routine maintenance. In this case, the 600 VDC limit in Section 690.7 applies (for one- and two-family dwellings). Expect to see new energy storage products on the market operating at higher voltages and intended for use in dwellings, but without accessible live parts. Higher voltages are permissible in commercial and industrial applications (subject to the requirements of Article 690 Part IX, Article 490, and *NEC* sections when greater than 1,000 V).

Guarding of live parts [110.27(A)] is required for equipment operating at 50 V or more (such as a battery bank enclosure that is accessible only to qualified persons). This is not the nominal voltage, so Section 110.27(A) applies to 48 VDC nominal battery systems (which, much of the time, actually will attain voltages in excess of 50 V). Section 110.27(C) requires "conspicuous warning signs forbidding unqualified persons" from entering rooms that have exposed live parts. Regardless of voltage, guarding is required for all live parts of battery systems in dwellings per Section 690.71(B)(2).

Section 690.71(E) requires that battery banks over 48 V nominal have a means to segment them into strings that are less than or equal to 48 V nominal. The means do not have to be load-break rated—they can be plug connectors or bolted connections. Section 690.71(F) stipulates that grounded systems must be have a means to disconnect the grounded battery circuit conductor for maintenance. Again, the means needn't be load-break rated, but must be accessible only to qualified personnel.

Sections 690.9(A) and 705.65(A) require that battery circuit conductors be protected in accordance with Article 240. Because of the tremendous amount of current that a battery can deliver during a fault or short-circuit, listed overcurrent protection devices (OCPDs) are required at the battery when its short-circuit current potential exceeds the interrupting rating of other OCPDs in the circuit [690.71(C)]. For example, a breaker used for overcurrent protection and as an equipment disconnecting means for an inverter may not have the required interrupting rating; in this case another OCPD, such as a fuse which does have the necessary interrupting rating, would also have to be installed at the battery. Consult the battery manufacturer for the short-circuit current rating of the particular battery (and battery bank configuration) being installed.

Section 690.8(A)(4) defines the maximum current for the battery input circuit to battery-based inverters as the "continuous inverter input current rating when the inverter is producing rated power at the lowest input voltage." Calculate this value based on the continuous AC output power divided by the lowest DC input voltage at which the inverter can operate. For example, a 3,600 VA inverter with a nominal 48 VDC might accept DC input as low as 42 VDC. This would result in a DC input current of at least 85.7 amps (3,600 VA ÷ 42 V), which would need to be adjusted for inverter efficiency—say, 94% at full output (consult the manufacturer specs for the actual value). The maximum DC input current would be 85.7 A ÷ 0.94 = 91.2 A.

This value is used for sizing conductors and overcurrent protection in accordance with Sections 690.8(B) and 690.9(B). Most inverter manufacturers provide specific conductor and OCPD sizes for their equipment. If this is the case, use their specifications. (See IEEE 1375-2003, *Guide for the Protection of Stationary Battery Systems*, for overcurrent protection and conductor sizing strategies.)

New in the 2014 *NEC* is Section 690.71(H), which requires OCPDs and disconnecting means at the battery end of any circuit where the batteries are more than 5 feet from connected equipment (such as the inverter or charge controller)—or where the conductors pass through a wall or partition, which is often the case when battery boxes are used, or batteries are separated from the balance-of-system equipment. This section also requires that the batteries be connected to the line side of the disconnecting means/OCPD, since this side of the switch or breaker will be energized even when the device is off.

If the disconnecting means at the batteries is not within sight of the inverter/charge controller, then an additional disconnecting means is required at the connected equipment. And finally, when the disconnect/OCPD required by 690.71(H) is not within sight of the PV system AC and DC disconnecting means, all of the disconnects must be labeled to refer to the locations of all of the other disconnects in the system.

Rapid shutdown (Section 690.12) applies to battery circuits when batteries are part of a PV system, and the conductors between the batteries are inside a building and longer than 5 feet in length. Note the difference in the language between 690.71(H), which is a physical distance, while 690.12 refers to cable length. Because of the high levels of DC current in battery-to-inverter circuits, there is limited equipment available to accomplish this. An option is a shunt trip breaker or contactor that opens the circuit and thus controls the conductors to meet the stipulations of 690.12 when rapid shutdown is initiated.

