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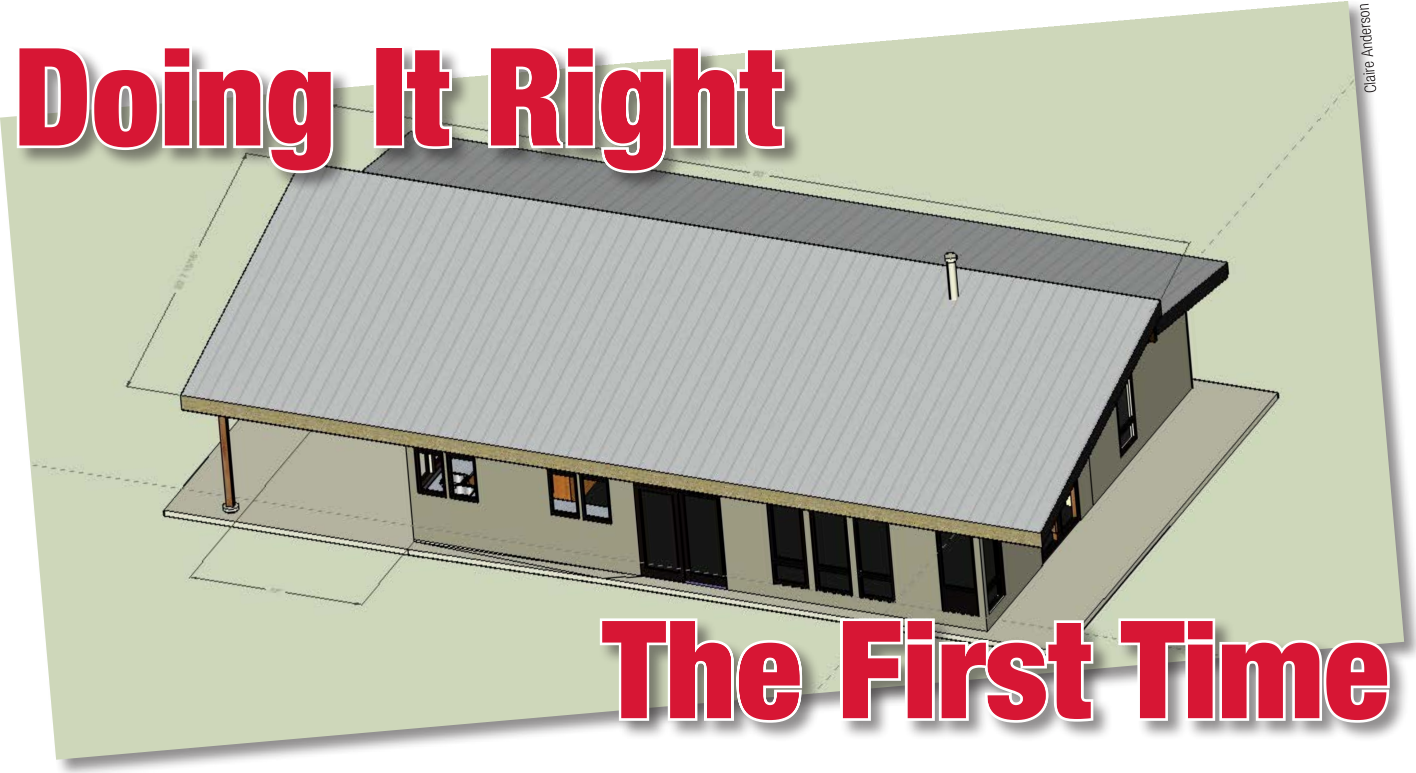
Doing It Right The First Time



There's wisdom in the old saying, "Poor folks have to do it right the first time, because they can't afford to do it again," and it can be applied to our energy dilemmas. Too often, we see new buildings going up without much thought about energy. As energy prices and environmental consciousness rise, we are seeing some improvement in the building industry. But still, most new buildings in North America are both energy hogs and net energy users, instead of using energy wisely and producing it on-site.

It is possible to design most buildings to be "zero energy"—to make all the energy they use. This means a focus on the quality of the building envelope—both its insulation and air sealing—which leads to low heating and cooling energy use. The type and size of the heating system is next, and passive solar design should be the first option to consider for some or all of a building's heating needs. Beyond that, a renewable energy rock star is the ductless minisplit heat pump, which uses 1 kWh of electricity to pump 3 to 4 kWh of ambient heat (and cooling in the summer) into a building.

Designing with all LED lighting and daylighting with judicious placement of windows and solar tubes can bring down lighting costs dramatically. A focus on appliance and other load efficiencies combined with user education and behavior modification can trim the energy load even further.

Once the up-front building design is an energy sipper, the appliances and heat pumps can use renewable electricity, most commonly PV-generated energy, and perhaps wind and hydro where appropriate. Solar hot water, biomass, and other renewable technologies can help, too.

So with wise design, building, and installation practices, we *can* have homes that are powered with the energy produced on-site, and they can be low-impact and low-waste. Unfortunately, most of us live and work in homes and businesses that were built without taking advantage of these strategies. How we apply our energy and environmental smarts and hearts is more complicated and expensive when retrofitting.

Sometimes it's hard to make it pencil out when poor energy decisions were made in the past. We might, for example, have difficulty upgrading the wall insulation in our homes without major remodeling. But often we can easily improve ceiling or roof insulation, and, sometimes, floor insulation.

Easier energy retrofits for homes and businesses include changing to more efficient lighting; eliminating phantom loads; and changing a few human habits. Bigger things (meaning more difficult and expensive, but high benefit) include switching to a minisplit heat pump and installing solar electricity.

While a retrofit won't usually get the performance we could get by doing it right the first time, we can make a huge dent in our energy gluttony, and make it easier to power our buildings with clean renewable energy.

—Ian Woofenden, for the *Home Power* crew

Think About It...

"In a consumer society, contentment is a radical proposition. Recognizing abundance rather than scarcity undermines an economy that thrives by creating unmet desires. Gratitude cultivates an ethic of fullness, while the economy cultivates emptiness."

—*Braiding Sweetgrass* by Robin Wall Kimmerer

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Main Features

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On the Cover

Brett and Kira Belan converted their VW bus to a PV-powered EV, loaded up the kids, and then road-tripped down the Pacific coast, powered by sunshine.

Photo courtesy Kim Brammer/Monterey Bay Virtual Tours

Photos: Courtesy Kim Brammer/Monterey Bay Virtual Tours; ©istockphoto.com/yarn & comzeal; ©istockphoto.com/pixel107

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Photos: Ben Root; courtesy Magnum Energy; courtesy Trojan Battery

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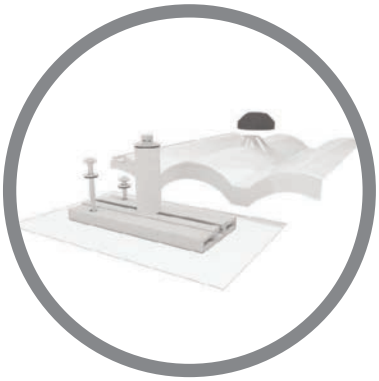

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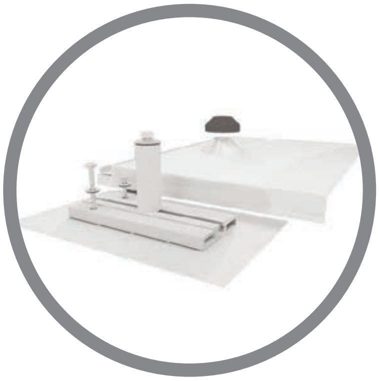

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contributors

this issue's experts

In 1977, **Windy Dankoff** started a business in New Mexico to supply wind power to off-grid homes. In 1980, he began to use PV systems for homes and well pumps. Eventually, his company, Dankoff Solar Pumps, became a worldwide supplier. Windy credits his success to taking a whole-system approach to energy efficiency. He retired in 2005 and continues to write, teach, and explore.

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 systems. His company, Buckville Energy Consulting, is an accredited continuing education provider for NABCEP, IREC, and ISPQ.

Steven J. Strong is the president of Solar Design Associates, Inc., an engineering and architectural firm dedicated to environmentally responsive buildings and the engineering and integration of renewable energy systems to power them. Over the past four decades, he's earned the firm an international reputation for pioneering the integration of renewable energy systems with environmentally responsive building design.

Steve Dyck is the president of Guelph Solar. "The sun shines for everyone—it is a very democratic power system," he says. "I am committed to a fair and just society, and installing solar in my community is an expression of this hope." Steve enjoys politics, is active in the Citizens Climate Lobby, and was a candidate in the 2011 provincial election. He enjoys spending time with his family and giving back to the community by being involved with Guelph Green Drinks, the Bridges Out of Poverty, and FairVote. Steve founded Guelph Solar in 2009 after a fulfilling career in the the automotive industry.

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

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

Kira and Brett Belan have been talking about building an electric vehicle since they first met, and their PV-powered electric Volkswagen bus conversion is the culmination of that dream. Drawing on her homeschooling, hands-on background, Kira helped build the kitchen, sewed the tent for the popup, and put in the floor. With a degree in mechanical engineering, Brett tackled the design and implementation of the van's mechanical system, from the electric motor to the PV system and batteries.

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.

Sean Chastain is a project manager at Yes Solar Solutions of Cary, North Carolina. A graduate of North Carolina State University (NCSU), he holds a NABCEP certification for PV installation and has completed courses through Solar Energy International, Imagine Solar, Tesla, and the Solar Center at NCSU for PV. Sean is a U.S. Army veteran and served in Operation Enduring Freedom in Afghanistan.

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. Justine has been an instructor with Solar Energy International since 1998, and leads PV design courses. She previously worked with the National Renewable Energy Laboratory (NREL) in the Solar Radiation Resource Assessment Division. After leaving NREL, Justine installed PV systems with EV Solar Products in Chino Valley, Arizona.

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

Contact Our Contributors

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Trojan J-200RE

Flooded Lead-Acid battery

Courtesy Trojan

Trojan Battery (trojanbattery.com) is manufacturing the J-200RE, a 12 V, 200 Ah flooded lead-acid deep-cycle battery. Trojan uses a carbon additive to reduce the effects of operating at a partial state of charge, a situation common to batteries used in off-grid systems that can lead to reduced battery longevity. Cycle life is stated at 1,600 cycles (at a 50% depth of discharge). These batteries come with a five-year warranty.

—Justine Sanchez

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Courtesy Sensata Technologies

Magnum Energy PT-100 MPPT Charge Controller

Magnum Energy (sensatapower.com) released its 100 A MPPT charge controller that automatically detects system voltage and is compatible with 12, 24, and 48 V battery banks. The PT-100 can be used with a PV array up to 6,600 W, and has a 200 VDC maximum input voltage. A battery temperature sensor is included. Ground-fault detection and interruption (GFDI) and an arc-fault circuit interrupter (AFCI) are integrated into the PT-100. A five-year labor-and-parts warranty is included.

—Justine Sanchez

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Utility Charges

Regarding the *HP175* "From the Crew" piece entitled "The Grid-Tied PV System Compensation Shake-Up": The electric utilities' claim that "customers without PV systems end up contributing more than their fair share for the cost of maintaining their grid" is a disingenuous argument.

That's like saying, "People who have jobs pay more than their fair share in taxes than unemployed people." Or to be more pointed, only in America could the rich people—who pay 86% of all income taxes—be accused of not paying their '"fair share" by people who don't pay any income taxes at all.

These "customers without PV systems" are so by choice—either due to the impractical nature of embracing PV (i.e., they are renters, have no practical sunlight available, etc.) or they simply cannot afford it. Perhaps the electric utilities can help these customers by giving them a substantial reduction in their rate.

And these are the same electric utilities that, in addition to charging for the electricity consumed, also gouge customers with "delivery charges," which always seems to be more than the consumed charges.

So in summary, they bill me for:

- Power supply energy used
- Delivery/distribution charge
- Energy optimization charge
- LIEAF factor charge (whatever that is?!)
- "Other" delivery surcharges
- State sales tax

I have no doubt that worldwide there are thousands of clever people who are working on a practical way to harvest and use the free energy that engulfs us. Soon, there will be a practical and inexpensive way to experience the reality of "self-sufficiency is the greatest of all wealth," as aptly stated in your editorial. At that point, the greedy utilities will become irrelevant. I'm eagerly looking forward to that day.

Tom China • Ann Arbor, Michigan

The Power Grid: A Beautiful Thing

I have been a reader of *Home Power* and a big fan of renewable energy for many years. I have solar panels, a small wind generator, and small hydro system, all charging batteries at my house. Take it from me, batteries can be a huge pain to deal with. They are big, expensive, and require constant care. And in the end every battery will fail. I understand that in many cases batteries or a fossil fuel generator is the only choice. But many solar systems are tied directly to the power grid. What a great and awesome privilege it is to use the grid as a battery bank.

I have been an electric lineman for almost 24 years. I have a perfect understanding of how amazing the U.S. power grid is. A lot of people have no clue what it takes to make the power grid work. A lot of money, resources, and very hard work go on 24/7, 365 days a year, to make grid power happen. Think about life without the power grid—we would have no light, no heat, no A/C, no fresh food, no clean water, no internet, no smartphones, no stock market—and the list goes on and on. The off-grid folks would have no solar panels, deep-cycle batteries, gasoline, propane, and so on. Think about the amount of energy and nonrenewable resources it takes to make solar panels, deep-cycle batteries, wind turbines, and a coal or natural gas power plant. Every form of energy requires some form of nonrenewable resource. Hydro is the best thing we have. Once it is built, it can provide carbon-free, 24/7 base-load power; no batteries needed. One day, I think we will wish we had built more hydro power plants. The West is drying up, and we will have wished we saved as much water as possible. More dams in the right places might be a good thing.

One day, I hope to install a grid-tied PV system at my house and use the grid as my battery bank. I will be more than happy to pay whatever my local power company charges to hook the system to the grid. I know that will be a way better deal than dealing with the nightmare and expense of batteries. And I will gladly take whatever payback they give me. My money will go to help maintain the grid, to keep it at its perfect 60-cycle 120-volt AC. As more and more consumer generation hooks up to the grid, it will be harder to maintain it. In Texas, for example, backup generation cannot come online fast enough when the wind stops as wind farms serve hundreds of megawatts of load on the grid. This causes the grid to become unstable and shut down, causing a huge power outage. It takes awhile to get it all back up and running.

The power grid has a hard time dealing with intermittent consumer generation. But it can handle some. That's why we need to pay our share to help maintain the grid. I think before consumer generation becomes a problem for the grid we will find a way to make it all work together, but it will cost us. The power grid needs to evolve and change to deal with large intermittent sources of energy. And that will not be cheap. But I think it is possible. The U.S. power grid is the single largest, most impressive machine on the planet and there is nothing else like it—and we need to keep it that way.

Dan Oberosler • Crested Butte, Colorado

Courtesy Steve Lyon, www.flickr.com/photos/chicanerii/8233428545/in/photostream

Solar EV

In 2014, we installed a 6 kW PV system on a homebuilt rack in our backyard (see *HP164*). This past April, we purchased a used 2013 Nissan LEAF EV. We've put almost 7,500 miles on the car in six months and just love driving it. So now, rather than pumping all that extra PV-generated electricity back onto the electric grid, approximately 280 kWh per month go into the LEAF.

The LEAF replaced an old ICE vehicle, which averaged about 35 mpg. Since we're making double the price of electricity (present electricity cost = $0.13 per kWh) by using it in the LEAF versus sending it back into the grid, our PV system's return on investment actually improves! Here's how I calculate this result (based on five months of our actual LEAF's efficiency, as well as local average regular gasoline prices):

Equivalent Electricity Cost = (Cost of Gasoline ÷ ICE Car Fuel Efficiency) × LEAF Efficiency

Equivalent Electricity Cost = ($2.30/gal. ÷ 35 miles/gal.) × 4.1 miles/kWh = $0.27/kWh

The higher gasoline prices go, the faster our PV system pays for itself.

Willi Hampel • via homepower.com

Address Efficiency First—Then Tackle PV

This energy conundrum we find ourselves in makes me chortle. I live in Alberta—the Canadian version of Texas, just smaller. We are in a battle with OPEC and, of course, the United States, for energy to market. That said, I've been involved with solar—including net-zero and Passive House programs—for the past five years.

During that time, I've found that folks who want to take their existing stick-built home to net-zero energy seem to feel that if they install a PV system (grid-tied, of course), they have done their part to working toward net-zero.

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However, when they find out that the PV system is unable to offset their winter loads, reality sets in. Without addressing their consumption…well, the laundry list gets very big very quickly in a conventional stick-built home that's built to the code minimum.

I agree with Pete Gruendeman in his recent letter (*HP175*) about addressing the envelope first. I advise anyone to start first with the shell of the home. Insulate, seal, and be sure to provide proper ventilation to the newly sealed-up home. Second, I advise them to upgrade all windows and doors to triple-pane, thermally broken, multipoint turn-and-tilt systems. I also advise them to reduce the size and number of *all* north-facing windows to reduce exposure. Most of all, this change helps to improve the whole-wall R-value.

I then advise people to examine their appliances and, if necessary, upgrade to more than "energy-wise" appliances, with the overall goal of reducing their carbon footprint and lowering energy consumption. Next, I suggest that they monitor their consumption habits for a month. At the end of that month, a review helps determine energy consumption habits. Then we examine what can be addressed/changed to reduce the load. It's only then that a PV system is discussed and sized to the new reduced energy usage.

Steven Bell • Calgary, Alberta

PV Canopy

It was very encouraging to read the story on the PV canopy for a bocce court in *HP175* and see a financial planner buying into all of this. Financial viability is the ultimate answer for any renewable energy naysayers.

