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May & Jun. 2017, Issue 179

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The Revolution Starts at Home

Trump's "energy independence" executive order, asserts Brandon Hurlbut, former Department of Energy chief of staff, "has nothing to do with energy independence." Signed in late March, the order calls for weakening federal regulations on carbon emissions and fossil fuels under the premise of achieving greater energy independence and expanded economic growth.

But Hurlbut doesn't buy it, saying that the "administration is being disingenuous, just as they have on many other things, including the fact that he promised coal workers he would bring their jobs back. That's like saying we're going to save the VCR industry. We have moved on. We have better technology out there." One responsibility of effective governmental leadership is to drive advancements that improve citizens' health, safety, and standard of living. A second is to support its citizens with vocational retraining policies and programs that protect individuals when new—and hopefully better—technologies and industries surpass old ones.

After being an active part of the sustainability, renewable energy, and regenerative design community for a quarter-century, I find it surreal that the new administration is attempting to turn back the clock on energy progress. But this threat gives me new resolve to make sure I'm channeling my energy into positive, life-affirming projects for myself, my family, and my community—for a better future for all.

We have strategies that should supersede technological fixes—like conservation and energy efficiency. Then overlay these actions with appropriate technologies, such as high-efficiency and water-saving appliances and renewable energy systems. Finally, replicate them—household by household, and business by business. There's action to take on many fronts, but some of the most powerful ones we can implement are in our own lives and in our own homes.

My family and I are getting ready to renovate a 1965 ranch-style home that has an electric furnace that is more than four decades old, a 20-year-old water heater, R-11 walls—and $300 electricity bills. We'll first do an energy assessment, including a blower-door test and infrared imaging, to see what we're starting with; then we'll start implementing the necessary upgrades, adding insulation and air-sealing. Once we've buttoned up the house as much as possible, and replaced old energy hogs with efficient appliances, we'll do another audit. Only then will we design a grid-tied PV system to match our new load profile. Along the way, we'll also be sharing information with our neighbors and the wider community to spread the knowledge and inspiration that everyone has the power in her (or his) own hands to be an everyday agent of positive change.

—Claire Anderson, for the *Home Power* crew

Think About It...

"Joy is a radical act in a world of depressing news. A warrior's life isn't easy, but the beauty of transformative action is the great, joyful nectar that sustains us and reminds us of what is real."

—Lyla June Johnson, musician, public speaker, and performance poet


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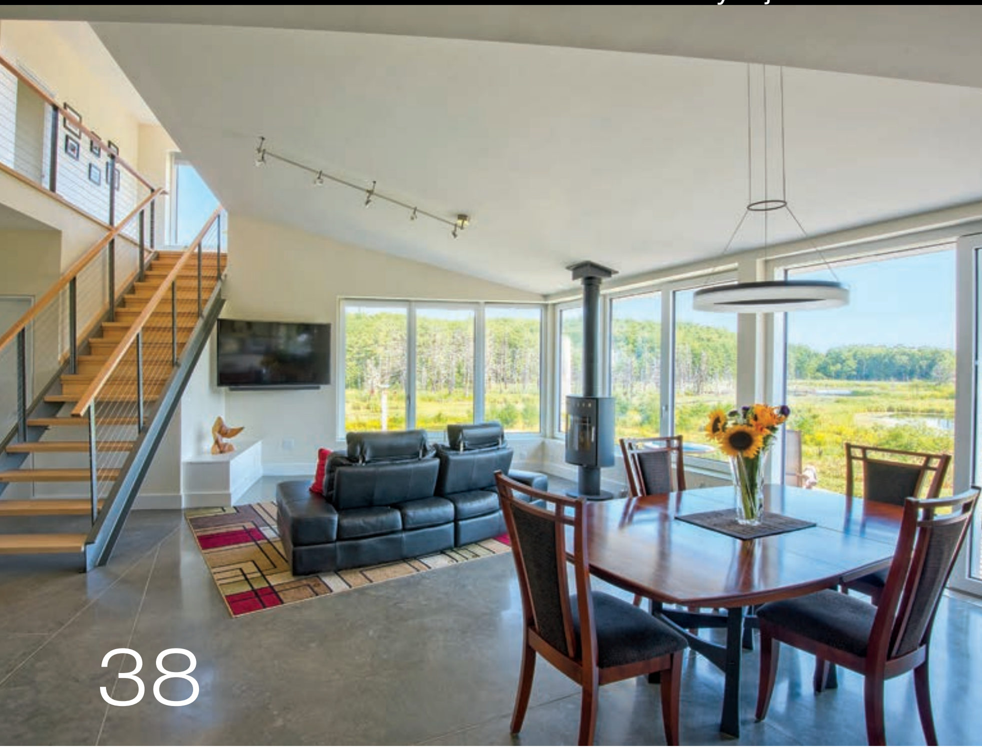

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On the Cover

Integrating with the natural environment, as well as having a small energy footprint, was the goal for this New Hampshire home.

Photo courtesy Chris Smith, Oceanexposure

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Photos: Courtesy: Chris Smith, Oceanexposure; Iron Edison; MidNite Solar

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Photos: Jim Riggins (2); courtesy Ray Hoyt

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contributors

this issue's experts

Home Power Managing Editor **Claire Anderson** is currently developing energy-efficiency and renewable energy plans for her family's "new" home—a 1965 rambling rancher. Her kids are spending their energy planning where the organic blueberries and raspberries will be planted, picking morels, and quarreling over whose room the dog will get to sleep in.

Chuck Marken is a *Home Power* contributing editor, licensed electrician, plumber/gas fitter, and HVAC contractor who has been installing, repairing, and servicing SWH and pool systems since 1979. He has taught SWH classes and workshops throughout the United States for Sandia National Laboratories, Solar Energy International, and for many other schools and nonprofit organizations.

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

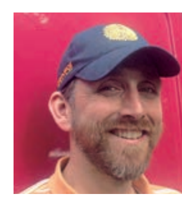
Sean Chastain is a Project Manager at Yes Solar Solutions of Cary, North Carolina. A graduate of North Carolina State University, he holds a NABCEP certification for PV installation and has completed courses through Solar Energy International, Imagine Solar, Tesla, and the Solar Center at NCSU for PV.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

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

Roland Shackelford is vice president and energy storage specialist at Renewable Energy Services, a family-owned and -operated PV system design and installation firm. Since 1992, RES has installed hundreds of off-grid and grid-connected PV systems on Hawaii Island, with a special focus on integrating energy-storage technology.

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

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



Vaughan Woodruff owns Insource Renewables, a solar contracting firm in Pittsfield, Maine. His firm, along with Assured Solar Energy, was selected to run the Solarize Freeport campaign. He is a NABCEP-certified PV Technical Sales professional, a NABCEP-certified Solar Heating Installer, and an instructor for Solar Energy International.

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

Jacob Racusin co-owns New Frameworks Natural Design/Build, offering services in green remodeling, new construction, consultation, and education featuring high-performance natural building technologies. Jacob directs the Certificate in Building Science and Net Zero Design at the Yestermorrow Design/Build School. His most recent book, *Essential Building Science*, was published by New Society Publishers in 2016.

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.

Sarah Lozanova is an environmental journalist who has experience working with small-scale solar energy installations and utility-scale wind farms. She earned an MBA in sustainable management and is an adjunct professor for Unity College. Sarah resides at Belfast Cohousing & Ecovillage in Midcoast Maine with her family.

Jim Riggins is a retired energy rater, building analyst, Energy Star partner, and EPA WaterSense inspector. He volunteers with the Colorado Renewable Energy Society and Habitat for Humanity. He and his family live in a net-zero-energy passive solar home he designed, featured in *HP141* and *HP150*.

Contact Our Contributors

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

Enphase Energy

IQ Microinverters

Courtesy Enphase Energy

Enphase Energy (enphase.com) released its sixth generation of microinverters. The IQ 6 is for 60-cell modules (up to 330 W DC), and the IQ 6+ supports both 60- and 72-cell modules (up to 400 W DC). The maximum continuous output power is 230 VA for the IQ 6 and 280 VA for the IQ 6+. Both have a CEC weighted efficiency of 97% at 240 VAC. The maximum number of units per 20-amp branch circuit is 16 and 13, respectively. These microinverters have a polymeric enclosure, making it lighter (30%) than its predecessors. Also, the new two-wire "Q Cable" system uses half of the copper, making it 50% lighter than the previous cabling system.

These microinverters are "smart-grid ready" and satisfy upcoming utility requirements like Rule 21 in California and Rule 14H for Hawaiian Electric Company. These rules are anticipated to set new standards for power factor, voltage, and frequency regulation. Additionally, like other module-level power electronics (MLPEs), the IQ series provides an easy way for PV systems to comply with the 2014 and 2017 *NEC* rapid shutdown requirements.

—Justine Sanchez

SMA America

Power+ Solution

Courtesy SMA

SMA's (sma-america.com) Power+ Solution for Sunny Boy US series inverters includes DC module-level power electronics (MLPEs) manufactured by Tigo Energy. These MLPEs are either installed as a retrofit component to select modules (the TS4-R), or with "smart modules," into which the MLPEs are already integrated. Different interchangeable covers offer various features. The TS4-S cover provides module-level monitoring and rapid shutdown capability compliant with the *National Electrical Code's* 2014 and 2017 requirements. The TS4-O covers have all the TS4-S features, plus optimization (module-level MPPT). This cover can be installed on select units (such as those on modules with shading issues).

A rooftop communications kit allows TS4s to communicate module data wirelessly with a gateway (installed at the center of the array), and uses an RS485 cable to the inverter. Up to three gateways can be daisy-chained together with RS485 cabling. For the inverter, a power supply and the Cloud Connect Advanced are included in the kit to be installed inside the inverter.

—Justine Sanchez

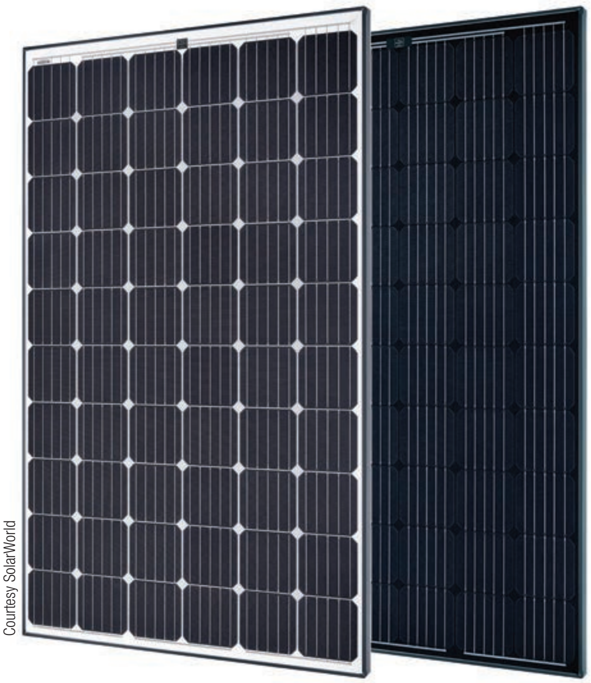
PVComplete

PVCAD Software

Courtesy PVComplete

PVComplete's (pvcomplete.com) PVCAD AutoCAD plug-in is used to create PV project designs and drawings for rooftop or ground-mounted systems. It integrates a database of module, inverter, and rack specifications. PVCAD can produce array layout options, a bill of materials, single-line drawings, wind-zone calculations, shadow modeling, and hour-by-hour production modeling via NREL's system advisory model (SAM). A full version of AutoCAD 2013 or newer is required to run PVCAD.