In addition to labeling requirements specific to the system type—such as the requirement for stand-alone systems in 690.56(A)—PV systems, including grid-tied systems with energy storage, must have labeling indicating the maximum operating voltage. This number should include the equalization voltage and the label must include the polarity of the grounded DC conductor (if it is a grounded system) per Sections 690.55 and 705.80.


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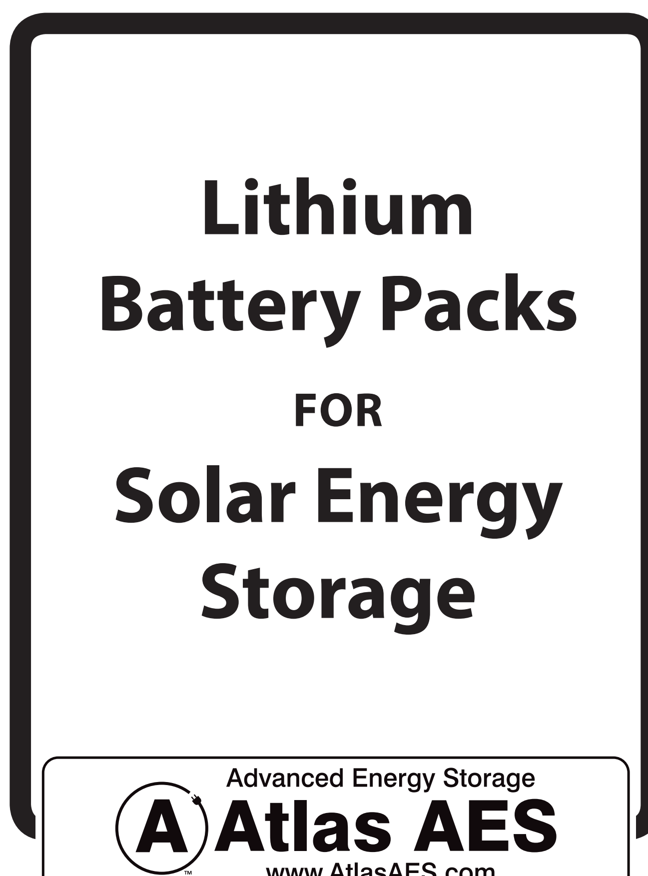
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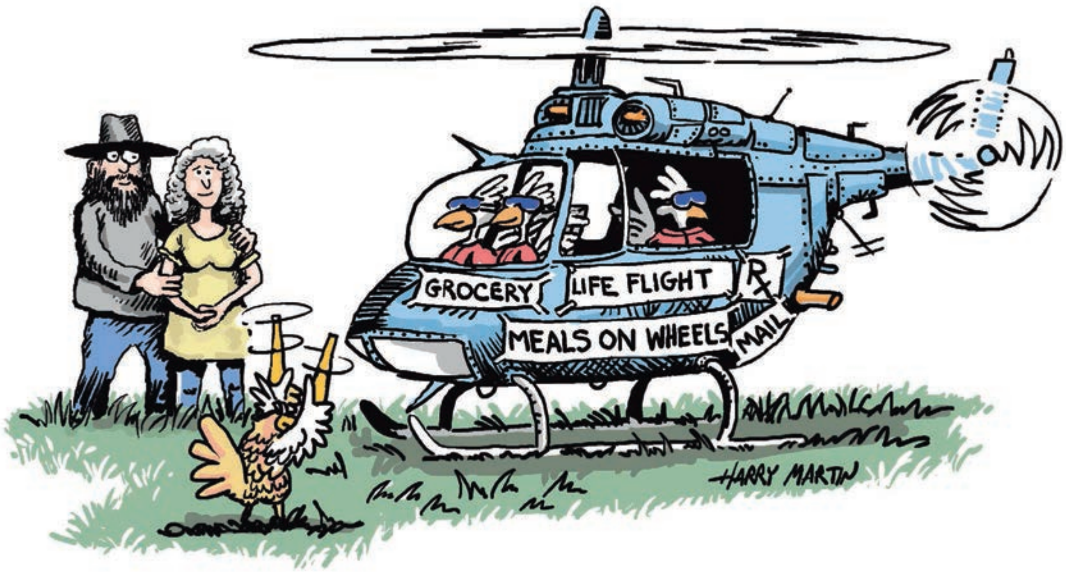
Aging, Off-Grid

by Kathleen Jarschke-Schultze



You have to be a certain kind of independent person to live on your own, way out in the country. You are the "utilities"—providing water, power, heat, and garbage disposal—and that can be a physically demanding job.

