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RE Outpacing Fossil Fuel

While exciting renewable energy news cropping up in my inbox isn't unusual, some of the recent sources are. For example, take this March 1, 2016, statement from the U.S. Energy Information Administration (EIA):

> *Electric generating facilities expect to add more than 26 gigawatts (GW) of utility-scale generating capacity to the power grid during 2016. Most of these additions come from three resources: solar (9.5 GW), natural gas (8.0 GW), and wind (6.8 GW), which together make up 93% of total additions. If actual additions ultimately reflect these plans, 2016 will be the first year in which utility-scale solar additions exceed additions from any other single energy source.*

So why is this projection so exciting? Let's consider how renewables stacked up last year. According to the *Solar Market Insight 2015 Year in Review/Q4 2015* published by SEIA and GTM Research:

> *For the first time ever, solar beat out natural gas capacity additions, with solar supplying 29.4% of all new electric generating capacity brought on-line in the U.S. in 2015.*

The same report also shows that wind power additions accounted for 39% of all new generating capacity, while natural gas additions accounted for 29%. Coal wasn't even on the chart for 2015.

That brings us back to 2016—how are energy capacity additions from renewables comparing with fossil fuels thus far? The *Solar Market Insight Q1 2016* reports that in the first three months of 2016, 1,665 MW of solar came online, representing 64% of all new capacity additions. The remaining 33% came from wind; 1% from natural gas; and 3% from "other" (which includes biomass and hydro). So far, renewable energy capacity additions are substantially outpacing conventional energy sources.

Since homes are our focus here at *Home Power*, let's take a look at the residential PV market. Again referencing *Solar Market Insight*, residential PV was cited as the fastest-growing sector in U.S. solar, and that market had:

> *2,099 MW (DC) installed in 2015, representing 66% growth over 2014. The residential PV market experienced its largest annual growth rate to date, an impressive feat given that 2015 marked the fourth consecutive year of greater than 50% annual growth.*

So why is this so exciting? It's a strong sign that the renewable energy revolution has finally arrived in the United States. You too can be a part of this revolution. With the average installed PV system pricing hovering at \$3.20/W combined with the extension of the federal 30% solar investment tax credit—and possibly even more local or state RE incentives—the timing could be perfect for your home to be next!

—Justine Sanchez, for the *Home Power* crew

Think About It...

The Department of Defense, the largest single energy consumer in America, is bullish on solar.

—Bernie Sanders, Vermont senator

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july & august 2016

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Hydro pro and *Home Power* senior editor Ian Woofenden shows the scale of two Pelton-wheel turbine runners at Canyon Industries in Deming, Washington.

Photo courtesy Dana Brandt

Photos: Courtesy EcoInnovation; Timberhomes Vermont; Sunsense Solar


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Photos: Darin Anderson; Khanti Munro; courtesy Simpliphi Power

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Senior Technical Editor	**Justine Sanchez**
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contributors

this issue's experts

Darin Anderson is a computer programmer accidentally turned green builder. He and his wife live in the backcountry of Colorado where he volunteers as a firefighter in his community. In his free time, he spends as much time outdoors and as far away from big cities as possible.

Christopher LaForge is the CEO of Great Northern Solar and a NABCEP-certified Photovoltaic Installation Professional. He is an IREC Certified Master Trainer in Photovoltaic Technologies. Christopher volunteers with the Midwest Renewable Energy Association and NABCEP. He has a master's degree in philosophy from the University of Wisconsin at Madison and is an organic gardener.

Allan Sindelar installed his first off-grid PV system in 1988. He retired from Positive Energy Solar of Santa Fe, New Mexico, in 2014, and now designs, services, and consults on off-grid and water pumping systems. He is a licensed electrician with dual NABCEP certifications.

Author and educator **Dan Fink** has lived off the grid in the Northern Colorado mountains since 1991, 11 miles from the nearest power pole or phone line. He started installing off-grid systems in 1994, and is an IREC Certified Instructor for both PV and Small Wind. His company, Buckville Energy Consulting, is an accredited Continuing Education Provider for NABCEP and IREC.

Ryan Mayfield is the principal at Renewable Energy Associates, a design, consulting, and educational firm in Corvallis, Oregon, with a focus on PV systems. He also teaches an online course in conjunction with *SolarPro* magazine and HeatSpring.

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, and lecturing, teaching, and consulting with homeowners.

Kelsey Gibb joined the Sunsense Solar team in the spring of 2014 after receiving her bachelor's degree from Colgate University with a major in sociology and a minor in women's studies. She currently manages the company's residential and small commercial solar rebates and interconnection agreements while also contributing to the Sunsense marketing department.

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.

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.

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.

Contact Our Contributors

Home Power works with a wide array of subject-matter experts and contributors. To get a message to one of them, locate their profile page in our Experts Directory at **homepower.com/experts**, then click on the Contact link.

Courtesy Adara Power

Adara Power 8.6 kWh Lithium-Ion

Energy Storage Systems

Adara Power (adarapower.com), formerly JuiceBox Energy, offers an 8.6 kWh, 48 VDC energy storage system comprised of lithium-ion nickel manganese cobalt (NMC) cells—the Li-ion chemistry commonly used in electric vehicles. It includes a battery management system (BMS), and is designed to be integrated with the Schneider Electric Conext XW+ 5548-NA battery-based inverter. Up to two Adara Power units can be stacked for 17.2 kWh, and can be deployed on- or off-grid. Included is a controller to manage the energy flow between the battery bank and the Conext equipment. Redundant protection mechanisms help prevent overvoltage, overcurrent, undervoltage, and overtemperature conditions. The storage system includes an indoor/outdoor NEMA 3R aluminum enclosure, weighs 280 pounds, and can be wall- or floor-mounted. The included Adara Power Cloud provides remote control and monitoring through a cellular connection and mobile app. This storage system comes with a 10-year (or up to 4,000 cycles) warranty.

SimpliPhi Power PHI2.6 & 3.4 Smart-Tech

Lithium-Ion Batteries

SimpliPhi Power (simpliphipower.com) offers 24 V and 48 V lithium iron phosphate (LiFePO4) batteries in 2.6 and 3.4 kWh models. Each battery has a BMS, a built-in 80 A DC circuit breaker (on/off switch), and is compatible with standard 24 V and 48 V battery-based inverters. These batteries can be drop-in replacements for lead-acid batteries in on- or off-grid systems and have a 10-year warranty. These modular units are scalable and deployable in both small and utility-scale (MW) systems. They weigh 57.5 pounds and 75.5 pounds, respectively. Both versions have a wall-mount option. LiFePO4 battery chemistry is touted for safety, as it is not prone to thermal runaway.

—Justine Sanchez

Courtesy SimpliPhi Power

PV Pioneer Documentary: Photos Needed

Thanks to everyone at *Home Power* for your decades of service to the solar community. I have a deep respect for your pioneering work in PV education and your contributions to cultivating the rich culture of the solar community, my extended family.

I have found myself in the role of executive producer of a documentary film about the pioneers of PV. This project grew out of the Solar Pioneer gathering in southern Humboldt County in October 2015. Never before had so many pioneers of PV gathered in one place at one time. The experience was magical.

What grew from that event was a film project of the birth of home PV power. We are honored to have participation from dozens of industry pioneers, including Richard Perez, Bob-O and Kathleen Schultze, David Katz, Sam Vanderhoff, Jonny Hill, Johnny Weiss, and Ed Eaton. Our filming locations include Humboldt and Mendocino Counties in California, plus Colorado, Oregon, and Arizona. We will wrap up filming in Grass Valley, California, at the second annual Solar Pioneer Party in October 2016.

Our documentary will tell the story of the off-grid homestead movement and how these inventive homesteaders and farmers created the first major market for PV modules. This story starts in the late '70s and wraps at the dawn of the grid-tie market in the early 2000s. We anticipate a theatrical release by the summer of 2017.

We need photos, videos, and film of the early days of living with PV systems, including period photos of off-grid activities like chopping wood and hauling water, kerosene-lit homes, and people playing musical instruments. *Home Power* readers who have photos or video that might help our project can contact me at jeff.spies@quickmountpv.com.

Jeff Spies • Chandler, Arizona

Joe Schwartz

Videographer Jason Vetterli with *Home Power* founder Richard Perez in front of the "democracy rack" of early PV modules at the fondly named "Funky Mountain Institute."

Goal: Low Energy Consumption

I could not agree more with Ken Last's letter in *HP173* about energy-wasting behemoth net-zero-energy homes. I would extend that to all net-zero-energy homes—regardless of size—that achieve that milestone by adding enough PV to atone for their energy-hog ways.

With PV costs to consumers continuing to decline, anybody with enough money can transform their existing home into a net-zero-energy one—without doing anything to reduce energy use. However, more than half the electricity consumed in a grid-tied home comes from the electric utility at night and on cloudy days, a substantial amount of which is typically fossil-fueled. This is the energy usage that needs to be reduced, at least until practical economic electricity storage is available.

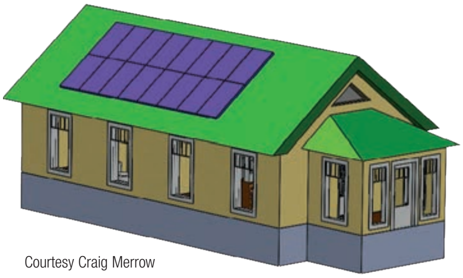
So, rather than having net-zero-energy as the goal, we should have low energy consumption by the home as the goal. Homes should be rated accordingly, and the best way to rate homes is with a "home heating and cooling index," which objectively rates the structure's energy requirements for maintaining a comfortable indoor temperature year-round. The house with the lower Btu of energy per square foot per heating-degree-day and per cooling-degree-day is the more energy-efficient home. An value of 4 or less would indicate an energy-efficient home.

Because the energy a home consumes over its lifetime is the single biggest amount of energy involved, the index is the most valuable energy measure of a home. My home's value is 4. What's yours?

Tom Wehner • Santa Fe, New Mexico

Small Home

You asked *Home Power* readers if they have or are building a small efficient home, so here's mine: 684 square feet of living space, one bedroom/one bath with a loft, and off the grid—Central Maine Power wanted $35,000 for a line extension, and being located in the middle of conservation land helped my decision to stay off-grid.



Courtesy Craig Merrow

I had the concrete floors done a couple weeks ago, and am getting ready to start framing soon. I designed it in Solidworks, using a small cottage I found online and the apartment I'm renting in a former mill building for inspiration and scale. It's taken a long time to get to this stage—with a lot of planning, designing, and research—but it's all coming together and will be well worth the wait! I will keep you posted...

Craig Merrow • Wells, Maine

E-Bikes

I was glad to see Ted Dillard's article on electric bikes in *HP172*. For the last 40 years, I have been a bicycle commuter and recreational biking enthusiast, putting tens of thousands of miles under my wheels. During the last six years, a disability required a shift to electric bicycles. To date, I am 8,000+ miles and three e-bikes into that experience.

My first electric was a hub motor conversion to an existing bike with an eZee kit. They have a planetary gear motor drive instead of direct drive. They make a little more noise and have no regenerative capability, but are a lower-price conversion alternative.

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Courtesy Miles John

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In my experience, the option for regenerative braking capability in a bicycle proved to be more hype than utility. I never got more than 10% recovery in either bike with that capability, and that was over a wide variety of terrain and conditions.

On motor controllers, a number of manufacturers, such as BionX, build them into the hub; others, such as Crystalyte, have them as an external device. Keep in mind when doing a conversion that external controls have to be placed somewhere, generally in the vicinity of the hub.

Low and central battery placement gives the bike a better feel and balance. Placement behind the seat post has the effect of extending the wheelbase, thus increasing the turning radius and making the bike less responsive. Batteries on a rack over the rear wheel make the bike more top-heavy and likely to fall over if placed on a kickstand.

Most manufacturers now use 36-volt lithium as the standard. Faster bikes are shifting to 48 V. Nearly all new bike batteries use lithium-iron-phosphate or some comparably reliable battery chemistry. In used electric bikes, be advised that lithium polymer batteries, a first-generation battery type, have problems with capacity fading much quicker than with later battery chemistries.

Finally, a comment on “you get what you pay for.” I paid more than $4,000 for my current bike, but would not say the price matches the quality. The bike looks good, is designed well, and gets a lot of positive comments when I am out and about. Unfortunately, the company used an off-shore manufacturer and they installed low-quality drive components and substandard parts like the seats and brakes. Given the price, I expected a lot better. I am now looking to invest $1,000 to replace the drive system, brakes, and seat, so I can have the bike I expected. Given how much I like the basic design, I am willing to do it.

I suggest that people in the market for an electric bike examine independent reviews and be very cautious with a bike that is new to the market. There is an assurance benefit to having a track record that speaks to the true nature of the beast.

I very much enjoy riding electric bikes. I can continue being on the saddle when a medical condition could have curtailed that part of my life. I am happy for the option of electric assist, and feel fortunate the technology progressed so I can continue enjoying a lifelong passion for riding.

The bike I currently (no pun) ride is a Stromer ST1 Platinum—500-watt hub, 36-volt, with a 14 amp-hour battery. The range is 60 to 75 miles depending on terrain and aggression in riding. I can connect an additional 12 Ah battery in parallel and extend the range to 125 miles. I am considering an upgrade to a Grin hub, controller, Cycle Analyst, and charger. I’ve used Cycle Analyst displays on all my bikes and like the quality, reliability, and documentation for their products.

Jack Herndon • Seattle, Washington

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Thanks for your letter; it's well stated. Significant research is the key to being happy with an electric bicycle choice.

My first electric bike was also an Ezee kit with a 48 V battery, both purchased from Grin Technologies (ebikes.ca). I liked it very much, and my replacement is likely to also be an Ezee kit. My only complaint was the battery location. I selected the rear double-rack mount because there was no elegant means of mounting it low in the center triangle. I hope that's changed by the time I buy my replacement kit.

Michael Welch • Home Power *senior editor*

Students Visit Off-Grid Cabin

Recently, several Rich Mountain Community College physical science students and their instructor, Dr. Gaumani Gyanwali, visited our 3,725-watt solar-electric installation and off-grid cabin on our farm in western Arkansas. There are not many solar installations in western Arkansas, and even fewer off-grid installations.

Even though many of the students had an understanding of solar power, most of them had not toured an off-grid solar installation. The students asked me some tough questions regarding battery banks and voltage, battery type, and storage capacity. They also quizzed me on module size, array orientation, financial break-even points, and tax credits. And then they wanted me to explain to them how sunshine is converted into electrical energy. I thought that I was fairly knowledgeable about renewable energy, but then I got a little bit nervous, and ended up asking their instructor to help me explain how the PV cells actually generate electricity. Dr. Gyanwali did a great job!

One student questioned me about the hydropower potential from a spring. And another one asked how much insulation was in the walls and ceiling of the cabin. During our discussion of the cabin's solar-powered heat pump water heater, their instructor—who is from Nepal—explained to all of us how common rooftop solar water heating installations are in his country.

In spite of my blunders, it was a genuine pleasure to see the students' high level of interest in renewable energy and the environment! What I learned from the college students was this: renewable energy is pretty cool and all, but the next time I invite students to look at our project, I going to do my homework first!

Joe Corcoran • Mena, Arkansas

Courtesy Joe Corcoran

Electric Skateboard

One day I woke up with an idea in my head—several months later, I was riding on a self-designed and assembled work of engineering—an electric skateboard. With my experience with remote control cars, I knew it was the next project for me. After weeks of research and persuasion of my parents to give me the go-ahead, I began my project.

I used a computerized design program to create a 3D model of the board I was going to build. It was important to consider safety,

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Courtesy Ryan Needle

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durability, ease of use, appearance, top speed, and maximum distance. The length and width of the deck was designed to provide stability when riding at high speeds.

I designed a motor mount to be cut out of a sheet of aluminum and welded to the trucks, finding a welder and machinist to provide assistance. They were impressed and delighted to see a young student pursuing something as complicated as this project.

Choosing the right motor and gearing were important since the skateboard needed to have enough torque and acceleration for hills, and enough speed to make it an efficient mode of transportation. The motor is a brushless motor, and can spin at a maximum of 6,370 rpm with the batteries—lithium-polymer, a lightweight but powerful option. I used a smaller gear on the motor and a larger gear on the wheel to keep the speeds of the board safe, not overheat the motor, and provide enough torque.

The board is controlled by a handheld remote, which can also control the regenerative brake that recharges the battery powering the board. I thought it would be beneficial if I could charge my phone while riding the skateboard, so I created a charging system that uses the motor as a generator. This required changing the AC coming from the motor into DC to charge a phone via a three-phase rectifier. I needed only 5 V to charge my iPhone; the motor generates from 12 to 24 V, so I used a transformer that converted that to 5 V.

During a number of test rides around a high school track, I registered a top speed of 25 mph and found that the board has a maximum range of about 4 miles. If more distance becomes necessary, I could use batteries with a higher capacity or add two more batteries wired in parallel. One full ride on the board can boost an iPhone's battery level by 40%. Riding the board is an exhilarating experience where I can carve up hills, cruise on flat ground, and coast down hills.

I entered this project in a local science and engineering fair and received many awards. Looking back, I think about how much I learned about mechanics, electricity, and so much more. I am so grateful for the assistance and wisdom from the people I met along the way. The board is a blast to ride, and every time I hit the throttle and zoom uphill, I put one more person in awe.