—Justine Sanchez



Courtesy SolarWorld

SolarWorld

Extended Product Workmanship Warranty

SolarWorld (solarworld.com) has doubled its product workmanship warranty—from 10 to 20 years—on all new SolarWorld modules. The extended warranty applies to modules shipped after January 1, 2017, and protects against defects due to production flaws. This warranty is in addition to its 25-year linear Sunmodule performance guarantee of at least 97% of initial output during the first year and to not decline by more than 0.7% per year for the remaining 24 years. Sunmodule's Protect glass-on-glass modules have a 30-year linear guarantee against annual degradation exceeding 0.35% per year after first-year losses, which are not to exceed 3%. At the end of year 30, output of at least 86.85% of initial output is guaranteed.

—Justine Sanchez

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Self-Consumption Hawaiian Style

Hawaiian Electric's net-energy-metering (NEM) program was put to rest in October 2015, and was replaced by two new programs, only one of which—Customer Self-Supply—has not reached its cap. However, under the Customer Self-Supply program, grid-connected customers are prohibited from exporting their PV-produced energy to the utility grid.

Our client, Ray Hoyt, was paying more than $5,000 a year to the utilities and hoping to reduce that by installing a system to produce solar electricity on-site. Since exporting energy to the grid was no longer an option, we designed a system using Chilicon Power microinverters. The company was among the first to manufacture inverters that comply with the zero-export requirement. A sonnenBatterie energy-storage system captures some of the solar energy so it can be used at night or during utility outages.

The sonnenBatterie system contains a "smart" AC-coupled battery-inverter that monitors PV production using a current transducer (CT) and relay. When PV system production exceeds the house loads, the battery itself becomes a load, absorbing the surplus PV energy. When the battery is fully charged, it stops absorbing energy and the Chilicon microinverters begin to throttle PV production so that it doesn't exceed the remaining household loads. As the sun begins to set or as clouds pass over the PV array, the sonnen units sense the drop in production and export energy from the battery to cover the house loads. The sonnen units have a 200-amp automatic grid-bypass that can seamlessly transfer the home's loads to the grid whenever battery state-of-charge reaches a designated low level, or if the loads exceed the battery-inverter's capacity.

Courtesy Ray Hoyt (2)

Two sonnenBatterie units provide 24-hour self-consumption of PV-generated energy without exporting to the utility.

To size the system, we installed an eGauge load meter at the property and monitored the customer's electricity usage for several weeks. We created a load profile based on that data, and then sought to size the combination of PV modules and batteries to maximize electricity offset and minimize system cost. We sized the PV array to generate enough energy to cover Ray's average daytime load. By overlaying the PV production curves and the load profile, we determined that he was averaging 63% of his daily energy use outside of the solar window, and sized the battery to cover that usage. The design includes 55, 300-watt LG NeON 2 PV modules and inverters, and two sonnenBatterie eco 16 energy-storage systems. This combined system is projected to offset 96% of Ray's total electricity demand.

The sonnen units use Sony lithium iron phosphate (LFP) battery cells, which are among the safest lithium battery chemistries available. The batteries are integrated into a sealed cabinet and have a sonnen monitoring and control system. The batteries have a 10,000-cycle life at a 100% usable depth of discharge and come with a 10-year warranty. They can also be remotely monitored by the manufacturer. Each battery cabinet also contains an 8 kW OutBack Radian inverter that has been modified to operate with the sonnen battery management system controls and balance-of-system components.

The units can be programmed via a simple touch-screen interface to be in self-consumption mode, or to reserve energy and provide backup power in case of a grid outage. In self-consumption mode, the battery will fully discharge in an attempt to offset a larger portion of Ray's electricity needs. However, if the grid goes down when the battery is at a 0% SOC, there will be no electricity available for Ray's household loads. In backup mode, however, the battery transfers the loads to the grid sooner. While this results in a higher electricity bill, if the grid goes down, the batteries will have enough power to keep all of the loads on.

Presently, battery-integrated PV systems are more expensive than conventional net-energy-metered (NEM) PV systems. Return on investment takes about double the time of a traditional NEM system. However, the new regulations in Hawaii are necessitating the addition of batteries. It has been a rocky start as consumers and solar contractors become familiar with these complex battery systems. Ultimately, however, they may offer a more sustainable path forward for rooftop PV installations. This approach eliminates the complexities of trying to manage uncontrolled distributed energy on the utility grid, and provides consumers with greater energy autonomy. In our view, it's only a matter of time before NEM programs in other parts of the country reach their end. We hope that Ray and other early adopters of these next-generation battery-integrated PV systems pave the way for more reliable and affordable battery technology to come and make the transition easier for solar contractors and homeowners in other areas.

—Roland Shackelford

Overview

System type: Battery-based PV for self-consumption and grid backup

Installer: Renewable Energy Services

Date commissioned: January 2017

City: Kailua-Kona, Hawaii

Latitude: 20°N

Average daily peak sun-hours: 5.5

System capacity: 16.5 kW DC PV

Average annual production: 22,051 kWh (estimated)

Average annual utility bill offset: 96%

Equipment Specifications

Number of modules: 55

Manufacturer and model: LG 300N1K-G4

Module rating: 300 W STC

Inverters: 55 Chilicon Power CP-250

Rated AC output: 13.750 kW (total)

Energy storage: 2 sonnenBatterie eco units, 32 kWh total

Array installation: Standing-seam metal roof; ProSolar RoofTrac

Array azimuth: Multiple

Tilt angle: 18.34°

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Conduit Sizing

Whether it is loading the dishwasher or packing for vacation, humans have a propensity for filling spaces with as much stuff as we can cram in. Unfortunately, the electrical world does not play by the same rules. When determining the proper size of conduit to use for a project, it is often more about maintaining enough empty space in the conduit than how much wire can fit.

Several factors must be considered when determining conduit size: fill, run, and future expansion.

Conduit fill. What wire size is required for the project's current and voltage-drop needs? How many wires will occupy the raceway? What wire type is required?

While the limitations of stuffing more wire into a raceway than will physically fit are obvious, what may not be obvious is the heat generated by the wiring within. Energy is moving through the wires—energy strong enough to cause an arc flash or weld materials together. Just like having too many people in a tiny room, these wires can get very hot when cramped together.

To avoid overfilling and the risk of overheating, the *National Electrical Code (NEC)* specifies the maximum number of wires that can be squeezed into a conduit based on the number of conductors, wire size, and wire type.

Conduit fill is also based on the assumption that there are no more than 180° of turns. To account for every 90° past 180°, the fill capacity must be decreased by 15%. For 360° of turns, that is 30% less conduit fill.

Conduit run. In a conduit run longer than 100 feet, upsize the conduit by one size to ensure an easy wire pull. While the fill may be within *NEC* requirements, attempting to pull the maximum number of wires through conduit over a long distance will be extremely difficult and can damage wire. Greater force is required to pull the weight of the wire through a longer run. Plus, longer runs tend to have more couplers, resulting in more edges to potentially abrade wire.

Future additions. If there's a chance that circuits may be added in the future, conduit should be upsized to accommodate additional wires. Upsizing conduit is especially useful when it's installed in difficult-to-access areas, such as in trenches or behind walls. You'll be glad later.

Maximum Conduit Fill

Number of Conductors	Maximum Fill
1	53%
2	31%
3 or more	40%

Calculating Conduit Fill

As long as you have the specifications for the wire and conduit, conduit fill can be determined using simple calculations. First, determine how many conductors will be placed inside of the conduit. The maximum percentage of conduit fill depends on the number of wires within.

While there are tables that detail how many wires can be safely fit into conduit, it helps to understand how these values are determined and where these numbers come from.

To use the "percentage of fill," the cross-sectional area of the wire, including insulation, must be determined. Using geometry: Area is the radius, squared, times *pi* ($r^2 \times \pi$). When using multiple wires in a raceway, the cross-sectional area must be calculated for each wire (or simply looked up) and added together. With wires of the same size, multiply the area times the number of wires. Use Table 4 in Chapter 9 of the *NEC* to find conduit cross-sectional area of different raceway types and Table 5 for wire area. (As insulation thickness can vary, it may be necessary to look at the manufacturer's specifications to determine the diameter.)

Once the cross-sectional area of all wires is determined, take the total area and divide it by the inside area of the conduit of choice. This gives you the percentage of fill for that conduit size. If the percentage is greater than the maximum fill percentage detailed in the fill table, you'll need larger conduit.

Next, conduit run comes into play. If your conduit route has less than 180° of bends, no further calculations are necessary. For every 90° bend beyond 180°, 15% must be deducted from the inside diameter of the conduit to account for the shrink in conduit during the bend, and pulling through the bend. For a conduit run of 360°, the conduit loses 30% of its fill capacity. Beyond 360°, a conduit body or pull box must be installed.

Here's an example: Four THWN wires—three 1 AWG wires and a 4 AWG ground wire—must go through conduit to a main panel. Using *NEC* Chapter 9, Table 5, we find that 1 AWG has a cross-sectional area of 0.1562 square inches; the 4 AWG has an area of 0.0824 square inches. With three wires at 1 AWG, multiply the area by three for the number of wires, which gives 0.4686 square inches. Add this to 0.0824 square inches (the 4 AWG area), for a total wire area of 0.551 square inches for all four wires.

Consider using 1-inch EMT, which has an inside diameter of 1.049 inches, or an area of 0.864 square inches. Dividing your total wire area by the area of conduit (0.551 in.^{2} ÷ 0.864 in.^{2}), this wire would fill 63.8% of the conduit. Since this fill exceeds the allowable 40% fill for three or more wires, a larger raceway must be chosen. With an inside diameter of 1.380

Maximum Number of Conductors Allowed in EMT Conduit

AWG	Conduit Size: 1/2 in.	3/4 in.	1 in.	1 1/4 in.	1 1/2 in.	2 in.	2 1/2 in.	3 in.	3 1/2 in.
14	12	22	35	61	84	138	241	364	476
12	9	16	26	45	61	101	176	266	347
10	5	10	16	28	38	63	111	167	219
8	3	6	9	16	22	36	64	96	126
6	2	4	7	12	16	26	46	69	91
4	1	2	4	7	10	16	28	43	56
3	1	1	3	6	8	13	24	36	47
2	1	1	3	5	7	11	20	30	40
1	1	1	1	4	5	8	15	22	29
1/0	1	1	1	3	4	7	12	19	25
2/0	0	1	1	2	3	6	10	16	20
3/0	0	1	1	1	3	5	8	13	17
4/0	0	1	1	1	2	4	7	11	14

Table for THHN, THWN, THWN-2 in EMT, the most frequently used wire and raceway type for home power installations

Source: *NEC* Informative Annex C, Table C.1

inches, 1.25-inch conduit has an area of 1.496 square inches, or a fill of 36.8%. Since this is less than the 40% maximum, 1.25-inch conduit is the minimum conduit size you may use, assuming no more than 180° of bends.