Being the kind of people who research every project, every large expenditure, every eventuality, my husband Bob-O and I have been discussing an issue that truly cannot be avoided forever. What will we do when we can no longer pursue the physically active, hands-on off-grid life?

Independence

Having lived off-grid for the last 30-plus years, we have several friends and contemporaries facing the prospect of leaving their very-rural off-grid homes as age and its accompanying infirmity become an issue.

There really are just two choices: To go or to stay. So, go where? Somewhere closer to whatever services have become too hard to provide for yourself. Most times this includes health care, which means living much closer to town. That would be a huge life change.

In times past, many people lived in the country on farms—family farms—where generations lived together. Parents and older children worked the farm, while grandparents took care of the younger children and helped where they could—every age together and helping each other. Around the turn of the 20th century, most Americans lived rurally on farms; after the 1920s, more than half of the population had moved to urban areas. Nowadays, families can be scattered across great distances from each other—none of our family lives very close by.

In preparation for their elder years, our friends bought a house in a town they had lived in before and were familiar with. They will rent it out to pay the mortgage until they feel the need to move closer in. Some people move closer to or in with other family members who already live in town. So many factors are involved. Can you afford another home, even if the rent will pay the mortgage? At an advanced age, do you really want to take on a 30-year mortgage? Would you have to sell your country home? What is your home worth in the real estate market?

Experience

The "back-to-the-land" folks of the '60s were the vanguard of electrified off-grid living, happily replacing kerosene lamps with 12-volt light bulbs powered by car batteries. *Home Power* cofounder Richard Perez once told me he blamed it all on the Grateful Dead. He and his wife Karen lived hours away from grid power. In their cabin, they used a 12 V car tape deck (Google it, kids) to listen to music, i.e., the Grateful Dead. Richard had two truck batteries that he would rotate from the house to the truck for charging. When he heard about PV modules, he was hooked. His first solar-electric system served to power that car radio. He soon started selling PV systems to others, and then passed this business on to Bob-O after starting *Home Power*.

Throughout the decades, power lines have moved closer; some now even pass right by homes that were once beyond the grid. Because of this, many former off-gridders have opted to bring the grid into their homes. Being power conservative all those years pays off, with lower bills and net-metering for excess power produced.