Ryan Needle • Potomac, Maryland

write to:

mailbox@homepower.com

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

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

Complexity

It is becoming too complicated for the average person to install and enjoy any type of renewable energy (RE) system. I suppose *Home Power* has to sell the idea that only professionals are capable of sorting out all the varieties of PV modules, shunts, inverters, and what-not, but do you have to confuse me in the process? When everyone is an expert, who are we to believe?

I'm never going to go "off-grid" or even put up a single PV module—because if the module costs $100, you have to buy $400 more in equipment and spend a $1,000 more in "expert" installation costs. Using the information from your magazine as a guide, I would be tearing my installation down every month, just to install some new gizmo. Just like the electrical grid, you are pricing renewables out of the reach of most average people, and your magazine is partially responsible for tripling the complexity of renewables.

Brian Richard • via homepower.com

As a professional installer, I can appreciate your frustration. Residential PV systems have become more capable and complex, with more professional installations. While homeowners have installed their own off-grid systems for remote homes for decades, I see far fewer homeowner installations these days.

I have seen some truly frightening self-installations, some with overheated connections and no overcurrent protection. The earliest PV systems were often on plywood with exposed wiring and terminals and a surplus voltmeter and ammeter.

There are still many simple systems out there, new and old. This industry started as a do-it-yourself, backwoods replacement for car batteries and generators. Now it's a global industry with huge consequence, including the widely shared dream of a carbon-free future.

Home Power's role is to chronicle the ongoing evolution of the solar industry from the end user's and residential installer's perspectives. One size doesn't fit all.

Much of the increased complexity and cost is the result of changes needed to make homes safer. When systems were only in remote homes, electrical codes were often an afterthought. As PV popularity and capability have grown, the professionals who revise the *National Electrical Code* every three years address multiple safety issues. The *Code* is ultimately more responsible for the complexity of today's PV systems than *Home Power*, which simply chronicles the changes in the industry.

While the price of a modern system may exceed one from earlier years, its superior capabilities outweigh cost increases. An early PV system might have powered only a few loads, but was a huge improvement over running a generator. For similar cost, a modern system can run a full-featured efficient home, sending surplus energy to the grid and also operating much more efficiently than those early systems. Today we expect far more from our investment in PV systems, and we receive it.

Most modern systems are installed by solar contractors because of the complexity of the *Code* and required permits and inspections. Installation labor remains a relatively small part of overall system cost. You'll save little by doing your own installation, considering the learning curve needed. Experienced contractors deal every day with these issues and know them well.

If you want to do your own installation, shift your thinking toward seeing the whole system rather than a complex interplay of components. Once you have done your homework, having designed and installed a quality system, enjoy it. Don't change or add components unless there's a compelling reason.

One of my favorite longtime clients built his own home 30 years ago. He had an off-grid system installed in 1988. Twenty-eight years later, the same inverter is still powering his home, having never needed repair. While he has added to his PV array and replaced batteries and a controller, this system continues to meet his needs. I simply advise him to keep some money in reserve for eventual replacements, but never to replace his inverter or other components just because they're old. What he has is adequate.

A system from a reputable installer allows you to just enjoy the benefits. Find a local installer who you trust. Just as the system from 28 years ago is still running with equipment now considered "obsolete," yours will be producing energy for decades to come.

Allan Sindelar • Sindelar Solar

Courtesy Allan Sindelar

Wind Turbine?

I will be building a new house in the near future and am very interested in obtaining solar and wind technology to power it. I use approximately 20,000 kWh during the year (it is cold here in Wyoming and I only have baseboard heat in my inefficient home). So, with that in mind, what type of wind turbine would I need? I see that turbines are measured in watts, but are those measurements per hour, per month, per year? I would also like to know what type of solar system I can use in conjunction with the turbine.

David Hendrix • Laramie, Wyoming

A wise first move will be to design your new home with energy efficiency and conservation in mind. Focus on low energy use in every building decision you make—the size of your home, its building envelope, insulation levels, heating system (examine the suitability of heat pumps), appliance choices, solar orientation, daylighting, etc. This will make the biggest impact on your energy footprint, and will reduce the cost of the electricity generation system dramatically, since the less energy your home needs, the smaller the system it will require.

It is quite possible to build a "zero energy home"—one that makes all its energy on site. But to do this sensibly, you should focus first on the load end of things, not on generating energy. Shrink your energy *usage* down to the minimum, and making the energy you need on site will be much easier. See our many articles on home design and construction, energy efficiency, and load analysis.

Watt (power) ratings for wind turbines are almost meaningless, since they describe the peak instantaneous output, *not* the energy yield. (Wattage is an instantaneous rate of energy generation, transfer, or usage; watt-hours and kilowatt-hours are actual units of energy.) Power ratings can be a bit of a shorthand when comparing wind generators to each other, but since a wind generator rarely works at its maximum output, and because each site has a different wind energy resource, you can't use turbine power ratings to predict your system's energy (kWh) yield.

The three things you need to know to size a wind turbine are:

- The estimated energy consumption, in kilowatt-hours, of your new home
- The average wind speed at tower-top height
- The projected kWh at the tower-top average wind speed for each wind turbine you are considering

With this information, you can compare the available equipment and see what will be a good match. Looking at seasonal wind data will be especially helpful if you are considering being off-grid. Wind turbine energy curves (not power curves) show kWh per month or year—read the fine print—in various average wind speeds. Get good data on your site, and then be conservative when applying manufacturer numbers.

Courtesy Pika Energy

Solar site analysis is also needed, including finding out the "peak sun-hours" (the solar equivalent of average wind speed) for your site. Consider the shading on any potential array location from nearby trees, buildings, and landforms, and the orientation and tilt of your roof (if you are considering a roof-mounted PV array). Monthly data will help you estimate your potential production from a solar-electric system, and determine how it could match with wind-energy production. Finding the right balance between the two can be tricky for off-grid systems; on-grid systems are much more forgiving. Often on-grid people will chose to use one or the other instead of both, depending on the quality of each resource and the project budget.

Integrating wind and PV systems in a battery-based system is straightforward—both charge the same battery bank, and downstream equipment is in common for both. Without batteries, you may end up with two separate systems or two systems integrated together, depending on the equipment chosen.

Overall, you'll need to either find experienced help or educate yourself to design, install, and operate these systems well. In either case, think carefully about who you are working with and buying from, and make sure that substantial support is part of the package—not just low price. Wind especially is difficult to make work long-term, and buying cheap is a big mistake. Check out our website for many articles on all of these topics, and enjoy pursuing your clean energy projects.

Ian Woofenden • *Home Power* senior editor

PV Roof Setbacks

I'm wondering why so many of the photos shown do not comply with the roof setback requirements that are used by and required for firefighters?

Bill Loesch • Saint Louis Solar

There are a number of photos that likely don't adhere to the various fire code requirements in the *International Fire Code* and in local jurisdictions, but part of the problem is the varying degree of implementation across the country and the year in which the codes are adopted. So the photos used may be in full compliance for their locations at the time the systems were installed. And there are situations for which variances may have been granted, or in which there are differences between the *IFC* and local requirements.

To quote Matt Paiss of the San Jose, California, fire department from a *SolarPro* article:

Each state or jurisdiction adopts the fire code of choice according to its own procedures, and updates code editions according to its own calendar. According to a database maintained by the ICC, as of March 2014, approximately 23 states have adopted the IFC *at the state level. Ten of these states—including California—have already adopted* IFC *2012, which includes the new requirements for PV systems; seven states are still enforcing the 2009 edition; four states have yet to update from* IFC *2006; and two states are still enforcing the 2003 edition.*

The exact numbers may have changed since Matt wrote this, but this illustrates the difficulty of representing all systems as *IFC*-compliant even more. I think as time passes and more jurisdictions adopt current codes, the discrepancies will diminish, but there will always be some differences—just as there are with *NEC*-compliant systems.

Ryan Mayfield • Renewable Energy Associates

Solar Performance

We recently installed a roof-mounted solar-electric system. It is supposed to be an 8.2 kW system. It is a fixed array, parallel to the 30° roof pitch and faces within 3° of true south. SMA America sends us daily solar production numbers from their website application. The greatest production we have seen is just under 7 kW. Is it normal to not get the full rated 8.2 kW, or is something not working correctly?

Andy Stark • Polson, Montana

The peak output of a PV system will often be less than the system's rating. One reason is that a PV system is usually rated in DC capacity of the PV modules, but the system's output is AC—and some energy is lost in converting DC to AC, and some is lost in the wiring. Modern inverters are very efficient, but still may lose 2% to 5% in the conversion.

continued on page 26

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Courtesy SMA America

continued from page 24

A larger reason is that PV modules are rated under laboratory conditions called “standard test conditions” (STC), and real-world conditions deviate from STC. For example, module cells are usually operating under higher temperatures than their test temperature of 77°F, and hotter modules produce less power. On a hot, sunny day, the temperature of a module may be 160°F. For most silicon PV modules, this will result in about 20% less energy production than their STC rating.

The second difference between STC and real-world conditions is that the sun is not always the same brightness on the surface of the earth. If you are at 10,000 feet elevation with perfectly clear blue skies, there is a lot of sunlight (irradiance). Closer to sea level, the sunlight has to travel through more atmosphere, which means less irradiance and production.

Also, the sun travels through the sky during the day, so is not always at the ideal angle for the PV modules—directly perpendicular to them—and again, the atmosphere is thicker in the morning and evening. This means that the amount of sun an array receives is always varying, even before you take into account clouds and other weather effects.

The important thing in the end is not really the instantaneous kW output (power) you see from the array, but the kWh production (energy) from the array over time. Solar production is more like an endurance race than a drag race—the top speed doesn’t matter as much as how far you manage to go by the end of the day. So what you should be looking at to determine whether the array is working properly is the kWh production for each month. Compare that to the expected production for your array, which the installer should have given you (or you can find an estimate at pvwatts.nrel.gov). It can vary up to 20% depending on weather from year to year, but more variation than that could be a cause for concern. If kWh production is lower than expected, your installer may be able to test the modules’ temperature and insolation received and calculate expected instantaneous power (see Methods in *HP172*). But don’t worry if the peak kW you see is lower than the array’s rating, this is normal in most cases.

Zeke Yewdall • Mile Hi Solar

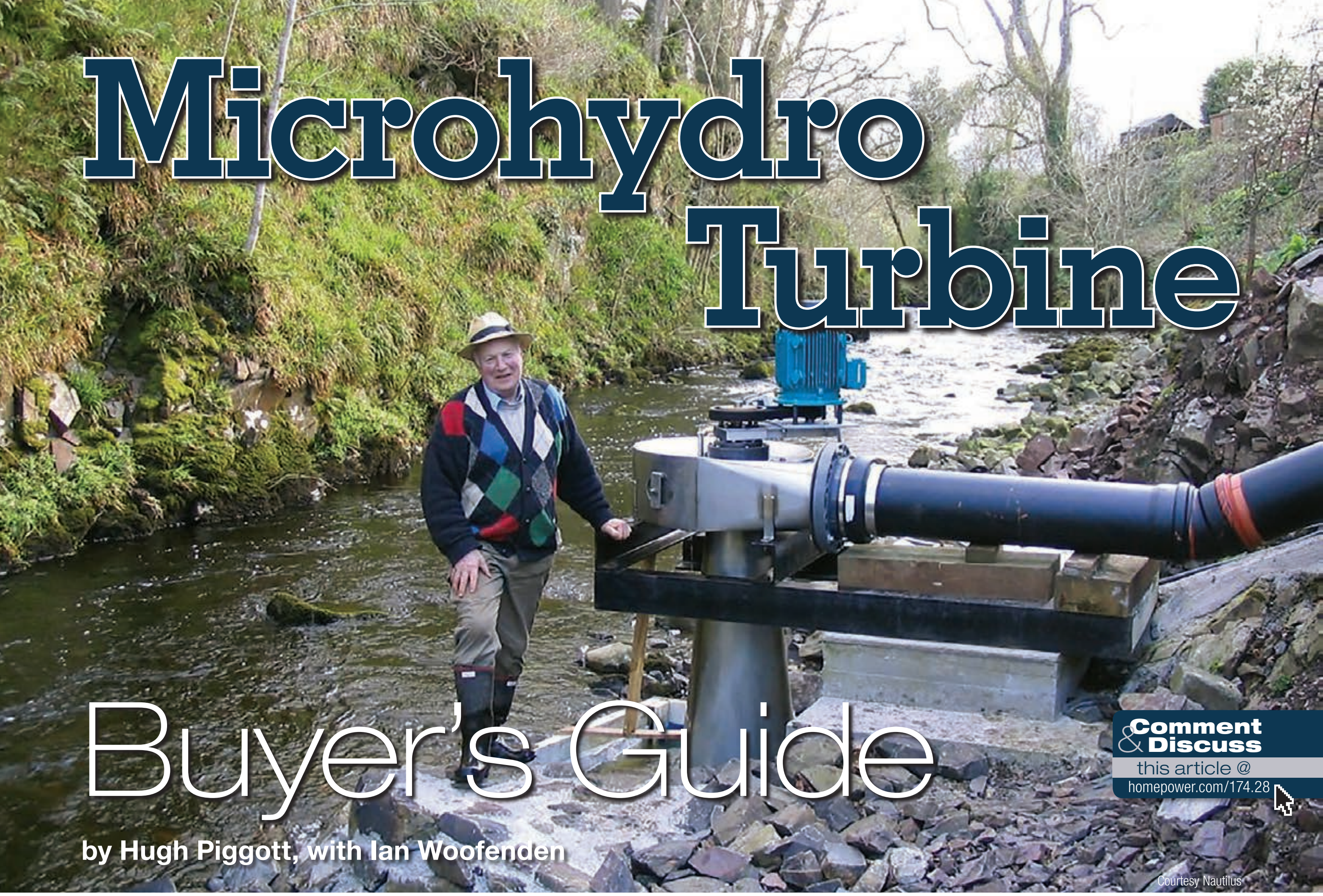
write to:

asktheexperts@homepower.com

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

Microhydro Turbine Buyer's Guide

by Hugh Piggott, with Ian Woofenden



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Courtesy Nautilus

The late Chris Mason with his Nautilus propeller turbine producing 2.6 kW from 18 feet of head at Ironmacannie Mill in Scotland.

If you have a site for a microhydro system, it can be the best value of all the renewable sources you might use to power your home. As long as the water flows, your turbine will provide electricity. That means that a 1 kW hydro turbine can produce as much daily energy as a 5 kW solar-electric array, and with less reliance on batteries.

Hydro and solar electricity can work well together since the best solar season is often when streams are at their lowest flow. Off-grid hybrid systems help to keep the engine generator silent, come rain or shine.

web extras

"Microhydro Systems: Advice From The Pros" by Ian Woofenden in *HP146* • **homepower.com/146.66**

"Hydro Design Considerations" by Ian Woofenden in *HP132* • **homepower.com/132.78**

"Get Started with Microhydro Power" • **homepower.com/HydroBasics**

What is a Microhydro System?

There are many parts to the whole system that you will need. The turbine is not likely to be the most expensive, although you should choose it with care. You will need:

- Intake/diversion to collect the water
- Penstock—the pipe that carries the water
- Manifold, to distribute the water to turbine nozzles
- Turbine with generator
- Tailrace, to return the water to its course
- Transmission wiring
- Electrical balance of system (BOS) gear

Since the electrical energy produced is often more than is consumed by a home, consider what's to be done with the excess. If the system is grid-tied, this energy can be put on the grid and, often, credited to your utility bill through "net metering." For off-grid systems (or in places without net-metering or other utility payment programs), heating water or even heating your house in winter are good uses for the extra energy. This can be done using normal AC heaters and controlled by "auxiliary relays" in charge controllers or inverters, or by independent control devices.

Courtesy Ken Gardner

Left: A successful hydro system is a unification of elements. The intake, a site-specific component, can be as simple as a screened pipe or a complex engineering and construction endeavor.

Courtesy Hydro Induction Power

Right: Power-conditioning and control equipment, especially load management (such as a diversion heating element), are key components to getting your turbine to work best for safety and energy needs.

System Planning

Siting your intake and turbine is the first step. Look for the best flow of water falling the most height over the shortest penstock length, and not too far from your home. Learn to measure the head and flow accurately (see "Methods: Hydro Measurements" in *HP170*). Then see the table (or equations) below to estimate energy production. Compare this to your current usage and future needs. Take into account that stream flow varies over the year. Most turbines can be adjusted to use less flow and still produce useful energy.

Once you have some data, you can look for turbine suppliers. Visit their websites and use online calculation tools to help you design the penstock and transmission wiring. Check out manufacturers' online documentation and product manuals.

Find a local dealer or installer with plenty of microhydro experience, or ask the manufacturer for advice about your specific system setup. It's important to secure good technical support at the outset or you may find yourself in trouble later. You may well need to hire some help with wiring or the pipework. Note that microhydro systems are often poorly understood by many grid-tied PV installers, because it is often outside their realm of experience.

Consider compliance with local codes and environmental standards. Very few microhydro turbines come with certifications that would put an inspector at ease, and the systems have numerous potential hazards associated with them. Runaway open-circuit voltages can be very high, even on "battery voltage" circuits. Avoid exposed rotating parts and electrical terminals. Turbines connected directly to the battery can be hazardous if the diversion-load controller fails, leading to overcharge and possible explosion of the battery cells. Even high-pressure water can be dangerous. Interference with the flow of water can also have an impact on your local ecology. All of these issues need to be considered at the design stage.