Our house (and a million others) is in a similar circumstance, and some of us are incorporating a strategy for our cars, too. This project is in a perfect position to capitalize on battery storage technology, but personally I think the bocce court owner is a year ahead of what he will need: a great big lithium-ion battery to store at least 40 kWh of electricity. The bigger, the better. However, that costs anywhere from $150 to $450 per kWh right now. Additionally (I'm sure he's done the calculations already), he'll have to assess how his driving habits or how many times per week he'll need to charge the car. Traveling 200 miles per week in a Chevy Bolt requires an 80% charge once per week, which would be about 50 kWh of electricity.

A system would have to generate—not use, but save in its battery—7 or 8 kWh per day for that charge. The beauty of the system—once it's worked out—is that no other equipment besides the battery (and a charger) is needed and he'll be using almost every watt-hour his PV array is making. That's very good and worth imitating.

I have roof challenges, too. Our roof is 45 years old. I'm a general contractor who cut his teeth fixing snow-load roofs—no way will I be putting any modules up there. But we live in the low desert, and shade is the name of the game, so there are two good locations on our lot for a shaded, power- and food-producing area. It's California, so I might grow a little medicine, too…

Robert Pollock • via homepower.com

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Designing a Solar-Heated Spa Tub

I live in Washington State and want to install a solar water heater to directly heat a spa tub. Can you guide me to some solutions?

Fernando Lopez • via homepower.com

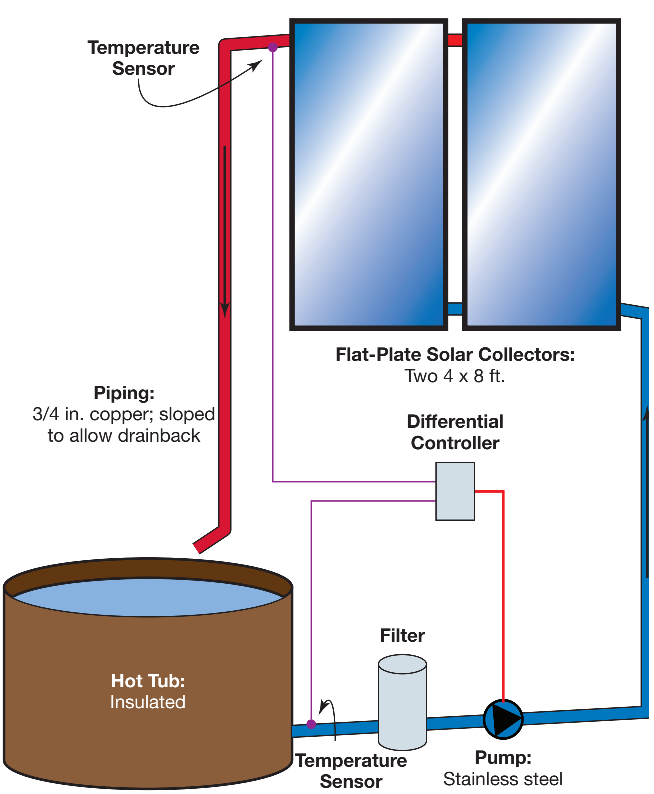
Soaking in a solar-heated spa tub is a great way to enjoy the sun and water together. You can relax, while using nonpolluting energy from the sun.

In most climates, the best design to serve a hot tub is a drainback solar water heating (SWH) system because drainback systems have freeze and overheat protection built into the design. Drainback systems are protected from frost damage by draining the heat-transfer fluid out of the exposed collectors and lines when the sun isn't heating it. All the lines must be sloped so the heat-transfer fluid can drain into the freeze-protected area once the solar pump is off. In the summer, a drainback system with flat-plate collectors and copper heat-transfer lines will withstand the excess heat that builds up when your hot tub has reached its maximum temperature.

For spa tubs, the storage is the tub itself, which will lose heat when temperatures outside the tub are lower than the tub water temperature. To slow the heat loss, use a well-insulated tub with an insulated cover.

If you are OK with the tub's temperature fluctuating depending on the amount of sun and the season, then one 4-by-8-foot solar collector is a good start. In moderate conditions, a typical hot tub might require 300 kWh per month (10 kWh per day) to heat. With lower temperatures, such as those encountered during the winter, it could require double that amount.

Basic Solar-Heated Hot Tub System



You can look up the estimated energy produced by a solar thermal collector at the Solar Rating and Certification Corporation's website (solar-rating.org). One typical 4-by-8-foot flat-plate collector could produce about 4 to 15 kWh of heat on a sunny day, depending on the collector, time of year, and ambient temperature. Where you live in Washington, during fall, winter, and spring months (and depending on how well-insulated your tub is and what temperature you desire), you will likely need a second collector, or a source of backup heat could be added.

It is important that the water pH (acidity) not be allowed to drop below 7, or copper can be dissolved and this can result in green stains (even make your hair turn green—really!). A filter is needed to protect the pump and collector from tub debris. Use copper lines at the collector, since PEX lines will not survive the high temperatures coming out of the collector.

A key component of any SWH system is a differential temperature controller—common manufacturers include Goldline, Resol, Steca, and ArtTec (for PV-direct pumping). The controller will compare the solar collector's temperature to the tub water's temperature. When the temperature at the collector is higher than the tub water, the solar controller will turn on the circulation pump. Once the tub water reaches the set-point temperature, the controller will turn the pump off. This also is a protective measure to prevent someone from being scalded.

Evacuated-tube solar collectors might be seen as an attractive solution because they have lower heat loss in winter. However, installing them as part of a drainback system may void their warranty. That means more complexity and expense—you'd need a heat exchanger, glycol fluid, and a heat dump (this could be as simple as leaving the spa cover off) to keep the tubes and tub from overheating.

Steve Dyck • Guelph Solar Mechanical

Aesthetic PV for Historic Buildings

I'm a long-time subscriber, and have been interested in renewable energy since the 1970s. I own an historic house and barn, and I've tried to keep them both looking like they did 260 years ago. Although the cost of a PV installation is not a big obstacle, I don't want to disturb the appearance of the barn or house with a PV array—and don't want to disturb the surrounding grounds with an array.

I have asphalt-shingle roofs that have the general appearance of slate from the ground. Can you advise me as to the kind of PV modules that would complement the appearance of these roofs?

Lawrence Friedhoff • via homepower.com

You have a problem that might be best solved by investing in "green power" or a community solar project in your area. The concept of a PV shingle or tile may be attractive to the uninitiated, but it is a risky investment. Here's why.

Each shingle is a small PV module that has to be connected electrically in series to reach the DC voltage needed by the power electronics. For example, each of CertainTeed's PV shingles produces about 7 volts. The typical DC input voltage for residential and small commercial inverters is 375 to 500 VDC. That means more than 50 shingles need to be wired in series. This configuration requires long strings of plug-together module-to-module connections that are all hidden beneath the finished roof—and difficult to access. When one module or its connection(s) fail, all the modules in the string go out—just like a set of cheap holiday lights. A service tech has no easy

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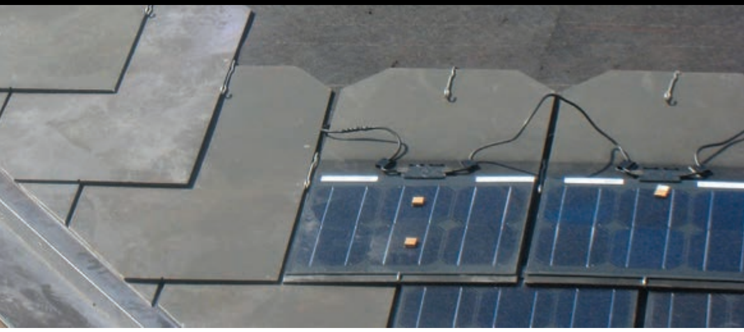

Courtesy Atlantis energy

PV shingles might look good, but present challenges.

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way of knowing which shingle is defective. A big portion of the roof often needs to be taken apart, and all components tested. Then, if the owner is in luck and extra replacement shingles are available, the array may be able to be reassembled.

If there is an electrical arc caused by a faulty shingle-to-shingle connection, it could start a fire in combustible tarpaper and wood roof sheathing. Electrical arcs in DC systems do not extinguish themselves—they may get bigger. The arc's high temperature causes the affected opposing current-carrying components to erode metal, shrinking away, and making the arc progressively larger.

Historically, PV shingles have been nailed (or screwed) into place as the marketers wanted to entice roofers to be installers. However, roofers are not allowed to install solar-electric systems in many jurisdictions (such as Massachusetts), so an electrician will still be required.

The "new and improved" PV shingle from CertainTeed offers rated output of about 12 watts per square foot, whereas today's best single-crystalline modules offer about 20 watts per square foot. Since there is no back-surface convective airflow, the all-black shingles run hotter than conventional, meaning lowered efficiency and possibly shorter product life.

PV shingles have been a transitory product. How long will companies selling this product keep producing them? For example, after five years, Dow ceased manufacturing and distributing PV shingles. There is no long-term experience with the products and they may or may not last. Will the warranty be supported over the roughly three decades that a rooftop array should provide service? If the product is still available, will it be in the same form and electrical configuration to allow replacement? Even if PV shingles stand the test of time, the conventional asphalt roofing that typically surrounds them will need to be replaced at least once during the system's lifetime, so there will be additional expense in the labor involved in removing and reinstalling the shingles.

This is not an easy-to-accept answer—many people still believe that integrating PV and roofing will be a big step forward. But so far, the history of the industry has shown that the "bright idea" has not turned out well in practice (though there are some custom—read "expensive"—options out there that might be considered). Currently, there's no mass-produced integrated solution for retrofit PV. If the historic house has a black roof, using conventional black-on-black modules installed coplanar to the roof may offer an acceptable solution for some. Standard framed PV modules have been reliable and productive, and we know how to install them well for the long term. In your situation, where aesthetics are paramount, there may not be a "perfect" solution. For many people, the solution is to accept the beauty of a product that will produce clean electricity for 40 to 50 years.

Steven Strong • Solar Design Associates

Deep Well Pump

The AC pump that provides water for my livestock and house from a 325-foot-deep well is a 3/4 horsepower, 240 VAC model. I'd like to retain the system setup, but switch the pump to PV power.

Anne Ellis • via e-mail

Unfortunately, keeping your AC pump is not the most economical approach to solar pumping. A typical well pump (single-phase AC) requires a high starting surge, and therefore would need a substantial battery bank and inverter just to wake it up. Even then, its energy efficiency is low. Specially designed pumps, which run directly from a PV array, are used for most PV pumping applications. This direct-power system doesn't require a battery bank, but does need a storage tank large enough to hold four to 10 days' worth of water, depending on your climate. If the tank is elevated or located uphill from your watering application, it can supply water for animals and gardening by gravity flow. For a house, an additional pressure pump is normally required. For a solar-powered system, your home would require a battery so the pressure pump could work on-demand at any time of day.

The material cost of a solar-powered pumping system for a deep well ranges from about $3,000 to $15,000, not including a storage tank. Installation will be extra.

To determine the size and cost of a PV pumping system, contact an experienced supplier who can design a system based on your situation. Accurately estimating the depth to water in the well during pumping (dynamic level) may save you from purchasing a more powerful pump than is needed. Your well contractor may be able to help you with this. You must also estimate how much water you use daily, during both summer and winter. You may want to install a water meter to measure your usage. Then, knowing your location and climate, the material cost of a PV pump and PV array package can be determined.

Depending on the well water level, skilled homeowners may be able to install systems themselves. A solar pump system that pumps all day uses a smaller pump to meet daily requirements and can also use smaller-diameter pipe. This makes installation by hand feasible for depths less than 220 feet. For other systems, you will need professional help. But, beware—most well contractors aren't educated about PV pumping. Instead, contact a solar supplier who specializes in off-grid PV systems.

As in all applications of renewable energy, reducing consumption will save on the system's cost. Start with water conservation and recycling, then add storage and gravity flow. Not only will you have

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This solar-powered, deep-well water pumping system in New York State includes a 1,000-gallon storage tank.

Courtesy Roy Butler, Four Winds Renewable Energy

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a source of water during utility outages, but adding a solar pump will be more affordable. It will cost far less than trying to use your standard AC pump with a PV system.

Windy Dankoff • Founder, retired, Dankoff Solar Pumps

Submetering for a Guesthouse

I would like to install an inexpensive meter to record the electricity usage in a detached guesthouse, so I can equitably divide the bill between the main house and guesthouse tenant. The guesthouse has four circuits that are supplied from the main house.

Carl C. • Columbia, South Carolina

Monitoring the whole house with TED.

Courtesy The Energy Detective

There are many options for submetering individual circuits or groups of circuits. They generally fall into two categories—either directly measuring the energy by having it flow through the meter, or by using a current transformer (CT), a ring that surrounds a wire to measure the current without splicing into the wire.

Individual plug meters are an example of the first type. For larger loads or for metering whole buildings, kWh meters, just like your utility uses, which fit in meter sockets, are available refurbished for very reasonable prices—often for less than $50 for a meter and socket. The drawback is that they require wiring skills to insert into the circuit—usually done by an electrician, which can increase the overall cost significantly. They can also measure only a single line—if you have multiple circuits to measure, you need to run them all from a subpanel, and then meter the supply to the subpanel. It sounds like a utility-style kWh meter would meet your needs.

CT-based power meters vary widely in quality, price, and capabilities. Some can only measure one circuit, and some can measure dozens of them. Some are very accurate and some may be off by up to 20% at times. Many of them have online or web-based viewers, but some just have a display on the meter. They are usually easier to wire than utility-style kWh meters, though you still may want an electrician to do it because of hazardous voltages present when the electric panel is opened to install them.

A web search for "home energy use meter" reveals several options. You'll find meters that can measure only one or two circuits, or the house as a whole (by measuring the input circuit), which cost about $100. However, these may not measure voltage or power factor, which can introduce an error of 10% to 20% at times.

In the $200+ range, more accurate ones like TED (The Energy Detective), are available. Most of these measure only the whole house. Sense Labs is now offering their Sense home monitor that can identify common loads and differentiate them on the display—without having individual CTs on them.

Searching for "100-amp AC power meter" gives many choices for a $20 single-load monitor, useful for measuring a large load, such as an air conditioner or water heater that's too large to measure with a plug-based meter. These can measure either 120 VAC or 240 VAC circuits.

If you are a looking for a high-quality web-based meter that can be revenue-grade certified, the Egauge is my favorite. It can monitor up to 12 circuits, so it's ideal when you are trying monitor individual appliances, or individual rental units. The drawback for this is the price—starting at $600, before installation.

Zeke Yewdall • Mile Hi Solar

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A 1973 VW Conversion

by Brett Belan

Courtesy Kim Brammer, Monterey Bay Virtual Tours

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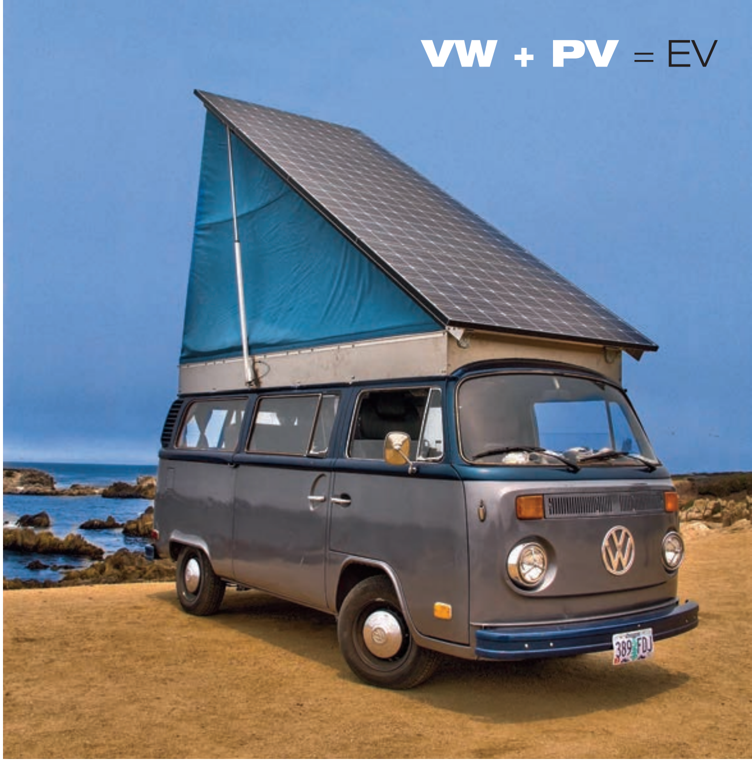
I've spent much of my life building cars. One of my earliest memories is sanding the wooden spokes on a 1926 Ford Model T. My teenage years found me hot-rodding early Camaros, Chevelles, and a 1932 Chevrolet. I have always enjoyed building motors. I went to engineering school, and worked for Ford Motor Co. as well as Jaguar Land Rover in England, but never found creative outlets for my motor-building passion.

Then I found electric motors, with their "clean" design and alternative fuel possibilities. This interest combined well with my enthusiasm for renewable energy—for the last 15 years, I've been passionate about off-grid power. I've designed and installed about 30 off-grid PV systems. I've also retrofitted some golf carts with PV modules. So by the time I was ready to build my electric vehicle (EV), I had it all planned—not only would I convert a gas-engine vehicle to electric, but I would add a PV system to supply the energy for traveling and off-grid camping.


Courtesy Kim Brammer, Monterey Bay Virtual Tours

Life in the Slow Lane

I chose the Volkswagen Transporter for its large roof surface, which could accommodate several PV modules on a tiltable rack. I spent many hours in the design phase to figure out how best to make a watertight installation. My wife Kira pieced together canvas to make a large tented area underneath the array—there's enough headroom to stand up. She also made a door with a screen and removable window for a rear exit.

The array consists of four 305-watt LG Solar modules, for 1,220 watts. One edge of the array is hinged in the front of the van, and actuators (one on each side) tilt the array up to 40°, creating a large space above the van. Being able to move the van allows positioning the array to receive great solar exposure. When we stop driving for the evening, we can orient the array to capture the evening sun. Facing the array east in the morning ensures that the array gets the best exposure at that time.