continued on page 62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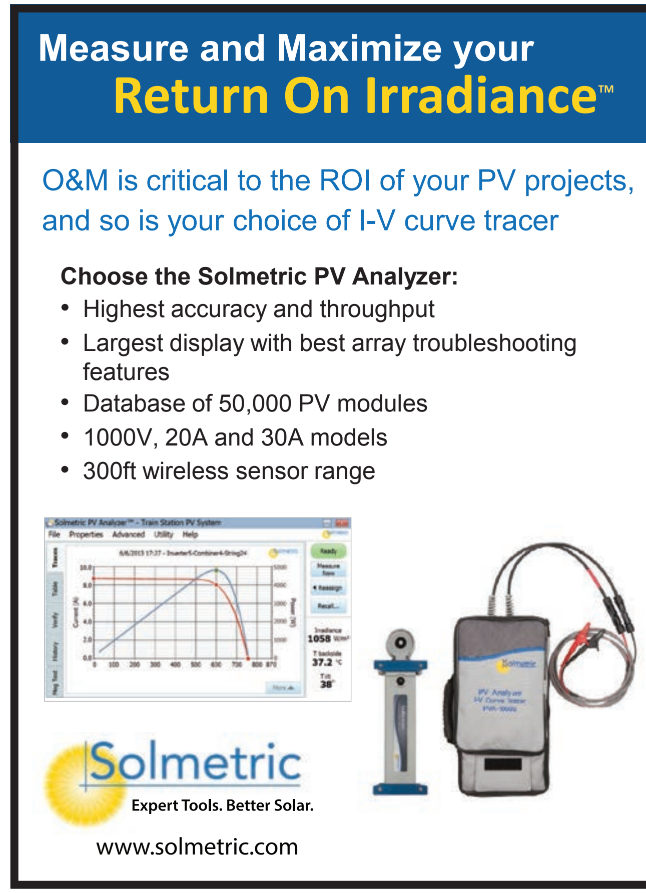
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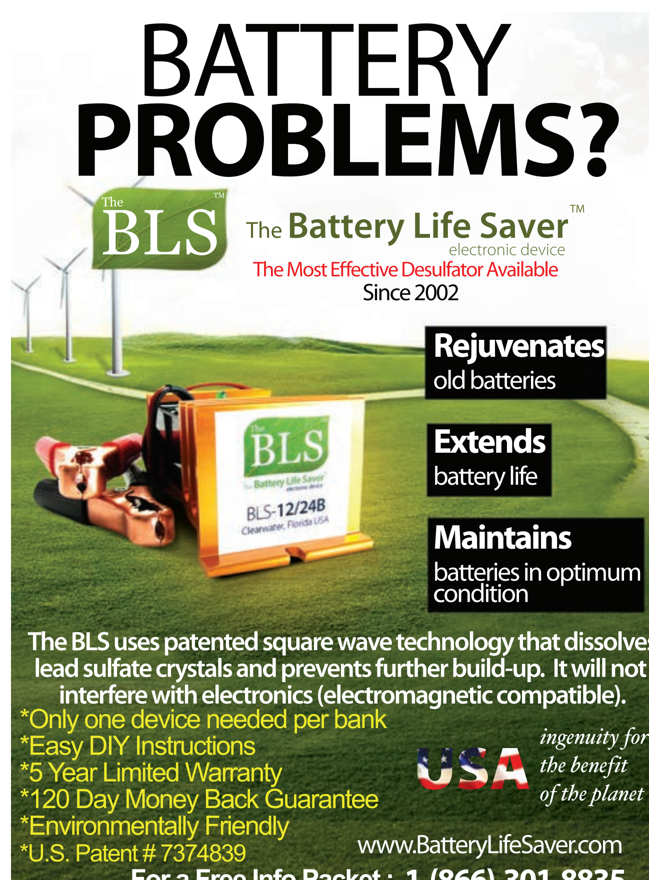
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continued from page 60

Although we have lived in our little canyon for 25 years, the utility power grid has ventured no farther up the creek. The closest power line is still almost 2 miles away, where the pavement ends. Our home will remain off-grid for the foreseeable future.

Accessibility

A major consideration of staying is access to health care. Appointments can be scheduled, but it's the emergency situation that is the most daunting. Lucky for us, we have a large, fairly flat meadow that can be accessed by vehicle, allowing us to become members of a program that covers air ambulance helicopter costs. That would be a substantial savings in travel time in case of a medical emergency—especially important in winter.

Very specific or specialized medical needs are a major consideration. Out here, help is not minutes away. On a good day, in good weather, and during daylight hours, a helicopter would take at least 25 minutes to reach our meadow. And that doctor you need to see every week? Most medical specialists do not live in the wilderness. They live in a city, near a hospital.

I am replacing a set of steps that lead to our deck with a ramp. I want to be able to wheelbarrow my load of firewood to the door of the house rather than hand-carry it up the steps. Just about any improvement to our home now has the added consideration of making it easier for our older selves. For example, we love lever-type door handles. It's a small thing, but wonderful. If I were building a home today, I would incorporate as many "elder" modifications as practical (see bit.ly/ElderMods).

Another modification I would like is a small freight elevator to ferry laundry and other goods between the house and the basement. The old style used weights and pulleys, and needed no electricity. This is going to take some hard pondering and possibly fantastical engineering. But I'm not in a hurry and I enjoy pondering.

Another factor is the future need for a caregiver. If we decide to stay here in our dotage, we will need help. I have seen several off-grid homesteads that were built with a small, complete, but separate, apartment or cabin for caregivers.

I admit Bob-O and I have not decided what we will do yet, nor is such a decision pressing. We are leaning toward the caregiver cottage idea. The idea of leaving our homestead is just too foreign to contemplate. Time and events will tell. But whenever an old friend sells their homestead and moves to town, we can't help but think of our own future. There is not just one answer to suit everyone, just as no two off-grid renewable energy systems are alike. Needs and location are the two most important factors. For now, our location is perfect and our needs are few.