Do not rush to buy your turbine. Start instead by installing the penstock, having carefully specified the necessary internal diameter. Prepare the intake, and install appropriate valves and gauges. Monitor changes in flow. When the penstock is completed and filled, measure the static head with a pressure gauge. All too often the turbine does not work properly because the site head and flow are incorrect or the penstock diameter is too small.

Courtesy AP&M

Pelton

Courtesy Dependable Turbines

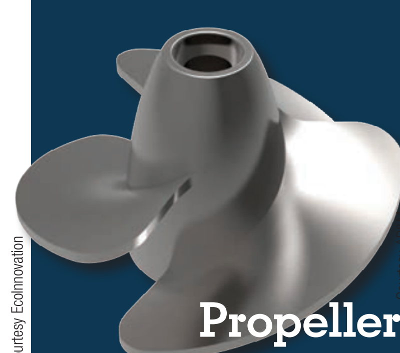
Turgo

Courtesy Scott Hydro

Crossflow

Courtesy Hongya

Francis



Courtesy EcoInnovation

Propeller

Courtesy Asian Phoenix Resources

This PowerPal turbine by Asian Phoenix Resources is a propeller turbine running on only a few feet of head.

Courtesy Alternative Power & Machine

This Alternative Power & Machine turbine at Pholia Farm Creamery in Oregon utilizes a Pelton runner and a permanent-magnet alternator.

Choosing a Turbine Manufacturer

The following charts will help you. Using the measured head and flow at your site, find the nearest corresponding square and see which manufacturers can help you.

The figures in the table represent *nominal* energy production in kWh per day, but bear in mind that your site may do much better—or much worse. There are many possible power losses. We used these simplified rules to predict output:

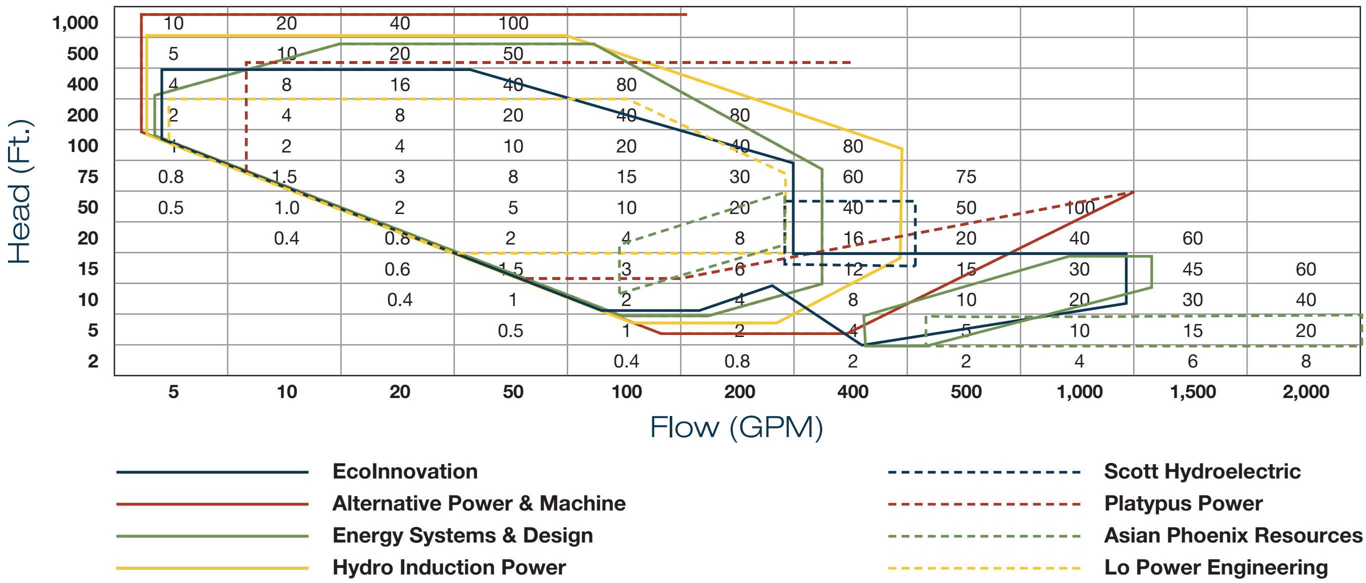
Power (W) = Net Head (ft.) × Flow (gpm) ÷ 12 (estimation factor)

Energy (kWh per day) = Net Head (ft.) × Flow (gpm) ÷ 500 (estimation factor)

The first chart is for smaller-turbine manufacturers: If a penstock offers more flow than a single turbine can handle, consider multiple parallel turbines rather than using a single, larger turbine. Shipping and installation logistics are easier due to the smaller units. Flow control is more flexible. In drier times when a larger turbine would have to shut down, one of several small turbines can keep going. Maintenance can be done without interrupting generation, using standard, lower-cost spares. Finally, one failed turbine will not disable the entire power plant.

The second chart shows operating ranges for manufacturers of larger turbines. This is the bottom end of their product ranges. They may not need batteries to meet high power loads, so the systems are usually AC-direct. The turbines are more heavily built, with industrial-grade components, which is reflected in the prices.

Low-Head Turbines: Estimated Energy Production (kWh/Day)



Courtesy Energy Systems & Design

Three Energy Systems & Design Turgo Stream Engines offer redundancy and adjustability for seasonally changing flow rates.

Courtesy EcoInnovation

A two-nozzle PowerSpout Pelton turbine by EcoInnovation installed by Harvey Mudd College students.

Turbine Types

Turbines are designed for high head or for high flow. There are different types of runners (the turbine components that transform water power to rotating power), but their operating ranges overlap considerably. Here are the main types supplied for home-scale use:

Impulse turbines are generally used in higher-head, lower-flow applications. The runners are not immersed in the flow, and are driven by high-speed jets of water. They are controlled by adjusting the number and size of nozzles that produce these jets.

- Pelton is used for the least flow/highest heads
- Turgo can typically handle more water
- Crossflow is closer to a mid-range solution

Reaction turbines are used in higher-flow, lower-head (LH) situations. The runners are fully submerged. Water pressure acts directly on the runner; flow is harder to control, but will depend on the turbine rpm and can be tuned by MPPT devices.

- Pump-as-turbine (PAT) for ingenious adaptations
- Francis for low heads
- Propeller for the lowest heads

Some low-head turbines stand at the top of a "draft tube" that sucks water through the blades. Some, therefore, do not even need a pressurized penstock. One advantage is that the turbine can be kept clear of floodwaters. While the difference in turbine details is fascinating, the end result makes little difference to the buyer.

High-Head Turbines: Estimated Energy Production (kWh/Day)

Head (Ft.) \ Flow (GPM)	5	10	20	50	100	200	400	500	1,000	1,500	2,000
1,000	10	20	40	100							
500	5	10	20	50							
400	4	8	16	40	80						
200	2	4	8	20	40	80					
100	1	2	4	10	20	40	80				
75	0.8	1.5	3	8	15	30	60	75			
50	0.5	1.0	2	5	10	20	40	50	100		
20		0.4	0.8	2	4	8	16	20	40	60	
15			0.6	1.5	3	6	12	15	30	45	60
10			0.4	1	2	4	8	10	20	30	40
5				0.5	1	2	4	5	10	15	20
2					0.4	0.8	2	2	4	6	8

Nautilus
Hartvigsen Hydro
Canyon Hydro
Dependable Turbines

Smaller Microhydro Turbines

Manufacturer	Business Profile: Years in Business	Business Profile: Sold Per Year (< 3 kW)	Business Profile: Sold Per Year (3–10 kW)	Business Profile: Location	Turbine Types: Pelton	Turbine Types: Turgo	Turbine Types: Cross-Flow	Turbine Types: Pump as Turbine	Turbine Types: Francis	Turbine Types: Low-Head Propeller
EcoInnovation, "PowerSpout" **powerspout.com**	18	300	7	New Plymouth, Taranaki, New Zealand	✔	✔				✔
Alternative Power & Machine **apmhydro.com**	18	153	8	Grants Pass, Oregon	✔					
Energy Systems & Design, "Stream Engine" **microhydropower.com**	30	100	0	Sussex, New Brunswick, Canada	✔	✔				✔
Hydro Induction Power **homehydro.com**	34	34	2	Redway, California	✔	✔				
Scott Hydroelectric **scotthydroelectric.com**	5	30	0	Republic, Washington			✔			
Platypus Power **platypuspower.com.au**	30	26	14	Yorkeys Knob, Queensland, Australia		✔				
Asian Phoenix Resources, "PowerPal" **powerpal.com**	18	24	3	Victoria, British Columbia, Canada		✔				✔
Lo Power Engineering, "Harris Hydro" **harrishydro.biz**	16	21	0	Fortuna, California	✔					

Turbines are ranked by number sold; *No MPPT, but has high-voltage DC input (for transmission) and steps down to DC battery bank voltage

A four-nozzle Hydro Induction Power Turgo turbine sits in a modified plastic barrel and uses an induction generator.

Courtesy Hydro Induction Power

This Scott Hydroelectric unit uses a crossflow runner and produces 1,000 W from 28 feet of head.

Courtesy Scott Hydro

	Generator Types				System Types					
	Wound-Field Auto Alternator	**PM Alternator**	**Induction Generator**	**Brushless Synchronous**	**Direct AC**	**Direct Battery Charge**	**Battery + High-Voltage Transformer**	**MPPT Battery Charging**	**Batteryless Grid-Tied**	**Direct Heating**
		✓				✓		✓	✓	Optional
	✓	✓	Optional	Optional		✓	✓	✓	✓	Optional
		✓				✓	✓	Optional	✓	Optional
		✓	✓			✓	✓	DC-DC*	✓	Optional
		✓						✓	✓	
		✓	✓		✓	✓		✓	✓	Optional
		✓			✓					
		✓				✓		DC-DC*		

A Platypus Power turbine with Turgo runner and induction generator produces 7 kW from 240 feet of head.

Courtesy Platypus Power

A Lo-Power Engineering Harris Hydro four-nozzle Pelton turbine with a permanent-magnet alternator, ready for installation.

Courtesy Lo-Power

Larger Microhydro Turbines

Manufacturer	Business Profile: Years in Business	Business Profile: Sold Per Year (< 3 kW)	Business Profile: Sold Per Year (3–10 kW)	Business Profile: Location	Turbine Types: Pelton	Turbine Types: Turgo	Turbine Types: Cross-Flow	Turbine Types: Pump as Turbine	Turbine Types: Francis	Turbine Types: Low-Head Propeller
Nautilus waterturbine.com; ricklyhydro.com	30	0	10	Greenfield, Massachusetts; Columbus, Ohio		✔	✔		✔	✔
Hartvigsen Hydro h-hydro.com	16	4	3	East Kaysville, Utah		✔				
Canyon Hydro canyonhydro.com	40	0	1	Deming, Washington	✔		✔	✔		
Dependable Turbines dtlhydro.com	38	1	3	Surrey, British Columbia, Canada	✔	✔		✔		

Turbines are ranked by number sold

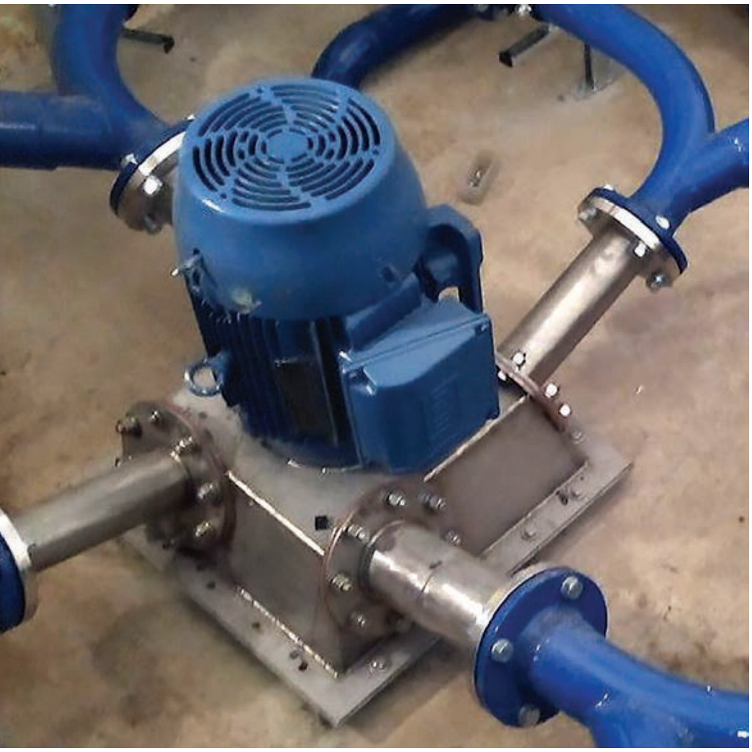
Off-Grid

Connecting directly to all home loads via the main distribution panel is an option more common in large systems (beyond residential scale). Direct AC hydro turbines less than 5 kW do not offer good enough power quality for modern appliances. Also, the available peak power is limited by the turbine output. When you use less than peak, the rest is often dumped into waste heat by the onboard voltage regulator.

Connecting via a battery is an obvious choice if your home is off-grid. You may already have a battery-based solar-electric system in place, and the extra charging input from the microhydro system can help balance out the system's production, especially in the wintertime.

The wonderful thing about a microhydro turbine is that (unlike PV) it produces electricity continuously. Because it works over many hours, a small amount of power (W) can

This four-nozzle Hartvigsen Hydro Turgo turbine has an induction generator driven by 56 feet of head for 4 kW output.



Courtesy Hartvigsen Hydro

A large, single-nozzle Pelton turbine by Canyon Hydro produces 8 kW from 215 net feet of head.

Courtesy Canyon Hydro

	Generator Types				System Types					
	Wound-Field Auto Alternator	PM Alternator	Induction Generator	Brushless Synchronous	Direct AC	Direct Battery Charge	Battery + High-Voltage Transformer	MPPT Battery Charging	Batteryless Grid-Tied	Direct Heating
	✔	✔	✔	✔		✔	✔	✔	✔	✔
	✔	✔	✔	✔		✔	✔	✔	✔	✔
			✔	✔	✔				✔	
			✔	✔	✔				✔	Optional

add up to a large amount of energy (Wh) put into a battery. Used with an inverter, it can deliver both high peak surges and high-quality power, with excellent reliability.

Connecting directly to a heater is doable with simple, low-cost parts if all you want from your turbine is some heat, and you do not need other electrical power. A special heater or generator winding may be needed to optimize the turbine speed. Complications can arise if a thermostat is used, because the load will need to be transferred to another heater to prevent turbine overspeed.

A Dependable Turbines Pelton turbine with a brushless AC generator delivers 8 kW from 250 feet of head.

Courtesy Dependable Turbines

Controller Options for Battery Charging

Direct connection to the battery, using a pulse-width modulated (PWM) charge controller in diversion mode (independently connected to the battery). The controller manages any excess energy by sending it to a diversion load. There is a danger of overcharging the battery if the controller fails, so you should follow the *Code* requirement to have two independent diversion-load controllers.

Battery voltage may be unsuitable for long wire runs. But many hydro manufacturers offer high-voltage alternators designed for AC transmission and a transformer with rectifier to step down the voltage at the battery.

Connecting to the battery via an MPPT controller is recommended by some manufacturers instead of direct connection. MPPT controllers combine three functions:

- Stepping down to battery voltage from higher-voltage DC wire runs
- Optimizing the input (turbine side) voltage to maximize power
- Controlling battery charge rate by unloading the turbine to shed power when target battery voltage is reached. (However, a controller unloading the turbine may cause it to become noisy and wear out its bearings.)

Just as with a PV array, you need to take care that the Voc of your turbine cannot damage the controller. The maximum safe voltage for many MPPT controllers is 150 V. The OutBack FM is ideal for hydro below this limit. A turbine's "runaway" voltage must be safely below this. But a turbine's operating voltage or Vmp may only be one-third of its Voc, which is therefore 50 V. This is better than 12 or 24 V for wire sizing, but is too low to charge a 48 V battery.

MPPT for Microhydro Systems

Advantages	Drawbacks
High DC input voltage reduces wire losses	Voltage must not exceed the maximum or the unit may be damaged
The controller's MPPT function will automatically "tune" the turbine for maximum output	The controller is not 100% efficient, so it won't give the maximum power that a manually tuned turbine would
Changes in the net head or the battery voltage will shift the sweet spot, and the MPPT controller will follow it	The controller is more expensive than diversion controllers, which may be needed anyway
Built-in auxiliary relays can be used to control diversion loads	The controller will allow the turbine to run away when the battery is charged unless some power diversion is active
It will not overcharge your battery, whereas relying on diversion controllers is dangerous if they fail	Failure means no battery charging—from an expensive and vulnerable component
A display shows the amount of power and energy produced	Setup requires using an obscure menu system

MidNite Solar serves the microhydro market with its Classic controllers, which can survive voltages above their nominal limit. The Classic has 150, 200, and 250 V versions. For a 48 V battery, or for saving on cable cost, use a higher-voltage Classic that allows a higher-voltage turbine. MidNite's smaller Kid controller is worth considering for lower-power systems. It's affordable and contains a built-in solid-state relay that can send energy to a diversion load.