Four Drok DC/DC converters boost each module's voltage from 40 Voc to 50 Voc for better power transfer from the modules to the batteries. These converters are wired in series for about 200 Voc. The array generates 8 A total (at 150 V) into the battery. I can adjust the converter output voltage and manually power point track the modules.

Above: Using actuators, the PV array tilts up to 40° for optimal exposure. Underneath, a homemade bunk provides sleeping and storage.

Above: The charging port.

Our family has lived with a 1,200 W PV system for years, and we know how to use electrons wisely. Camping loads, such as our small Dometic fridge, a clamp-style work light with a 7 W compact fluorescent bulb, and a 1,200 W cooking element, also consume energy from the array. Other loads include a water pump under the sink and a swamp cooler. However, our daily camping load (about 800 watt-hours) isn't much compared to what the van uses for propulsion.

First step: The author removes the internal-combustion engine components and the fossil-fuel grime that goes with them.


Courtesy Brett & Kira Belan (3)

An 88-horsepower HEPVS AC51 motor is mated to the stock transmission with an adaptor plate from Canadian Electric Vehicles.

The VW needed more than just a power plant transplant to make it functional: the interior got an upgrade, too.

Twelve voltmeters on the dash measure each battery's voltage, an indicator of state of charge. The switches allow real-time control of various fans and certain controller functions.

The Batteries

Twelve Trojan T-1275 lead-acid batteries provide 150 Ah at a 20-hour rate. Since I load the batteries at a minimum of 50 A (at a discharging rate of C/3; up to C/2), I use about 80 Ah out of the batteries for an approximate 80% DOD, or 11,520 Wh (80 Ah times 144 V). The slower I discharge the batteries, though, the farther they take me. Finally, a good reason to slow down! Twelve Murata Power Solutions digital volt meters, one for each battery, alert me to any performance issues.

These batteries were selected for affordability. For three times the price, I could have installed some lithium iron phosphate batteries, but I'm trying to make a point about the economics of having a converted electric vehicle. I've spent a lot of time working with lead-acid batteries, and know how to maximize their life and performance.

The battery gasses are fan-driven from the battery box out past the motor. The battery posts are covered with rubber boots for each post. The solid copper wires give a good connection and rigidly solidify the pack, which is good for bumpy roads. The battery box is secured to the floor to survive full inversion of the vehicle. There is a liner at the bottom of the box to contain spills.

A reupholstered bench seat folds into a bed and hides the battery box.

Twelve Trojan T-1275 flooded lead-acid batteries in a custom enclosure provide energy for propulsion and coach appliances.

Courtesy Brett & Kira Belan (5)

DC-DC Converter

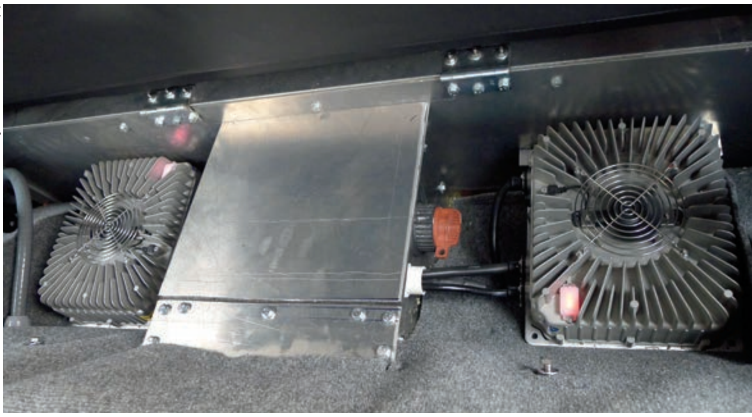
A MeanWell 12 V, 53 A DC-to-DC buck converter keeps the 12 V accessories operating in efficient isolation from the main pack.

Motor/Controller

I'm using an AC motor and 500 A, 144 V controller from Hi Performance Electric Vehicle Systems. At first I ordered the AC76, a larger motor with a lot of torque, but it had a misplaced winding and burned a black streak down one of the phase wires, making my maiden voyage disappointing. I swapped it for a smaller AC51 motor, which lightened the load by about 100 pounds, and it has more power than I need. I almost exclusively use the economy mode on the Curtis 1239-8501 AC motor controller. It keeps energy consumption to a minimum.

I will be boxing in the entire rear engine bay so none of the components back there will need individual weatherproofing. Just the motor will be exposed.

Courtesy Brett & Kira Belan (2)



Between the batteries and motor compartment hide the two ThunderStruck AC chargers and the main disconnect (center).

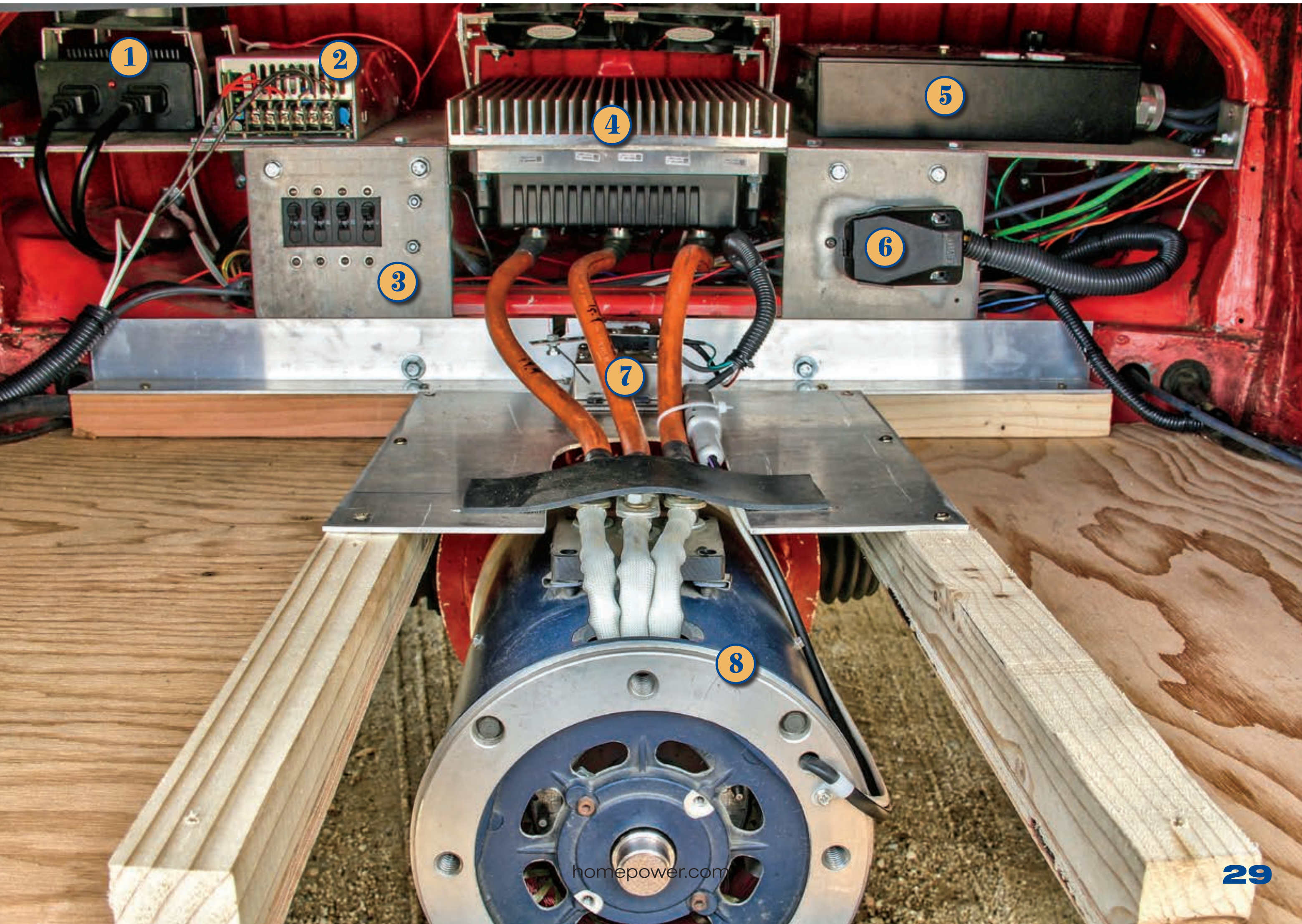
Inverter

The inverter is a 2 kW EV Enterprises Blue Flash, which inverts 144 VDC to 120 VAC quite efficiently without any magnetic component. We can cook, cool, and run my electric chain saw, which is great for prepping firewood for campfires.

Charging from the Grid

I have two ThunderStruck 2,500 W chargers. At 20 A each, a full battery recharge takes two hours and 20 minutes. Programming the chargers is a snap; I can create charging profiles for 110 VAC as well as 220 VAC at any current draw I choose.

In the "motor" compartment: 1. Inverter; 2. DC-DC converter; 3. DC breakers for (L to R) PV array, inverter, DC converter, AC chargers; 4. Curtis controller; 5. Control for AC chargers; 6. 240 VAC input; 7. Throttle control; 8. HPEVS AC51 motor.



Courtesy Brett & Kira Belan

A Spyglass meter for the Curtis motor controller displays amps, volts, rpm, and controller and motor temperatures.

Regenerative Braking

I use a small vacuum pump for the brake booster, which runs when 12 V key ignition is on. The brakes work nicely. The regenerative brake adds stopping control for the heavy VW. Regeneration engages the moment I take my foot off the accelerator. I recently took the fully charged van up a mountain, climbing a steep hill for 18 miles. I recharged with PV at the top of the mountain, then traveled another 20 or so miles on the plateau. By the time I made it back down the mountain, the van's batteries had a full charge from a half hour of regenerative braking—I was able to put 20 miles of range back into the pack on the downgrade.

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VW Transporter: EV Conversion Costs

Item	Cost
HPEVS AC51 motor & Curtis 144 V controller	$5,000
VW Transporter, 1973	4,000
Replacement seats	4,000
12 Trojan T-1275 plus batteries	2,800
4 LG Solar NeON PV modules, 305 W	1,600
Battery box, custom	1,000
PV rack, custom	1,000
Misc. electrical (wire, conduit, etc.)	1,000
2 ThunderStruck Motors TSMchargers, 2.5 kW	1,000
Canadian Electric Vehicles VW adapter & coupler	825
Canvas fabric, hook & loop closures, screen, etc.	500
Misc. hardware	500
12 Murata Power Solutions digital battery meters	480
Vacuum pump for brakes	425
Foam mattresses	250
Kitchen sink, pump, jugs, faucet, plumbing, wood	250
2 Thompson linear actuators	250
EV Enterprises Blue Flash 2 kW inverter	200
Mean Well DC/DC converter, 12 V, 53 A	150
4 DC-DC 600 W voltage boosters	100
4 Cooling fans	100
4 Breakers	80
Total	$25,510

Tech Specs

Overview

Project name: Belan PV EV

System type: Battery-based solar-electric (for EV charging & auxiliary appliances)

Installer: Brett Belan/Apparent Energy

Date commissioned: 2016

Home base: Ashland, Oregon

Photovoltaics

Modules: Four LG Solar MonoX NeOn LG305N1C-B3, 305 W STC, 32.1 Vmp, 9.5 Imp, 40 Voc, 10.10 Isc

Array: One four-module series string, 1,220 W STC total, with DC-DC converters string outputs: 150 Vmp, 8 Imp

Array combiner box: Drok DC-DC converters with 20 A fuse, located behind custom fan-cooled panel

Array disconnect: 15 A breaker

Array installation: Custom rack with adjustable tilt

Energy Storage

Batteries: 12 Trojan T-1275, 12 VDC nominal, 150 Ah at 20-hour rate, flooded lead-acid

Battery bank: 144 VDC nominal, 150 Ah total

Battery/inverter disconnect: 25 A DC breaker

Balance of System

Charge controller: JLD 404 meter with internal relay. This relay activates depending on voltage and amperage. One relay activates the ventilation fan in the battery box; relay No. 2 is a solid-state power relay activated by a smaller relay in the JLD404 EV meter.

Inverter: EV Enterprises Blue Flash, 2,000 W continuous, 4,000 W surge, 144 VDC nominal input, 110 VAC output

Battery metering: JLD404 meter for EV, 12 Murata volt meters—one per battery

AC charger: 2 Thunderstruck 2.5 kW chargers

EV Drive System

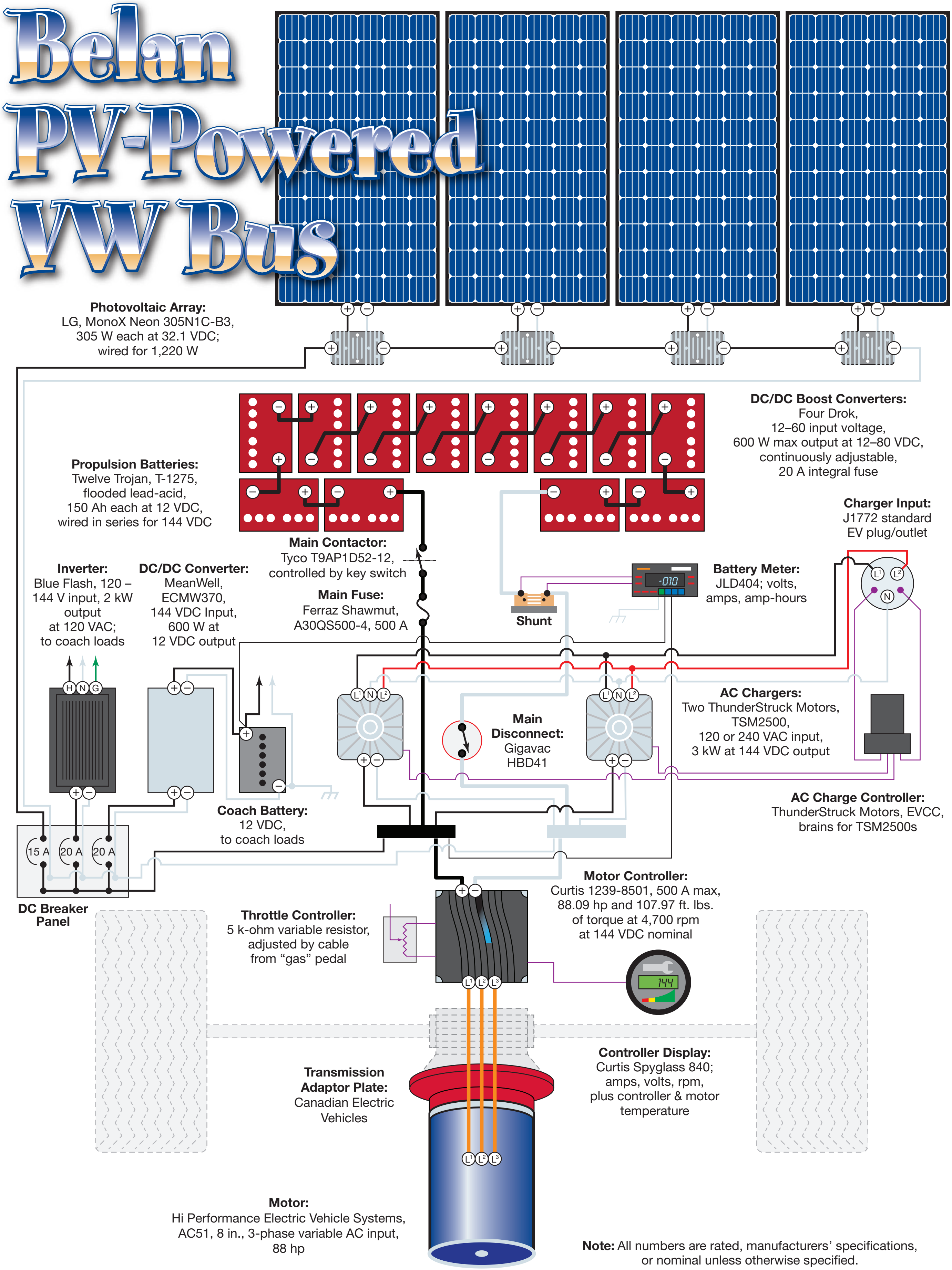
Controller: Curtis 1239-8501

Motor: Hi Performance AC51

Motor/transmission adaptor plate: Canadian Electric Vehicles Ltd.

Converter for 12 V Accessories: Mean Well 53 A DC/DC converter, 144 V input, 12 V output

Belan PV-Powered VW Bus



Note: All numbers are rated, manufacturers’ specifications, or nominal unless otherwise specified.

Solar-Powered Road Trip

Above: EV conversions aren't usually known for their range, but with on-board PV charging and a little patience, this VW is ready for extended road trips, and luxury camping with electric appliances.

Our first long trip in our electric VW van was quite an adventure! We wandered from Ashland, Oregon, to Monterey, California, traveling a total of 1,400 miles. We spent most of our time traveling on Highway 1, a winding, narrow road that was a perfect fit for the van. It's amazing how much more you see when you're going slow! Driving through the redwoods and along the ocean, we really got to take in the beauty going more slowly.

My main job was navigating and finding the charging stations and campgrounds/RV parks. I used the PlugShare app to locate them. Although I was grateful to have this resource, it was not always accurate. Sometimes, we would get to a listed charging station, but the people there would have no idea about how we could plug in the van for recharging. Some were willing to let us use their power and some were not, which meant that we had to cross our

Right: The Belan kids—Lyric (left) and Brook—enjoy the upper bunk. Mom Kira sewed the tent canvas, while dad Brett designed the pop-up structure.

Courtesy Brett & Kira Belan (4)

Below: Camping is just a bit cushier with the on-board amenities offered by the PV system.

Below: Time for a recharge—Kira and the kids nap in the upper bunk, while the PV array charges the batteries.

Left: The kids enjoy the view from the rooftop pop-up PV tent. The back sheets on the modules allow ambient light into the tent space.

Right: A Dometic fridge fits between the front seats for easy access to chilled treats.