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15. Extent and Nature of Circulation:	Avg no. of copies of each issue during preceding 12 months	No. of copies of single issue published nearest to filing date
a. Total No. of Copies	18,851	16,318
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e. Total Free or Nominal Rate Distribution	1,625	2,339
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h. Total	18,856	16,318
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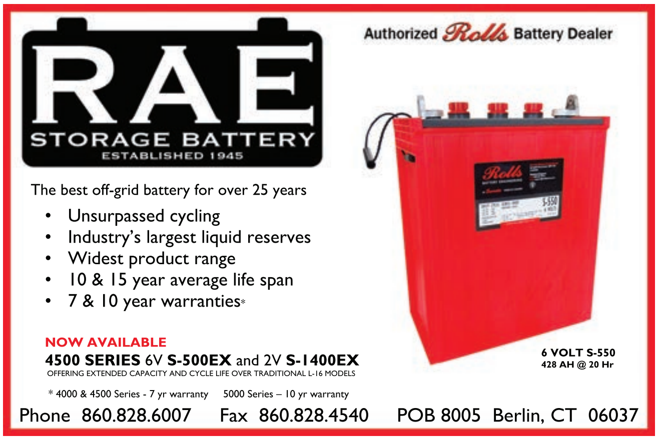
17. This statement of ownership will be printed in the November/December 2015 issue of this publication.

18. I certify that the statements made by me above are true and complete. Joseph Schwartz, Editor, 9/30/15.



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Battery Basics

Battery storage is a hot topic right now, so brush up on these common terms.

Battery Capacity

Think of a battery as a bucket that holds energy for later use. As such, "battery capacity" defines the size, usually in amp-hours (Ah) but sometimes watt-hours (Wh), of our bucket. For example, a 200 Ah, 12-volt battery has twice the storage capacity as a 100 Ah, 12 V battery. We can calculate the energy storage in each battery by using the equation: volts x amp-hours = watt-hours. The 200 Ah battery can store 2,400 Wh, while the 100 Ah battery has 1,200 Wh of energy storage.

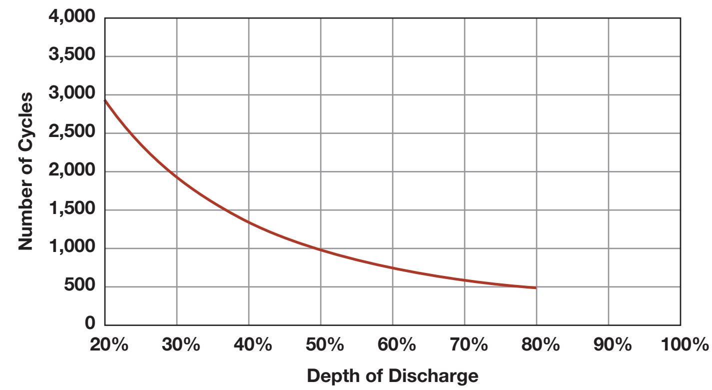
Depth of Discharge

Depth of discharge (DOD) describes the percentage of battery capacity that has been used. For example, if we discharge our 2,400 Wh battery by 20% (20% DOD), then practically, we have pulled 480 Wh from that battery.

State of Charge

Conversely, state of charge (SOC) describes the percentage of battery capacity remaining. So our 2,400 Wh battery that has been discharged 20% is now at an 80% SOC, and still has 1,920 Wh of energy stored.

Life Cycles vs. Depth of Discharge Example



Charge & Discharge Rate

Charge & discharge rate is the speed at which you charge (or discharge) a battery, stated in terms of capacity over time. For example, if you have a 200 Ah battery, and you are charging it at 10 A, your charge rate is C/20 (200 Ah ÷ 20 hrs = 10 A). Conversely, if you discharge the battery at a rate of 2 A, then your discharge rate is C/100 (200 Ah ÷ 100 hrs = 2 A).

Battery capacity is also dependent on the speed at which you discharge it, and batteries will actually offer a slightly higher capacity if discharged more slowly. For example, one type of 12 V battery has a 200 Ah specification if discharged over 20 hours (C/20), but offers 212 Ah if discharged over 100 hours. Home PV system batteries most often use the 20-hour rate since it closely relates to the 24-hour cycle common in those systems.