Morningstar and Schneider make 600 V controllers that can handle a turbine at 200 V without fear of turbine open-circuit voltage damaging the controller. But always check with your turbine supplier before using it with any MPPT controller. A controller designed for solar MPPT may not always track a turbine's maximum power. And very few controller manufacturers offer warranty or support for microhydro applications.

AC coupling is another option for using MPPT with battery-charging hydro.

Optimizing Turbines Runner RPM

A turbine should be tuned to its "sweet spot;" the maximum output occurs when the runner is spinning at optimum rpm, which depends on your site's net head.

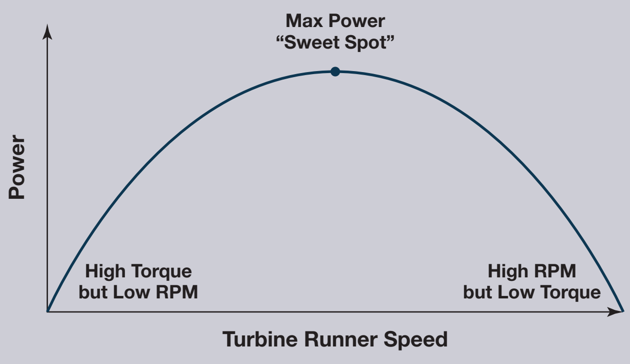
This applies to all types of turbines, but let's use the Pelton wheel as an example. The speed of the jet of water that drives the turbine will depend on its kinetic energy, which in turn depends on head (accelerating it through the nozzle). The Pelton's buckets also have their own optimum speed (related to wheel diameter and rpm) that determines how well they capture that energy.

If the bucket it not moving at all, the water will exit the bucket at high speed. Forced backward, it provides good torque, but no captured energy. This is the situation at startup.

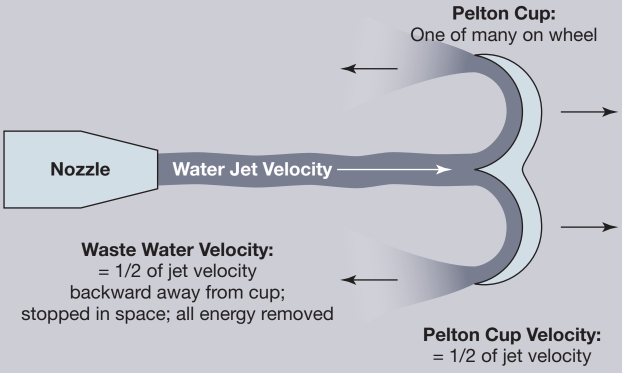
At the other extreme, if the bucket moves as fast as the water, the jet of water will spray out beyond the turbine without creating any torque. Again, nothing is achieved. This might happen if the electrical load is disconnected, which removes resistance to spinning, and the turbine overspeeds.

The optimum runner speed is when the water exits the bucket backward at the same *relative* speed as the bucket is moving forward. This brings the water to a virtual halt, and all of the energy is converted to driving the generator. This will happen when runner speed is about half of the jet speed.

Turbine Runner Max Power "Sweet Spot"



Pelton Jet-to-Rotation Power Transfer



To hit this sweet spot, your generator must absorb the available power at the optimum rpm where the buckets move at the right speed. In turn, a generator's operating speed depends on how its coils are wound in relation to the voltage of the circuit, and on how strong the magnetic field is within it.

Several ways to optimize this relationship for a given head are to:

- Select the best runner diameter
- Choose suitable pulleys on a belt-drive transmission system
- Choose a different generator winding, to change its voltage/speed characteristics
- Adjust the magnetic field strength in the generator to change voltage/rpm
- Choose a different operating voltage for the generator output

All of these methods are being used. For gross adjustments, start at the top of the list. For fine-tuning, adjust the magnetic field or use a MPPT controller to track the optimum operating voltage. Often, the net head from the penstock will vary with changing flow, or the voltage of the battery will vary with its state of charge. MPPT can adjust for these changes.

Generator Types

Early battery-charging turbines used automobile alternators with a wound-field coil on the magnet rotor, and these are still available. They are designed to charge batteries, when run at the right speed, and are easy to buy. The speed can be tuned using a resistor to limit the magnetic field current. But efficiency is poor and the brushes need to be replaced regularly.

The most popular option below 2 kW is a permanent-magnet alternator (PMA). It has no brushes because the rotor has permanent magnets. It may be a modified auto alternator, a modified PM motor, or even purpose-built by the hydro manufacturer. Using no energy for magnets boosts the efficiency at low-power sites where field coils would use much of the precious output. You can often tune the speed by adjusting the machine's geometry (typically by increasing the air gap between rotor and stator) to reduce the effect of the magnetic field. The PowerPal PMAs have regulated AC output (that can be used directly for some appliances), but the others use rectifiers to convert the "wild AC" to DC.

Larger turbines (above 2 kW) often use induction motors as generators (IGs). These can be grid-connected (through a code-compliant automatic disconnect means), but often they are wired as stand-alone units, with capacitors providing the magnetic field "excitation." Another popular generator type is the brushless alternator normally found on engine-driven generators.

Grid-Tied

Batteryless grid-tied inverters (GTIs) made for PV systems are an attractively simple way to connect a turbine to the utility grid because they are already approved by the utilities. Another popular arrangement is to install a permanent-magnet alternator or stand-alone induction generator producing three-phase AC that is rectified to DC and fed to a GTI. The alternative is to connect an IG directly via a code-compliant relay, which is harder to find.

Not all GTIs will work properly with a microhydro turbine, since their MPPT often tracks too fast. It is hard to find suitable products, and the market changes rapidly. Ask your supplier for advice before buying a GTI.

You can also use some battery-inverter systems on-grid if you want to be independent during outages; they can also export surplus energy to the grid when connected. Use the hydro to charge the battery directly, or connect the hydro power (via a PV GTI) to the inverter output and feed your system by "AC coupling."

Clippers and voltage clamps are products that protect your MPPT controller or inverter against excessive voltage by diverting turbine power to a heater or by short-circuiting the alternator. MidNite Solar and some turbine manufacturers offer suitable products. The advantages are that you can run your turbine at a higher operating voltage and that it will not over-speed when unloaded. Such products are expensive and rare.

Hydro Dreams

Whatever road you follow, we hope that you will persevere and enjoy the process of creating your own hydro system. Use the information here to connect with the right manufacturers, and work your way up the hydro learning curve with their help. It is hard to beat the satisfaction of getting all the energy you need from a local source using a hydro system that generates energy night and day.

web extras

"AC Coupling" by Zeke Yewdall in *HP162* • **homepower.com/162.24**

"Adding Battery Backup to Your PV System with AC-Coupling" by Justine Sanchez in *HP168* • **homepower.com/168.38**

Roaring Fork Energy Club

by Kelsey Gibb

In 2010, a group of Carbondale Middle School (CMS) students in the small mountain town of Carbondale, Colorado, formed the Energy Club that would create a lasting impact on the school and local community. On January 28, 2016, the students gathered outdoors to celebrate the installation of a 385-kilowatt PV array, sized to offset 100% of the school's energy needs.

CMS math teacher Michael Logan started the Energy Club with the goal of making the school more energy efficient. Logan's knack for experiential learning had already made an impact on many students in the school. Jimmy Serrano, one of the founding members of the Energy Club, describes meeting Logan through a rock-climbing enrichment class he took the year before. Not only did the students rock climb, Jimmy explains, but they also designed a climbing wall for their school, raised the needed money, and hired contractors to build it. Logan took this same hands-on approach to the Energy Club.

Originally, the club focused on teaching the kids about energy. Tavia Teitler, an Energy Club member, remembers Logan bringing a pedal-powered generator that, under human power, illuminated lightbulbs. He used this to help students understand the concept of power (watts) and energy (kilowatt-hours). A further skill the students picked up was how to read and interpret energy graphs. Energy Club member Fiona Laird says that learning these skills allowed her to "see in very concrete terms how much energy our school was using and how easy it was to make changes." Logan was able to take the relatively abstract concept of energy and translate it into terms that middle school students could understand and act upon.

The second project for the club was to identify energy-efficiency strategies to implement at the school, focusing on awareness and easy behavioral changes. This included regular assemblies when the students would talk to the fellow students about the importance of saving energy. They also conducted room-by-room "shutdowns." The Energy Club would break up into groups, go around to every room in the school, and unplug appliances that were not being used to cut down on their phantom energy consumption. Then they would compare the school's normal energy use to the use measured during the shutdown. New Energy Technology (NET), based in Grand Junction, Colorado, installed a computer-based monitoring system at CMS, which recorded energy consumption in one-hour intervals during the day. This is how the students quantified the results of their educational efforts and shutdowns.

The Energy Club students also created displays to demonstrate energy use. For example, having learned that a calorie is a measure of energy, the club taped empty candy boxes together to show how many calories of energy were needed to power the school for one day.


Courtesy Kelley Cox

Above: A 385 kW grid-tied PV system provides 100% of the electricity needed at Roaring Fork High School in Carbondale, Colorado.

Below: The Energy Club originally organized by middle school students was re-established by some of the same students when they entered high school.

The CMS club took their initiative one step further by partnering with Carbondale's Crystal River Elementary School for the U.S. Environmental Protection Agency's National Building Competition. With assistance from New Energy Technology and a grant from Clean Energy Economy for the Region (CLEER), the Energy Club was able to use monitoring data and their knowledge and experience to help the elementary school become more energy efficient. Crystal River Elementary came in seventh out of 14 buildings evaluated, raising its Energy Star rating from a 37 to a 54 on a 100-point scale and saving the school district about $19,000 on utility bills during the competition. Student Tavia Teitler remembers how inspiring this competition was. "We were a bunch of 11- and 12-year-olds, and we could do just as much as any adults and…make a difference on a national level. That was really exciting and empowering."

Carbondale: Clean Energy History

Although it may seem a bit unusual for high school students to set such lofty goals, these students have grown up in a community that values environmental stewardship.

"Growing up in Carbondale, you have a greater sense of the relationships humans have with the world. It's a very progressive community," says Energy Club member Fiona Laird.

Carbondale, located in the Roaring Fork Valley of western Colorado (between Aspen and Glenwood Springs), was originally centered on agriculture, ranching, and coal mining. But over the past 25 years, Carbondale has become a beacon of sustainability. The town of 6,500 has a progressive local government that has made sustainability a primary focus. For instance, through a partnership with local energy-efficiency nonprofits, the town set aggressive energy efficiency goals for city government called "Carbondale 2020," aiming to:

- Increase energy efficiency of buildings by 20% by 2020
- Reduce petroleum consumption 25% by 2020
- Obtain 35% of its energy from renewable sources by 2020

Despite a growing population, from 2009 to 2014, the town as a whole had reduced electricity consumption by 6.5% and natural gas usage by 3.5%.

Carbondale is also close to energy-focused organizations, including The Rocky Mountain Institute, the Community Office for Resource Efficiency (CORE), Garfield Clean Energy, and Clean Energy Economy for the Region (CLEER). Through rebates, research, education and outreach, these nonprofit organizations, along with other advocates, have helped create a community that makes sustainability and energy efficiency a priority. The students of the Energy Club were able to tap into these resources, expertise, and support that are not consistently available in other parts of the country, to pursue their goal of installing a solar-electric array at their high school.

Courtesy Sunsense Solar

RFHS Fun Facts

The Roaring Fork High School PV array will save the school district an estimated $389,000 on electric expenses over 20 years.

This PV array is large enough to provide energy for about 85 average U.S. homes. Over the school's 20-year power purchase agreement, the PV array will prevent the following pollution from being released into the atmosphere (based on EPA Power Profiler results and the PV array's monthly kWh production):

- 23,833,900 pounds of carbon dioxide
- 25,880 pounds of nitrogen oxide, which contributes to smog and acid rain
- 21,060 pounds of sulfur dioxide, a precursor to acid rain and atmospheric particulates

Over a 20-year period, the amount of carbon dioxide the RFHS PV array prevents from entering the atmosphere is the equivalent to:

- 2,284 cars driven for one year
- 3,431 tons of waste sent to the landfill
- 1,216,482 gallons of gasoline consumed
- 280,176 tree seedlings grown for 10 years

Courtesy Sunsense Solar

The PV array, which consists of more than 1,000 310 W PV modules, is wired in 69 separate series strings. The modules are mounted at a 30° tilt.

Fourteen Fronius Symo inverters send the PV energy to the utility grid.

Courtesy Sunsense Solar

Energy Club Graduates to High School

Moving on to high school, the students found themselves busier and more scheduled than before. In between student council, sports practice, and keeping up with their studies, the students realized that the Energy Club was going to have to grow and evolve just as they were.

Instead of their normal assemblies, shutdowns, and a focus on making their school building energy efficient, the Energy Club students expanded their goals to making their school more sustainable. Besides using less energy, the students wanted to make sure the energy they were using came from a clean source. With their new club advisor, math teacher Wendy Boland, the students decided to step up their meetings to once a week.

While talking to upperclassmen at the high school, members of the Energy Club realized that there were a lot of students who thought it would be "really cool" if their school was powered by solar energy. The idea of having a PV-powered school was something the Energy Club had discussed for their middle school. At this new school and with clear support from the larger student body, the Energy Club felt that exploring a PV system aligned perfectly with their new goals.

The students reached out to Katharine Rushton of Sunsense Solar and were also involved in design brainstorming sessions with Rushton and Sunsense's commercial designer, Jeff Lauckhart. In addition, they helped present the project to the school board, town officials, and community members.

Solar Feasibility

The Energy Club's involvement with Rushton was important to advancing the project. Since Rushton spent most of her career working with municipalities and other tax-exempt entities, she understood the complex process and metrics of how a sizable project is accomplished economically.

After meeting with the students and examining the situation, Rushton recognized that, with the performance-based incentive (PBI) offered by the school's utility, Xcel Energy, the PV project would be a great candidate for a power purchase agreement (PPA). Rushton had put together several PPA projects in Carbondale, including Colorado's first at the Carbondale Recreation Center.

The only hiccup was that, although the high school was newly built, it still consumed a lot of energy. Under those loads, the PV system would have been too large to fit in the allotted space. A team of technical experts suggested new heating, cooling, ventilation, and control systems to decrease the school's electrical energy use and demand, and a technical analysis done by Engineering Economics of Golden, Colorado, estimated that new HVAC equipment could cut electrical use by about 15%. With CLEER's help, the school district applied for and received a $200,000 grant from the Garfield County Federal Mineral Lease District. That improvement allowed Sunsense to downsize the PV array enough to fit the available space.

Design Options

Originally, the plan was to install the PV system on the school's roof. However, the school district had concerns about ice damming and the potential for the PV array to void the roof warranty. The Sunsense design team then considered PV-roofed carports. Although not always an ideal choice in snow country—typically, the tilt angle on a carport is not steep enough to efficiently shed accumulated snow—solar carports don't take up additional land and would have provided shade for the students' and faculties' cars. However, during the design process, the utility incentive was reduced from $0.07 per kWh to $0.06 per kWh—enough to make a PV carport too expensive.

Next, Sunsense researched a ground-mount system that could be constructed on open school land directly south of the school. There were some drawbacks to this site, as it is a low, north-facing slope, is in an animal migration corridor, and was close to the school. However, the land was not slated for construction or school expansion in the next 20 years, and the ground-mounted design proved to be economically sound.

School District & Community Approval

With the design finalized and the incentive reserved, Sunsense Solar and the Energy Club students presented the ground-mount design and economics of the project—including the PPA model—to the School Board.

Shannon Pelland, the district's finance officer, said a big concern for the district was to make sure the PV system was a good investment. "We were unwilling to pull dollars away from classrooms to make this happen. The project had to perform at break-even or better," Pelland says.

But combining the utility incentive and PPA model meant no out-of-pocket costs for the school district.

"The persistence of the RFHS Energy Club students and Sunsense was, quite frankly, key in bringing this project from a dream to a reality," says Pelland. "We supported this project understanding the importance of the environment and energy conservation to our communities."

The project won unanimous approval from the Carbondale Board of Trustees and the RFHS faculty and staff. The next step was for the RFS Board to execute the PPA contract. The School Board was willing, but first wanted to host a community meeting to discuss the project. Many people attended to hear about the project and to voice their support.

With a community upswell of support for the project, the school board agreed to it, with three conditions. First, to avoid reflections from the array on nearby homes, Sunsense conducted a study using the solar glare hazard analysis tool

Tech Specs

Overview

Project name: Roaring Fork High School

System type: Batteryless grid-tied solar-electric

Installer: Sunsense Solar

Date commissioned: February 2016

Location: Carbondale, Colorado

Latitude: 39.4°N

Solar resource: 5.3 average daily peak sun-hours

ASHRAE lowest expect ambient temperature: -18.4°F

Average high summer temperature: 88°F

Average monthly production: 51,518 AC kWh (predicted)

Utility electricity offset annually: 100%

PV System Components

Modules: 1,242 ET Solar-P672310WW, 310 W STC, 37.71 Vmp, 8.23 Imp, 45.8 Voc, 8.79 Isc

Array: 69 series strings – 5 strings each for the (13) 24 kW inverters and 4 strings on the 20 kW Inverter; 18 modules per string for all strings; 385,020 W DC STC; 678.8 Vmp; 567.9 Imp; 824.4 Voc; 606.5 Isc

Combiners: One per inverter of Sunny Connection Unit (1,000 V version); model CU1000-US-10 ; 15 A fuses

Array installation: S:Flex ground mounts; installed at a 30° tilt and 177° azimuth

Inverters: 14 Fronius Symo 24.0-3 480, 24.0 kW rated output, 1,000 VDC maximum input, 500–800 VDC MPPT operating range, 480 VAC output; 1 Fronius Symo 20.0, 3 480, 20.0 kW rated output, 1,000 VDC maximum input, 450 - 800 VDC MPPT operating range, 480 VAC output

System performance metering: Fronius Solar.web

Courtesy Kelley Cox

The Energy Club was instrumental in bringing together the professionals necessary to complete this showcase project.

developed by Sandia National Laboratories. It showed that any glare would be minimal. Second, it required a corridor for elk migration through the parcel of land. Third, the school board was concerned about the cost of removing and relocating trees that would have otherwise shaded the array. Sunsense included $10,000 in the contract for landscaping and allocated much these funds to relocating the trees.