Courtesy Brett & Kira Belan (4)

fingers and try to make it to the next station. During the day, if the van's batteries got depleted, we could park it in the sun for a couple hours and get enough energy to get to our destination. At night, though, it was a different story. Only one time in our trip did we run out of energy at night. We were only about a mile from the charging station, but had to climb a big hill to get there—and we didn't have enough in the batteries to do that. Then, my 8-year-old son, spying a nearby house, suggested that we stop and ask the homeowners if we could plug in. Hesitantly, we trusted his innocence. It turned out to be a sweet couple that let us plug in the van and camp in their front yard!

We lived off-grid for many years, so we're all used to using energy conscientiously. We had plenty of electricity to charge our phones, laptops and iPad. The appliances we chose used very little power. This was our first trip in the van, and there were a lot of things in building the camper part of it that we had to design by imagining what it would be like on the road. For the most part, everything worked well, but we got some insight into how we can make some things better and easier for the setup and take-down process.

During the trip, I turned into a amateur videographer and social media junkie. We wanted to have a way that people could "follow" us on our trip and a place where people could find out more information about our project. The week before we left, I created a website and opened Facebook and Instagram accounts (see "Web Extras").

We met some really great people on our journey and had some serendipitous connections. I think one of the biggest lessons for me was trusting and opening ourselves up to the good that is in everyone. Yes, we did get some angry honks from people who were in a hurry, but we just smiled and waved to them . For the most part, folks were very interested, helpful, and kind. This is the world that I want my kids to experience and I think they will have fond memories of this summer for the rest of their lives.

—Kira Belan

web extras

Find out more about the Belans' electric VW at **solarelectricvwbus.com**

On Facebook and Instagram, find them at **Solar Electric VW Bus**

Right: A custom kitchen includes a sink, potable and graywater storage, and fold-out tables that reveal an induction cooktop.

Belan Off-Grid System Loads

AC Loads	Qty.	× Watts Each	= Total Watts	× Hrs. / Day	× Days / Wk.	÷ 7 = Avg. Daily Wh
Laptop chargers	2	120	240	1.00	2	68.57
Living/kitchen/dining lights	3	9	27	0.50	7	13.50
Tablet charger	1	12	12	0.50	7	6.00
Smartphone charger	1	24	24	1.00	7	24.00
Utility room light	1	15	15	0.25	7	3.75
Electric chain saw	1	1,500	1,500	0.10	2	42.85
Electric cooktop	1	900	900	0.50	7	450.00
Total AC Peak Loads (For Inverter Sizing)			2,748		**Total AC Wh**	608.67
DC Loads						
Refrigerator/freezer	1	36	36	4.00	7	144.00
Water pressure pump	1	40	40	0.25	6	8.57
Lights	3	6	18	2.00	7	36.00
Cooling fans	6	12	72	4.00	1	41.14
					Total DC Wh	229.71
					Total Avg. Daily Wh*	838.38

*Total doesn't account for inverter efficiency losses

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Range

After resolving some brake issues, the van went from a 35-mile range to a 50-mile range. The pistons on the brake calipers were stuck and dragging on both front brake rotors. I was happy to get the added range. If the vehicle is driven casually (30 to 35 mph), a 75-mile range is possible. This is a camper and I'm in no hurry. I'm definitely the minority.

Locally, there is no need for plugging in. This means it is a "zero-fossil-fuel" vehicle, since it charges the batteries with free solar energy. The van usually sits for 5 hours in the sun every clear day, with the PV system providing 40 Ah—25 miles—to the batteries. It's a joy to have your fuel tank refilling on its own! A car like this, for the proverbial soccer mom, provides a way to get the kids to and from activities, and her to and from errands, with no impact on the budget or the Arctic ice caps.

With that said, how does it do on longer trips? We decided the next test was to see how the van performed on the open road.

I built this vehicle with the dream of taking my family to the Pacific coast for camping trips, and that was our first test (see "Solar-Powered Road Trip" sidebar). The van performed beyond my expectations, getting consistent 40-plus mile runs (and sometimes even 50 miles on a full charge). Unfortunately, the coast was cloudy most of the time, so it was necessary to find charging stations for recharging the batteries. After a couple of hours of charging and the batteries full, we'd hit the road again.

We drove about 100 miles per day, traveling slowly, and averaging about 40 mph—which was scary at times, with traffic screaming by. It felt like we were trying to slow down the whole human race and its frantic affinity for speed. But I soon got familiar with the necessary style of driving the van and found a cadence for yielding to faster traffic while maintaining an efficient 40 mph or so. Heading up long, steep grades was rough, requiring lots of energy from the batteries and going slowly. Fortunately, we

A JLD404 meter monitors battery performance—displaying volts, amps, and amp-hours.

Courtesy Brett & Kira Belan

Safety Notes

While the '73 VW Transporter is not even in the same category of safety as a modern vehicle—no air bags, no crumple zone—I did take pains to address safety. First, driving slowly reduces the impacts of a head-on collision. We also avoid driving at night. There's a good crumple zone in the rear of the VW. New seat belts and strong seats from a Sprinter were installed. The top is lightweight aluminum, and a platform separates the modules from the vehicle's interior. The glass is tempered and will not break into shards in the event of a fracture.

The battery bank sits in front of the rear wheels, and the van handles perfectly. Likely, it now has better weight distribution that the original van with its internal combustion engine. The 1,000 pounds of lead battery makes a nice ballast for the VW, since it sits on the floor, nearly at the vehicle's center. High winds hit our extended tent many times and the van barely budges. In the event of an inversion, the batteries are the danger, since they will eventually leak sulfuric acid. The battery box is bolted to the VW's frame and the cover is tightly fastened. The battery box is designed to vent to the outdoors continuously during charging.

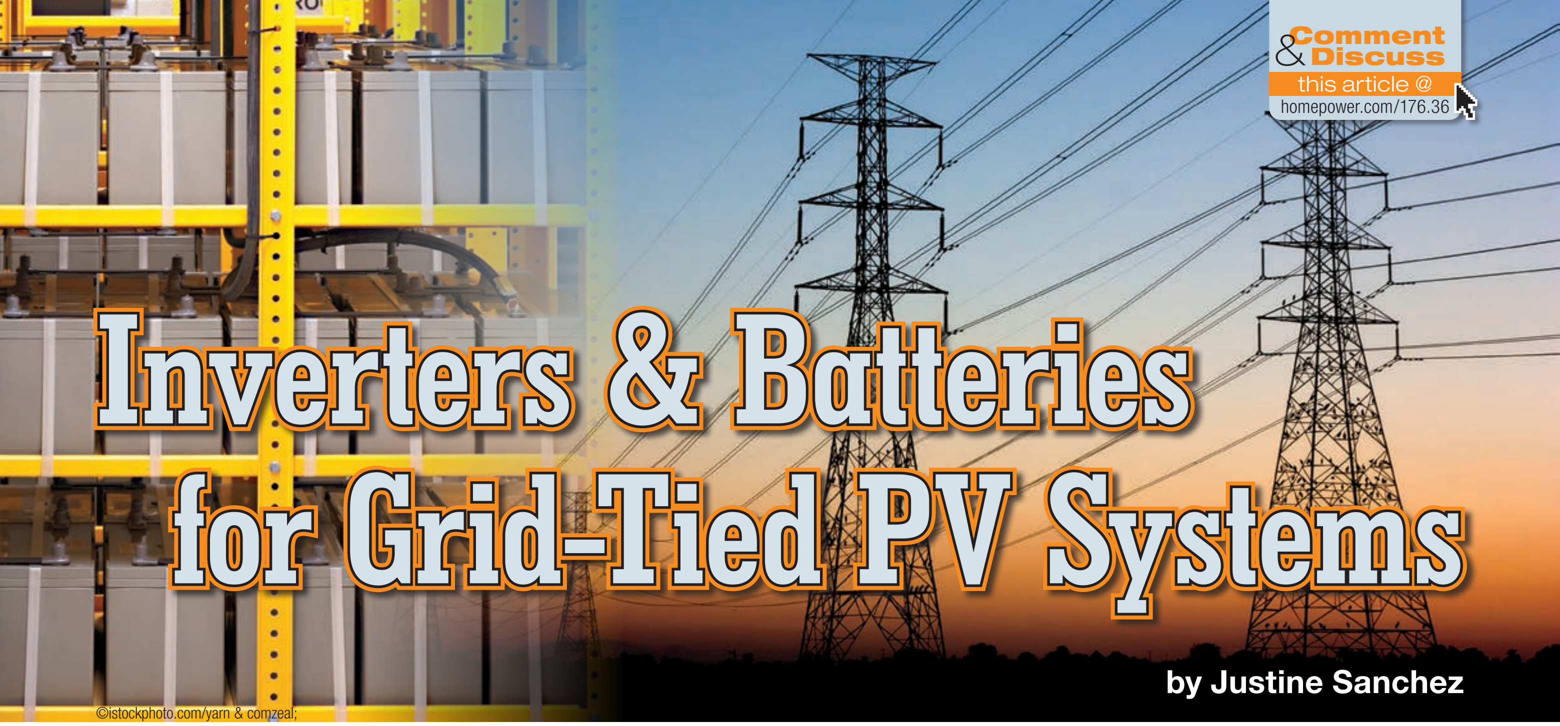
Courtesy Brett & Kira Belan

weren't alone—big trucks and RVs kept us company. It wasn't until the last leg of our journey—camping beside the Smith River—that the PV array generated 55 Ah of charge from the sun in one day, as shown on the JLD 404 meter. I designed the system to provide a full charge to the batteries on a full day of summer sun. However, my Drok controllers were limiting the energy transferred from the array to the batteries. The meter showed only 6 to 7 amps of output. In the cool redwood forest climate, the meter had shown 8 amps, revealing to me that the modules were losing performance as ambient temperature climbed.

The ability to power electric appliances is terrific—I can run my electric chain saw to cut firewood or cook on the induction cooktop. An hour of cooking is equivalent to one-eighth of the van's daily range. The refrigerator runs at 36 watts, for 15% of the day, consuming about 150 Wh daily. Nothing else is a significant load.

It took me two years of patience and steady focus to build this safe, functional vehicle, and the payoff has been rich. We had only two malfunctions the whole trip—one battery meter stopped working and a brake clip from the brake pad area broke. Other than that, things went smoothly.

There was something really special about pushing through the anxiety of going 40 mph when everyone else was going 60. Settling into that stillness was something we'll take with us forever, and slowing down gave me a perspective of my family I never would have had speeding along and missing the view.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Inverters & Batteries for Grid-Tied PV Systems

by Justine Sanchez

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Most grid-tied (GT) photovoltaic systems do not include energy storage. However, there is a notable shift in the industry causing many to reconsider installing a battery bank. Because most batteryless GT systems cannot supply energy when the grid is down, the desire for backup power is often a motivator. There are now additional factors that are driving people to consider batteries, in order to enable energy management in their systems.

Utility time-of-use (TOU) rate structures, in which utilities value energy differently throughout the day, can take advantage of a system that stores PV energy when rates are low and exports that energy to the grid when rates are high. Also, shifts in incentives and net-metering programs—along with changing utility interconnection rules and requirements—make storage more attractive in some locations. Where incentives are disappearing and net-metering is nonexistent, storing and later consuming solar energy (self-consumption), rather than sending it to the grid, can make economic sense. This article explores the different types of batteries and inverters used in battery-based GT systems to supply backup power or energy management.

Concorde Sun Xtender PVX-12150HT: 2 V AGM

Crown Battery Power Module 2CRP2030; 2 V FLA

Fullriver DC1150; 2 V AGM

Dyno 12 V FLA

HuP Solar-One SO-6-100-33; 12 V FLA

All photos courtesy respective manufacturers

Battery Options

Lead-acid (LA) rechargeable batteries were invented in 1859, but more recent battery developments are providing additional choices. Options include sealed and flooded LA, lithium, nickel-iron, and saltwater batteries.

Lead-Acid

Deep-cycle flooded lead-acid (FLA) batteries have dominated the residential energy storage market. They continue to be a cost-effective choice for many systems because of their low up-front cost. These batteries should not be located in living spaces and require vented battery boxes to allow flammable gases to escape. They also require monitoring the electrolyte and the periodic addition of distilled water, either manually or with watering systems.

Sealed LA batteries (valve-regulated LA or VRLA) are available as absorbed glass mat (AGM) and gel cell. Sealed batteries do not need water additions, making maintenance easier—an important consideration for GT systems, where system owners are not accustomed to maintaining their energy systems. They are easier to transport and employ, since they can be upright or on their sides, and only require minimal venting. They are more expensive, about two or three times the cost of their FLA counterparts. (However, an unmaintained flooded battery bank quickly loses its cost advantage if you have to replace the bank prematurely.) If your aim is a battery bank providing occasional backup for a few critical loads, the bank can often be smaller than one designed to supply all of the home's energy needs, which can make up for the higher upfront cost of sealed LA batteries.

Lead-Acid Batteries

Manufacturers for commonly used deep-cycle LA batteries include:

- **Concorde Battery/Sun Xtender** (VRLA)
  sunxtender.com
- **Crown Battery** (flooded and VRLA)
  crownbattery.com
- **Dyno Battery** (flooded)
  dynobattery.com
- **EnerSys/ HUP Solar-One** (flooded)
  hupsolarone.com
- **Fullriver Battery** (VRLA)
  fullriverbattery.com
- **MK Battery** (flooded and VRLA)
  mkbattery.com
- **Outback Power** (VRLA)
  outbackpower.com
- **Rolls/Surrette Battery** (flooded and VRLA)
  rollsbattery.com
- **Trojan Battery** (flooded and VRLA)
  trojanbattery.com
- **U.S. Battery** (flooded and VRLA)
  usbattery.com

MK Battery AVR95-21; 12 V AGM modules

OutBack Power Energy Cell 200 RE; 12 V AGM

Rolls 2 YS 62P; 2 V FLA

Trojan J200RE; 12 V FLA

U.S. Battery RE L16; 2 V FLA

Lithium

Lithium battery use has seen recent growth from decreasing prices—partially due to use in electric vehicles—and is now gaining a foothold in RE systems. Lithium batteries offer high energy density (about half the volume and one-third the weight of an LA battery), high charging efficiency, low self-discharge rates, long cycle life, and less reduction in capacity in cold environments. Plus, they are maintenance-free.

While the high cost and need for a sophisticated battery management system (BMS) previously kept lithium batteries out of most RE systems, decreasing cost and integrated (and third-party) BMS solutions have become available, launching this technology into the GT PV market. The cycle life for lithium batteries can be more than four times that of LA batteries (for banks cycled down to 80% DOD)—important for systems designed for self-consumption or TOU programs, where batteries may be cycled daily.

Lithium batteries use various chemistries, each with their own advantages and disadvantages. The most common ones for PV energy storage are lithium nickel manganese cobalt (NMC) and lithium iron phosphate (LFP). LFP batteries are not prone to thermal runaway (i.e. increasing temperature which can cause the venting of toxic and flammable gases, possibly leading to flames and explosion) and have about double the life of NMCs. NMC have about twice the energy density of LFPs, but can experience thermal runaway at high charge rates.

Nickel-iron

Nickel-iron batteries also offer a long lifespan, and are not harmed from over- or undercharging. However they are expensive and require a lot of watering.

Other Battery Types

Lithium

Manufacturers are too numerous to list, but a few lithium batteries are being marketed for RE systems. Information in parentheses as follows: battery chemistry, capacity, DC voltage(s), warranty:

- **Adara Power** (NMC, 8.6 kWh, 48 V, 10 yr. warranty) adarapower.com
- **Iron Edison** (LFP, several capacities, 12/24/48 V, 7 yrs.) ironedison.com
- **Tesla Powerwall** (NMC, 6.4 kWh, 350-450 V, 10 yrs.) tesla.com
- **SimpliPhi** (LFP, 2.6/3.4 kWh, 24/48 V, 10 yrs.) simpliphipower.com

There are also several packaged lithium battery and inverter systems available (see "Packaged Systems" sidebar).

Nickel-Iron

- **Iron Edison** (NiFe, several capacities, 12/24/48 V, 10 yrs.) ironedison.com

Saltwater

- **Aquion Energy** (Aqueus hybrid ion, 1.9 kWh/24 V & 2.2 kWh/48 V, 5–8 yrs.) aquionenergy.com

Saltwater

Saltwater batteries are new to the industry and are being installed in some GT systems. They are maintenance-free and nontoxic, and offer a long lifespan. They can be left at a partial state of charge, and even discharged 100%, without damage—although doing this regularly will reduce their lifespan. They are expensive and can't provide much surge current without paralleling stacks, which means more total capacity than you need.

AdaraPower 8.6 kW ESS; 48 V Lithium (NMC)

Iron Edison LFP 48 V; 7.5 kWh

SimpliPhi PHI 2.6 kWh; 24/48 V LFP

Iron Edison nickel-iron; 48 V bank

Aquion Aspen 48S; 48 V Aqueus hybrid ion

Battery-Based GT System Types

There are two BBGT system configurations—**DC-coupled**, in which the PV array is connected to the battery bank on the DC side of the system, historically through a charge controller. A battery-based inverter is needed to process the array and battery DC into AC. Excess energy can be sent to the utility. The inverter includes a battery charger, which can use grid energy to charge batteries if needed. It is important to note charge controllers aren't always employed in DC-coupled systems, such as in the new high-voltage hybrid inverters, where the array is connected directly to the inverter (see "Upcoming" sidebar).

Adding batteries to an existing batteryless PV system is usually accomplished with **AC-coupling**, in which the AC output of the existing batteryless GT inverter is connected to that of an added battery-based inverter. The new battery bank is wired to the battery-based inverter's DC input. Both the batteryless GT inverter and the battery-based inverter AC outputs commonly feed a critical load subpanel. The battery-based inverter provides the AC that keeps the batteryless inverter functioning, even during a utility outage. There are many nuances to AC-coupling—see "Adding Battery Backup to Your System with AC-Coupling" in *HP168*.

A batteryless GT inverter must be compatible with the battery-based inverter. There are a few inverter manufacturers that produce both inverter types (for example, SMA's Sunny Boy and Sunny Island) designed to be used together. If you're retrofitting a previously installed system, you'll need to research inverter compatibilities before deciding on equipment.