If there are 270° of bends, 15% must be deducted from the conduit area. For 1.25-inch conduit, then, that would be 1.496 in.^{2} - [(0.15) × 1.496 in.^{2}], or simply 0.85 × 1.496 in.^{2}. The result, 1.2716 square inches, fills 43% of the conduit. Given this extra bend, conduit must be upsized to the next standard size (1.5 inches) to accommodate the wires.

For most simple applications, the math-averse can simply follow *NEC* Informative Annex C, Table C.1. However, these tables do not account for long runs or bends greater than 180°, in which cases you'll need to apply the equations. Beware of websites with tables or conduit-fill calculators—these are often incorrect or misleading.

—Sean Chastain

Remembering *Home Power* Founders Richard & Karen Perez

Thank God for Richard and Karen Perez. If not for their good work, their persistent direction, the magazine they founded, and the acumen that they developed, we might have lesser renewable energy-related expertise and equipment, less grasp of facts involved, and lower public desire for renewable technologies.

There's plenty of hard work ahead, because the sustainability of comprehensive modern civilizations, cultivations, and conservations on earth are dependent on the perfection of dependable, affordable, versatile, and durable renewable technologies—whether for independent sites or grid-connected users.

This, I believe, now more than ever (even if I haven't yet attained it): The independent house—especially if comfortable, practical, easy to maintain, passive-based, and of low taxation and market values, but with high-performance qualities—remains the best definition, the best demonstration, the best object, and the best fulfillment of "home power."

Lawrence Smith • Lawrence, Kansas

"I imagine Richard is still teaching, as he is just in another place to spread the 'mutant spore.'"

My first encounter with Richard Perez was in the fall of 1991. A friend, Tom Deves, and I had just formed the Iowa Renewable Energy Association (IRENEW). Tom came back from the Midwest Renewable Energy Fair (MREF) in Wisconsin and informed me that Richard Perez was running a full-page ad in *Home Power*, promoting our energy fair for that fall instead of the next year. Richard just figured we should just do it—now, not next year!

In the next 10 years, Richard published many articles about IRENEW events. A solar-powered "Blues Mobile" and bike ride across Iowa, and the first PV system on a nature center in Iowa with donated PV modules from Brookhaven National Laboratory in New York. The point of these examples—and many more—is that without Richard pushing us to host an energy fair a year earlier than we planned, we would not have accomplished nearly as much. He just inspired (and, I think, expected) us to try new ideas to spread the "mutant spore."

His views concerning "DIY" and self-reliance are something that we should never forget. This DIY view connects us to nature and allows us to control our path in life. Education for DIYers in *Home Power* magazine was the right idea at the right time. I imagine Richard is still teaching, as he is just in another place to spread the mutant spore. He loved to teach.

When I met Richard in 2001 for our tenth anniversary energy fair, he was one of the most pleasant and unimposing "famous" people I have ever met. I still have his speech on VHS tape! And I still vividly remember all his emails and comments exchanged two days later (Tuesday, September 11, 2001) during and after the attack in New York. He really did deeply feel there is great potential for the United States. These are just a few of my impressions of Richard.

Tom Snyder • Dyersville, Iowa

I was very sad to read Richard has reunited with Karen. While we will miss them, I know they wanted to be together. They both created a wonderful magazine for us to enjoy, even many years from now! God bless you.

Fred Golden • via homepower.com

"...both have passed on to the next adventure (talk about off-grid!)..."

In the fall of 1987, I was a 30-year-old dude with a vision. Having had several years of experience in the solar thermal business and having recently been laid off (thanks, Ronald Reagan), I refused to let go of my renewable energy dream. So I packed up my Jeep and my dog, left my girlfriend (now my wife), and headed to Glenwood Springs, Colorado, and the Solar Retrofit Program at Colorado Mountain College.

It was a life-changing experience. Ken Olson, Steve McCarney, and Johnny Weiss laid it all out for me—energy efficiency, passive solar design, solar thermal, and solar electricity. I had never been more engaged.

It was also during this time that I was introduced to *Home Power* magazine…No.1. It still sits proudly on my office shelf—with every other issue. An interesting but not far-fetched point is that *Home Power* trumped any textbook in class, and quickly became required reading.

Following graduation and stints at Photocomm, as well as Rocky Mountain Solar Glass, I set out on my own. It has now been 26 years in business as Sunsense Solar, and the passion has never been stronger.

Over the years, my connection to Richard and Karen strengthened. I wrote numerous articles, hung out at energy fairs (like SEER in Willits, California), and made several pilgrimages to "The Flat." Visiting Richard and Karen was nonstop shoptalk over beverages, smoke, and the best off-grid cuisine you've ever tasted. There were plenty of animals to visit as well—Brown, the dog, was a favorite of mine.

Having accepted that both have passed on to the next adventure (talk about off-grid!), it comforts me greatly to reflect on those early days and the wonderful vibe that Richard and Karen carried with them throughout their time on Earth. I feel truly blessed to have known them as mentors, colleagues, and friends.

Rest assured, the vision is in good hands with all who were inspired by the love and passion for the technology and its impact on an ever-changing world. We at Sunsense are committed to the proliferation of solar and renewables, now and into the future. RIP, Richard and Karen. See you on the other side!

Scott Ely • Sunsense Solar, Carbondale, Colorado

Aloha from Maui. I was saddened by the passing of Richard and Karen. They gave so much. I built my first solar system in 1985—a 12-volt car battery and one Arco PV module. What a blessing when *HP1* showed up in my mailbox. I met Richard and Karen once at the SolWest energy fair in John Day, Oregon. We corresponded a few times over the years. Kathleen, I really liked your article on the Perezes, "The Ladder" (*HP178*)—thank you. To the rest of you who have made *Home Power* great over the years, thank you!

Karim Wingedheart • Maui, Hawaii

"Richard has passed...he's transitioned into sunlight."

Richard has passed. Bob-O Schultz says that he's transitioned into sunlight. :-)

As we all know, Richard and Karen Perez were instrumental in Solar Energy International's (SEI) beginning and evolution. As our very first Advisory Board members, they inspired, encouraged, and supported us in so many ways. Their generosity, integrity, and solidarity lighted our way forward in our early challenging days. The strategic alliance we formulated with *Home Power* magazine was critical to our early survival as a nonprofit solar education and training organization. SEI's success today is a tribute to their vision of a world powered by practical, renewable energy. Solar power forever…and forward into the light!

Johnny Weiss • SEI Cofounder

More Letters...

Simple Solar Changed My Life

I live in the country in a small cabin on the edge of civilization, but still on-grid. I didn't want a large solar power system to totally replace the grid, just something big enough to allow me to survive during outages, and also reduce my overall use of nonrenewable energy. So I went to a presentation given by a solar contractor and neighbor, Kelly Larson, who helped me decide to develop an independent battery storage system.

Dennis O'Brien's DIY off-grid PV array.

Courtesy Dennis O'Brien

I needed four basic components: solar modules, a charge controller, batteries, and an inverter. Kelly, who also teaches people how to become solar contractors, checked my plans for safety, and then helped me order the components. The total cost was about $1,200. The modules were rated at about 300 watts. We found a spot near my cabin that got enough sun. I learned that closer is better, as low-voltage electricity has a significant loss of energy the further it travels, and the thicker copper wire that would compensate for that is very expensive.

I built my own wooden frame for the modules, with adjustable tilt. This has given me a heightened awareness of the seasons and the sun's angle as it crosses the sky.

Every component came with detailed plans: fastening the PV modules to the wooden frame and connecting the wiring to the modules, charge controller, batteries, and inverter. Kelly inspected and approved it before making the final connection, confirming that a person with no special training could still build a simple solar power system.

It was with great pride, on the winter solstice in 2014, that I switched on the inverter. I could power all my lighting right away, but had to wait until spring to add my other electronics: computer, satellite modem, TV, satellite receiver, DVD player, and stereo. During the summer, the system also runs a fan. And during a power outage, I can light my home and stay connected with the world.

But the greatest sense of accomplishment came one day as I was standing on the back porch, admiring the modules and the work I had done. Behind them is a large stand of bamboo. It occurred to me that, no matter how efficient humans made PV modules, we would never achieve the productivity that plants do when they convert solar power, considering the green all around us.

Suddenly I had a strong feeling that the plants were thanking me, that somehow I had achieved a higher state of being by becoming more like them, becoming more sustainable in my use of natural resources. If we commit to living our lives without depleting nature, then nature will provide a paradise now and in the future. On many levels—practical, intellectual, emotional, and spiritual—I had freed myself. Simple solar produced the simple delights of being in tune with nature, and knowing that I'm doing my part to make the world better for future generations. It will change your life, as surely as it has changed mine.

Dennis O'Brien • Ukiah, California

What About Solar Water Heating?

I was looking at your off-grid solar water-heating article ("Off-Grid Water Heating" by Ian Woofenden & Vaughan Woodruff in *HP177*), and was disappointed by the lack of emphasis on renewable energy (except for solar thermal). In my house, we get most of our hot water from surpluses from the wind-electric and PV system, and that seems about right to me for a modern off-grid house. Often, we have more hot water than we know what to do with.

Solar and wind electricity were briefly mentioned, but the gist of your comment was that although possible, it was not a great idea. And it does not figure in the matrix of solutions at the end of the article.

I am a bit disappointed in *Home Power* lately with the emphasis on using propane. Propane fridge, propane hot water. If I were writing this article, I would not be telling people to choke their hot water taps so that they feel they are getting second-best service. I would be telling them to use abundant renewable energy. A lot of us longtime fans read it for the renewable stuff. Now, more than ever, we need more renewable energy, and it works better than ever!

As for solar thermal (although it is great), I think the money would be better spent oversizing an off-grid PV array. PV is really cheap. To provide ample electricity for as much of the year as possible, the system needs to be oversized. The result is loads of surplus energy in sunny weather that can be used to provide ample hot water. You will therefore not need solar thermal—that would be money wasted. Better to use the money to buy more PV, microhydro, or wind—whatever resource you have available at your site.

I agree with the two drawbacks you mention, but they are not serious. These surpluses are intermittent. Of course, you need a backup heating source—a wood heater or propane. It's not hard to combine these with surplus electricity—it's easier to do it with electric heat than solar thermal. Surpluses from a solar-electric system are inherently erratic, but if the system is properly designed, it can be a frequent and generous source of hot water.

Input and output temperatures on a wood stove's water-heating loop.

Ian Woofenden

You point out that it's not possible to use hot water as your *only* diversion load. This can pose a technical challenge. You may need a combination of charge control equipment or relays to handle the surplus. But what I don't understand is why there isn't a hot water diversion output built into every large solar controller. The technology is simple. Using hot water as a priority and then reverting to a true "dump" is also simple to do, and it should be mainstream. Let's ask the controller manufacturers to give us diversion with a solar priority and a backup space-heating output (if necessary) as standard in every controller.

This is the sort of off-grid water heating that we should aspire to, and it is achievable. I look to *Home Power* magazine to lead us toward this sort of solution rather than yesterday's SWH and propane. Effective use of renewable energy is high on the agenda, both on and off the grid. Let's get to grips with that.