Financing Options for Large Arrays

While large PV arrays can be an effective means to control energy costs and save on utility bills for tax-exempt organizations such as the Roaring Fork School District, the large upfront expenditure can be a significant barrier. Even if the organization has the capital, not being able to claim the 30% federal investment tax credit (ITC) or write off equipment depreciation can skew the project economics so that the investment is steeper than the rewards.

A power purchase agreement (PPA) is a financing tool that allows a third-party investor to take advantage of depreciation and the ITC. The investor provides the capital to build the PV array and recoups the investment over time through the ITC and other incentives, and by selling energy to the host organization. Since the investor owns the PV array they provide operations and maintenance, removing the burden of responsibility and cost from the host.

When the equipment is fully depreciated, the host organization (the school district) may be able to purchase the PV system at its depreciated cost—significantly less than when new. Or they can continue to purchase the power generated by the array until the end of the contract term—in this case, 20 years—at which point they could purchase the system, renegotiate the PPA, or even have the owner remove the equipment.

Construction Roadblocks

Once construction began with the ramming of the foundation posts, the ground was found to be rockier at shallower depths than was stated in the geotechnical reports. To ensure that the foundation could support the design loads, every post that did not reach the design depth was pull-tested. Those that could not meet engineering specs were replaced with concrete foundations.

Once the posts were set, the installation of racks and modules began. Since the school district had plans to build an addition on the school and did not want any underground conduit in that area, the AC wiring was routed up and over the existing building.

Solar for the School

On January 28, 2016—about six months after the project's start—the students and their supporters took great satisfaction in the 385 kW PV array's commissioning.

The Energy Club students have the satisfaction of knowing they pushed through a project that once seemed unattainable. Because of their efforts, their school is offsetting 100% of its energy usage with clean energy from the sun, and saving about $19,000 each year on its electric bill, which can be reallocated to other school programs.

The years-long experience, says Fiona Laird, was a lesson in how "change can happen. It's a reminder to feel empowered about making things different and improving the condition of something."

Jimmy Serrano, also a school senior, says, "The fact that middle school students and high school students were able to impact their community and school in such a deep way makes me feel good about the future."

As Tavia Teitler says, "If you're passionate about something, you can always find people who are also passionate about it, and who are willing to make it happen."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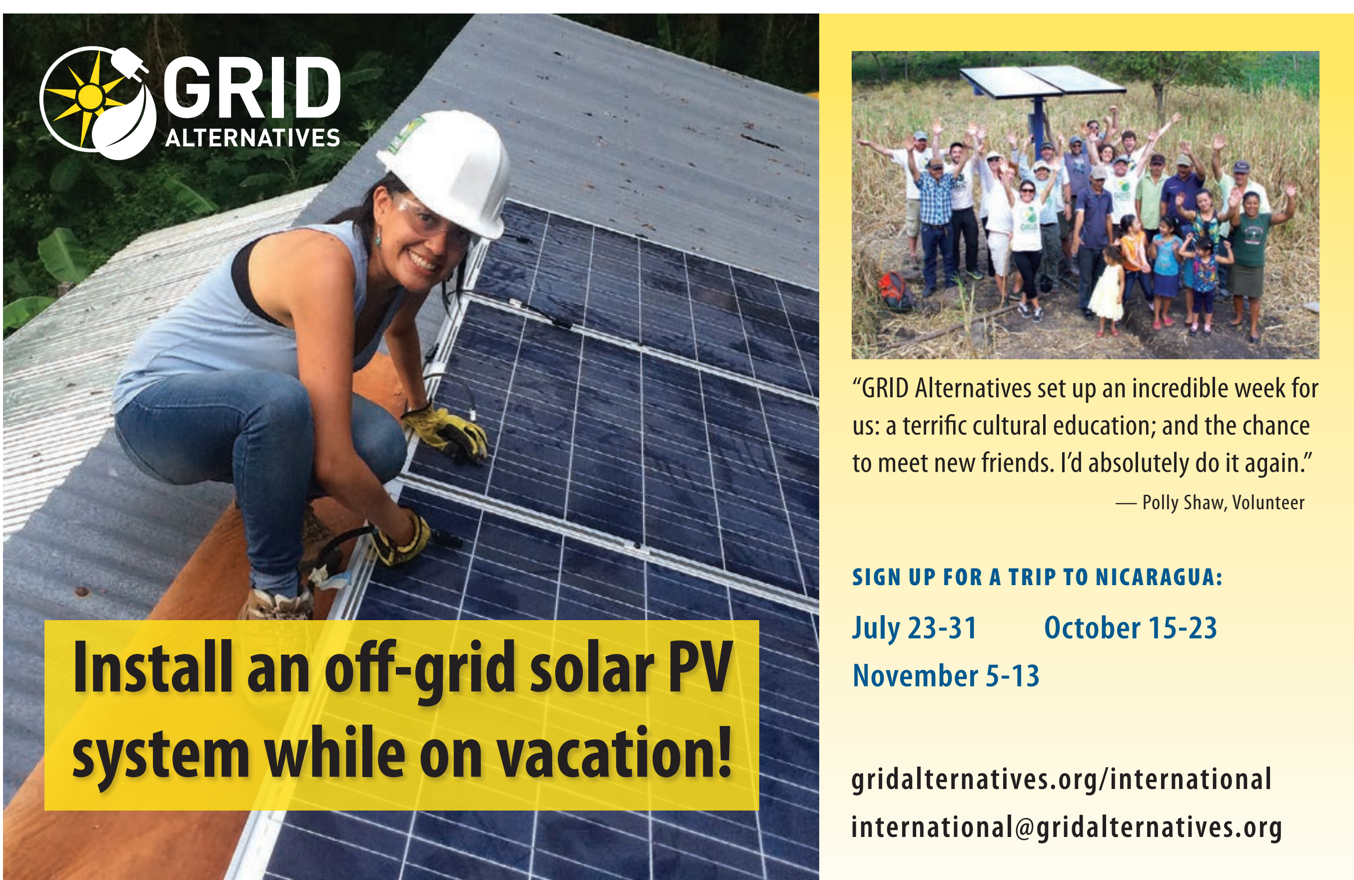
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Power Systems for

Off-Grid Vacation Cabins

by Dan Fink

Comment & Discuss this article @ homepower.com/174.44

Owning a cabin in the woods to escape during those all-too-rare vacations is a dream come true for many people. And where better to go for peace and quiet than a remote location, far from the nearest power line?

Off-grid solar-electric systems with battery storage are becoming more affordable every year as equipment prices drop. But cabins that are occupied only seasonally or on weekends present unique challenges for system design, operations, and maintenance compared to full-time off-grid residences, where the owners are home regularly to keep an eye on things.

The first thing to consider when designing a power system for a vacation property is the expected pattern of use. For how many weeks or months at a time will the dwelling be unoccupied, and does that use pattern change depending on the season? For example, in snowy climates the cabin might be occupied every weekend during summer with an occasional stay of a week or two, weekend stays during spring and fall, and only a rare weekend during winter for some cross-country skiing or snowmobiling. In warmer climes, the use patterns may not vary so much seasonally.

These use patterns can even change the basic system design parameters of battery bank capacity versus PV array size. With an off-grid home that's occupied year-round, it's common to size the PV array to bring the batteries from 60% state of charge (SOC) to 100% over the course of a single sunny day. But if a cabin is only occupied on weekends, the PV array could be smaller—it has all week to get the batteries back up to 100%, and it is possible to add more PV modules in the future if use patterns change. Battery bank autonomy time (how long the battery bank can run the cabin with no energy coming in from any source) is also important, and should be factored in when designing the system for both occupied or unoccupied periods. However, a backup generator, which will bring the batteries to 100% SOC in a short time, is highly recommended for most off-grid installations.

Occupied vs. Unoccupied Loads

It is essential to look at what loads need to be running while the cabin is unoccupied. Ideally, these will be minimal or non-existent. It is certainly possible to keep everything running as usual, but the system will have to be larger and more expensive, with more regular maintenance required. Possible loads during these periods might include wireless

Cabin Loads

Load	Qty.	Watts	Hours Per Day	Watt-Hrs. Per Day
Refrigerator (measured)	1	-	-	700
Entertainment center	1	50	4	200
LED lights	6	5	6	180
Wi-Fi router	1	6	24	144
Phone chargers	3	5	6	90
			Total Wh Per Day	1,314
			Wh Per Day, with 15% Efficiency Derate	1,546

internet for remote system monitoring, circulation pumps, fans and controls if solar thermal heating is also installed, or a remote security system. Larger loads, such as refrigerators and freezers, are best left emptied and unplugged if possible. Phantom loads can be eliminated by using switchable power strips, by unplugging the load, or turning off their circuit breakers before leaving.

Consider a cabin occupied only on weekends with some typical occupied loads (see table). When cloudy weather strikes, your battery bank may become quickly depleted unless you can also employ "load shifting"—running larger electrical loads only when the battery bank is fully charged and there is extra power coming in. This will bolster autonomy time. Simple energy conservation measures, like forgoing that DVD movie for a game of cribbage during a snowstorm, can make a big difference in autonomy time, too.

Sizing the Battery Bank

In the example above, we are looking for at least two days of autonomy, with a total energy consumption of 2.628 kWh—but that doesn't mean a 2.628 kWh battery bank will be enough. Efficiency losses of about 15% from our inverter and wire resistance bring that two-day need to 3.09 kWh (2.628 kWh ÷ 0.85). And, lead-acid batteries of any formulation—by far the most common and affordable choice for most off-grid applications (see below)—should rarely be discharged below 50%. That means only 50% of the battery bank capacity is actually usable without drastically reducing battery lifespan. A 6.18 kWh battery bank is required (3.09 kWh ÷ 0.5).

Off-grid batteries are rated and sold by amp-hours (Ah) of capacity, but fortunately the conversion to kWh is easy: Just multiply the Ah rating by the voltage of each battery and add them up. For example, a typical L-16 battery provides 350 Ah of storage at 6 V, and 6 times 350 equals 2,100 watt-hours (2.10 kWh). Our required capacity for two days of autonomy was 6.18 kWh, and 6.18 divided by 2.10 equals 2.94 of these batteries. At 6 V each, they must be used in pairs for a 12-volt system; groups of four for a 24 V system; and groups of eight for a 48 V system. Four would be the minimum batteries required here, offering 8.40 kWh of storage which actually increases autonomy time and also reduces average long-term depth of discharge for longer battery bank life.

Battery Sizing

	Days of Autonomy		
	1 Day	2 Days	3 Days
Wh used	1,546	3,092	4,638
Wh per day at 50% DOD	3,092	6,184	9,276
Batteries needed (6 V @ 350 Ah = 2,100 Wh)	2	4	6
Wh in batteries needed	4,200	8,400	12,600

System Design Factors

Before designing a PV system for your off-grid vacation cabin and selecting components, consider:

- For what duration will the cabin usually be vacant?
- For what duration will the cabin be occupied?
- Do these times vary seasonally?
- In cold climates, will the cabin need to be heated in the winter?
- What loads are required to run while the cabin is vacant, and how much power (watts) do they draw?
- How many kilowatt-hours of energy will these loads use each day? You can use an inexpensive Kill-a-Watt meter to measure both kilowatt-hours and watts for individual appliances.
- Will the PV array be mounted so that it can shed snow in the winter?
- Do you wish to monitor the power system remotely while you are away? If so, is wireless internet or cell service available at your site?

In an off-grid, part-time cabin, battery bank sizing and care are often more important than PV array size.

Courtesy Dan Fink

Courtesy Timberhomes Vermont

This off-grid cabin has solar water heating collectors and solar-electric modules.

Courtesy Jeff Hobbs

This tiny house, occupied part-time, requires only a couple of PV modules to meet its electricity needs. A solar water collector provides domestic water heating.

Sizing the PV Array to the Battery Bank

Here's where the occupancy patterns of a remote, off-grid cabin can significantly affect the system design and the budget. For a full-time off-grid residence, with such low prices per watt on PV modules, conventional wisdom now dictates designing a PV array to bring the battery bank from 50% SOC to 100% SOC over the course of one sunny "average" fall or spring day—likely less than a day of charging time during the summer months, and likely more than a day during the dead of winter. If the system has more days to charge the batteries to 100% before the next occupied period, the PV array could conceivably be sized smaller, with the option of expanding it in the future if usage patterns change.

Take a typical PV array in Colorado for the example above, sized for the loads, autonomy time, and battery bank for full-time occupation, with 100% of loads powered by PV during spring and fall, an energy surplus during summer and some backup generator run time required in winter. Bringing the four L-16 batteries (a total of 8.4 kWh of energy storage) from 50% to 100% SOC during spring and fall (including a derate of 30% for battery charging system inefficiency and PV output loss from higher-than-STC cell temperatures) would require 6.0 kWh (8.4 x 0.5 ÷ 0.7). With the site's insolation of 5.5 peak sun-hours per day during that season, about 1,091 W of PV would be required. With four or five days (in an unoccupied situation) to charge the system, it would be no problem to halve that amount of PV—perhaps two modules instead of four, and still have excess charging capacity.

PV Recharge for 50% DOD

# of Batteries	Charge Needed (Wh)	Peak Sun-Hours	Charging Needed (W)	PV Array Size to Recharge (W at 70% Charging Efficiency) 1 Day	2 Days	3 Days	4 Days
2	2,100	5.5	382	546	273	182	136
4	4,200	5.5	764	1,091	546	364	273
6	6,300	5.5	1,145	1,636	818	545	409

System Equipment Phantom Loads

Inverters are phantom loads—they still use power even if no loads in the home are running. Most off-grid inverters can be set for "search mode," which drastically reduces their no-load power use. Typical search-mode power drain is only 5 to 10 W. The inverter remains asleep, but will wake up quickly if a load that draws enough power is turned on. The watts required to bring it out of search mode are adjustable. This can be very convenient upon arrival back at the cabin at night for a vacation weekend, with no need for flashlights to find and turn on the inverter again. But too many phantom loads can keep the inverter on and out of search mode, so it's best to test carefully before buttoning down the system prior to an extended departure.

Set the inverter for search mode, and turn off or unplug all your loads. After a few seconds, the inverter should drop into search mode, usually indicated by a blinking indicator light or a message on the remote. If it doesn't do this, increase the search mode watts setting on the inverter. Now, turn on the first light you'll need when you arrive. If it doesn't work or it flashes, decrease the search mode W setting until the light operates properly.

Keep in mind that if you have equipment such as a Wi-Fi router and security system that must remain running when you are away, search mode won't be an option, since the inverter will remain on. Inverter power draw when on (but with no loads operating) varies by manufacturer, but 20 to 40 W is typical. And remember that even if your loads use less than that, the inverter's no-load draw will still be the minimum. You can find the no-load draw on the inverter specifications sheet.

Operations & Maintenance When Vacant

PV systems require very little regular operations and maintenance care, with one exception: the battery bank. Lead-acid batteries—no matter what type—will be permanently damaged by sulfation (deposits of sulfur on the lead plates, which partially block electrolyte contact with the plates) if left at a low SOC for an extended period of time. Simply shutting down the entire system including PV modules, inverter, and loads doesn't help this situation, as all lead-acid batteries "self-discharge" when sitting unused, noticeably lowering their SOC as time goes by. Therefore, it's essential to keep the PV to the battery-charging side of the system operational during absences.

Remember also that PV charge controllers themselves are phantom loads that use a small amount of power all the time, typically 1 to 4 W. That can be problematic in cold, remote locations where the PV array can be covered with snow for weeks or months at a time with nobody around to clear it. One solution sometimes used by wily remote system designers is simply a single PV module mounted vertically on a south-facing exterior wall. It doesn't have to live there all summer long, and can be quickly deployed just before vacating for the winter. That single module can provide enough charge to make up for battery bank self-discharge, plus charge controller and (possibly) inverter phantom loads, over an entire winter. (Note: This strategy assumes the module, charge controller, and battery bank voltages are carefully selected to allow the single module to charge the battery bank.)

All lead-acid batteries emit gas when charging, and some require the electrolyte be topped off regularly with distilled water. If this maintenance isn't performed and the electrolyte level drops below the tops of the internal plates, the batteries will be permanently damaged. Different strategies to solve this problem depend on exactly what type of battery is selected for the installation, and how often the batteries need to be topped off.