Battery-Based Inverters

Both DC-coupled and AC-coupled systems require a battery-based inverter. Options are available from several manufacturers:

Magnum/Sensata sensatapower.com

Magnum Energy battery-based inverters are common in off-grid systems and are not designed to export power to the grid. They can pull power from the grid for battery charging and may be used in GT systems when AC-coupled with a batteryless GT inverter. Models used in GT systems include MS-PAE and MSH-RE series inverters. Compatible battery bank voltages are 24 and 48 VDC and can accommodate both lead-acid and lithium batteries. In GT systems, they can supply backup and/or energy management with split-phase 120/240 VAC output from a single inverter.

Magnum Energy offers the MicroGT500, a GT microinverter that accommodates two modules each (up to seven MicroGT500s per 20-amp AC branch circuit). They can communicate directly with the Magnum battery-based inverters to handle PV-based battery charging during utility outages in AC-coupled systems.

Magnum Energy MS-PAE & MicroGT500

OutBack Power outbackpower.com

OutBack Power offers its GTFX, GVFX, and Radian inverters for GT systems. The GT and GV series inverters have 120 VAC output and one AC input connection (grid-only input), while the Radian has two and can accommodate the grid and an AC backup generator. These inverters are used to export power to the grid and offer backup power, but can be also used for energy management, for example in "GridZero" mode for self-consumption systems. The Radian series offers split-phase 120/240 VAC output and can be used in DC- or AC-coupled GT systems; the GridZero mode is not compatible for AC-coupled systems. Battery voltage options are 24 and 48 VDC. These inverters can be used with other battery technologies, such as lithium, nickel-iron, and saltwater batteries. OutBack Power also offers its SystemEdge packaged system (see "Packaged Systems" sidebar)

OutBack Power Systems Radian & GTFX

Pika Energy pika-energy.com

The Pika Energy Islanding Inverter/X7601 can be used for backup and energy management. The X7601 inverter works with PV Link S2501 optimizers to produce 380 VDC PV array strings, feeding a high-voltage DC bus. This DC bus is designed to be connected to a high-voltage lithium battery bank. On the AC side, inverter output is split-phase 120/240 VAC.

Pika Energy X7601

Schneider Electric Conext XW+

Schneider Electric solar.schneider-electric.com

Schneider Electric's Conext SW-NA and Conext XW+NA inverters can be used in GT systems. The SW inverters do not export power to the grid, but can be AC-coupled with GT inverters. The XW line is a battery-based GT inverter, with dual AC inputs. Like the SW, it can be used in either DC- or AC-coupled systems. Both offer 120/240 VAC split-phase output and can be used for backup or energy management using lead-acid batteries. The XW series also supports lithium batteries (several lithium battery packaged systems integrate the XW inverter). Battery voltage options are 24 and 48 VDC for the SW, and 48 VDC for the XW.

SMA America sma-america.com

SMA America's Sunny Island battery-based inverter is designed for AC-coupling with Sunny Boy batteryless inverters (although it can be used in DC-coupled systems as well). In GT systems they are most often utilized for backup, and while they can be used for energy management, they were not designed for this application. Battery bank voltage is 48 V, and compatible battery types include lead-acid and lithium (there is an RJ45 port to connect a communications cable to an external BMS). SMA maintains a list on its website of approved lithium batteries for use with the Sunny Island. The output of the Sunny Island is 120 VAC, requiring either a "Smartformer" or two Sunny Island inverters stacked for 240 VAC to match the batteryless inverter(s). Sunny Island inverters can communicate with Sunny Boy inverters to regulate power to the battery bank during utility outages.

SMA America Sunny Island

SolarEdge StoreEdge
with Tesla Power Wall

SolarEdge solaredge.com

SolarEdge offers its StorEdge SE7600A-USS inverter for battery-based GT systems. This inverter is designed to be DC-coupled at 400 VDC to the battery bank and PV array via power optimizers on each module, but it can be AC-coupled to an existing GT batteryless inverter as well. This inverter is compatible with the Tesla Powerwall, LG Chem, and RESU lithium batteries on a high-DC-voltage bus. There are two other SolarEdge components for the AC side, depending on the system design. For backup systems, its autotransfomer is used (to manage phase balancing between the inverter output and the backed-up load panel circuits). For energy management, the SolarEdge Electricity meter monitors energy import/export and consumption, and supplies that information to the inverter so it can manage the battery charge and discharge accordingly. And all components are required if the system is designed for both backup and energy management.

Packaged Systems

Consumers also have the option of purchasing a packaged energy storage system (ESS)—essentially a box containing the batteries, inverter, and required balance of system (BOS) components. This takes out the guesswork when trying to figure out equipment compatibility and installation. The ESS table includes current and upcoming (2017) options.

Packaged Energy Storage Systems

Manufacturer	Model	kWh Options	Battery Type	Inverter Manufacturer	Connection to PV Array	Target Application(s)	Warranty	Availability
Blue Planet blueplanetenergy.com	Blue Ion Continuum	5 models, 8 to 24 kWh	Lithium-LFP	Schneider Electric	DC or AC-coupled	Energy mgmt. & backup	10 yrs.	2017
Eguana Technologies eguanatech.com	AC Battery	5 models, 6 to 18 kWh	Lithium	Eguana	AC-coupled	Energy mgmt. & backup	10 yrs.	Did not reply
Enphase Energy enphase.com	Enphase AC Battery	1.2	Lithium-LFP	Enphase	AC-coupled	Energy management	10 yrs.	2017
OutBack Power outbackpower.com	SystemEdge	5 models, 20 to 100 kWh	VRLA	OutBack Power	DC-coupled	Energy mgmt. & backup	Per component*	Now
SimpliPhi simpliphipower.com	ESS	6.8/10.2	Lithium-LFP	Schneider Electric	DC-coupled	Energy mgmt. & backup	10 yrs.	Q4 2016
Sonnen sonnen-batterie.com	sonnenBatterie eco	7 models, 4 to 16 kWh	Lithium-LFP	OutBack Power	AC-coupled	Energy mgmt. & backup	10 yrs.	Now
Sunverge sunverge.com	Solar Integration System (SIS)	6 to 25 kWh	Lithium	Schneider Electric	AC-coupled	Energy mgmt. & backup	10 yrs.	Did not reply

*Separate warranty for each component in the system

Enphase Energy AC Battery

sonnenBatterie eco

SimpliPhi ESS

OutBack Power SystemEdge

Upcoming

Upcoming battery-based inverter options include the **Fronius** Primo Hybrid inverter designed to work with the Tesla Powerwall in 5.0 to 11.4 kW capacities. **OutBack Power**'s Skybox 5 kW hybrid energy system will work with batteryless GT systems and 48 VDC or high-voltage battery banks. The **SMA** Sunny Boy Storage 2.5 kW inverter was released in Europe in May 2016, and is designed to connect to a high-DC-voltage lithium battery bank (like those from Mercedes Benz, LG, and Tesla).

web extras

"Backup Power for GT Systems" by Zeke Yewdall in HP170 • **homepower.com/170.44**

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

OutBack Power Systems Skybox

Fronius Primo Hybrid

SMA Sunny Boy Storage

The Cost of Storage

Want to see how battery energy storage technologies compare on a dollar-per-kWh basis? Check out "Residential Storage Economics" in *SolarPro magazine* • bit.ly/StorageEconomics

Other Requirements

You'll need to consider what else is required to make the system functional and *NEC*-compliant, such as battery boxes, battery cabling, overcurrent protection, integration hardware (wiring, power distribution panels, and conduit boxes), metering, and a backed-up loads subpanel. Some of these issues are simplified by going with a packaged energy storage system.

Adding batteries and other equipment to the system results in efficiency losses. How large this efficiency hit will be depends on several factors, such as:

- whether the system is DC- or AC-coupled
- whether energy is consumed as it is produced or stored for later use
- the type of power electronics
- which battery types are used (how efficient they are)
- how often the batteries are cycled—for example, whether they are used only for backup and, thus, rarely cycled, or are cycled daily, as in self-consumption and TOU systems.

Including batteries in your system can be expensive. There's the upfront cost of batteries and the required BOS gear, plus installation. While energy storage prices are coming down, particularly for lithium batteries, the minimum investment may still be about $10,000.

The value of backup power or being able manage your PV energy needs to be carefully considered. If utility outages are frequent or extended, backup power can be valuable. For a self-consumption system, will the rate savings justify the energy storage investment? While the energy storage market is experiencing significant growth and garnering attention, in most locations, it is still difficult for it to compete with utility rates.

Regardless of the economics of installing batteries in residential GT systems, according to GTM Research, the energy storage industry is poised to grow to 2.1 gigawatts (GW) by 2021 (nine times the size of the 226 MW 2015 storage market). This means continued attention and excitement toward energy storage—likely resulting in continued cost reductions and thus increased battery installations in homes across the country.

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Choosing Your Off-Grid Refrigerator

by Dan Fink

Life off the grid requires a few adjustments in lifestyle and habits for most people. One of the most crucial is called "load shifting," which is simply running large loads only when there is extra power coming in that can't be stored, thanks to a fully charged battery bank.

Unfortunately, some very critical loads can't be shifted. Refrigerators and freezers are two of the worst offenders—they turn themselves on and off based on internal temperature, without any regard to the status of your battery bank or incoming power.

In the world of off-grid living, the answer to "Which refrigerator is the right one?" is almost always, "It depends." What's the most efficient power source—120 VAC or low-voltage DC? What sizes and models are available? What's the most efficient arrangement of doors, compressors, and compartments? Is propane a better option? Here are a few points to consider before you buy.

Going Electric

I had to add another 1 kW of PV to run a conventional AC-powered, upright electric fridge/freezer, which replaced the 20-year-old propane model I started my off-grid life with. That big freezer up top opened new worlds for me—like the frozen-food aisle at the local wholesale club and freezing wild game from hunting. Extra bread on the counter that is at risk for growing mold or going stale? Freeze it! Herbs in the garden? Cut 'em up, put them in ice-cube trays with a little water, and pesto-freezo!

But different households have different energy budgets (and different levels of expendable income). My conventional 120 VAC refrigerator/freezer from a big box store cost me $800, plus about $700 to expand the PV array, $500 for a new controller, $2,500 for additional batteries, and another $1,400 for a new inverter I didn't realize I would need (see "Off-Grid Fridge Vagaries" sidebar). These additions, though, helped the efficiency and performance of my entire home's energy system. Here are some options and considerations to weigh when you're choosing a refrigerator and/or freezer for your off-grid home.

web extras

Rebates for energy-efficient appliances • **dsireusa.org**

Energy Star rebate-finder • **energystar.gov**

Sun Frost Fridges

Venerable fridge manufacturer Sun Frost stopped making refrigerators this year, after about 30 years and 17,000 refrigerators delivered. According to founder and owner Larry Schlussler, the company has closed its factory and has moved into a smaller space. Sun Frost continues to provide repair services and replacement parts for its models. Larry is now consulting with another manufacturer of off-grid fridges to help improve their product.

—Michael Welch

High-Efficiency Upright Refrigerator/ Freezers

If having high efficiency in a standard format (i.e., upright fridge/freezer) is your priority, **high-efficiency uprights** come in both DC (12, 24, or 48 V) and 120 VAC versions. They feature efficient compressors, thick insulation, tight door seals, clever ways of removing condensation from the interior using natural ventilation—without running heating elements—and more. Even blank door and side panels are available so you can customize them to your décor.

Expect to pay between $3,000 and $4,000 for a full-size, 19-cubic-foot two-door fridge/freezer. The DC versions are a bit more efficient, as they won't have inverter losses. One advantage of a DC refrigerator compared to an AC one is that an inverter doesn't have to be sized to handle the compressor motor startup surge—see the "Powering an Off-Grid Electric Fridge" section. Another advantage is, if the inverter fails (for example, from a nearby lightning strike), you still have refrigeration.

Going DC requires a DC circuit in your kitchen, which is likely not already wired. Either way, these appliances are an investment that will serve you well for at least a couple of decades. The downside, in addition to the price, is that you'll need to order these units and have them shipped and, unless you can find a local dealer, you won't be able to inspect the product until it's paid for and at your doorstep.

Are these specialty units really worth the extra cost, with conventional models available from the local big box store? It depends on both your situation and your budget.

Manufacturers: Northern, Nova Kool, SunDanzer, and Unique

This 10-cubic-foot Unique Off-Grid Appliances unit runs on 12 or 24 VDC.

Courtesy Unique Off-Grid

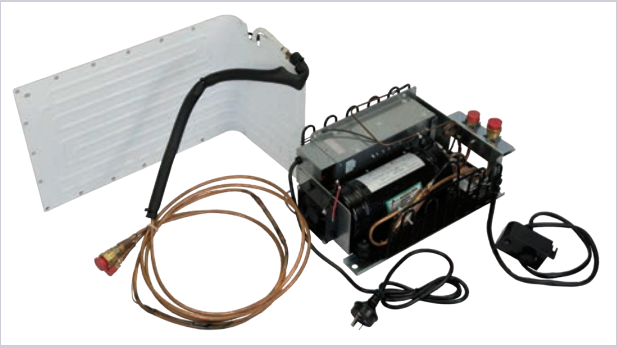
This Nova Kool RFU 9000 can run on 12 or 24 VDC—or 120 VAC.

Courtesy Nova Kool

DIY Fridges & Freezers

In specialized off-grid built-in refrigerators and freezers, the efficient compressors and the rest of the refrigeration parts used are also available separately, if you are willing to build your own—including interior compartments, door, wire or glass racks, and a heavily insulated shell. These kits are often used by the builders of high-end yachts, letting them fit high-performance refrigeration into small, oddly shaped galley spaces. This sounded like a great, money-saving DIY project, with creative opportunities for the shell—until I heard from a couple of folks who had tried it. What could possibly go wrong? Mold, for one. If your interior compartment is not perfectly designed, fabricated, and sealed, mold can grow in the insulation around it, and it's impossible to remove. You'll be starting your project from scratch, again. Door seals are another tricky proposition, as they must function perfectly, every time.

Components for DIY Fridges:
Engel Coolers • engelcoolers.com
Frigoboat • coastalclimatecontrol.com
Norcold • norcold.com



Courtesy Engel Australia

Courtesy Steca

Courtesy Phocos

Courtesy SunDanzer

From top: Steca, Phocos, and SunDanzer specialize in solar-ready applications with DC chest fridges and freezers in various sizes.

Chest-Type Freezers & Refrigerators

If you're looking for the highest efficiency, have plenty of floor space, and don't mind some access inconveniences, **chest-type freezers and refrigerators** are a great match. These appliances capitalize on dense, cold air settling to the lowest point—unlike an upright model, in which cold air spills out the bottom every time you open the door and is replaced by room-temperature air. Combined with thick insulation, chest refrigerators are excellent, efficient choices, and at a much more reasonable cost ($1,000 to $1,500) than specialty vertical models.

Chest refrigerators have a couple of downsides. You'll have to practice loading them so that frequently used items are readily accessible, though they come with wire baskets to help you stay organized. And, they don't come in combination fridge/freezer models—you'll need to buy separate units. I've seen some innovative kitchen solutions to this issue with the chest refrigerator on a sturdy shelving unit in easy reach, with the freezer on a heavy-duty slide-out shelf underneath it. Others may put them side-by-side, with handy shelving or wall cabinets above. Your creativity and adaptability will be key to living well with a chest refrigerator and freezer solution.

So how much room will you need? A conventional 20.1-cubic-foot refrigerator/freezer combo, for example, allocates about three-fourths of this capacity (15 cubic feet) to fresh-food storage and the remainder (5 cubic feet) to freezer space. At about 8 cubic feet, SunDanzer's chest refrigerator offers about half of the capacity of a conventional refrigerator.

Manufacturers: Dometic, Nova Kool, Phocos, SunDanzer, Steca, and Unique

Chest Freezer Modifications to Make a DIY Refrigerator

An inexpensive and easy DIY way to convert any chest freezer into a chest refrigerator is to use an external thermostat with a remote sensor. Standard chest freezers are available at any appliance or big box store at low cost ($150 to $500, depending on the size), and they sport thick insulation, reasonably efficient compressors, and an excellent door seal. All you need to do is drill a hole in the side (don't hit any of the piping!) and add an external thermostat with a remote sensor (about $50). Seal the hole around the thermostat wire, set the freezer's original temperature control to the lowest setting, and plug it into your new external thermostat set for 36° to 40°F, which is then plugged into the wall. You now have a chest refrigerator! You might have to get creative with food baskets, handles, and such for easy organization and access, as most chest freezers don't include many, but the cost benefits and efficiency gains are significant.

On the BuildItSolar website, one person reported that their freezer-to-fridge conversion averaged 0.204 kWh over a 24-hour period. Extrapolated to a year of usage, that's about 75 kWh annually. If you are buying a new chest freezer to convert, be sure to select one with a high efficiency rating so you'll reap the best energy savings possible.

External thermostats for DIY Refrigerator: Honeywell and Johnson Controls

Courtesy Johnson Controls

Specialty Off-Grid Fridges & Freezers

Uprights	Fuel Type	Notes
Northern northernfridge.ca	Electricity	12 or 24 VDC
Nova Kool novakool.com	Electricity	12/24 VDC or 100-240 VAC
SunDanzer sundanzer.com	Electricity	12 or 24 VDC, AC/DC add $135, DC thermostat kit avail.
Unique uniqueoffgrid.com	Electricity	12 or 24 VDC
Chest Types		
Phocos phocos.com	Electricity	12 or 24 VDC
Steca steca.com	Electricity	12 or 24 VDC
SunDanzer sundanzer.com	Electricity	12 or 24 VDC
Unique uniqueoffgrid.com	Electricity	12 or 24 VDC
Propane-Fueled		
Crystal Cold crystalcold.com	Propane	--
Diamond Refrigerators gasrefrigerator.com	Propane	--
Dometic dometic.com	Propane	Two-way (propane or 115 VAC electricity)
E-Z Freeze ezfreezerefrigerator.com	Propane	--
Norcold norcold.com	Propane, plus AC/DC	12 VDC, 120 VAC, LP gas
Unique uniqueoffgrid.com	Propane	--

Conventional Fridges

Many U.S.-sold appliances have caught up with European ones in energy efficiency. You can now choose from a wide selection of refrigerator/freezer models, sizes, and colors, and base your decision on those factors plus the Energy Star rating and yellow EnergyGuide sticker. That's what I did.