Hugh Piggott • Scoraig, Scotland

Heating Water with Wood, Off-Grid

I enjoyed the article in *HP177* on off-grid water heating. We heat our off-grid, renewable energy-powered home in the winter using an indoor wood heater. Several years ago, I installed a stainless steel loop inside it and placed it on a parallel propylene glycol loop to the second coil inside our hot water storage tank. The first loop is attached to our evacuated-tube solar water-heating system. Both loops use El Sid low-wattage DC pumps operated by an Art Tec controller.

I purchased the stainless-steel loop and a kit for cutting through the cast-iron side of our wood heater from Hilkoil, which specializes in making these loops. We have continuous hot water even in the solar shoulder season, because the pumps come on whenever they sense a heat source that exceeds tank temperature. I had so much hot water that I had to install a second hot water storage tank to contain it all!

James Li • Coastal Maine

Connecting a heat exchanger to a wood heater is an excellent low-tech solution that I use in my off-grid homestead as well. My solar water heating system is set up as a pumped glycol system, and my wood heater is passive thermosyphon with domestic water. Both systems deliver heat to the same tank. I never run out of hot water—summer or winter—and the backup propane heater has been off for a few years now.

But caution is in order: If something happens in your system to cause the pump to stop working, the water in the coil could quickly flash into superheated steam, which can be quite dangerous—possibly even explosive. Safety is one reason why thermosyphon systems are better, and why pumped wood heater systems have fallen out of favor.

Ian Woofenden • Home Power *senior editor*

Off-Grid System Upgrade Design Questions

Your *HP178* article ("An Off-Grid Education") on upgrading an off-grid system interested me, since I'm frequently called to do just that. The Bowkers started out with a 24-volt inverter and an OutBack MX60 charge controller. Good stuff. The article indicates that they now have two strings of two Canadian Solar 310-watt modules in parallel. Each module has a Vmp of 36.4, so each string would run at 72.8 VDC under load. I'm not sure what the "48 V nominal" means on the diagram. There is no 48 V anything in this arrangement, especially with 72-cell modules. More critically, each Canadian Solar module also has an Imp of 8.5 amps, so those same two combined strings would be pushing 17 A into the MX60.

The four-per-string Mitsubishi modules, with a Vmp of 17.6 VDC, would mean 70 V in each string, nicely matching the Canadian Solar strings. Their Imp of about 6.5 A per string would result in 13 A for the two combined Mitsubishi strings. Adding all of the array strings together results in 30 A running at 70 V. Sounds good—but wait.

The 24 V battery bank will be spending a lot of time at, let's say, 26 V. So the MX60 will drop the array voltage to the battery voltage: 70 VDC ÷ 26 VDC = 2.7, which will increase the output amperage by roughly the same amount resulting in 30 A × 2.7 = 81 A, which seriously exceeds the MX60's rating. It might also exceed the bigger OutBack charge controller, the FM80.

Maybe in the real world, this maximum performance would never be attained, but I'm not sure that's a safe design option. How about the batteries? It's not optimal to have multiple battery strings, since they don't operate and age identically. If the batteries were all connected in series to make a 48 V nominal system, the amperage increase through the MX60 would only be 1.25x, which would bring the output to less than 40 A. This is well within the MX60 rating. But the inverter is 24 V. Hmmm. Converting to a 48 V inverter would solve the overcurrent problem and the multiple battery string issue. Perhaps the 24 V OutBack inverter could be sold to offset the inverter upgrade. I like 48 V systems and one-string batteries (you've already got eight). Or, sigh, get an additional charge controller and split the array.

Charlie Gulyash • Solar Pacific

I thought my sidebar might draw a few comments. I think we are in agreement on the math in the first part of your letter—the two strings of two Canadian Solar 310s and the two strings of the four Mitsubishi 110s have very similar string voltages, and the amperage from each string is combined (paralleled) in the combiner box.

I also agree, at least partially, with your comment objecting to the use of "48 V nominal" describing the array in the system's line diagram included in the article. "Nominal" was perhaps more appropriately used back when array voltage and battery voltage were more closely matched in these battery-based systems.

Perhaps a little more complicated (and controversial) is your comment on the MX60 charge controller being undersized. The intent is not to exceed the current or power rating of the MX60, but rather to increase array production during extended cloudy periods with low production (winter in Wisconsin). The Bowkers' array does exceed OutBack's "recommended maximum array size," but this recommendation is based on the module's STC rating, not the more realistic PTC rating. Other efficiency derates come into play as well, including module mismatch, voltage drop in the PV source circuit, soiling, module degradation, array orientation, etc.

These controllers are also "current limiting," which means that the user programmable "maximum amps" setting in the controller's "charger" menu will effectively limit the amperage to that setting (60 A is the default). The "oversized" array may be capable of producing more amperage in bright sun than the MX60 needs to hold the current at that limit, but it only draws what it needs to deliver that amperage, limiting the current from the array.

I spoke with OutBack, and although they acknowledge that the array can be sized larger than their recommendations, and that the controller will limit the current as described, they cannot recommend doing that. In some cases, it may even void the warranty. Over the years, I have upgraded a few systems with MX60 charge controllers beyond OutBack's recommended array size, and have never encountered a problem. I believe as long as other requirements are met (proper breaker and conductor sizing, and applied deratings), these charge controllers will give many years of service.

On your final point, if I were designing the Bowkers' system today, it would likely be at 48 V. But the Bowkers have some 24 VDC loads, including their Sundanzer freezer. It's nice to know that the freezer won't thaw out if the inverter is off. When paired with good and caring owners (such as Jerry and Sally), a battery of two paralleled strings can work just fine.

Kurt Nelson • SOLutions

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

Solar Gain & Low-E Coatings

Chris Magwood's article about a low-carbon house ("Building a High-Performance, Low-Carbon House" in *HP177*) left me with some questions about low-e glass. I've recently replaced several large double-pane windows on the upper-level south side of my passive solar house. I ordered low-e glass and installed it in the sash with the "E" sticker facing the inside. My understanding was that this coating allows shorter-wavelength light to pass through, but prevents the infrared (longer wavelengths) from getting back out.

I bought an infrared temperature gauge. Using it inside the house during cold weather, I compared one of my new low-e windows with the same-size window beside it that wasn't low-e. The low-e glass typically shows a temperature 1°F or 2°F higher than its neighbor. That made me think I'd gotten it right, but now I'm questioning that. I'm hoping you can shed some light on my window puzzlement.

Paul Killough • Chapel Hill, North Carolina

Chris said this in his article:

"Triple-glazed windows from Inline also help to keep temperatures comfortable. The window glazing is 'tuned' for each side of the building, with no low-emissivity (low-e) coatings on the south windows to maximize solar gain. There are double low-e coatings on the inside of the north and east windows to keep heat in the building, and on the exterior side of the glazing on the west, to reflect out unwanted gains."

Given the information you provided, it's difficult to answer your question as to whether your installation was correct. On a south-facing window with good solar gain, if the "E" sticker indicates the film placement on the glazing face, and that pane was installed with the sticker facing the building interior, this will result in a unit that allows in slightly more solar gain than if the pane were placed with the sticker facing outward. With the coating toward the room interior, this setup with will help solar gain in winter, but will be less favorable in the summer if shading is not provided. That said, the performance difference that results as a function of coating placement is negligible compared to windows without any coatings—your new windows are a big upgrade compared to your old ones.

The accuracy of the temperature measurement is also hard to confirm without knowing if the sun was shining on that unit, and what the relative temperatures were across the assembly. If no sunlight (night) and cold outside, this reading would indicate improved performance compared to its counterpart without the low-e film.

In the United States, the National Fenestration Rating Council (NFRC) rates all windows for commercial sale, with three metrics required to be listed: U-value; solar heat gain coefficient (SHGC); and visible transmittance (VT). This allows us to easily compare windows' performance. Note that the entire unit is evaluated—frame, spacers, and glass—not just the pane.

U-value is a measurement of the unit's conductivity; the higher the U-value, the greater the heat transfer. Divide 1 by the U-value to get the unit's R-value, which is used to evaluate the heat transfer of insulation materials; the higher the R-value, the less heat transfer that takes place. SHGC is the fraction of solar radiant heat that can transfer through the unit, expressed as a number between 0 and 1. The higher the SHGC, the more solar heat is transferred through the unit. A high SHGC is desirable for passive solar gain. VT is the fraction of visible light that can transfer through the unit, expressed as a number between 0 and 1. The higher the VT, the more visible light can transmit through the unit.

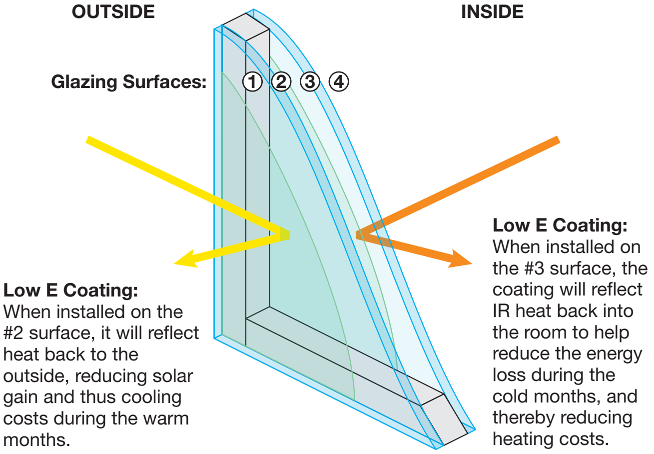
Most windows now use a low-e coating to reduce the amount of radiant heat transfer through the glass, effectively reducing the U-value of the unit. These coatings, made of metals or metal oxides, are only a few molecules thick, and can either be an invisible film suspended between the layers of glass, or it can be applied to surface of the glass itself. There are different types of coatings, applied in different ways. While the point of the low-e coating is to reduce the U-value of the window, some coatings are more effective at allowing solar radiation to enter the building than others. Accordingly, some windows can have a higher SHGC while maintaining a lower U-value, whereas others feature both low SHGC and low U-values. The former is favorable in a cold-climate building that takes advantage of passive solar gain through south-facing glass. The latter is favorable in warmer climates where passive solar gains can lead to greater cooling loads.

The location of the coatings can vary. Window manufacturers label the face of the glass from exterior to interior. In a double-pane window, the outer face of the exterior pane (facing outdoors) is surface No. 1. The inner face of the exterior pane (facing into the space between panes) is surface No. 2. The face of the interior pane that faces into the space between panes is surface No. 3, and the face of the interior pane that faces the building interior is surface No. 4. In most double-pane windows, the low-e coating is either applied to surface No. 2 or No. 3. When a soft-coat (more fragile, but more effective) low-e coating is used, placing it on surface No. 2 or 3 serves to protect it.

The south side of Paul Killough's house shows off new low-e windows.

Courtesy Paul Killough

Low-E Coatings & Thermal Performance



The biggest differences occur between windows with and without low-e coatings. With the addition of one low-e coating, a double-pane window's U-value can go from 0.48 to 0.37. However, there are subtle distinctions in where the coating is placed. When placed on surface No. 3, more of the passive solar gain is allowed into the unit. This will result in a warmer interior glass surface temperature, and accordingly will be less effective in keeping heat out during the summer months. When placed on surface No. 2, less solar gain is transmitted, and a cooler interior glass surface temperature results.