Temperature also plays a role in battery selection for an unattended system. Consistently high temperatures (greater than 80°F) cause all battery types to age prematurely, which can be a problem in desert and tropical locations. Cold temperatures won't damage most fully charged batteries. Common lead-acid batteries are good down to -50°F (and lower)—but only if fully charged. If deeply discharged, their electrolyte is mostly water with the sulfuric acid essentially absorbed into the lead plates; they can freeze and even burst at temperatures near 0°F. *Never* try to charge a frozen battery; it must be removed from the battery bank, allowed to thaw, and then charged very carefully to see if it is salvageable. Most likely, it will need to be sent for recycling and replaced. I highly recommend a sealed, vented, and insulated battery bank enclosure for all battery types. This tempers both heating and cooling of the batteries.

Types of Off-Grid Inverters

Typical residential direct grid-tied inverters cannot be used to charge battery banks; they only convert incoming DC power into outgoing AC power. However, "multimode" inverters can send and receive grid power and receive power from a backup battery bank, operating in off-grid mode. "Stand-alone" inverters can't interface with the grid and operate in off-grid mode only; these are generally less expensive than multimode inverters.

Desirable inverter features for off-grid cabins include:

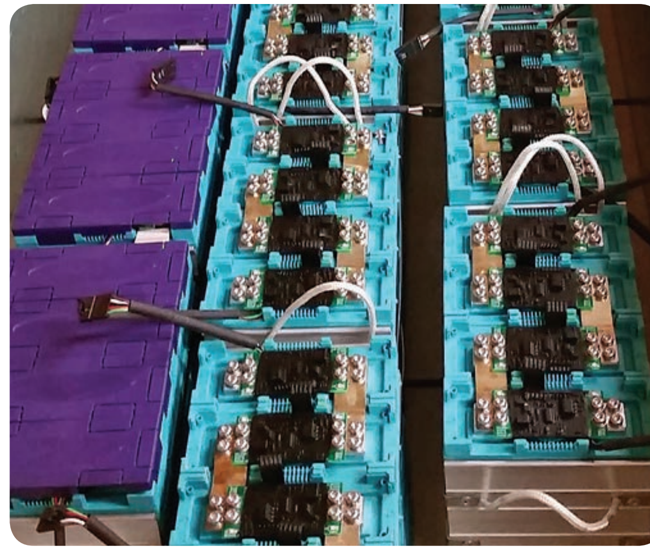
- Built-in 120 VAC battery charger for use with a portable generator
- Sine instead of modified square waveform for better load efficiency and compatibility
- "Search" mode to reduce power consumption when no loads are running
- Remote display so the inverter can be controlled and monitored from the living area

This compact, modified sine wave, off-grid-only inverter is offered in 600 W and 1,500 W versions. It has a built-in 120 VAC charger for charging the battery bank from any AC source, such as a generator.

This multimode inverter can receive grid power and send out PV power, and can also operate in off-grid mode.

Courtesy Iron Edison

Nickel-iron batteries are an "old" technology that offers superior longevity, but also has efficiency and financial costs.



Courtesy Art Weaver

High-performance lithium-ion batteries are light and small, but require sophisticated charge management and are expensive.

Battery Types & Charging Strategies for Unattended Locations

Using the proper battery type is crucial when the system won't be receiving regular maintenance for an extended period of time. Ambient temperature is an important consideration, as is the specific charging regime programmed into the charge controller.

Flooded lead-acid batteries are a common and cost-effective choice for many remote installations. They handle low ambient temperatures gracefully and without damage, as long as they are kept at full (or nearly full) by the PV array. Their biggest disadvantage is that they require regular watering—at least four times per year, and sometimes more frequently. Automated watering systems with a central reservoir and valves in each cap are available, but will not function if the battery enclosure can reach temperatures below freezing. Catalytic re-combiner caps are also available, but do not entirely eliminate the need for regular watering—they simply reduce the frequency.

Flooded lead-calcium batteries are another option, though they are more expensive and difficult to source. They use calcium instead of antimony in the plates, resulting in less water use and a slightly lower voltage versus SOC curve.

Clever PV installers have found that it is possible to change the charging regime to reduce gassing in flooded lead-acid and lead-calcium batteries by changing the charge controller settings. Setting the absorb voltage high (for example, 15.0 V for a 12 V system), absorb time to only an hour or two, and the float voltage quite low (around 13.0 V for a 12 V system), minimizes water loss. This runs the risk of not charging the batteries to 100% SOC, but during an extended absence of a month or more, they will likely fill with no trouble if there are no loads during this time.

Absorbed glass mat (AGM) batteries are the star when it comes to remote systems that receive little or no maintenance, but their benefits come at a price—they are two to three times the cost of flooded cells for a battery of the same capacity. AGMs use lead-calcium chemistry and contain integral catalytic recombiners to prevent gassing under normal charging conditions. They are sealed so they can't spill, and are almost immune to freeze damage no matter what their SOC. But because they are sealed, there is no way to top off the electrolyte if too much gassing occurs, so following the battery manufacturer's charging instructions precisely is essential.

Nickel-iron (NiFe) battery technology goes back more than 100 years, and has recently been experiencing a resurgence in popularity for off-grid systems. NiFe cells have an extremely long lifespan—at least 25 years compared to the four to 10 years expected from lead-acid chemistry—but are considerably more expensive. They can be left idle in storage, not charging or discharging, for long periods of time over a range of temperatures (-40°F to 140°F) without damage, and are not harmed by a low SOC. However, during daily cycle use, they consume a lot of distilled water. NiFe cells would be best-suited for a remote vacation cabin in which the entire system—including PV input, all controllers, and inverters—is shut down for long periods of time.

Lithium batteries (there are many different specific chemistries available) are the relative new kid on the block, and certainly show promise. (See "Gear" in this issue for a few Li-ion options.) They are expensive (but coming down in price), and require a sophisticated battery management system to keep

Courtesy Aquion Energy

Saltwater batteries are quite new to the scene but the industry is hopeful about their efficacy.

them healthy during cycling. Advantages include long cycle lifespan; efficient charging; very low self-discharge rates when left idle; and small size and weight. Be sure to check their specified operating temperature range, both high and low—charging at low temperatures can permanently damage them.

Silicon salt batteries are a promising newcomer to the world of remote off-grid system design. They claim to handle a high rate of charge and discharge, are nontoxic and maintenance-free, and are rated to perform in a very wide temperature range (-40°F to 158°F). They are more expensive than AGMs, and have not been around long enough to know if the claims of a 15-year lifespan are accurate.

Saltwater batteries are another very new addition to energy storage technology for off-grid systems. They are expensive and can't provide much surge current (for example, to start an off-grid well pump) without paralleling additional stacks, which can create a battery bank capacity that is larger than necessary. While they can survive temperatures as low as 15°F, their capacity will be permanently lowered. On the positive side, they are maintenance-free, nontoxic, nonflammable, and can be left at a partial state of charge and even discharged to 0% SOC without damage.

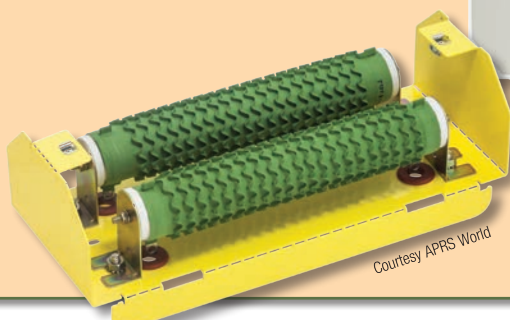
Diversion-Load Controllers

Diversion-load controllers work very differently than standard PV controllers, though some of those can be programmed to work in diversion mode. Instead of controlling how much power is coming into the battery bank from the PV array, they always let maximum power in while charging. When the battery bank is at 100% SOC, incoming power is diverted to "diversion" or "dump" loads, usually special air or water heating elements. In certain situations, this can be very effective, providing supplemental heating for a cold cabin or a tank of hot water when you arrive back at the cabin in warmer climates. However, you can't rely on diversion loads all of the time, as their efficacy is entirely weather-dependent.

Diversion-load controllers don't provide electronic maximum power point tracking (MPPT) to maximize PV-generated charging. By adding ganged circuit breakers to a system, it's possible to switch between two different controllers for occupied and unoccupied times of use, so the system can use diversion when you are away and MPPT when the cabin is in use. The question is whether the extra equipment is worth the amount of heat gained.

This charge controller can be used for diversion load control, allowing excess solar energy (once batteries are full) to be diverted to other tasks, such as space or water heating.

Courtesy Morningstar



A resistance air-heater element (shown with its safety cover removed) turns diverted excess energy into hot air.

Courtesy APRS World

Automatic Generator Start (AGS) Systems

For larger remote cabins in which owners don't want to shut off all the loads and drain the pipes during extended absences, most off-grid inverter/chargers can be programmed to automatically start a backup battery-charging generator if battery voltage (or even battery SOC) gets low (i.e. reaches a certain threshold setpoint). Gasoline, propane, and even diesel generators are possible for AGS with the addition of some simple circuitry from the inverter/charger manufacturer or third-party companies. Complicated startup routines for diesel generators are no problem—AGS circuitry can preheat the glow plugs, attempt to start the generator, sense if it actually starts or not, and, if unsuccessful, retry the whole procedure after a waiting period.

Unfortunately, there are a lot of "ifs" in the process, especially when no humans are available to intervene when (not if) things go wrong. My informal survey of remote, off-grid system installers here in the remote Colorado mountains match my own experiences: All of the various AGS systems from different inverter/charger manufacturers and third parties work equally well—it's the generators themselves that are cantankerous. Dead starting batteries due to multiple failed starts can be caused by a generator that's low on fuel, or low on coolant, or has low or dirty crankcase oil; by an owner who accidentally messes up the inverter AGS settings while trying to reprogram; if AGS settings are lost when the owner shuts down system for regular maintenance; a generator buried in snow, that overheats due to lack of ventilation; a wasp nest in the generator electronics box that shorts AGS circuitry...the list goes on. I prefer to keep things

Right: AGS units usually work fine—it's other, less reliable parts of the system (like the generator and fuel supply) that cause many pros to discourage using them.

Courtesy Magnum Energy

Courtesy Generac

Though often less than desirable because of the noise and pollution it generates, a backup generator for battery charging during times of little sun can be a necessary addition.

Cabin Shutdown

It is difficult to remember all that needs to be done, so using a checklist can be an important part of shutting down your cabin before an extended absence. Here's an example checklist, used for my Colorado family guest cabin.

- Hot and cold water pipes drained and blown out
- Refrigerator emptied and defrosted
- All propane appliances shut off individually (furnace, refrigerator, range, and on-demand hot water heater), and main propane shutoff on
- DC load breakers off
- AC load breakers off
- Inverter off (unless you want to use the inverter's search mode function and/or have no AC loads that need to be powered when you are away)
- DC PV breaker on
- Main DC battery breaker on
- Batteries topped off with distilled water
- Mousetraps baited and set
- Insulated window drapes closed
- South-facing window drapes open
- All doors locked
- All gates locked

See you next spring, cabin!

Courtesy Dan Fink

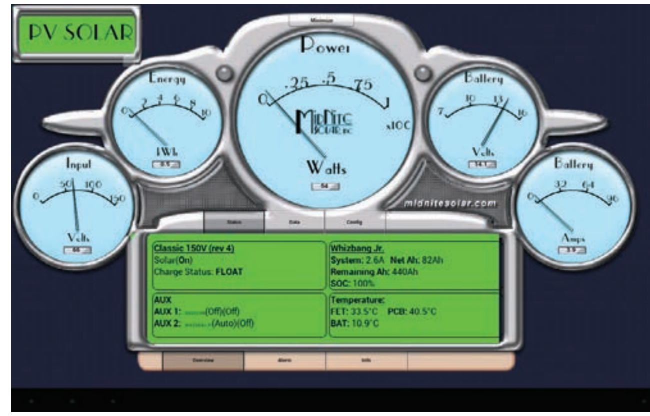
The author's family cabin, at 8,200 feet of elevation in the northern Colorado mountains, uses a small PV array to keep full-time loads running and batteries well-charged, even when it's vacant.

simple by reducing cabin loads to zero (or as close to zero as possible) when the property is vacant—and avoid AGS systems entirely.

Remote System Monitoring

If your vacation cabin location has internet service, installing remote monitoring equipment is often simple and inexpensive, requiring only a router that uses only a few watts and, possibly, an outdoor antenna. Most inverter and charge-controller manufacturers include data ports on their equipment that can talk directly to the internet via Wi-Fi, and third-party companies also provide this service. In most cases, you don't need your own website to view your system data live from anywhere in the world—it appears on the company website after you log in. These services usually are free initially; after a year or two, a small yearly fee is charged.

If your only internet connection is broadband satellite, it gets more complicated, as the satellite dish and modem can draw from 50 to 100 W when turned on. For most systems, that draw is usually too large to leave on unattended for weeks or months at a time. Ham radio can also be used to remotely send data about the status of your home temperatures, power system, and battery bank SOC while using very little energy, as can satellite short-burst data transmitters. The sky's the limit on remote system monitoring, if it fits your budget.



Courtesy MidNite Solar

Most inverter manufacturers and third-party companies offer remote system monitoring, but you'll need always-on internet access at your cabin.

Plan Carefully, Then Go Remote!

Keeping a vacation cabin power system alive and well during extended absences is not difficult—it just requires pre-planning, careful component selection and using a thorough checklist before you button up. One last piece of advice: don't forget to turn off the lights before you leave!

Capturing Sun & Water

In the High Rockies

Story & photos by Darin Anderson

Diana and Darin Anderson in front of their solar-powered home, at 9,200 feet of elevation in the Rocky Mountains.

In the early 2000s, I was deep into my computer programming career, traveling across the country. It was during that time that I decided to build my dream house—a log home in the mountains of North Carolina. But after poor luck with contractors and design problems, I knew there had to be a more sustainable way to build a home.

My wife Diana and I were both in the technology field, so we had the option of working remotely from anywhere. We chose Colorado and launched our new dream.

Over the next two years, I spent as much time as available researching, planning, and designing our new home. We came up with a set of lofty design goals (see sidebar), and I knew I needed to be the general contractor to ensure the necessary attention to detail by all construction contractors working on the project.

web extras

"Heading for Zero" by Jim Riggins in *HP141* • **homepower.com/141.88**

"Net-Zero Performance: Year 1" by Jim Riggins in *HP150* • **homepower.com/150.62**

Planning & Design

There was still a lot I didn't know, so I enlisted Jim Riggins, whose superinsulated solar home, Heliospiti, was featured in *Home Power* (see Web Extras). We discussed house shape; orientation; foundation/wall/attic design; insulation profiles; air sealing; advanced framing; green building materials; efficient windows and doors; and efficient water and electrical fixtures. We went over his experiences and what to expect, which led to more research and even more questions.

Once I felt I had a solid understanding, I designed the general house layout and started incorporating the various systems. Including some of the systems was straightforward, but others were more experimental—like the water cisterns also used for passive heating and cooling, an internal greenhouse, and a "cool pantry" room that would use only fans and a differential thermostat.

Once in a final version I modeled the house in 3-D using Home Designer Pro software, laying it out in complete detail down to the locations of every electrical outlet and light switch. I also created several supplemental construction documents for various trades to remove any interpretation or ambiguity. This included the wall design, ERV ducting layouts, PV module locations, subslab plumbing and electrical, and the rain harvesting system.

We broke ground in early April 2014, which in Colorado is like playing Russian roulette with the weather. I anticipated we would need about eight months to complete the project before the winter cold and storms would prevent contractors from getting to the site. Favorable weather prevailed, and we were able to meet that timeline.

Construction Details

The house is single-level, with two bedrooms and two baths, and a rectangular shape for optimal passive solar gain. A floating slab foundation was selected (with a thermal break from the stem wall). The wall design differed from the main living area and the garage (a choice I would regret later). The main living area is a double wall—an advanced framed 2-by-6 exterior wall separated by a 3-inch space from a 2-by-4 interior wall—while the garage walls are an advanced framed 2-by-6 wall with 1.5 inches of EPS foam on the exterior.

Meticulous attention was given to air-sealing and minimizing penetrations through the building envelope. Knowing that proper sealing is as important as good insulation, I spent many hours in the evenings foaming and caulking gaps. I performed

A snow-capped horizon is reflected in the south face of the home's high-efficiency, triple-pane windows, which admit solar heat gain while protecting from low winter temperatures.

Design Goals & Complications

Our work was cut out for us. We wanted this house to:

- Be superinsulated and passive-solar driven
- Avoid fossil fuels and wood heating
- Be a net-zero energy user
- Use rain harvesting for all water needs, even in drought years
- Incorporate a year-round greenhouse with only passive heating and cooling
- Emphasize function over form
- Have redundant key systems, like water, electricity, etc.
- Leverage design elements to have multiple uses or purposes to increase their ROI
- Include a "cool pantry" for long-term food storage with minimal energy consumption
- Utilize local and U.S.-made "green" materials as much as possible
- Minimize construction waste via recycling and wise material usage
- Be low-maintenance throughout its lifetime
- Minimize the risk of wildfire to the structure

To make design and implementation even more complicated, the property we had chosen also had a few obstacles to overcome:

- The house site was 9,200 feet above sea level
- Its rural location could make hiring contractors and sourcing materials difficult
- In Colorado, rain harvesting systems are allowed (with restrictions) but are not always well-understood by building inspectors
- Rainfall and snow melt for the past 50 years averaged only a little more than 10 inches annually (making meeting our water needs challenging)
- The area has a high wildfire potential and the closest firefighters would be more than an hour away
- Colorado has high radon levels. This county averages almost 7.1 pCi/L (picocuries per liter)—the national average is 1.3 pCi/L, with remediation required at levels exceeding 4.0 pCi/L.
- The local electric co-op has made net-metering quite expensive, with monthly fees and a one-time connection charge
- The location is in a moderate earthquake and high wind-gust area

two blower door tests—one before the drywall was installed to identify missed penetrations and the second when the house was complete. There were a few electrical penetrations I had missed, but the majority was improper sealing of the plastic vapor barrier in the main ceiling area by my framers. The final blower door test resulted in a reading of 161 CFM at 50 pascals, much better than the related Passivhaus standard of 280 CFM.