I didn't want to spend money on a specialty off-grid fridge, was leery of tackling making my own built-ins, and didn't have the kitchen space for a chest fridge and freezer, so I shopped by size, estimated kWh usage, and color. The model I chose offers 19 cubic feet of capacity, uses about 350 kWh per year (just under 1 kWh per day), and cost about $800, delivered. Once we finally learned to get along power-wise and energy-wise (see "Off-Grid Fridge Vagaries"), I was satisfied with the investment.

Be aware! When used off the grid, refrigerator "features" that no city dweller would do without can cause excessive energy use and unexpected problems. Here are a few things to look out for when selecting a standard electric refrigerator for off-grid use:

Top freezer, bottom freezer, or side-by-side configuration? Top freezers are the most efficient, as warm air rises while cold air sinks. Bottom freezers need a fan to make this heat exchange, but tub-style bottom freezers hold cold air better than door-style top freezers. Side-by-side freezer/fridge models are the least efficient, spilling more cold air from both compartments whenever opened. These should be avoided.

Ice makers. These cost you about 10% to 15% in increased energy usage as they have electric valves, actuator motors and, possibly, heating elements, to make sure the ice cubes fall cleanly into the bin. They also require a pressurized cold-water connection. I was willing to sacrifice that extra energy usage for the convenience, but you may not be able to. Refrigerator/freezers without ice makers (or in-door cold water dispensers for that matter) may be less expensive, but may have to be special ordered.

An **automatic defrost cycle** runs heating elements for an hour or so every few days to prevent ice crystal buildup. This is

Off-Grid Fridge Vagaries

It was a happy day in 2014 when the two burly young men in a truck from the big box store found my remote address for the fridge delivery. They had to remove my front door at the hinges to fit the thing in here. We plugged it in—and nothing happened. After some consternation, one of them asked "Is that a GFCI (ground-fault circuit interrupter) outlet? It says right in the owner's manual that won't work." But no, it wasn't. Then he asked, "Is it downstream from a GFCI outlet?" It was. I started my generator, and plugged the new fridge into it. Everything worked fine, and those lads left with a healthy tip. I then plugged it into the nearest non-GFCI outlet. Everything worked great—for a while.

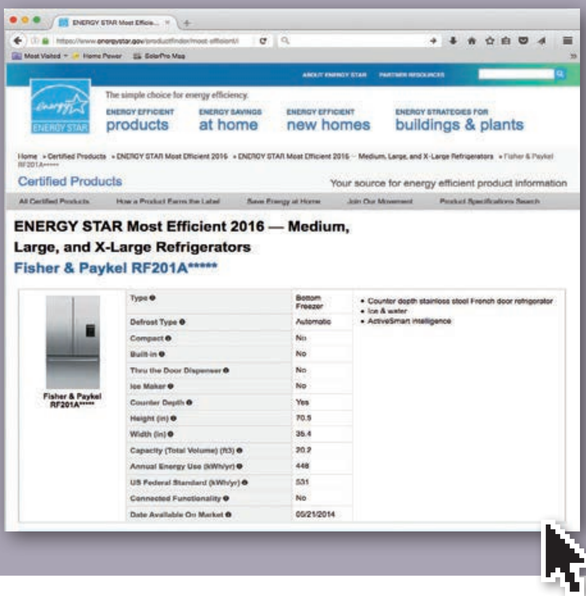
Two weeks later, I noticed strange behavior from the fridge. The freezer compartment had reached -35°F, and the fridge compartment was room temperature. A quick call to Frigidaire tech support revealed the automatic defrost cycle was not operating, and the air plenum between the freezer and fridge compartment was clogged with ice crystals. But why? "Do you have any unusual power issues at your home?" the gentleman asked. Well, yes—I'm off the grid and was using a modified square-wave inverter to power the whole house. "I've seen that before from RV people," he said. "The computer in the fridge needs a clean waveform. Give that a try." I didn't even know refrigerators contained computers, but I guess that's modern life.

One week and a few hundred dollars later, a new sine-wave inverter rated for 1,000 W continuous duty and 1,500 W surge arrived. I wired a new circuit so that the inverter powered only the fridge, and plugged it in. The inverter immediately went into overload and shut down. Yes, even though the nameplate rating on the new fridge was only 350 W (which doesn't account for the surge load from the compressor), the inverter (from a reputable manufacturer, no less) couldn't supply the startup surge. A new 2,000 W inverter with 3,000 W surge capacity arrived after another $1,500 and yet another week living out of a cooler with ice.

Was it all worth the hassle and expense? I still say yes. While the new sine wave inverter was a significant expense, now all my appliances and lights run more efficiently. I no longer have the hassle of manually defrosting, I have ice on demand, and I no longer have to pay exorbitant prices, delivery charges, and tank rental fees for propane—my solar fuel source is free.

web extras

Find the most efficient conventional (120 VAC) refrigerators and freezers of 2016 • **bit.ly/EnergyStarFridges**



essential for the fridge's proper function, but can often turn on when a battery bank's state of charge is low. Time to run the generator for a couple of hours! In older refrigerators, it was possible to simply disconnect the heating element wires and defrost manually when needed, or install a switch so the defrost cycle could be turned on when it was warranted. In newer computer-controlled models, this can cause error codes that shut the entire defrost system down. In my case, I was again willing to expend the extra electrical energy for the convenience but had to sort out the bugs in the system first. It can be difficult to find full-size refrigerators that don't have the automatic defrost feature—without it, unless you regularly defrost manually, the ice buildup can cause the fridge's efficiency to plummet more than the efficiency losses from the defrost cycle itself.

Anti-sweat condensation control systems also use heating elements to keep moisture from condensing on the outside of the refrigerator in warm, humid climates. They should be avoided in any off-grid power system.

Powering an Off-Grid Electric Fridge

Continuous and surge load. The yellow EnergyGuide sticker will give you an idea of how many kWh the fridge will use annually. You can extrapolate its daily energy requirements by dividing by 365. For example, an EnergyGuide sticker on a conventional fridge/freezer estimates 404 kWh per year—divided by 365, that's 1.1 kWh/day.

The appliance's nameplate rating (usually located inside the main compartment, next to the model and serial numbers) will tell you the maximum wattage it can draw. This includes when the defrost cycle and ice maker are running—but most of the time, it will be far less. A typical compressor load for a full-size fridge would be about 150 watts from the compressor, and 350 watts during defrost. Don't assume that a smaller refrigerator will have lower continuous or surge ratings, either—dorm-sized models can draw as much as full-size ones. Always refer to the nameplate and EnergyGuide ratings.

When starting up, the compressor surge load will be significantly higher—often well over 1,000 watts (see sidebar), so make sure your inverter can handle it. Unfortunately, you won't find surge load information from the refrigerator's nameplate or in the spec sheet, so a bit of guesswork is involved. It's possible to add a "hard-start capacitor," which lowers the surge to the compressor, but many modern, efficient refrigerators already have one—adding another can damage the compressor.

Inverter waveform. Many modern refrigerators won't run properly on a modified square wave inverter, with possible problems ranging from the internal controls not functioning properly (disabling the auto defrost cycle and the ice maker) to a drastic shortening of the compressor lifespan.

Non-Electric Refrigeration

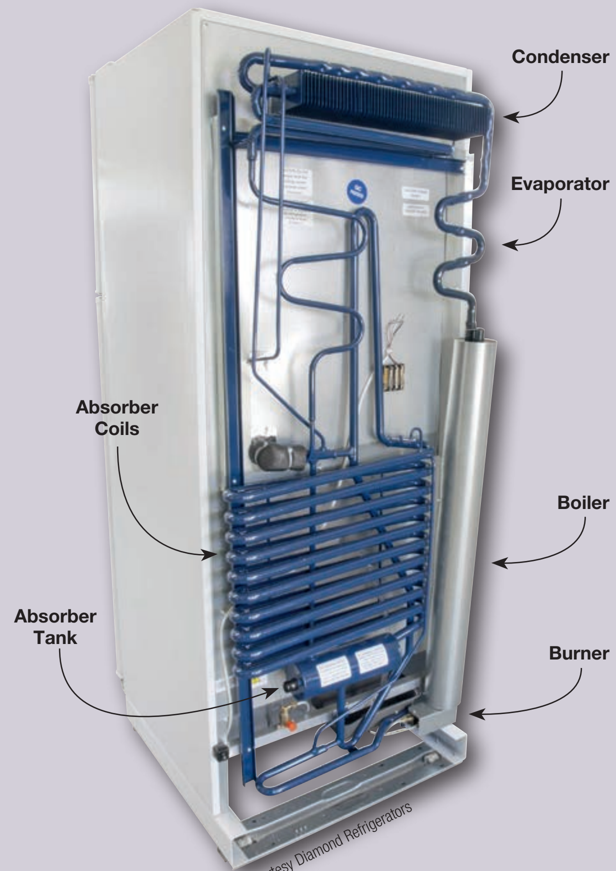
Propane refrigerators use heat to generate cooling, without electricity. Propane (and even kerosene) refrigerators have been around since the early 1930s, using an absorption cooling system developed by Michael Faraday in 1824. The advantages of a common fuel source and quiet, reliable operation were huge for rural areas that had not yet been electrified, and still relied upon iceboxes and ice deliveries.

Propane refrigeration has downsides, though. Besides being a nonrenewable fossil fuel requiring drilling, refining, and transport (i.e., pollution, pollution, and pollution), propane's price can fluctuate wildly and you may be subject to annual tank-rental fees and propane delivery charges.

Dometic's two-way (120 VAC or propane), freestanding 13.5-cubic-foot Elite 2+2 RM 1350 has a water/ice-in-door option.

Courtesy Dometic

Propane-Fired, Ammonia-Absorption Refrigeration



Courtesy Diamond Refrigerators

How It Works: A small flame from the burner heats the boiler. Ammonia gas is boiled out of the water solution and moves into the condenser. Here, the ammonia gas cools to a liquid, releasing its heat. The liquid ammonia moves to the evaporator, where it expands to a gas and becomes very cold. The evaporator is found on the inside of the freezer and refrigerator sections. From there, the ammonia gas moves down to the absorber, where it is absorbed into a water solution. The water solution moves to the boiler, where it is heated again, and the process continues.

Courtesy E-Z Freeze

Courtesy Diamond Refrigerators

Courtesy Norcold

Courtesy Unique Off-Grid

All-propane or propane/electric units (from top): The E-Z Freeze 21SS; Diamond Elite 19-cubic-foot model; Norcold 1210 Ultraline three-way; and the Unique UPG18.

With propane units, such amenities as automatic ice makers, water dispensers, and automatic defrost cycles are rare or unavailable. From the moment you first light the pilot flame, ice starts forming on the interior condenser plates. As it builds up into a miniature glacier and starts creeping ominously, it's also impacting cooling efficiency and increasing your propane use. The only way to make the glacier recede is to remove the food (to some place that will keep it cold), fill pots and pans with hot water, and close them inside. As the water cools, this process is repeated—usually all day. You may have to do this two to three times a year,

Propane Fridge Safety

Propane refrigerators have no moving parts, and are very reliable and quiet. There are some from the 1930s that are still operational today, and have a cult following. But in 1990, the Consumer Product Safety Commission ordered one manufacturer (Servel) to recall all propane refrigerators manufactured between 1933 and 1957, pay consumers for their disposal, and send the owners a giant orange "Killer Fridge" sticker for the door—plus a $100 check for their trouble. Why? More than 22 carbon-monoxide (CO) poisoning deaths had been reported in the United States (and more in Canada) from emissions from these refrigerators.

The problem was simply lack of maintenance—when propane fridge burners and chimneys get fouled, CO can be produced. And while it's not difficult to find RV shops with the special equipment and training needed to service and maintain modern three-way RV fridges, it's very difficult find anyone willing to work on the old Servels or even modern full-size units, especially in remote areas. And unlike in an RV, you can't easily drive a full-size propane refrigerator or freezer to the service shop.

New propane refrigerators are safe and rarely need maintenance, but a burner and chimney cleaning periodically by the homeowner is required, and the seller can direct you to the closest service technician if you think something is going awry. Most importantly—always have a CO detector in the same room as your propane refrigerator, and indeed in every room of the house where any propane appliance is located! In Canada, propane refrigerators and freezers are required to have an integral CO detector that shuts the unit down if CO levels in the room get too high.

Courtesy Dometic

web extras

"Off-Grid Appliances—Ultra-Efficiency Required" by Ian Woofenden in *HP140* • **homepower.com/140.106**

"Converting a Chest Freezer to a Refrigerator" from Build-It-Solar • **bit.ly/FreezerConvert**

American Council for an Energy-Efficient Economy •**aceee.org**

Enervee • **enervee.com**

depending upon the humidity and how often you open the door. Some modern propane refrigerators have a defrost setting that bypasses the cooling system and sends burner heat directly to the compartment plates, but this still makes for a long defrosting process.

Don't even think about jabbing at the condensers with a screwdriver or other tools to knock the ice loose—you are likely to puncture the coils, thereby ruining the fridge or freezer. You can use an electric hair dryer and complete the task in couple of hours. But if you are off-grid and can't spare the hair dryer's 1,500 W, it's hot water for you. Watch your toes.

Small rural gas cooperatives may deliver to your off-grid location—and also disclose their prices. I recently switched to a rural company after years buying fuel from one of the biggest national propane corporations. The corporate rate was $3.76 a gallon. The cooperative charges $1.79 a gallon, delivering to exactly the same location.

Portable propane tanks are an option, but you'll be doing a lot of work swapping out tanks, even with an automatic tank-switching device. A full-size (19 cubic feet) propane fridge/freezer will burn through 1.5 to 2 pounds (0.36 to 0.47 gallons) per day, and possibly more depending on your ambient indoor temperature.

Three-way propane refrigerators, which can use propane, 120 VAC, or 12 VDC, are common in RVs, come in compact sizes, and may seem like a flexible off-grid option. Some can automatically switch between the energy sources depending on what's available. But don't be fooled—these units work fine with propane, but are all very inefficient when used electrically. They do not have high-efficiency compressors and instead use an electric heating element in lieu of the propane flame. They are intended for use in an RV or boat with a 120 VAC shore power connection, or for short periods of time on 12 VDC until you can go to town and get your propane tank refilled.

With all that said, propane refrigeration can still be an excellent option—and sometimes the only option—for homes, cabins, and RVs with smaller (or non-existent) off-grid power systems. If a home doesn't already have a large PV system and battery bank, installing all that equipment just to have electric refrigeration may not make much sense.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Clean Conduit Installation

by Sean Chastain


Sean Chastain

The solar world is dominated by news of the latest, greatest modules, easier-to-use and more streamlined mounts, and the newest inverter technology. But what is often overlooked is everything in between—like wiring and conduit.

While there may be exposed conductors behind the modules, once PV circuits leave the array, conduit becomes a necessary part of each project—the raceways protect source wires and inverter outputs from damage. It protects our homes and families from the inherent dangers of electricity. When poorly implemented, conduit can turn an install into an eyesore. Well-done conduit, on the other hand, can set your installation apart from others.

Site Assessment

The initial site assessment will help determine array placement and size, and identify limitations of the installation. Once array and balance of system (BOS) locations are determined, potential conduit runs should be investigated. The primary considerations are overall aesthetics, creating the most efficient runs, and adherence to the *National Electrical Code (NEC)*.

Assessing a raceway must be done before a design is finalized for several reasons. Wire size is dependent upon conduit length and temperature differentials along the route, and in turn conduit size is based on the type, size and number of conductors within (watch for a future article on conduit sizing). If these factors are not considered, the project may be completed with conduit too small for the correct wire size or wire too small for the installation.

Roof Mounts. When faced with a typical roof-mount installation, the first step is to check for attic access. While checking structural support for the array, a raceway path should be determined. Attics are often somewhat open and can present a pathway to the BOS equipment. If you are lucky, a chase will lead directly to the area where the inverter is to be located. However, you may be working with a vaulted ceiling that cannot be penetrated, or with multiple attics with no access between, which will require routing external conduit.

BOS location must be *Code*-compliant first and foremost, but aesthetics must also be taken into consideration. The logical place to mount equipment may be in the worst possible area visually.

Pole Mounts. In determining conduit runs for a pole mount, the type of mounting system makes a difference. Many pole mounts have hollow bodies in which wiring can be routed to a junction box at the mount's bottom. Other poles are NEMA-rated to allow wiring to be spliced inside the pole body. If the pole is rated to contain wires, then they can be used with internal conduit. Most often, they are not and require external conduit. In areas where moisture is not an issue, but sharp edges are, split-loom tubing is necessary. To protect wires inside a pole, ensure bushings are used on all fittings. Split-loom tubing may be used near sharp edges for additional protection. If access to the pole is not available, however, conduit may be installed on the outside of the pole to take source wires to the BOS equipment.

Ground Mounts & Awnings. Ground mounts, awnings, and pole mounts typically have the same conduit goal—take wire from the modules or junction box through a trench to the

Sean Chastain

Getting off the roof is usually one of the trickiest maneuvers. Here, a roof penetration comes through the eave. Then, using an LB and a sweep, EMT is routed cleanly along the home's architectural lines. If a downspout cannot be followed, use the existing trimwork as a guide.

Sean Chastain

Left: Wires can sometimes be routed inside a pole mount. Or if not, attached to the outside of the pole.

Ben Root

Right: Pole mounts and ground mounts often require trenching back to the BOS or main distribution panel. Here, due to the 360° rule, a pull point will be covered with an in-ground box.