In the case of triple-pane windows, there are six surfaces available, allowing for multiple low-e coatings to be applied. It is not uncommon for two low-e coatings to be installed; some of the most efficient windows have U-values below 0.20. However, as more layers are added, it is more difficult to achieve higher SHGC values. High SHGC low-e coatings must be used.

For the house's windows described in the article, different configurations of coating placements were made relative to the potential solar gain, while trying to keep the U-value as low as possible. On the home's south-facing windows, no low-e coating was used since the goal was to maximize passive solar heat gain. Presumably, energy modeling was conducted to ensure that this trade-off yielded a net gain in energy for the building, as more radiant heat loss at night can be expected as the U-value is higher without the low-e coating. In the north and east, where there is little to no solar gain to capture, the priority was to have low U-value windows, so ones with double layers of low-e coatings applied to the interior surfaces were chosen. On the west, where overheating from afternoon sun can be a problem, windows with a low-e coating on surface No. 1—presumably a low-SHGC hard-coat (more durable) coating—were chosen to reduce unwanted solar heat gain.

In any case, it is important to remember the VT, as adding multiple panes and coatings can affect the quality of visible light coming through the window. Some very efficient windows also have very low VT values, resulting in windows that look grey or dim.

Jacob Racusin •
New Frameworks Natural Design/Build

Wind Power for Charging Batteries

I have a few questions regarding charging batteries with a wind-electric system. First, does the direction the turbine is spinning affect how the battery is charged (will switching directions charge or draw on the battery)? A turbine I'm considering only spins in one direction, but I have seen others that will spin in either direction.

Second, can the turbine be in series with other devices? Or does it need to be run directly to the battery and have the power diverted from there?

Third, what specs does a car-mounted wind turbine need in order to keep the battery charged?

Jacob Johnson • via e-mail

There are some wind turbines on the market that spin clockwise, and others that spin counterclockwise. If you're buying a turbine, this is of no concern. If you're building your own, work with existing plans to match the blades to the alternator.

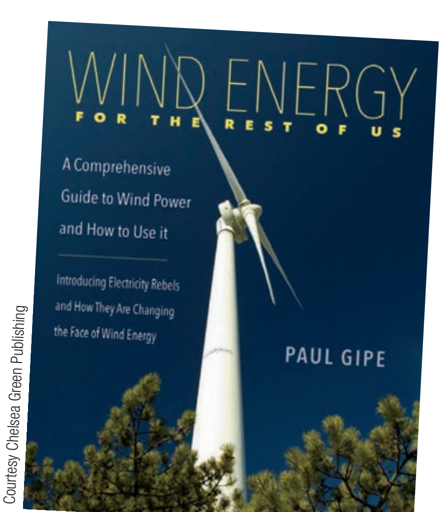
There are systems in which wind turbines power loads directly, though they are uncommon. Appropriate loads for this configuration might include water pumps and heating elements. These systems run at variable voltage (dependent on the rotational speed), so they work only with certain loads. There are also wind turbines that tie directly into the utility grid, either via an inverter or via an induction generator. Battery-based systems—either on-grid or off—use the turbine to charge the battery, and the loads run off the battery.

If a battery is 12 volt, the turbine that charges it needs to be 12 V nominal, or be stepped down to that voltage via electronics. Beyond that, the battery capacity and the energy (kWh) load, plus the site's average wind speed, will determine the size of wind turbine needed. A load analysis and site analysis are critical to turbine and battery sizing.

Using a wind turbine on a vehicle is a losing proposition. A vehicle is powered by fuel, and its body is designed to reduce wind resistance. Putting a wind turbine on it adds wind resistance, requiring more fuel to overcome that resistance. Any electricity generated will be less than the additional fuel used to overcome this resistance.

For a deeper understanding of wind electricity, see the many articles at homepower.com, and a variety of books on the subject, including Paul Gipe's *Wind Energy for the Rest of Us.*

Ian Woofenden • *Home Power* senior editor
and author of *Wind Power for Dummies*



Courtesy Chelsea Green Publishing

Books (and *Home Power* articles!) can help you clarify the variables of implementing effective wind power systems.

Solar Pool-Heating System

I'd like to install an evacuated-tube solar heating system for my house and for my 40-by-20-foot swimming pool. What kind of system do you recommend, and how much would it cost? I will need permission from my homeowners association and a township permit to install it. Also, will the system be eligible for the 30% federal tax credit?

Sami Poykko • Cherry Hill, New Jersey

Good solar water heating system design depends upon several factors, including the targeted delivery temperatures, the heating demand, the climate, and the auxiliary fuel being used.

The delivery temperatures for a swimming pool and for domestic hot water commonly result in two different solutions if the systems are separate. Since pool water is typically heated within 20 to 25°F of the outdoor temperature, polypropylene solar collectors are usually the most cost-effective. Medium temperature collectors, such as flat-plate and evacuated-tube types, are commonly used in domestic water heating because their insulation helps the absorber retain the collected heat—even when outdoor temperatures are below freezing.

To heat both a pool and domestic water, a glazed flat-plate collector is most suitable. Evacuated tubes are less efficient for applications like pool heating due to collection inefficiencies. They also will be more prone to overheating in the winter, since a large system will be required to meet a swimming pool's heating demand, and you will only be using that hot water for a portion of the year.

Unless your domestic hot water use is heavy, the solar collector's size will be driven by the pool's heating demand. Since evaporation is responsible for roughly 70% of a pool's heat loss, solar pool-heating systems are sized based on the pool's surface area. In New Jersey and given a reasonable solar orientation, collectors equal to 50% to 60% of the pool's surface area should be sufficient. For a 20-by-40-foot pool, that would equal roughly 400 square feet of collectors. You might add one or two additional collectors depending upon your domestic hot water needs during pool heating season.

Flat-plate collectors are designed to operate at the higher temperatures required of a domestic water heating (DWH) system. Using them for DWH and pool heating may add unnecessary complexity and cost to the system.

Pool collectors are relatively inexpensive and designed to operate at lower temperatures. They can be drained for freeze protection during the non-swimming season.

Vaughan Woodruff (2)

Since you are in New Jersey, the system needs freeze protection. A standard pool-heating system uses the pool water to collect heat by diverting the water through the collectors after it is filtered. Freeze protection is provided when the system is drained for the winter. Since your system would also heat domestic water, you will need to install heat exchangers—one for the pool loop and one for the water heater. The heat exchangers will transfer energy from the solar loop, which will need to be filled with propylene glycol or configured as a drainback system. If the system is drainback, this would also resolve overheating issues. Finally, how the system integrates with your water heating system will depend upon how you currently heat your water. Integrating a system with a traditional gas-fired water heater will require a different solution than one that uses an electric element.

Ultimately, combining these systems may not be the best idea. You will be paying substantially more for heating your pool than if using a standard solar-pool heating system, and, when the pool is not in operation, the system will be oversized for heating your domestic water. Using one system for two purposes could cost between $14,000 and $16,000 in parts, will require a complex design, and could easily take 100 hours to install.

The federal tax code excludes systems used to heat pools from the 30% tax credit. You'd need to discuss with your tax preparer whether any of your expenses related to heating domestic water would qualify. If you separate these systems, the parts could be $8,000 to $9,000, the labor could be reduced to 70 to 80 hours, and the solar domestic water heating of the system will qualify for the tax credit.

Vaughan Woodruff • Insource Renewables

continued on page 28

This is where your investment in Solar & Wind Power Equipment pays off.

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continued from page 26

Thermoelectric Generators

My off-grid house uses a gas generator for primary power. I charge a large pack of Iron Edison batteries and have a 4 kW inverter. I also have six PV modules that charge the battery pack, but they produce negligible energy in the cloudy, short daylight hours of winter.

I am interested in designing a thermoelectric generator (TEG) system to reduce my generator run-time in winter. My idea is to use a combination of solar water collectors and a wood heater for the heat source, and a deep well as the cooling source—and maybe also heat my greenhouse with waste heat. Can you point me to a book or a website where I can get help designing my TEG-based system?

Ric Barline • via email

TEGs are fascinating cousins of photovoltaic (PV) cells, and preceded the discovery of the PV effect by almost 20 years. TEGs must have a temperature differential (ΔT) to function; one side must be heated and the other side cooled.

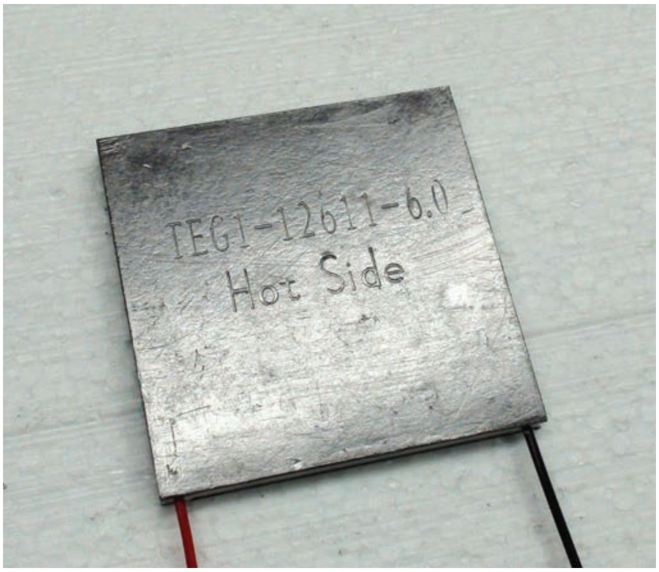
The most glamorous use of TEGs today is in spacecraft traveling so far from our sun that PV arrays won't work. The heat is provided by the decay of radioisotopes, such as plutonium, strontium, and others. TEGs have also been used to power remote military installations, and today are used for recovering waste heat from industrial processes. Automotive TEGs are being developed to recover part of the large amount of engine power (~30%) that is wasted as tailpipe heat.

The biggest drawbacks of TEGs—especially for an off-grid home application using wood heat—are efficiency, cost, and reliability. Commercial wood heater TEGs run $10 to $20 per watt, and are only 5% efficient. Compare this to PV modules that cost less than $1 per watt and are 20% efficient. Manufacturers of wood heater TEGs have come and gone. The biggest problem is TEG burnout—if your heater is running hot and the cooling on the other side of the TEG can't keep up, the unit can be ruined.

There are a few manufacturers of wood heater TEGs, but the limitations are many. The information for DIY units focuses on small applications, like propane camp stoves that can charge a smartphone or run a small LED light. I did the math for my wood heater. Covering all the usable surfaces with TEGs would cost about $3,000, and produce less than 300 watts. And cooling the other side of the TEG would be a challenge. I'm going to stick with PV and a small, reliable backup generator. If your project is a success, though, please let us know. The TEG concept does have potential in certain applications, and many people will be interested in your findings.

Dan Fink • Buckville Energy Consulting

A Tecteg thermoelectric module—at 2.2 square inches, it can make between 5.5 W and 15.6 W at temperature differentials between 100°F and 210°F.



Courtesy Tecteg

Air-Vent Valve

I have a solar water heating system for potable water and need to replace the air-vent valve located on the roof next to the solar collectors. I have searched the Internet and made numerous inquiries, but have been unable to find a valve suitable for potable water.