The slab is insulated underneath to R-20 (5 inches of high-compression-strength EPS) and the external side of the stem walls were covered with 1.5-inch EPS board for another thermal break. The main living area walls have a weighted value of R-45.4 provided by 3 inches of closed-cell spray foam and 9 inches of dense-pack cellulose fill. The garage area walls are R-25.3 with

Above: The main living spaces are all aligned across the south wall to receive solar gain into the high-mass stained-concrete floor. Abundant natural light and stunning views are a bonus.

Right: The home's long east-west orientation incorporates living, dining, kitchen, and gym space into one "room."

Below: An integrated greenhouse provides space for vegetable growing and aquaponics (fish farming).

5.5 inches of dense-pack cellulose and 1.5-inch EPS foam board on the external face. The attic is R-60 from 18 inches of blown-in cellulose.

We built the walls 24 inches above the ceiling level, which allows full ceiling insulation depth all the way to the edges of the walls. I also incorporated dropped ceilings in northern sections of the house which simplified wiring, HVAC, and plumbing runs while

Left: The workout space contributes to the occupants' sustainability by allowing healthy indoor activities during winter.

Right: A solarium with spa tub provides a four-season experience.

minimizing penetrations. We choose fiber cement board on the exterior for wildfire protection and ability to install it ourselves to cut costs.

All the doors are insulated, even the interior ones, for thermal and acoustic separation. For optimal temperature management, the two exterior doors both open to a buffer room that is separate from the main living area. Triple-locking exterior doors increase air sealing and security.

All windows are fiberglass-clad, triple-pane units, but air-filled, instead of gas-filled (given the elevation gain, gas fill would have been lost in transit). There are few windows on the east, west, and north sides; and most windows are non-operable ("fixed") for the best insulation. The majority of operable windows are awning type, which offer the best air-sealing. Casements were used only where required for emergency egress.

Rolling exterior insulated metal shutters by Rollac were installed for all windows. The economic justification was their additional insulation of about R-1.2 to R-2 to the thermally weakest spaces in the walls, providing security when we are away, and providing wildfire protection. To further decrease the risk of fire damage, all external surfaces are non-flammable.

The standing-seam metal roof met our requirements for ease of maintenance, wildfire protection, and effective rain harvesting. Most roof pitches in Colorado are 6:12 or greater to shed snow, but that was too steep to maximize rainwater harvesting. A 3:12 pitch was selected and snow guards added to "hold" snowfall until it melted and could be captured. Continuous soffit and ridge ventilation help prevent ice damming. A 3-foot overhang provides seasonal shading for the windows.

During the winter months, the average night temperature inside the main living area is in the high 60s to low 70s. Over an average winter night (anywhere from the teens to single digits), that space will lose 3°F to 4°F by morning. In general, with the house temperature "charged" with a couple of days' worth of winter sun, it can sustain three days of cold temperatures in the low teens and no sunshine before dropping into the very low 60s.

A single perforated tube was buried under the entire length of the slab and stubbed into the garage space for any future radon mitigation needs. The building design also follows many of the FEMA construction recommendations for earthquake and wind loads.

Double-stud, advanced framing provides room for ample insulation. The outer cavity is foam-filled (left); the inner cavity is filled with high-density cellulose (center). Right: A blower-door test revealed 161 CFM air exchanges—exceeding Passivhaus standards.

Above: The greenhouse dominates the southeast end of the home, providing good morning light. The solarium occupies the center space, with the living area on the southwest corner.

Left: Having few windows on the west face reduces summer afternoon heat gain. Metal roll-down shutters and cement-board siding help reduce fire hazard.

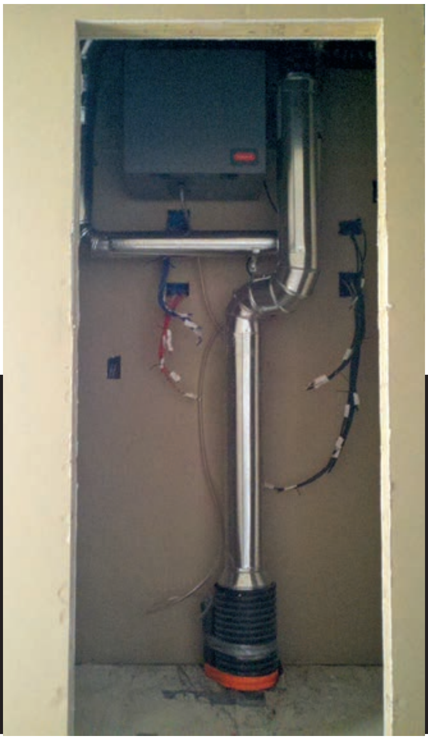
Mechanical Systems

Ventilation. Operable, adequately sized windows help passive chimney-effect airflow, but for this tight house, mechanical ventilation is necessary. For the main house, an energy recovery ventilator (ERV) with a 140-foot-long "earth tube," buried at a 10-foot depth for pre-warming, provides fresh air to the home. For the needed air changes, it runs 15 minutes out of every hour. A separate "spot" ERV was installed in the garage ceiling for ventilation and moisture reduction. The incoming air for this ERV gains some passive pre-heating from the garage below via a rigid-insulation thermal tunnel that encapsulates the ductwork above the ceiling.

In the greenhouse area of the garage, auto vents are opened with beeswax-filled pistons that are triggered by temperature increases to boost summertime ventilation.

Heating. At this elevation, no cooling is needed other than simply opening a few windows. Heating is the priority, with 6,964 average heating degree days and an average temperature of about 28°F in the coldest winter months. Lots of thermal mass—concrete floors, cisterns, dual layers of south-facing drywall, the kitchen countertop materials, and even the iron weights in the weight room—absorb solar gain during the day and then release that stored energy when temperatures drop. The county building codes required a backup heating system, which we met with a 2,500 W electric baseboard unit.

Renewable electricity. The site had access to utility power so it made economic sense to install a grid-tied system—but installed with an eye toward disconnecting from the grid in the future. The PV system consists of twenty-eight 260 W modules in two strings mounted in two rows on the roof. While pole-mounts for PV arrays are common in high-elevation snowy climates—they can be set high and seasonally tilted to quickly shed snow—installing one in our county required



Tight construction necessitates an ERV for efficient ventilation. Its ductwork connects to a 140-foot-long earth tube that tempers incoming air.

Right: Twenty-eight 260 W PV modules on tilt-up racks provide enough energy annually to offset all household energy use and, in the future, charge an electric car.

Below: Two SMA 3000TL-US inverters provide grid-tie. During a grid outage (and if the array is receiving sunshine) up to 1.5 kW of power per inverter is available at two dedicated outlets.

an extra permit. Coupled with additional construction costs and the fact that the only pole-mount locations would have negatively impacted the views of the surrounding areas, we opted for a roof-mounted array. So far, we have found that the strong Colorado sun, even in the winter, coupled with the standoff gap under the modules, cleans both levels of arrays fairly quickly, without any intervention.

While a single inverter could have covered both strings, we selected two for redundancy. Each inverter has a built-in AC electrical outlet that can be used when the grid is down during sunny weather. The system was sized to meet our daily usage (after a rigorous review of our monthly anticipated loads), a future electric car, and the monthly cost to be connected to the grid. A 13 kW propane generator provides electricity backup for the entire house.

We originally estimated a yearly consumption of 10,056 kWh (house only) or a 12,182 kWh (the house with a future electric car). For 2015, the PV system produced 12,786 kWh, with 6,202 kWh actually being consumed. That means it produced roughly 5% more than the expected amount, and we are using 38% less than planned—enough to readily accommodate an electric car. This overproduction also allows us to more quickly recoup our monthly interconnection fee ($28), as well as the one-time $945 net-metering connection fee. The utiilty co-op is a bit convoluted in terms of compensating us for any surplus energy production, paying us at their "avoided cost"—the most recent average *wholesale* cost for energy.

Water harvesting. Even though rain harvesting was legalized in Colorado in 2009, few local plumbers were comfortable with implementing it. I even had to educate the state plumbing inspector on the topic at times, and this was five years after the legalization. At one point, the entire rainwater harvesting system was in jeopardy because of those misunderstandings—the only saving grace was the head supervisor who I ended up working with directly on the design to get it approved.

The result is that captured rainwater is stored in three 4,000-gallon concrete cisterns. This provides the water for all house needs and the fire sprinkler system, and is large enough to cover significant drought conditions. High-efficiency water fixtures and low-water-use appliances, such as 0.5 gallons-per-flush toilets, decrease water use.

The rainwater harvesting system was filled to capacity for the first time in March 2015, about four months after its commission. Since that time, it has (at the most) been drawn down by one-eighth of its capacity, and that was after a couple of months of very low rainfall. Given the size of the catchment surface, just one-tenth of an inch of captured rain equates to a 1 inch increase in water level across all three cisterns, or roughly a 130-gallon gain. In the spring, the cisterns were at full capacity after the melt of a 12-inch snowfall.

Sustainable food storage. Cool rooms were included in the home's design for food storage and a more comfortable sleeping environment. These rooms are air-sealed and have insulated walls—even inside the house perimeter—to thermally isolate them from adjoining rooms. In both the "cool pantry" and master bedroom a Kera Technologies DSD-2RT differential thermostat tracks the external temperature versus the internal temperature, comparing both against the desired temperature. When the external temperature drops below the internal temperature setpoint, a Fantech FR100 fan turns on, bringing in the colder external air to decrease the internal room temperature.

Left: Three 4,000-gallon rainwater catchment tanks that provide a year's worth of water storage and huge thermal mass sit between the garage area and greenhouse.

Right: The north side of the house contains a cold-storage room and the bedrooms, which are thermally isolated from the living space.

The cool pantry has maintained an average temperature of 55°F—even during the summer months—using just the external fan and differential thermostat.

Greenhouse growing. The greenhouse area in the garage space was one of the project's biggest design gambles. The main goal was to grow food year-round without having to actively heat and cool that space. The cisterns, with their large concrete and water thermal mass, were employed, with the sun providing the heat source. Both raised beds and an aquaponics system were built into this space to see which would work the best, both efficiently and productively, year-round.

In an attempt to decrease the garage-building expenses, I chose 2-by-6 wall construction with a layer of external EPS as a thermal break. However, the labor to install the EPS, add angle iron to support the heavy fiber cement board cladding, and the use of extended-length fasteners negated my planned savings. Besides less insulation in the walls, it also introduced a moisture issue given the exposed and thinner part of the stem wall (versus the double wall used in the remainder of the house). This lower-temperature stem-wall section exposed in a warmer, higher-humidity space causes water condensation, introducing mold concerns if left unchecked.

The greenhouse area has performed very well (validating the passive heating and cooling approach with the cisterns), but has also introduced some other issues. The aquaponics system showed a growth rate of about 30% greater than the raised beds at growing the same vegetables, and I was extremely excited about expanding that system. However, when the temperature dropped into the high 50s and low 60s in the greenhouse, the Rocky Mountain white tilapia went dormant or died off, which then also slowed the symbiotic growth of the plants. This can be remedied by using slower-growing, colder-temperature fish varieties like blue gill, catfish, and carp, but tilapia have easier maintenance characteristics that make the other species less desirable.

The aquaponics system has also considerably increased the humidity levels in the garage. In the summer, the humidity is exhausted outside through the automatic vents. However, in the winter when the windows need to stay closed to preserve heat, the humidity levels rose from 30% to roughly 60%, causing some mold and moisture issues across that entire garage space. I installed an ERV there to conserve energy and heat while exchanging the internal moisture-laden air with less-humid outside air.

The winter temperature in the garage-greenhouse dipped to 58°F at its very lowest; it was usually in the low 60s. This is an almost 2,000-square-foot space that is not actively heated, but uses passive solar gain and the thermal mass in the concrete slab, along with the cisterns and the water within them. I expect that performance to increase next year, since the cistern water is estimated to gain 7°F to 10°F over the summer, becoming a significant thermal battery for the greenhouse to draw from in the winter.

Final Thoughts

I must admit, we were holding our collective breath the first year as we tracked how all the systems operated. When the initial results started coming back, I became cautiously optimistic. As the year progressed, those results continued to be very positive and some of the systems demonstrated performances above their predicted capabilities. By the end of the year, we knew we had made good choices and now we can't imagine living any other way. There are some things I would have done differently in hindsight, and some that I didn't predict well, but overall, we are thrilled with the results.

Our friends and neighbors walk through our house and are amazed at how it operates so well with so few energy inputs. Many of them expect to find us huddled, wearing blankets for warmth, and trying to figure out which few appliances we can run from the PV modules. Instead, what they see is a "normal" house—but one that operates with few external inputs besides the sun and rain.

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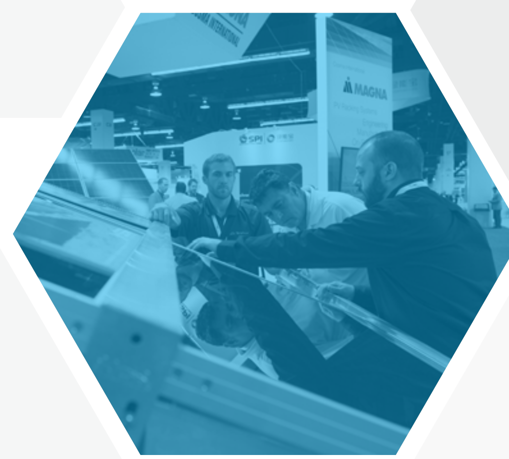

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Difficult Utility Interconnections

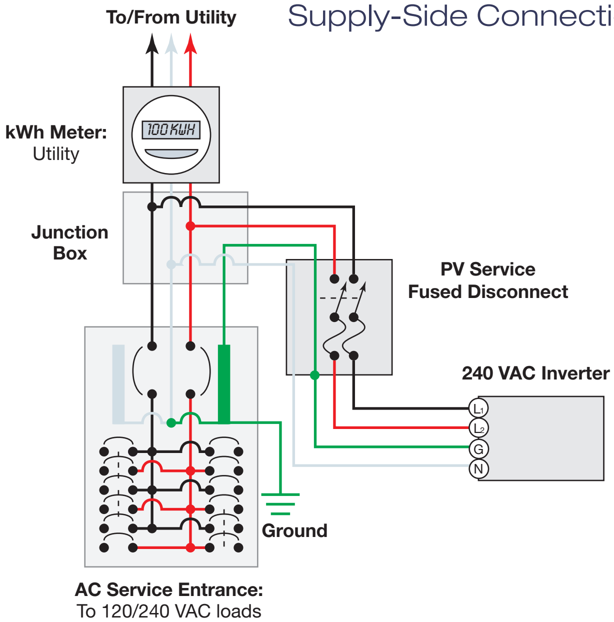
by Ryan Mayfield

Making the utility interconnection for PV systems can be a very straightforward process or wildly difficult. This "Code Corner" examines those challenging situations, both in residential and commercial applications; evaluates the *NEC* implications; and discusses the approaches installers can take to make a *Code*-compliant and utility-accepted connection.

Supply-Side Connections

One common method for utility interconnection is a supply-side connection. This approach allows interconnecting a larger PV system than a load-side connection would allow. This method connects the inverter output to the service conductors, which were sized for the service overcurrent protection devices (OCPDs). By verifying that the new PV interconnection OCPDs don't exceed the original service, the existing service conductors will not be exposed to more current than they were designed for and the PV system can have up to the same amperage output as the incoming service.

As has been discussed in previous "Code Corners" (*HP162* and *HP150*), the supply-side connection requires leap-frogging through the *NEC* to apply the appropriate rules—unfortunately, there isn't just one *Code* section we can refer to for the connections. Section 705.12(A) states that making a connection to the service conductors is allowed, but doesn't provide many details. This leads the installer to picking through Article 230, Services, to determine the best plan.



Supply-Side Connection

Some relatively consistent approaches have been established in the PV community, although they aren't universally accepted by AHJs. The main problem is the way these connections are defined. Per *Code* definitions, these systems are not services, yet we are connecting to service conductors. Some like to call them "taps." While this is an effective descriptor of the physical connection, the term often leads *Code* officials to the "tap rules" of 240.21. The issue here is that those tap rules are for feeders and not for a true supply-side connection. The connection occurs on the service conductors, not feeders. The service conductors are those that originate from the utility and terminate on the line side of your service equipment—typically, at a disconnecting means like a main breaker. The feeders then start on the load side of that disconnect and can feed distribution panels.