Three-quarter-inch conduit, left to right: Liquid-tight flexible nonmetallic conduit (LFNC), liquid-tight flexible metal conduit (LFMC); flexible metal conduit (FMC); rigid metal conduit (RMC); electrical metallic tubing (EMT); and polyvinyl chloride (PVC), schedule 80 and 40.

BOS equipment. Should the BOS equipment or disconnects be located at the array, routing conduit between equipment will be a concern. Knowing where the BOS components are located, the trench location, and the array string layout will be extremely important in determining conduit routing.

Types of Conduit

There are several raceway options, but determining the correct one for a specific application is important.

Electrical metallic tubing (EMT) is the most common raceway for PV installations. It is lightweight, easy to cut and bend, relatively inexpensive, and approved for wet locations. An advantage of EMT over other raceway choices is that it comes in straight 10-foot sections and clean bends are easily made with an approved bending tool. The rigidity of EMT can make it difficult to work with in tight spaces and bending does take some practice. Thankfully the price of EMT allows installers to make a few mistakes even if several sticks find their way into the scrap bin, with standard sizes being only a few dollars per stick.

Flexible metal conduit (FMC). When working in a dry location, such as inside an attic or along interior walls where routing conduit is difficult, flexible metal conduit (FMC), also known as "flex" or "Greenfield," is a good choice. FMC does have some downsides, notably that it cannot be used in battery storage rooms where corrosive gases may degrade the wire, is not rated for hazardous locations, and cannot be used in high-traffic areas prone to impact, as FMC may easily crimp or break when force is applied. Aesthetically, FMC tends to sag on horizontal runs, especially under the weight of the wire. It must be strapped every 4.5 feet and within 1 foot of conduit terminations. When pulling wire, FMC is prone to unwinding or pulling loose from compression fittings. Although the *NEC* does not specify, some jurisdictions allow only 6 feet of continuous flex, as it may lose its bond to ground. It is worth checking with the authority having jurisdiction (AHJ) before installing FMC to determine if this is enforced.

Liquid-tight flexible metal conduit (LFMC) is similar to FMC, but with a sunlight- and water-resistant flexible PVC jacket. If routing conduit in a wet location is difficult due to limited space or tight turns, LFMC can make routing much easier—90° fittings are available for tight knockout locations and this conduit can be buried. Just as with FMC, LFMC can sag easily. The coating also has a tendency to become discolored and mildewy when exposed to humidity and weather, sometimes within only a few months of installation, compromising aesthetics.

Polyvinyl chloride (PVC). Where conduit comes in contact with the ground or areas prone to corrosion, PVC conduit is the standard choice. For burying conduit, large-gauge wire, and conduit sizes 2 inches and above, this will often be your first choice. Inexpensive, relatively strong, somewhat flexible, and resistant to moisture and corrosion, PVC boasts a high

Raceways, Conduit, Tubing & Schedule

While these terms are often used synonymously, they do have different meanings.

Raceway is the channel in which wires, cables, or busbars travel. Conduits, tubing, boxes, wire-ways, and gutters are all raceways.

Although the *National Electrical Code* does not define the difference between conduit and tubing, they are technically not the same. Tubing is typically a thin-walled raceway measured by the outside diameter of the tube. One-inch EMT, for instance, will be exactly 1 inch across. Tubing is often limited to diameters that are 4 inches or less. Conduit, on the other hand, is measured by nominal pipe size (NPS). Up to size 12, the NPS denotes the approximate interior diameter, or bore, of the hole. Above size 12, the NPS denotes the outside diameter. The thickness of the pipe wall is referred to as its "schedule." The higher the number, the thicker the wall. In the field, "conduit" is most often used to mean both conduit and tubing.

Sean Chastain

Bending EMT takes the right tool, and a little practice.

The 360° Rule

The *Code* stipulation that most often affects conduit is the 360° rule. If the number of bends in a raceway approaches 360°, a conduit body (LB, LR, LL, UB, C, or T) or junction box must be included to continue the run. It is good to plan for these pull boxes or bodies before installing, rather than trying to fit one in somewhere in the run or, even worse, after wire pulling has begun. While it may seem possible to pull wire through more than 360°, it may cause stress on the wire over a long pull.

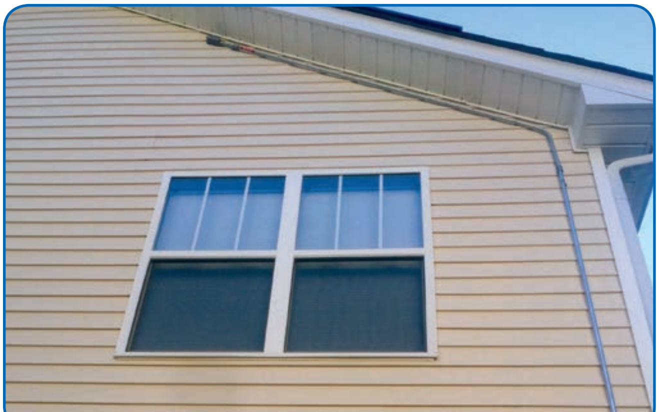
Ben Root

compression strength, while being lightweight, easy to cut, and easy to use. In areas exposed to large temperature swings, PVC is vulnerable—it's prone to sagging when hot and may become brittle when cold. Bends must be premanufactured or made by equipment listed to heat the pipe and bend at an approved radius. PVC may not be used inside of a dwelling for PV system DC circuits, as it is not metal-clad to protect wires from damage.

Rigid metallic conduit (RMC) is threaded steel metallic pipe, most often used for direct burial or in highly corrosive locations (near salt water, corrosive gas, or industrial chemicals). Areas prone to physical damage—such as industrial/commercial applications where forklifts, trucks, or other large equipment are used near the walls; areas where materials are stacked; or service entrance mastheads—are also good candidates for RMC. This conduit should only be used when absolutely necessary because it is considerably more expensive than EMT, heavy, and difficult to bend.

Romex, or nonmetallic-sheathed cable (NM) as defined by the *NEC*, is the standard, non-conduit wiring method in buildings today. In systems using microinverters or AC modules, Romex may be used inside of a building. Since

Exiting the attic at the gable end, this conduit follows the roof pitch and drops down the corner of the structure.



Sean Chastain (2)

Discretely following the bottom of the siding, this conduit turns a tight corner using an LB conduit body.

it is not covered by a metallic protective coat or rated for wet locations, Romex cannot be used for PV DC circuits or inside of raceways exposed to the outside of a building, with THHN/THWN-2 (in appropriate conduit) being the preferred wire for DC voltage and typical PV conditions.

If one type of conduit does not fulfill the needs for the run, a threaded coupler can connect two different types of conduit. It may be necessary to ground both sides of a long metallic conduit run when changing over to ensure a good bond to earth.

Conduit Aesthetics

The human brain interprets visual signals based on pattern recognition and creates an image. Anything that appears askew will draw attention, and seem out of place. This is important to remember when running conduit. What often catches someone's eye is a kink, loop, odd angle, or anything else that looks amiss. The brain thrives on symmetry, sharp lines, and clean angles. The goal should be ensuring your work stands out by blending in.

Following straight lines should always be the end goal. Imagine a working space as a plane broken up into vertical and horizontal grid lines. Every structure is inherently built using these lines, and a raceway should follow suit. Any bends, saddles, or offsets should find their way parallel or perpendicular to the original reference line. A level and tape measure are invaluable tools in keeping these lines straight and plumb.

An example of a neat EMT run to a J-box (which serves as the transition point from exposed array wiring to conductors in conduit), illustrating clean 90° bends and straps that support the run.

Sean Chastain (2)

Left: Please don't. This is a recipe for trapped ice and debris, and stress on the conduit and wire.

Above: Well-routed EMT follows the rafter layout and is 10 inches below the roof deck.

Right: Poorly installed FMC wanders through the attic.

Sean Chastain (2)

Blending conduit into a structure is aesthetically the best option. Instead of running conduit down the face of a wall, use existing features of the structure as a guide. Tucking in beside a downspout, along trim, below siding, along a rafter, behind barge boards, or beside existing conduit will keep the run more discreet. When conduit becomes the main feature of a space, it becomes the focal point and draws unnecessary attention.

Regardless of what type of conduit you choose, check that all turns are neat, even, and do not fall below the minimum bend radius the conduit manufacturer or *NEC* dictates. For example, sharp bends in EMT will kink, which not only looks bad but decreases the fill capacity of a raceway. FMC and LFMC can be stressed or break when turned too sharply, causing an edge, where ground faults may eventually result.

To ensure your raceway remains straight and supported for many years to come, conduit must be properly strapped. The *NEC* dictates guidelines for fixing each raceway type, but these are only minimum requirements. Strap material must match the type of conduit used. Double-check that straps are listed for the specific purpose to prevent galvanic action, rust, and discoloration. Ensure the straps are properly secured with screws or anchors appropriate for the application.

Routing Conduit

Attics. The attic is the most overlooked part of the run, often hidden from view and considered less important. What defines a good installation is treating each aspect of a project seriously. In attics, EMT and FMC are most commonly used—EMT is inherently straight with less strapping and FMC is easy to route to your roof penetration. The primary focus is following or moving perpendicular to the rafters, a support wall, or truss; or along the attic floor or wall studs. While a diagonal run in the most direct route will be tempting, lines

Through the soffit, or directly down and through the roof, is a good way to get out of the attic.

then suffer and conduit will appear sloppy. Raceway *Code* violations are common in attics, with the 360° rule quickly coming into play while routing to the point where the conduit protrudes through a plane. Although not included in the 2014 *NEC*, the *International Fire Code (IFC)*, adopted by many jurisdictions, requires the attic conduit to be greater than 10 inches from the roof surface.

From Attic to BOS. Taking wires from an attic to the BOS, usually requires stubbing out of the attic to an exterior wall. Should the inverter be located on a wall that is shared by the attic, the penetration is much easier. Routing as close to the corner of the wall as possible will keep your conduit away from the center of the exterior wall once it stubs out. If the goal is to reach a wall below the pitched section of the roof, penetrating the soffit can be the best option.

Soffit penetrations can be difficult due to limited working space. On a shallow roof, working space is limited to a few inches, making it difficult to connect and properly tighten a fitting. If possible, bending a piece of EMT to match the roof pitch will allow conduit to be pushed through the soffit and over the joist plate from the exterior. If FMC is to be used in the attic, the FMC can be connected with a threaded coupler and a short piece of EMT, then dropped through the soffit from the attic. Attics can be hot and cramped, so anything helps that can speed up the process without sacrificing quality.

Navigating around a wall is more straightforward, but conduit must remain discreet. If a stub-out cannot be successfully pinned in the corner of an attic, it is best to follow the roofline to the corner of the wall nearest the roof, taking the raceway to a downspout, corner trim, or next to existing conduit. If a roof pitch is 27°, subtract the pitch from 90° to determine the proper bend—63° in this case—to follow the roofline and end vertically on the wall.

The final BOS location determines how a raceway is positioned across a wall. If the inverter is near the conduit drop, a turn can be made directly into the inverter and terminated. If the inverter is further along the wall, however, conduit will need to drop down lower on the wall to prevent a run that visually takes up a large span of wall space. With siding, a raceway ideally would drop down just below the bottom piece of siding and across, following the natural line of the siding. On brick, it is a good idea to cross to the BOS equipment 1 to 2 feet above the ground. Leaving the raceway low on the wall allows the wall face to remain uncluttered.

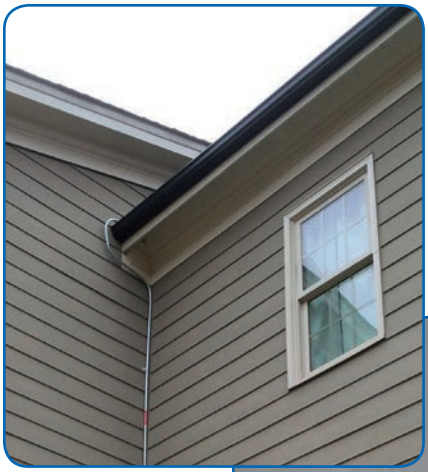
Crawlspace. If the BOS is located on the other side of the structure from the external conduit run, get the grubby clothes and grab a flashlight, because a trip to the crawlspace may be in your future. EMT or LFMC is usually used in crawlspaces, since these locations are prone to moisture and

Following an inside-corner wall, then the top of the stem wall, keeps the runs to the BOS clean and professional-looking.

Sean Chastain (4)

Above: Conduit routed through a crawl space, following the joists.

Right: Junction boxes must not be hidden in walls; this exterior cover will show after the drywall is finished.



Left: a shepherd's hook gets off the roof without a penetration; ideal for situations without attic space.

Right: A flashed and caulked boot roof penetration can transition into the attic or through to the eaves when a vaulted ceiling is present.

temperature swings. Just as with an attic, crawlspace conduit should run parallel or perpendicular to existing supports to keep the pathway neat. When installing a raceway in new construction or an unfinished wall that will be finished in the future, conduit should be routed on the inside of wall studs. This is a good opportunity to run conduit directly to the BOS location and, if the wall is going to be finished, provides the cleanest possible run. Remember that conduit bodies and junction boxes cannot be hidden behind a finished wall. If a pull box is required, a listed junction box with a cover must protrude from the wall so it will not be covered by drywall, much like a typical home outlet. It also must be installed at the appropriate depth for the drywall to be installed, and properly labeled as a PV circuit.

In rooms with finished walls, an important decision must be made—run conduit across the finished wall or cut through the drywall to install conduit behind. It all depends on the end user's preference. In a basement, closet, or low-visibility area, it may be easy to run conduit across the ceiling or wall. In other areas, however, it may be time to pull out the drywall saw and putty. Removing a section of sheetrock large enough that the hole stretches across at least two wall studs will allow ample space for installation of conduit and two secure points to reattach the piece removed.

Vaulted ceilings or flat roofs with no attic access pose another issue where external conduit may be the only option. Roof boots may be used in this case, allowing access through the eave to the sidewall directly from the roof. These boots must be appropriately sized, flashed, and sealed, as they are prone to leaks. For warranty purposes, it may be worth consulting with the roof contractor to handle the penetration and its sealing. A shepherd's hook, or conduit with two back-to-back 90° bends in an "S" shape, is another common option. If the wire must drop a great distance from the roof, however, a shepherd's hook may place too much weight on the conduit body and unnecessary stress on the wire after thermal expansion. Fittings are available to provide a strain relief inside a conduit body, which can ensure minimal movement of the wire over time.

Out of the Ground. Typical applications involving conduit burial will use PVC to protect source wires. A minimum of schedule 40 PVC may be used in the trench, which must be at a depth of no less than 18 inches under normal circumstances—unless otherwise dictated by the AHJ (check *NEC* Table 300.5 for depths). When stubbing up, or bringing conduit into and out of a trench, schedule 80 must be used between the trench depth and where the conduit exits the ground. In fact, even when direct burial cable is used, schedule 80 conduit must be used to protect the wire as it exits the ground. Coming out of the ground, conduit can ideally be routed directly into the bottom of the BOS equipment or a junction box. Expansion joints, which account for earth movement and thermal expansion, may be required where conduit leaves the ground. Should turns be required, it is necessary to follow the natural lines and ensure clean bends.

Go for Gutters

If your installation contains more than one inverter and several pieces of BOS equipment, a gutter trough is a good option to tie everything together. Troughs allow all wire routing to take place inside one accessible box, and conduit can neatly stub straight into a knockout for each piece of equipment. Troughs can be expensive and must be properly sized depending the size of conduit entering the box. Keep in mind that the 2014 *NEC* (section 690.31(B)) dictates that inverter input and output (DC and AC) circuits must be separated by a partition inside the trough. This can be accomplished by purchasing a partition specific to the trough, which can be expensive, or by fabricating one from insulated material or bonded metal. Of course, this depends on what the AHJ will allow.

Sean Chastain (3)

Poorly routed and sloppy arcs of LFMC affect the aesthetics of this BOS area.

The inverter and BOS are the perfect place for clean conduit work. Here, strategic component placement and clean sweeps make the installation look professional.

Connecting Equipment

Often the most visible part of conduit installation, the routing between BOS components will take some time and creative thinking to ensure it is well-executed. Making these raceway connections clean and neat can present several challenges, but is just as aesthetically important as the equipment mounting.

When mounting equipment, the installer must first determine how boxes will be staged. If a straight raceway is a primary concern, equipment will be mounted with side knockouts level between boxes. If an offset is necessary, however, enough working space must be provided to make a proper bend without stressing conduit between, ensuring fittings and locknuts are flush against the box. Often, this type of mounting is best accomplished by mounting one box, securing conduit to that box to the desired length, connecting an unmounted box to the other side of the raceway, and then securing that box when the conduit is level. It is recommended to have a level on the conduit and the box to ensure one is not askew.

If the decision is made to mount equipment so the tops or bottoms are level, all boxes will be mounted before conduit is formed. Boxes are often minimally spaced to emphasize the overall look of level equipment. This can require accurate conduit bends to meet knockout locations or call for the use of FMC/LFMC. For equipment of similar size, a "U"-shaped bend will provide the connection between the two boxes, as different boxes rarely share level knockout locations to allow for a short connection. Should equipment sizes vary, a 90° bend can reach the side knockout of the larger and bottom knockout of the smaller box, maintaining a clean look. Using a carbide or uni step-down bit can also allow straight conduit between boxes if internal components and manufacturer specifications allow.

Tightening Locknuts

Locknuts are used to secure conduit fittings when they enter a box. To properly tighten them, the most common method used is a simple tool every installer should have—a flathead screwdriver. With the flathead tip on the locknut, tap the end of the screwdriver with a hammer, turning the locknut until it is tight and bonded to the box. Alternatively, locknut wrenches can be used to grip the nut and turn it until tightened.