Carl Sebern • via email

Finding repair parts is easy on the Internet if you know the component's correct name and model. Photos are often the most help in identifying components. If a system is so old that the failed part is no longer manufactured, SWH firms can often recommend a replacement or workaround to bring an old system back online.

All of these SWH air-relief valves come from the HVAC industry. Although these parts may be recommended for nonpotable applications, I know tens of thousands have been used on potable systems in Florida and Hawaii. Here's one link that displays several air valves, maybe you can find yours among them: bit.ly/AirValves

Chuck Marken •
Home Power solar thermal editor

Air vents come in many styles. Finding the right one may take an Internet search.

Courtesy V&G Valogin

write to:

asktheexperts@homepower.com

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

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Battery Chemistry

by Justine Sanchez

©istockphoto.com/WichienTep

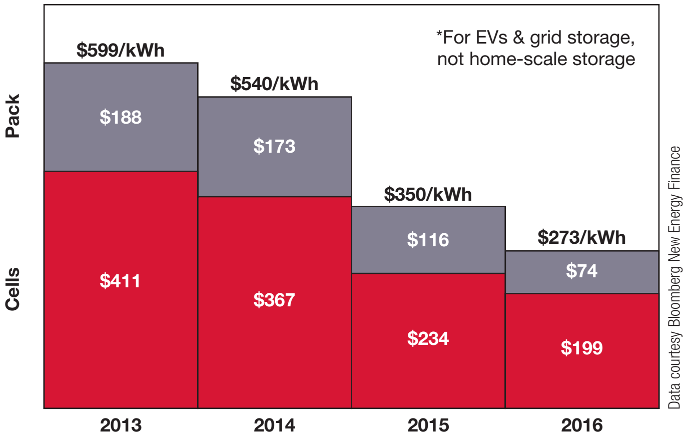
Courtesy Rolls

When the clouds roll in or the sun sets, solar energy stored in batteries can supply the needed power.

Comment & Discuss this article @ homepower.com/179.30

The intermittent nature of solar and wind resources works well with energy storage so energy can be tapped when the sun is not shining and the wind not blowing. This is true for home-scale renewable energy (RE) systems through utility-scale. Energy storage is "the missing link" for RE to become a large portion of our energy mix. This article is an overview of the different battery chemistries used for storing renewable energy.

Lithium-Ion Battery Prices*



Off-grid RE systems require energy storage, as there is no utility to rely on at night or during cloudy weather—as do on-grid RE systems that include outage backup. Recent changes in utility interconnection requirements and some net-metering programs are spurring more grid-tied RE system owners to include energy storage.

Battery storage has been around for more than 200 years. But recent price drops in lithium batteries (i.e., they are now about one-half the cost they were in 2014), primarily due to the increasing electric vehicle (EV) market, have propelled the energy storage topic to the media forefront. While most battery types operate under similar principles, there are significant differences that are worth understanding as energy storage options are considered.

web extras

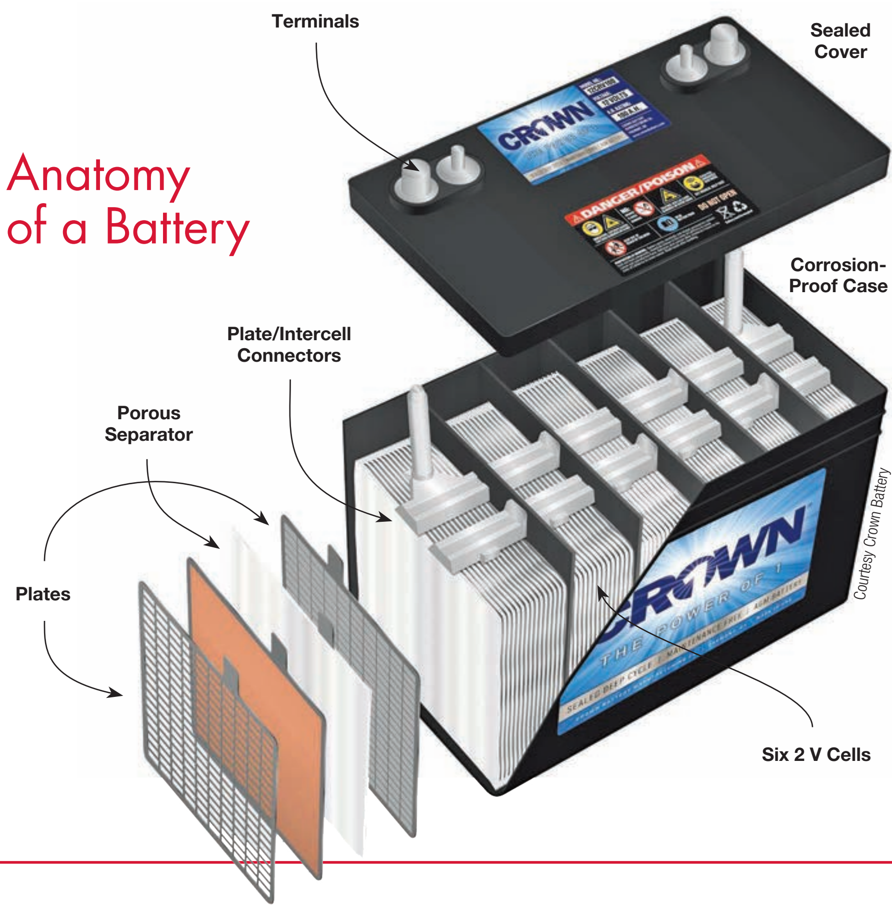
"Net Metering & Beyond" by Christopher Freitas & Carol Weis in *HP177* • **homepower.com/177.44**

"Maximizing Solar Self Consumption" by Carol Weis & Christopher Freitas in *HP178* • **homepower.com/178.46**

Fundamentals

RE storage batteries are made up of cells, each with two electrodes—a cathode (positive plate) and an anode (negative plate). The electrodes are submerged in an electrolyte, with a physical separator between the anode and cathode that allows ions, but not electrons, to flow through. Under charge and discharge, a chemical reaction occurs where ions flow though the battery's electrolyte between electrodes, while electrons flow through the external circuit placed on the battery posts. The direction of this electron and ion flow is dependent on whether the battery is discharging or charging.

Anatomy of a Battery



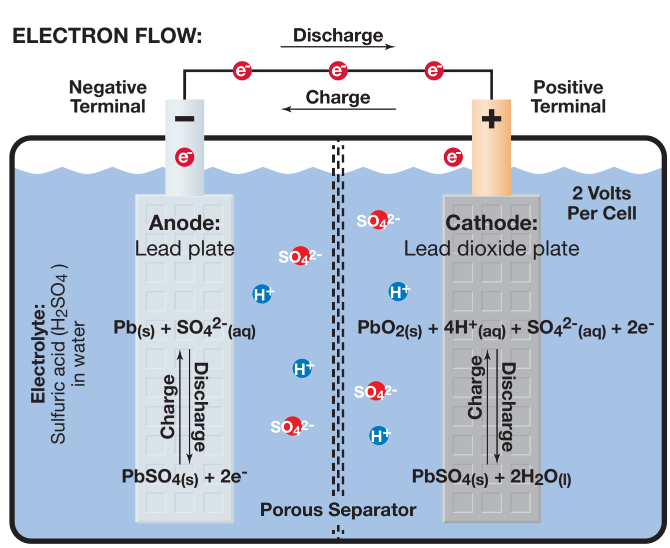
Courtesy Crown Battery

Lead-Acid Batteries

Lead-acid (LA) batteries were invented more than 150 years ago, and became the first commercially available rechargeable battery. LA batteries are the dominant battery type in home-scale RE systems, primarily due to price, availability, robustness (overcharge tolerance), and familiarity.

LA battery cells have lead (Pb) and lead dioxide (PbO_2) plates submerged in an electrolyte made up of sulfuric acid and water. When a load is placed on the battery (discharging), electrons are released from the negative anode (Pb plate) to the positive cathode (PbO_2 plate) stemming from the electrochemical redox reaction (see *Back Page Basics* in this issue) between the lead plates and the electrolyte. The sulfuric acid (H_2SO_4) is broken into positive hydrogen ions (H^+) and negative sulfate ions (SO_4^{2-}). The sulfate ions are drawn to both the anode and the cathode, while the hydrogen ions are pulled to the cathode, resulting in two electrons being released at the anode and two being pulled in at the cathode per reaction. During this process, lead sulfate ($PbSO_4$) is created and proceeds to cover both plates until there is no more surface area available for the chemical reaction to take place. At this point, the battery is fully discharged. Because sulfate ions are pulled out of the solution, a discharged battery's electrolyte has a higher concentration of water to sulfuric acid so specific gravity (a measure of liquid density, which reveals the acid-to-water ratio) can indicate a battery cell's state of charge (SOC).

Lead-Acid Chemical Reaction



OVERALL REACTION:

$$Pb_{(s)} + PbO_{2(s)} + 4H^+_{(aq)} + 2SO_4^{2-}{}_{(aq)} \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftharpoons}} 2PbSO_{4(s)} + 2H_2O_{(l)}$$

Flooded lead-acid is the least expensive technology, but requires watering. These HuP Solar-One batteries are available in large amp-hour capacity models (in 12, 24, and 48 VDC) that allow simple series-string configurations.

When an LA battery is charging, the process is reversed—electrons are driven into the Pb plate and pulled from the PbO_2 plate. This process breaks the chemical bond between the lead and the sulfate ions, releasing that sulfate (SO_4^{2-}) from the electrodes back into the solution, resulting in a higher concentration of sulfuric acid to water. During the charging process, some electrolysis takes place, which splits water into hydrogen and oxygen gas. For flooded LA (FLA) batteries, this must be vented and distilled water be periodically added to make sure the electrolyte always covers the plates.

An LA battery cell's nominal voltage is 2 volts. To reach a useful voltage, several cells are wired in series. For example, a 12 V LA battery will have six individual battery cells. While 2 V per cell is consistent for all LA batteries, the storage capacity (measured in amp-hours) of the battery is dependent on how large the battery cell is. Because larger battery electrodes have more surface area for the chemical reaction to take place, they also yield a higher rate of electron flow (amps) and can store more amp-hours.

FLA batteries generally have the lowest initial cost, but require regularly adding water. The water is their weak point—discharged FLAs can freeze, possibly causing the battery case to crack or the plates to warp, and thus need to be housed in a freeze-protected enclosure.

Gel-cell lead-acid batteries don't normally release gas or need water replacement. They may have sensitive charge regimes. This 12 VDC gel battery from Trojan is rated for 105 Ah (at the 20-hour rate), providing 1.26 kWh of energy storage.

Valve-regulated lead-acid batteries (VRLAs) are more tolerant to freezing temperatures and are nonspillable. They are designed to recombine minimal hydrogen and oxygen gassing back into water within the battery and do not have to be watered. While VRLA batteries have pressure valves that can let gas escape if overcharging occurs, the lost electrolyte cannot be replaced, and the battery's capacity will be reduced, and can cause premature failure.