The "Six-Handle" Rule

One scenario that often arises for commercial systems involves cases in which the service entering the building is protected by six different main disconnects. Per *NEC* section 230.71(A), this is acceptable and commonly used. For PV installations, the difficulty arises in the application of the "six-handle" rule. An allowance in 230.71(A) permits up to six switches or circuit breakers to disconnect the service conductors entering the building. Careful reading of the first sentence in this section reveals some additional "services" allowed to add to the initial six handles. The allowance is for six switches for each service as allowed in 230.2 or for each set of service entrance conductors as allowed by four different exceptions, as listed in 230.40. This allows for not only the six disconnects for the "normal" service conductors, but for six more disconnects for the four different exceptions.

One of those exceptions is listed in 230.40, Exception No. 5: "One set of service-entrance conductors connected to the supply side of the normal disconnecting means shall be permitted to supply each or several systems covered by 230.82(5) or 230.82(6)." Section 230.82(6) reveals this is the *Code* section that allows connection of PV systems to the supply side of the service disconnecting means. This *Code* section-jumping leads us to the allowance of adding up to six

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Khanti Munro

The production meter (right) feeds into the ConnectDER collar between the utility meter and meter base (left).

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disconnects for supply-side interconnections. In reality, it is highly unlikely that six disconnecting means would be used for such an installation, since the entire PV system is typically condensed to a single output for ease of interconnection, utility disconnecting requirements, and metering purposes. Grouping the new PV disconnect with the normal service entrance disconnects and making provisions for labeling to clearly identify all of the disconnects is required.

Solutions for Interconnections on Busbars

Another tricky situation in both residential and commercial installations is a supply-side connection where the only available connection point is a set of busbars. For residential services, this commonly occurs in "meter main" panels in which the meter and main breaker are in the same enclosure. Connecting to the busbar between the meter and main disconnect is generally not acceptable, since that would require modifying the busbars and violating the equipment's listing.

If a supply-side connection on the busbars is the preferred (or only) interconnection possibility, the options are limited for a *Code*-compliant installation. To use the existing equipment, a third-party field evaluation would be required to establish that the new configurations meets the listing agency's requirements. While this may work for a commercial installation's economics, this typically won't fit into a residential installation budget. Replacing the main service panel is very likely to be less expensive.

A different option, if allowed by the utility, is to use a new meter connection such as the ConnectDER (connectder.com; see "Methods" in *HP167*). This product is an interconnection collar that is placed between the meter and the meter socket. This is an easy and straightforward method for interconnection, if the utility allows it. This product can be a tough sell to many utilities as they often aren't willing to have field-installed components in their meter bases. So far Green Mountain Power in Vermont, the Orlando Utilities Commission, and Rocky Mountain Power in Utah have approved the ConnectDER, and this list will likely continue to grow. San Diego Gas & Electric offers a similar product, the Renewable Meter Adapter, but it can only be sold and installed by the utility within their territory.

Load-Side Connection in a Center-Fed Panel

Another interconnection strategy that has been gaining attention is a load-side connection in a center-fed panel. Here, the main breaker is located in the center of a busbar and there are loads on either side of the panel. This situation has proven to be difficult for AHJs to interpret under the 705.12(D) rules, which allow for 120% loading of the busbar when the power sources are located at opposite ends of the busbar. For a center-fed panel, what is considered the opposite end?

Some jurisdictions have taken the stance that there is not a legitimate opposite end, which rules out the use of center-fed panels for PV interconnections. In some regions, such as a large portion of California where these panels are common, it's an obstacle to integrating PV systems. Section 705.12(D)(2)(3)(d) of the 2014 *NEC* provides an allowance for connections to center-fed panels "where designed under engineering supervision that includes fault studies and busbar load calculations." This connection is technically possible, although it can still be difficult to satisfy the AHJ due to the preconceived notion of such interconnections being dangerous or if they don't have enough information about the equipment to feel comfortable with the method.

The result has been the replacement of service panels with new top- or bottom-fed panels, even though the original panels were functioning properly. Recently, a Tentative Interim Amendment (TIA) to the 2014 *NEC* was written, providing an amendment into the 2014 *Code* that duplicates language from an approved revision to the 2017 *Code*. This TIA would add a Section 705.12(D)(2)(3)(e): "A connection at either end, but not both ends, of a center-fed panel board in dwellings shall be permitted where the sum of 125 percent of the power source(s) output-circuit current and the rating of the overcurrent device protecting the busbar does not exceed 120 percent of the current rating of the busbar."

At this time of writing, the TIA is still open for public comment and has not been formally accepted into the *Code*. If it is accepted, it should help alleviate the issues seen with load-side connections in center-fed panels. Information on acceptance of the TIAs can be found on the NFPA's website (nfpa.org). For those still working under 2011 *Code*, this will require your AHJ to recognize the changes coming and allow the application.

Interconnection issues can quickly turn what appears to be a relatively easy installation into a nightmare. By being able to identify these commonly encountered problems, you can save time up-front. Most installations still have options for making the final connection, you just need to be able to identify them and work through them with your AHJ beforehand.


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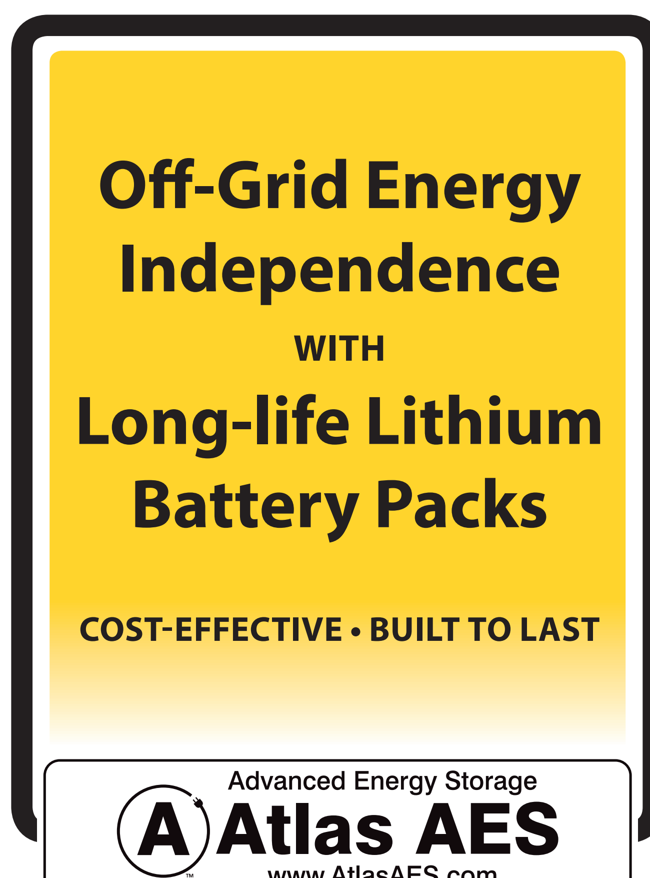
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Hot Tamale!

by Kathleen Jarschke-Schultze

My husband Bob-O and I are ever in search of the sweetest non-hybrid eating corn. Last year, I grew three different varieties of corn. Two were open-pollinated sweet corn. This season, we are growing the True Gold variety from Peace Seeds. But it is a third corn variety that continues to give us pleasure long after the summer sun has parted.

Painted Mountain

I got my Painted Mountain (PM) corn seed from our friend Ernie. He had been growing this multicolored open-pollinated corn and saving seed for years. This corn variety was developed in Montana from heirloom varieties grown by northern Native Americans. PM can grow in colder elevations with shorter growing seasons. It is also drought-tolerant, which works for our climate.

This corn can be eaten fresh, if picked when the ears are small and the kernels are still white. Ernie ground the dried kernels into flour. I have also favored drying the mature cobs and using the corn for flour, cornmeal, and polenta. The only difference between the three is how fine you grind.

I tried to make tortillas. I used the dried ground corn, and mixed it with a little water and salt to make a dough. I purchased a classic cast-iron tortilla press at a local bodega. After making the egg-sized balls of dough, I pressed each one flat and gently laid each tortilla on a hot griddle. After flipping the tortillas after a minute or two, we spread them with butter and ate them still hot. They tasted great! However, when we tried to fold a tortilla around any filling, they just cracked apart. We were limited to making tostadas and quesadillas—they were good, but not what I had intended.

Flat Tortilla

I was visiting my sister near Concow, California, when I picked up a magazine showcasing local attractions. To my delight, I found an article by a woman, Jennifer Greene, whose family runs Windbourne Farm, a diverse organic, biodynamic family farm. They sell their produce at the local farmers market and various buying clubs. One of the drying corns they grow is Painted Mountain (PM).

Jennifer did a lot of research, trials, and techniques on processing the dried PM corn. She now makes homemade tortillas to sell to an eager clientele. With some added Internet research, along with her tips and tricks, I was ready to try again.

Lime Time

I began the days-long process to make the nixtamal, the corn dough used for tortillas and tamales. On the first evening, I mixed 1/4 cup of pickling lime with 10 cups of simmering water in a stainless steel, 2-gallon stockpot. I turned off the heat, stirred the solution well, covered the pot with a lid, and left it overnight to settle the lime solids to the bottom. Pickling lime is caustic and great care must be taken when handling. Rinse any lime solution that touches your skin with cold water. The lime water has to be in a stainless steel or enameled pot. Use a wooden or other nonreactive spoon to stir.

In the morning, I used a paper coffee filter and a nonreactive mesh strainer to transfer and filter the lime water into a 1-gallon stainless steel pot. I added two cups of my dried Painted Mountain corn kernels. Covering the pot, I let the corn soak until the next morning.

The next step is tricky. You have to cook the kernels in the lime water for two or more hours, until they are completely saturated. The cooking temperature needs to stay at 190°F, or as close as you can get, the whole time.

My induction cooktop was well-suited to maintaining this temperature. In the spring, our PV, wind, and microhydro

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systems are all producing electricity, so having enough energy to run an induction burner was not a problem. My heavy steel pot was ideal for the induction plate.

After two hours, I began checking a few kernels at a time to see if they were cooked through. I would spoon up a few kernels with as little lime water as possible, drop the corn into a small bowl, fill with cold water. and swish it around with my finger. I would then rinse the kernels in my hand. You can bite the kernels in half to see how far in they have cooked. When 80% of the test kernels are done, you can stop cooking.

After, I took the pot to the sink and ran cold water into it to dilute the lime water. I poured off that water and refilled the pot with cold, clean water, and repeated that. I filled the pot one more time and then reached into the pot to rub the skins off the kernels. I then transferred the kernels by the handful to a large bowl. Most of the skins and nibs will stay behind. Some people soak the kernels for five or 10 minutes for a final rinse. The corn is now hominy.

Nixtamal

Nixtamalization enhances the nutritional value of the corn and allows it to be formed into dough. The kernels are ground while they are still wet. Jennifer bought a large electric grinder from Mexico specifically for grinding nixtamalized corn.

What excited me was that she said that the old Corona hand-crank mills were designed just for grinding limed corn into nixtamal.

Every hippie I know has an old Corona mill. They were "de riguer" for the back-to-the-lander homestead. Although we hadn't used ours in years, I knew right where it was.

Before the hominy could dry, I ground it all through the hand-crank mill. I now had nixtamal dough. I divided it and placed a wrapped half in the refrigerator. That night, I made tortillas again, rolling rounds as big as golf balls before putting each through the tortilla press. I used two halves of a plastic bag to keep the tortillas from sticking to the press.

These tortillas had that wonderful corn smell and taste. I was able to press these thinner so that a few steam bubbles rose on the top after placing them on the griddle. They just held together better when flipping and eating. They still cracked when folded in half, but that's the nature of a corn tortilla.

Hot Tamales

I still had half of my fresh nixtamal to experiment with. More Internet research on tamale dough, and I was ready. I beat lard, salt, and baking powder by hand until fluffy. I mixed in the nixtamal in little bits, working the mixture together. I added a little broth to get the consistency of thick hummus. I was rewarded with a masa (dough) that floated when a bit was dropped into cold water.

I soaked corn husks overnight to make them pliable, and prepared two fillings. In the first, I used Anaheim chilies, kalamata olives, and pepper jack cheese. The second filling was for a dessert tamale—a mixture of coconut, dried cranberries, dried blueberries, cream, and a little sugar.

I smeared a 1/4-inch-thick layer of masa on the corn husk and figured out how to roll it all around the filling—but tying the tamale with torn strips of husk eluded me. I used cotton kitchen string to bind them.

I layered the tamales in a steamer and steamed them for three hours. They were done when the masa was firm and the tamale was heated through.

Were they the best we ever had? No—but I have eaten some really great tamales. I have to say that the corny, spicy, and the savory and sweet flavors were enhanced by the fact that we were eating the food that we grew.


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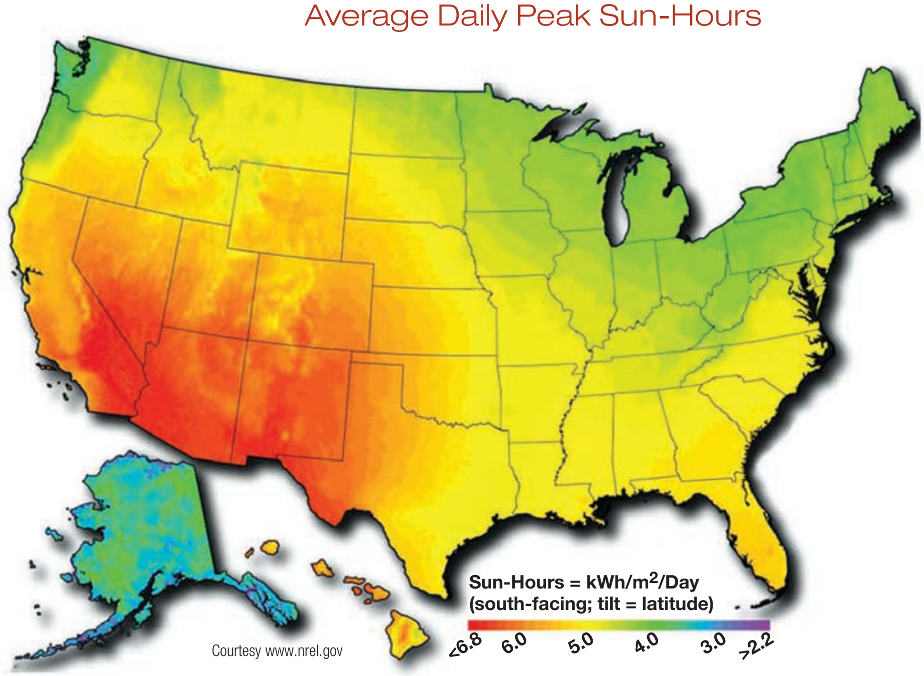
Peak Sun-Hours

A reader writes, "The sun comes over the top of a ridge in the morning at about 8 a.m. and sets at about 8 p.m in Ocean View, Hawaii—12 hours of usable light. So I'm confused when some PV system users claim that there are only 4.3 to 5.2 hours of "available light." Is this due to the fact that their modules are fixed in place? What else may be the cause?"

The daylight you are witnessing ("12 hours of usable light") and the available sun-hours for solar energy are indeed different. For making electricity, we use the way solar-electric modules work, and how they are tested and rated, to help us calculate what our site's solar resource (solar irradiance) will provide.

Because the sunlight has to go through more atmosphere, morning and afternoon sun is less intense (lower irradiance) than clear sun at solar noon. To plan for solar generation, we consider how modules are tested for maximum output—at an irradiance of 1,000 watts per meter squared (W/m^2)—and estimate how much of that intensity of irradiance is provided to a site throughout the day. We calculate the periods of low insolation and translate those numbers into the equivalent of 1,000 Wh/m^2, what we call peak sun-hours (1 peak sun-hour equals 1 kWh/m^2/day). The site's total peak sun-hours give us a multiplier for calculating what a *fixed* array will generate at that site over the day (for example, 5 kWh/m2/day = 5 peak sun-hours). Peak sun-hours are not a casual observation or timing of sunshine on your site; they are a scientifically measured unit of total solar energy available at a specific orientation and tilt angle. The peak sun-hour values account for all factors, including the ever-changing hours of sun each day and cloudy weather throughout the year, for the location at which the information is gathered.



A solar resource map shows kWh/m^2/day, or the number of peak sun-hours per day available, averaged over the course of the year for various regions.

The National Renewable Energy Laboratory supplies peak sun-hour data for locations throughout the United States, which assists in planning solar projects. To find the data for a specific site, you can use the NREL PVWatts calculator found at pvwatts.nrel.gov. Put in your location on the calculator and follow the simple instructions to find monthly peak sun-hours data and how much energy your proposed array would generate.

The peak sun-hour range of daily irradiance that the "solar users" referred to (4.3 to 5.2) reflects the difference during different months of the year. Peak sun-hours vary, and are usually greatest in the summer months and fewest in the winter. NREL provides the average monthly peak sun-hour values, along with an annual average.

The great advantage of being able to use the NREL data and calculator is that the numbers at NREL have been generated by irradiance measurements at sites in the vicinity of your site, and therefore take into consideration variances due to cloud cover and other site-specific solar effects. These numbers are assuming unshaded access to the path that the sun takes across the sky (the "solar window"). Shading effects must be measured and included in the calculations to provide an accurate assessment of generation potential. A Solar Pathfinder can be used to accurately determine a site's shading elements and calculate their effect on the available peak sun-hours of that site.

—Christopher LaForge