Sean Chastain (3)

Neatness Counts

You wouldn't install an array without squaring up the rails or hang an inverter without a level. Likewise, you should take pride in a conduit run to ensure it adds to the overall project's aesthetics. Running conduit is easy. Making conduit look great is easy too, but does take some forethought and time to do the job properly, ensuring *Code* compliance, safety, and adding to the overall appeal of the project. By choosing the correct raceway for a specific application, keeping straight lines, and blending conduit into the overall aesthetics of the structure, your conduit will add to the overall quality of the project and owner satisfaction.

Grounding & Bonding

by Ryan Mayfield

A favorite topic for PV installation professionals, or anyone in the electrical trade, is grounding and bonding. That the topic is one of the hardest to effectively navigate within the *National Electrical Code (NEC)* leads to fun and, sometimes, heated debates. We're moving closer to the adoption of the 2017 *NEC* for a number of jurisdictions—so let's discuss some of the biggest impacts of the *Code* affecting PV installations.

Grounding and bonding has been covered in many previous "Code Corners," including *HP149, HP152, HP153,* and *HP155*. Each of those articles has good background information to better understand *Code* definitions and rules specific to PV installations. In *HP149,* for example, the definitions for the different types of grounding and bonding conductors are discussed to help differentiate requirements.

Changes in inverter and module-level power electronics have made navigating the grounding and bonding requirements for modern PV arrays difficult as we have moved away from technologies that were prominent when the 2014 *Code* was written. For example, back then, the majority of the grid-tied PV systems used inverters with isolation transformers. These transformers isolated the AC and DC sides of the system and required the need for a DC grounding electrode system as defined in 690.47(C). Since that time, non-isolated inverters have become the norm, changing the need for DC grounding electrodes.

Equipment Bonding Requirements

Now that transformerless inverters constitute the majority of grid-tied PV installations, the requirements for grounding and bonding require closer examination. In 690.43 of the 2014 *Code*, subsections A through F outline the equipment-grounding requirements and 690.45 dictates the size of the grounding conductor. Regardless of system voltage, there is a requirement that "all exposed non-current-carrying metal parts of PV module frames, electrical equipment, and conductor enclosures shall be grounded in accordance with 250.134 or 250.136(A)." All of the metal components need to be bonded together. This equipment grounding eliminates the difference in voltage potential, thereby reducing the shock risk. This requirement pertains to systems both with and without an isolation transformer in the inverter.

Section 690.43 lists the rules for bonding the different components and the acceptable components that can be used. Since the inclusion of racks that use mechanical attachments to also make the module-to-rail bond under UL standard 2703, this aspect of the installation has become much easier for installers. One section that may trip up installers is 690.43(F), which requires that an equipment-grounding conductor (EGC) be run with the circuit conductors when they leave the array vicinity. Common mistakes are running the EGC exterior to a conduit containing circuit conductors or in a different path from the conductors.

Section 690.47 ("Grounding Electrode System") may be confusing for installers working with non-isolated inverters. This section is divided into four subsections. Prior to the widespread use of non-isolated inverters, installers focused on subsection C, since it pertained to systems using inverters with isolation transformers. "Code Corner" in *HP155* focused on how to meet that subsection.

For PV systems with non-isolated inverters, the requirement for DC grounding electrode conductors is eliminated, effectively making 690.47(C) inapplicable. But what is required to comply with this section when using non-isolated inverters?

A look back to 690.47(B) helps. The first sentence of 690.47(B) refers you back to 250.169 for ungrounded systems. But when you read 250.169, the section applies to separately derived systems. Going into the definitions of the *Code*, a non-isolated PV array does not meet the definition of a separately derived system—therefore, 250.169 does not apply and this grounding electrode conductor is not required.

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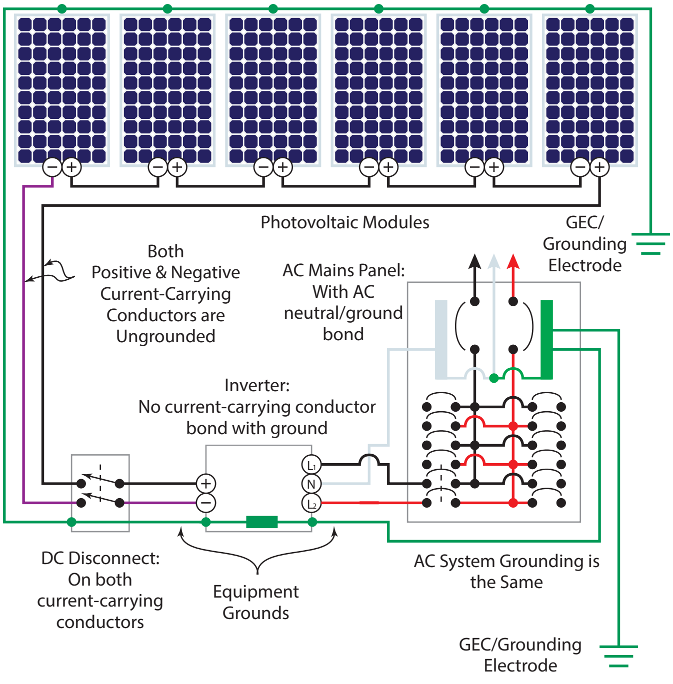
Grounding in a System Using a Non-Isolated/TL Inverter



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In the 2014 *Code*, a third paragraph was added to this section to cover ungrounded PV systems: "An AC equipment-grounding system shall be permitted to be used for equipment grounding of inverters and other equipment and for the ground-fault detection reference for ungrounded PV systems." Since the DC side of a non-isolated inverter has no connection to the grounding electrode, the need for the DC grounding electrode conductor is eliminated and we can use an EGC bonded to the AC grounding system to complete this connection. This is further solidified in the 2017 *Code* in which section 690.47 was edited for clarity. In the 2017 edits, the connection of the array and PV system output EGCs are explicitly called out for connection to the AC ground. We will include a deeper analysis of these 2017 changes in future "Code Corners."

The final subsection of 690.47—(D) "Auxiliary Electrodes for Array Grounding"—is likely the most contentious within the industry. Very few people defend this section and thus only a few call for its absolute use in PV installations. The subsection starts with saying "a grounding electrode shall be installed in accordance with 250.52 and 250.54 at the location of all ground- and pole-mounted PV arrays and as close as practicable to the location of roof-mounted PV arrays." The reference to 250.52 sets the requirements for grounding electrodes, such as concrete-encased electrodes and ground rods, along with other permissible electrodes.

The 250.54 reference makes it muddy, since this section outlines the requirements for auxiliary grounding electrodes. This is a permissive *Code* section, meaning that it uses the language "shall be permitted," and is not an absolute requirement. In addition, 250.54 states that this auxiliary electrode is not required to meet the requirements of a standard grounding electrode system. In the first few words of 690.47(D), we are required to install an electrode that is, by definition, optional and that doesn't have to meet the standards of the other electrodes installed at the premises. And for roof-mounted arrays, this is supposed to be in a location that's only vaguely defined.

The section defines the size of the grounding electrode conductor from the array to the grounding electrode. It allows using the structure of a ground or pole-mounted array as the grounding electrode if it meets the requirements of 250.52, or the use of the metal frame of a building or structure if it meets 250.52(A)(2) for roof-mounted arrays. The section concludes with two exceptions that can be interpreted so many ways that most people discount them as viable solutions.

Originally introduced in 2008, this *Code* section was noticeably absent in the 2011 *Code*. Its reappearance in 2014 was surprising, as it doesn't seem to solve any safety issues. In fact, it seems to create more potential problems, particularly for roof-mounted PV arrays because the *Code* requires a grounding electrode connected directly to a PV array frame. In addition, EGCs are still required to bond that same rack back to the inverter, which will be bonded to the existing grounding electrode for the building. Problems could arise, however, if this new PV grounding electrode is on the opposite side of the building from the existing grounding electrode system. If there is any voltage difference between the two electrodes, an induced current could flow up to the PV array and back down to the electrode with the lower potential. In lightning-prone areas, this could result in current flowing when it otherwise wouldn't and cause unintended problems like current flowing in the EGC conductors.

Between the hard-to-follow language and the potential risk introduced, it is no surprise that most installers shy away from installing this electrode—and many jurisdictions don't require it. In the 2017 *NEC*, the requirement did not disappear but rather became so watered-down that it may not be given consideration by installers and jurisdictions—at least for roof-mounted arrays. The biggest reason is that the language changed from being a mandate ("shall be installed") to being permissive ("shall be permitted to be installed").

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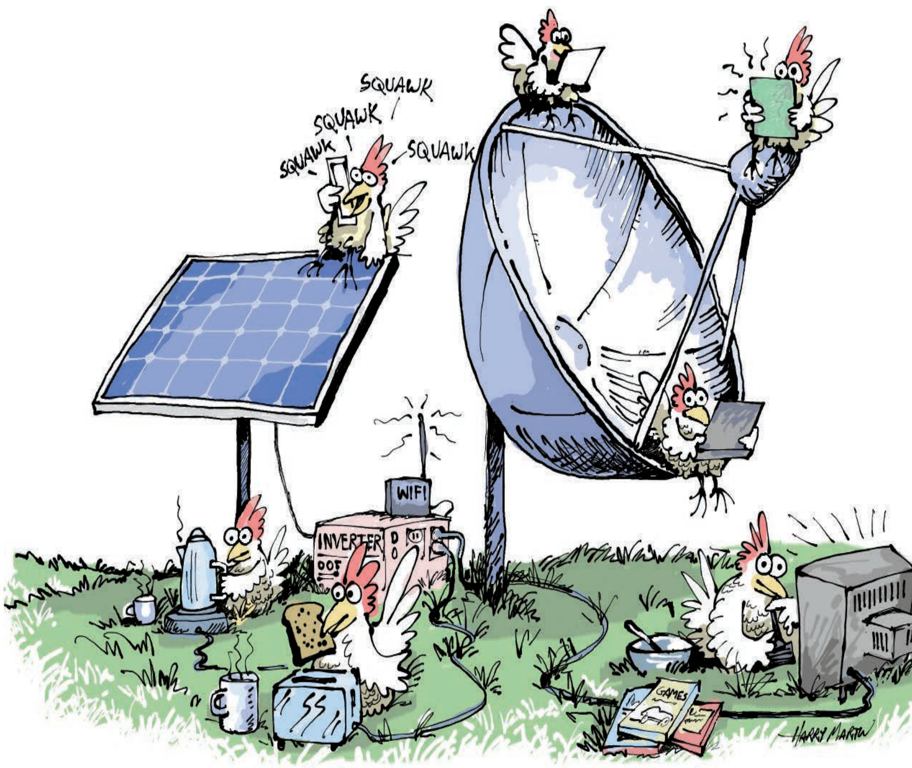
Off-Grid, On The Grid

by Kathleen Jarschke-Schultze



Through Facebook, I reconnected with an old friend from our junior high school Science Club. He recently posted that he would like to just "go off the grid." I happily commented back that I had been living off-grid for 31 years and it was not as hard as one might assume. Another of his friends responded that he would just like to drop off the grid also, and become invisible to data miners, advertisers, databases, and social media. Then, I realized, they were talking about the information superhighway grid—which, ironically, my husband Bob-O and I are fully connected to.

Multigrid

Our homestead is very rural—so rural that we have created a PDF map that we send to people who are coming to visit us so they can more easily find their way. Several years ago, dear friends from Manhattan's Upper East Side were visiting for a couple of days here in our wild paradise. They live a few blocks from Central Park in an apartment building with a doorman, and our country life was the closest my friend wanted to get to camping.

On the third day of their visit, they asked me what was the longest stretch of time I had been home without going to town. My answer was a little over a month. They were shocked—they thought I was going to say four or five days, not weeks. Bob-O and I only go to town for a reason—and never for just one thing. We keep a running list in the kitchen and before we leave for town, one of us takes the list and the other takes a picture of it with our phone. Then the list can be texted and referred to easily.

So being connected to this other grid—with access to social media, online shopping, and search engines—has changed our lives. When we joined Facebook, our social circle expanded immediately. I connected with friends who I last saw throwing their caps, shouting and running for the exits in the warm evening air at our 1972 high school graduation in Napa, California, where I grew up. Before Facebook, I would think about those people occasionally and wonder what paths their lives had taken. Now I know.

I also see many of the activities of my grandchildren, nieces and nephews, cousins, brothers, sisters, and friends. I belong to cooking groups, farming groups, gardening groups, beer geek groups, and political groups. I may not leave my home, but I visit with people I care about every day. I am an armchair traveler on all my friends' trips. It is truly wonderful.

There have been emergencies—wildfires, storms, flooding, and such—that this grid has helped us deal with. Two weeks ago, our local grapevine used social media to rally help for evacuating people and livestock in the path of a fast-moving wildfire. Offers of trailers, pasture, secure storage, and places to stay for displaced people and animals were posted in real time. Houses were lost, but no people or animals. This was because information was immediate—there was no waiting for "film at eleven." Five days ago, another wildfire took off, jumping a river and spreading fast. Offers of help and real-time updates, sometimes with photos, kept us all connected.

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Gridding

Before we retired, I was the office worker for our business—the voice at the end of the 800 number. So, weekdays I was here. Bob-O was out on installation jobs that took him all over our region of northernmost California and southern Oregon. When the weekend came, he was eager to work on our own home projects he had to put aside during the week. Because he was out in town all the time, he would pick up whatever we needed before coming home.

We try to shop locally when possible, but we do shop online and have for years. Package delivery services know where we are and will deliver to the house. If the purchase is big enough to be hauled as freight, we have to drive the 2 miles down to the pavement and meet the truck there. Then we can transfer the goods into our truck and head home. I'm afraid that if an item has been banged up in transit, it is always a mess to try to send it back at that point. That is why the side of my last washing machine had a dent in it.

My favorite way of shopping online is when you can buy something and have it delivered to the store. All the big hardware stores do this. It can really widen your choices when looking for just the right appliance or building material.

One recent example was when we needed a new dual-flush toilet to replace our old model. The old 1-pint flush model had no tank, so it sat very close to the wall. When we refurbished the bathroom, we used kitchen cabinets, 25 inches deep, which now made the distance between a new toilet with a tank and the sink very tight.

Researching, finding a retailer, purchasing, and coordinating delivery all happened because of this Other Grid. I searched every online site and blog devoted to equipping tiny houses, since I wanted to know what people used when they were short on space. Finally, I found an affordable toilet that would fit in this small space. We had to order the toilet online, and had it shipped to the store for pickup. It arrived two days early and Bob-O was able to inspect it before it was loaded into our truck. This, to me, is the superior method of product delivery.

In light of this "new grid" paradigm, I'm not sure how to classify my lifestyle. When friends at parties introduce me as "Kathleen, who lives off-grid," will the person they're talking to think I'm a hermit who lives in a tarpaper shack, with no running water? Maybe I should start using just letters, OG-OTG. It is ironic that some people want to have my life, but without the electronic media—while I, having lived this rural lifestyle, have embraced it.

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Which Generator Fuel?

Engine generators have a necessary function in off-grid homes, as they are most often used to keep batteries from getting too deeply depleted during periods of low renewable resource production. Some homes rely entirely on generators for their electricity, often running them constantly or for many hours every day. But the biggest users of generators are on-grid homeowners who use them occasionally for emergency power when the grid goes down.

Most of the millions of on-grid generators are gasoline-fueled portable units that are usually used with extension cords rather than being tied into the home's electrical circuits. More sophisticated generators are stationary and use automatic transfer switches that switch some or all of the home's circuits from the grid to the generator—and can even automatically start the engine—when a home's grid power is lost. Since they stay in one spot, it's easy to connect them to a home's natural gas or propane source—gasoline would not need to be stored. But sometimes in a disaster, utility-supplied natural gas can be interrupted, making a tank of propane in the yard an attractive alternative.

For off-grid homes, generator fuel choices are usually gasoline, propane, and diesel or biodiesel. Less mainstream options, such as alcohol, vegetable oil, hydrogen, compressed natural gas, and even homemade wood gas, require additional knowledge and effort, and are rarely used.

Gasoline is a highly volatile liquid that requires storage, but will also degrade over time. If left sitting in a generator's carburetion system, gasoline can gunk up the works and make the unit unreliable—though simply running the carburetor out of fuel after each use will prevent that. For standby use, siphoning gasoline out of your vehicle can usually provide enough fuel for a generator that's run only occasionally. There are many more gasoline generators available than any other fuel type.

Diesel fuel is not as volatile, but still is flammable. It can also degrade over time when no stabilizers are added. Moisture in the fuel is a common problem with diesel storage, as is the potential for filter-clogging algae growth. At low temperatures (about 10°F), diesel fuel becomes more viscous, causing flow problems. **Biodiesel** is similar, plus, it may separate if it is not well-made. Depending upon the original oils or fats used, it can gel at a higher temperature than petrol diesel—around 32°F. Some diesel-style engines do not do well with biodiesel because the fuel can deteriorate some types of seals and hoses. Check with the manufacturer, but seals and hoses can be replaced with Viton counterparts to take care of this problem. Diesel-style engines are generally more powerful than others, but are often noisier.

For off-grid generator use, by far the most popular fuel is **propane**. It is easy to store in large quantities, and is often already at a homestead for cooking and, sometimes, space heating and to run a refrigerator. The advantages of propane relative to gasoline are a cooler-running engine, which saves wear and tear. Plus, the fuel does not degrade over time. Propane generators are usually quieter and run cleaner than their gasoline or diesel counterparts. But their reduced noise also comes with providing a little less power. Kits are readily available to adapt gasoline generators to use propane.

What do I use at my off-grid home? I use the no-fuel plan. I dislike generators and made the decision many years ago to oversize my PV system, so that even in the winter months my batteries get enough daily charge without relying on a generator. Once or twice per winter, during lengthy rainy spells, I stress out and question the wisdom of that decision. But so far, I haven't done significant damage to my batteries—a set of highest-quality industrial cells, now nine years old. Were I to change my mind, I already have a propane "yard bomb" that supplies fuel for cooking and water heating, so a propane generator is a possibility. But I also run biodiesel in my vehicles, and if I decided to have a backup generator, I'd probably get a diesel one.

—Michael Welch