"Maintenance-free" AGM batteries require no watering or topping off of the electrolyte. This 6 VDC, L16 battery from U.S. Battery is rated for 390 Ah (at a 20-hour rate), providing 2.34 kWh of energy storage.

VRLAs come in two types—gel and absorbed glass mat (AGM). Gel cells have electrolyte thickened with silicon, so it's not very liquid. Because the electrolyte in AGMs is liquid within a fiberglass mat between plates, the acid is more readily available to react with the lead plates, and AGMs can be charged and discharged faster than gel-cell VRLAs.

LA Pros

- Lower upfront cost (FLAs)
- Good durability
- Readily available
- Recyclable
- Familiar technology
- Low to moderate self-discharge (5%–15% per month)

LA Cons

- Limited depth-of-discharge (DOD), ~50%–80% recommended
- Fewer cycles than other chemistries
- Maintenance required (FLAs)
- Moderate efficiency—the ratio of energy pulled out to energy put in. (FLAs: 80%-85%; higher efficiency for VRLAs: +90%)
- Higher weight per capacity
- Vented battery enclosure required because of outgassing
- Made with toxic materials (lead and sulfuric acid)
- Discharged FLAs can freeze

Lithium Batteries

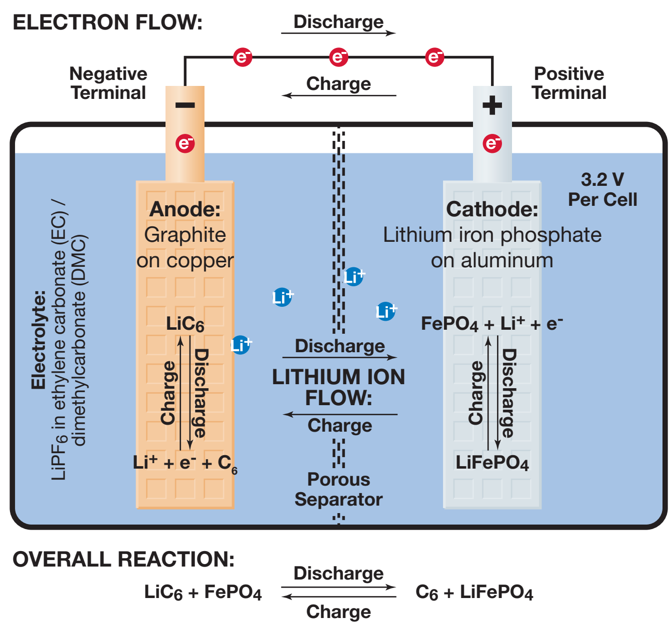
Lithium rechargeable batteries became available in the 1980s, but a large recall of metal lithium batteries happened in 1991 in Japan when a mobile phone released flaming gases and inflicted burns. Cycling of this battery type produced dendrites on the anode that penetrated the separator and caused the cell to short-circuit. This spurred the lithium-ion (Li-ion) battery, which uses graphite (carbon) anodes rather than lithium, and does not have this dendrite issue.

While LA battery cells store and release energy via a redox reaction, Li-ion batteries use intercalation—inserting lithium ions into the electrodes' crystal lattice structure without changing their structure. Unlike LA batteries, this process doesn't create new compounds.

Cathodes used in lithium batteries have a lithium metal oxide base. Ones most commonly used in RE systems include lithium nickel manganese cobalt (NMC) and lithium iron phosphate (LFP). Li-ion batteries have a lithium (non-aqueous) salt electrolyte and a polymer separator that allows the lithium ions, but not electrons, to flow through it. During discharging, positive lithium ions flow into the cathode, while electrons are released at the anode's external circuit and also flow to the cathode.

During charging, the process reverses—the lithium ions flow to the anode internally, and the electrons flow from the cathode to the anode externally. Because there is a non-aqueous electrolyte, no hydrogen or oxygen gas is created in the reaction, and there's no need to ventilate an Li-ion battery. NMC Li-ion batteries produce 3.7 V per cell, while LFP versions average 3.2 V per cell.

Lithium Iron Phosphate Reaction



Li-ion Pros

- High energy density. Li-ion batteries are smaller and lighter for the same capacity. This can be advantageous in homes with limited space for housing batteries.
- Higher voltage, fast recharge, deep discharge OK—80% is normal and 100% is possible
- Long cycle life (1,000 to 3,000 cycles)
- High battery efficiency (99%)
- No maintenance
- No voltage sag—a Li-ion battery at 20% DOD has the same voltage as when it's at 80% DOD.
- Holds capacity better at low temperatures than LAs. At -20°C, Li-ions will still have 80% capacity, while LAs will only retain 40% of their capacity.
- Low self-discharge (<5% per month)
- LFP is extremely stable

Courtesy Iron Edison

Lithium iron phosphate batteries don't gas, are extremely stable, and can handle high charge/discharge rates. These batteries from Iron Edison are offered in 12, 24, and 48 VDC, in capacities from 2.3 to 291 kWh. Pictured is a 48 VDC, 18.7 kWh bank.

Courtesy Tesla

Lithium nickel manganese cobalt batteries have exceptional energy density and, like LFP batteries, have a long cycle-life and do not require maintenance. This Tesla Powerwall 2 has 14 kWh of storage and an integrated inverter.

Battery Chemistry Characteristics

Characteristic	Lead-Acid: Flooded	Lead-Acid: AGM	Lead-Acid: Gel	Lithium-Ion: NMC	Lithium-Ion: LFP	Nickel-Iron
Recommended applications	Off-grid	Off-grid, backup	Off-grid, backup	Off-grid, backup, energy mgmt.	Off-grid, backup, energy mgmt.	Off-grid
Upfront cost	Low*	Low to moderate	Low to moderate	High	High	High
Maintenance-free	No	Yes	Yes	Yes	Yes	No
Efficiency	Moderate	High	High	High	High	Moderate
Acceptable DOD	Low to moderate	Low	Low to moderate	High	High	High
Cycle life	Low to moderate*	Low to moderate	Low to moderate	High	High	Highest
Power-to-weight ratio	Low	Low	Low	Highest	High	Moderate
Resistance to harm from overcharging	High	Low to moderate	Low to moderate	Low	Low	Highest
Freeze tolerance	Low	High	High	High	High	High
Self-discharge rate	Moderate	Low	Low	Low	Low	High
Stability	Moderate	Moderate	Moderate	Low to moderate	High	High
Venting required	High	Some	Some	None	None	High
Voltage sag with low SOC	Yes	Yes	Yes	Minor	Minor	Yes
Cold weather capacity	Low	Moderate	Low	High	High	Low
Ease of recycling	High	High	High	Low	Low	Moderate
Familiarity	High	High	High	Low	Low	Moderate
Cell BMS required	No	No	No	Yes	Yes	No

*Premium (industrial) FLAs can have moderate cost and high cycle life

SimpliPhi offers 24 and 48 VDC LFP batteries with 2.6 and 3.4 kWh capacities. They are designed to be a drop-in replacement for LA batteries.

Courtesy SimpliPhi

Li-ion Cons

- Expensive—while large-scale Li-ion pricing is rapidly declining, upfront costs for those used in home-scale storage are still comparatively high.
- Extremely sensitive to overcharge and needs battery management system (BMS) per cell. Newer Li-ion battery packages usually incorporate BMSs.
- Should not be charged at low temperatures (<32°F). Some sources say a slow charge at low temperatures is OK.
- Can be prone to thermal runaway (NMCs)
- Some have toxic and hard-to-source materials, such as cobalt

An LFP battery with 1.2 kWh capacity, the Battle Born battery is designed as a drop-in replacement for a 12 VDC lead-acid battery.

Courtesy Battle Born

Nickel-Iron Batteries

Nickel-iron (NiFe) battery technology was introduced around 1900 by Thomas Edison, so is referred to as the "Edison cell." These batteries were originally intended to power electric vehicles but were also used for backup power for mining and railroad operations.

In NiFe batteries, the cathode is nickel oxide hydroxide [NiO(OH)], and the anode is made of iron (Fe). The electrolyte is a solution of potassium hydroxide (KOH), a little lithium hydroxide (LiOH), and water.

When discharging, the active material of the positive plate changes from nickel oxide hydroxide to $Ni(OH)_2$, and the negative plate changes from Fe to ferrous hydroxide [$Fe(OH)_2$], with two electrons being released at the anode and pulled in at the cathode via the external circuit for each reaction. The electrolyte is only used as a medium for the hydroxide (OH-) ions to flow through.

The process is reversed during charging. Electrons are pulled from the nickel hydroxide electrode and driven into the ferrous hydroxide electrode. The potassium hydroxide and lithium hydroxide are not reflected in the chemical equations because the electrolyte is only a catalyst and does not participate in a chemical change with the active materials during charging or discharging. Unlike an LA battery, then, the electrolyte's specific gravity does not indicate the battery state of charge. Instead, SOC is usually measured by voltage while the battery is at rest. The nominal battery voltage is 1.2 V per cell. Nickel-iron batteries do gas during the entire charge cycle, and must be adequately vented and routinely watered.

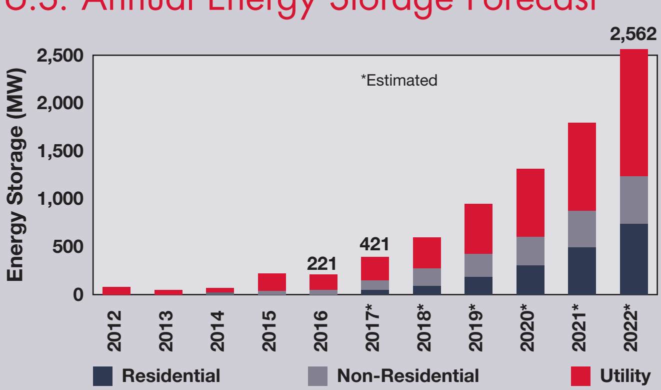
Courtesy Iron Edison

Nickel-iron batteries have exceptional durability and longevity, but require frequent maintenance.

Utility-Scale Energy Storage

Consider what happens when megawatts of grid-tied PV arrays are humming along and a cloud passes by or the sun sets—the utility has to compensate with a steep ramp-up of conventional power generation (commonly via natural gas "peaker" plants) to handle that decrease in available power. For the sun and wind to compete with conventional power sources, energy storage is needed to smooth out variations in energy availability.