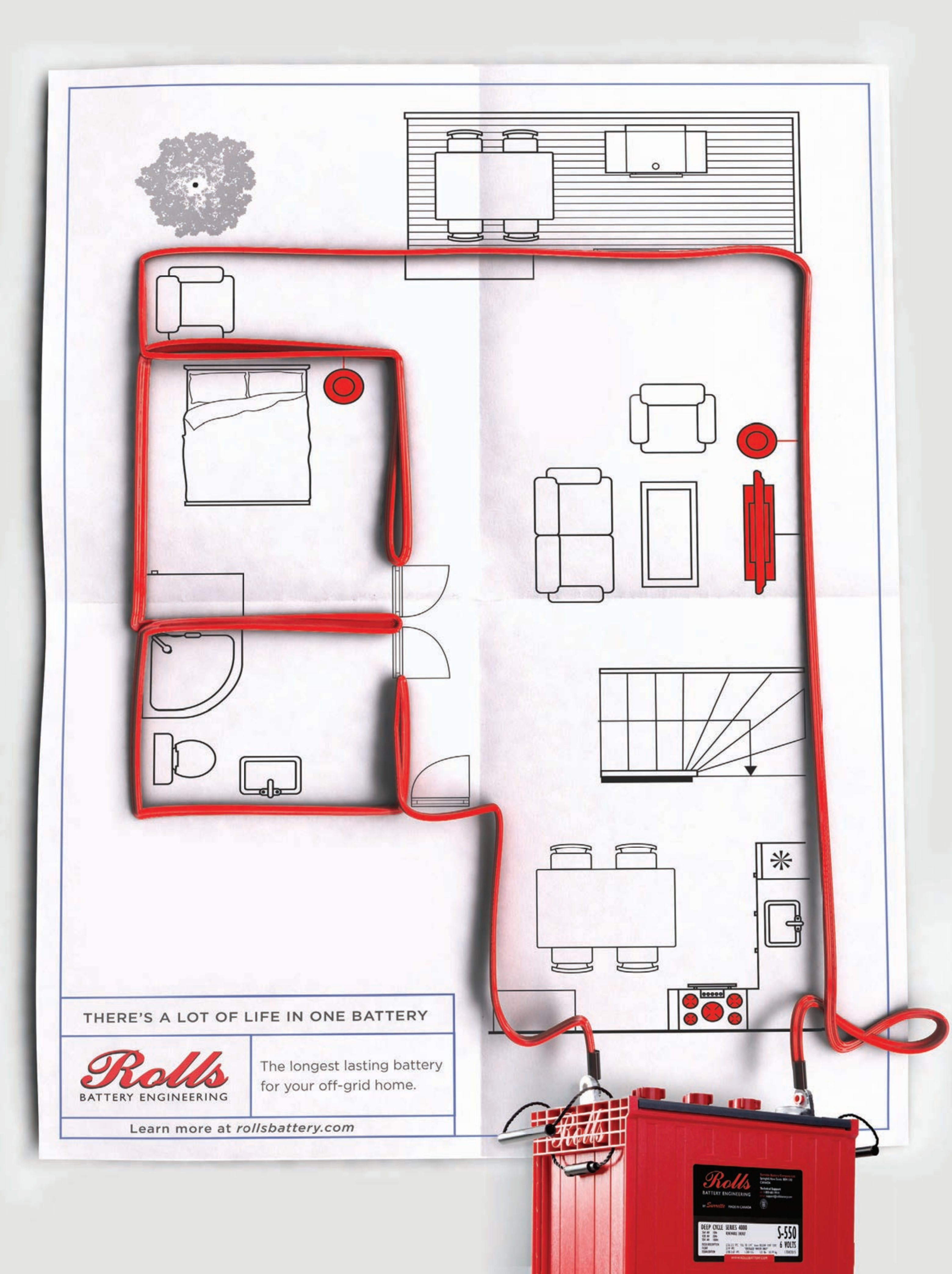
Cycle Life

Cycle life is the number of charge/discharge cycles a battery can complete during its "operational life," which is commonly defined as ending when it has dropped below 80% of its original capacity. Cycle life is dependent on how deeply the battery is discharged—battery manufacturers provide cycle-life graphs showing this relationship. For example, a lead-acid battery may provide 1,000 cycles if DOD is limited to 50% each time, but only 500 cycles if it is discharged by 80%. You can get by with a smaller battery bank and less initial cost by discharging it more deeply, but you will have the hassle of replacing the batteries more frequently.

—Justine Sanchez

Courtesy Trojan Battery (2)

This maintenance-free Trojan L16-AGM battery offers 370 Ah of storage at 6 volts.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