U.S. Annual Energy Storage Forecast



Data Courtesy GTM Research

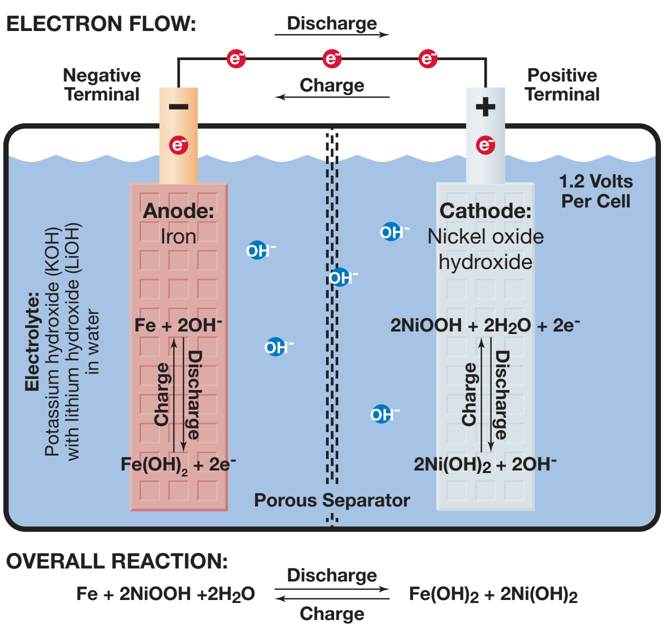
The utilities are moving toward large-scale energy storage. In California, a mandate requires 1.3 gigawatts of storage by 2020. Under the mandate, approximately 100 MW of storage came online in this first quarter of 2017 by Southern Cal Edison (SCE) and San Diego Gas and Electric (SDG&E). Interestingly, the rapid deployment of those southern California storage projects was a response to a fossil fuel disaster: the methane gas leak at Aliso Canyon near Los Angeles.

Outside of California, since 2012, 250 MW of energy storage have been added to the PJM Interconnection grid in the Midwest and Mid-Atlantic regions. Other pending large-scale energy storage projects include:

- The Kauai Island Electric Cooperative developing 20 MW of energy storage (with 28 MW of PV arrays) in Hawaii
- 20 MW of energy storage (total) to support two Texas wind farms (446 MW total)
- 10 MW of storage to support a 2 MW PV array for Tucson Electric Power in Arizona.

According to the *Energy Storage Monitor: 2016 Year in Review*, by 2022, energy storage deployments are projected to reach 2.6 GW per year over all sectors—that's about 12 times the size of the 2016 deployment.

Nickel-Iron Reaction



NiFe Pros

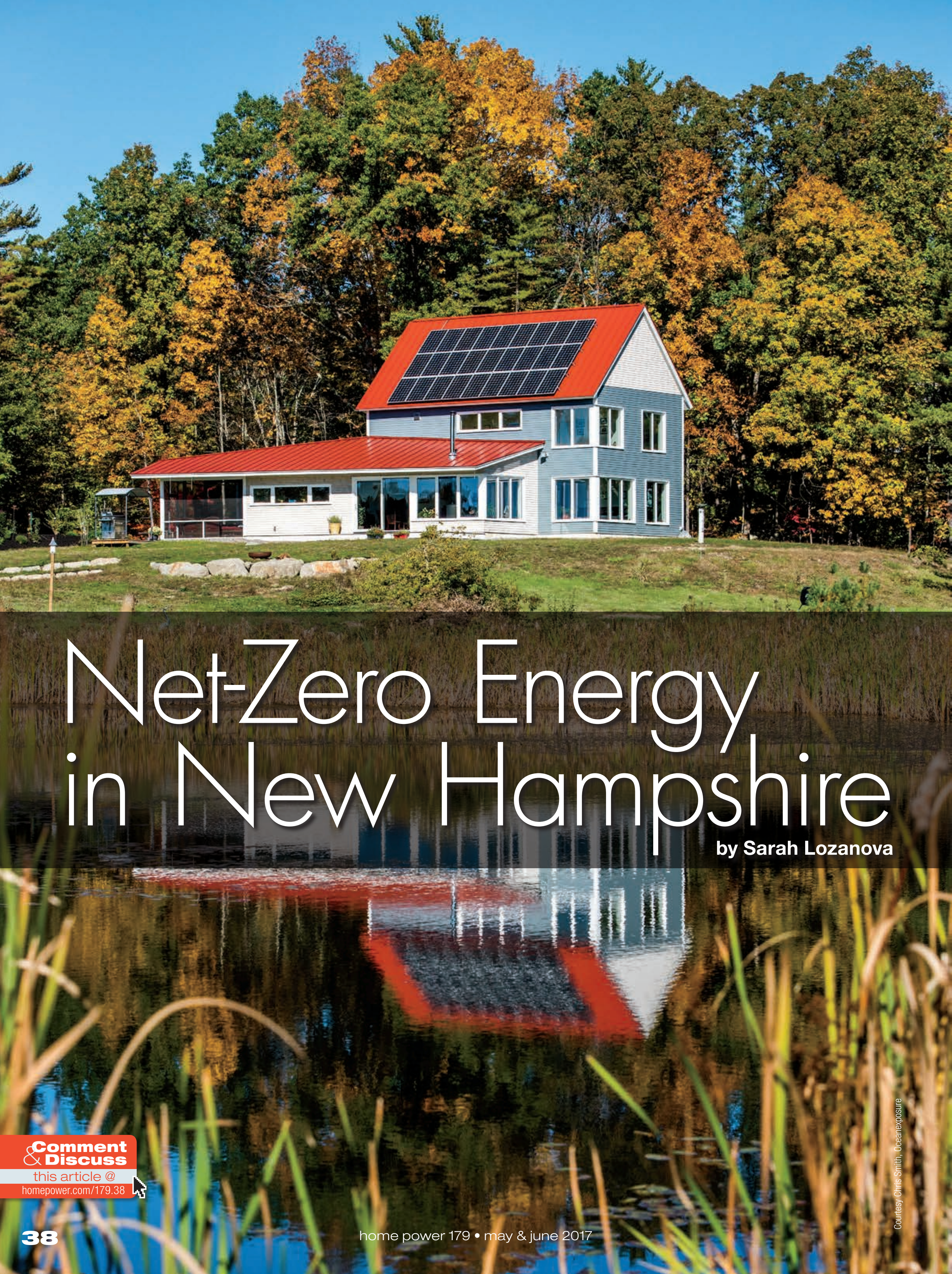
- Long life (10,000+ cycles)
- Robust (can be overcharged and deeply discharged)
- Freeze-resistant, even if discharged
- Large acceptable operating temperature range (approximately -20°F to 190°F)
- Best in systems with daily discharge/charge (not floating)

NiFe Cons

- High cost
- Moderate efficiency (80%)
- Need a lot of watering and venting
- High rate of self-discharge (30% per month)

Choosing Your Battery

Regardless of the type of battery, energy storage opens up new options for RE systems. For both residential and commercial, energy storage allows homes and businesses to operate off-grid, provides backup energy for grid-tied systems, and can change the financial equation for grid-tied systems in regions undergoing changes to their net-metering programs. At the utility scale, energy storage provides many potential services, from stabilizing the ebb and flow of solar and wind power plants to frequency regulation and voltage support. All of these energy storage services are widening the pathway for RE to become a much larger portion of our worldwide energy mix.



Net-Zero Energy in New Hampshire

by Sarah Lozanova

Courtesy Chris Smith, Oceanexposure

Opposite: Lubberland's Edge sits above a marshy estuary, a sanctuary for wildlife. With its many windows, the home is designed to maximize appreciation of flora and fauna, and provide a cozy, energy-efficient nest for its inhabitants.

Right: Large, triple-pane, low-e windows maximize efficiency, solar gain, and the expansive views. A concrete slab floor provides thermal mass for storing passive solar gain.

Courtesy Chris Smith, Oceanexposure

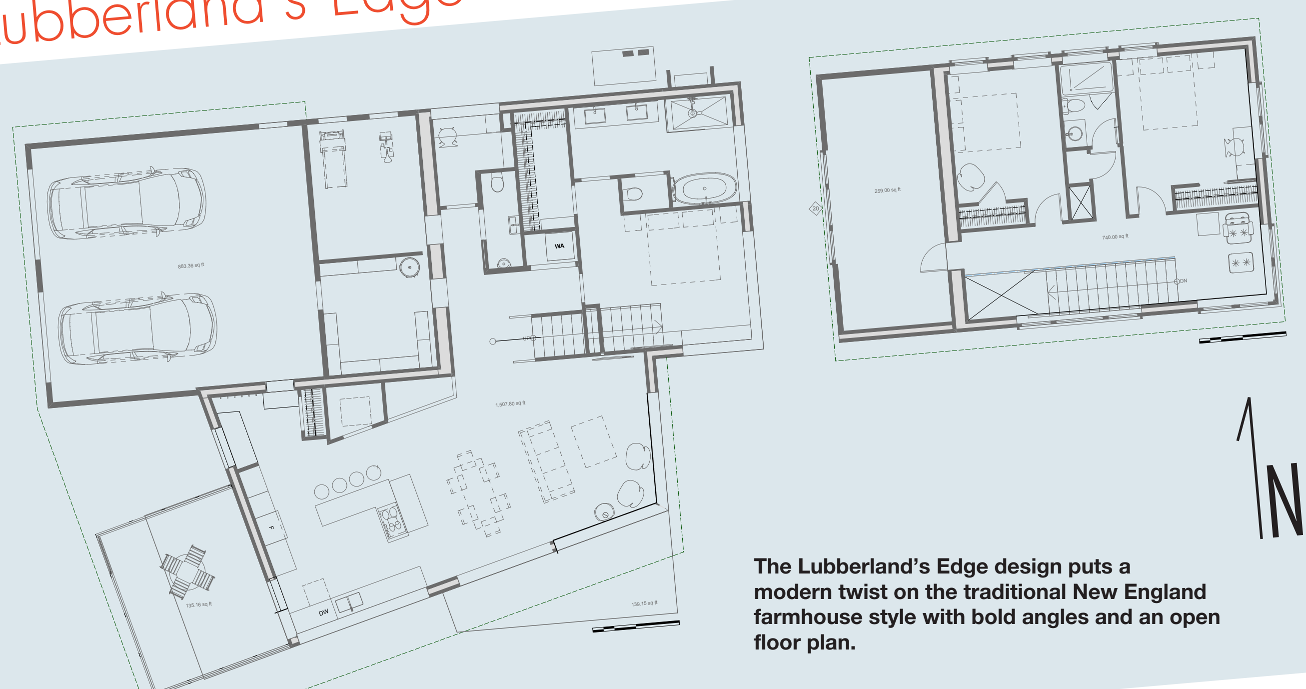
Courtesy Norbert & Robin Wesely

Above: The west side of the home sports the main entry and a screened porch, both amply shaded from the hot summer-afternoon sun.

For homeowners Norbert and Robin Wesely, morning at their Lubberland's Edge home involves live entertainment—on the wild side. With saltwater marshes, freshwater wetlands, and intact blocks of forest just outside the door of their new net-zero-energy home, its native residents—birds and mammals—put on a show.

The couple moved into their 1,900-square-foot retirement dream home in December 2015. The energy-efficient home is located on Lubberland Creek in Newmarket, southeastern New Hampshire.

Lubberland's Edge



The Lubberland's Edge design puts a modern twist on the traditional New England farmhouse style with bold angles and an open floor plan.

Courtesy Kaplan Thompson Architects

The main living area is angled slightly southeast from the main structure. Excess solar gain is controlled seasonally by large eaves.

The large east windows gain morning light for quick warm-ups on winter days, while the west side is shaded, and protected from afternoon overheating.

"We enjoy being in nature and hoped to build a home that did as little to disrupt the natural balance as possible," says Robin. "The windows allow us to observe the deer, turkeys, birds of prey, fox, and bobcats without disturbing them."

Designed by Kaplan Thompson Architects and built by Futuro Construction, this innovative home features energy-efficient technologies, passive solar design, and exceptional views. The end result is a net-zero-energy home that offsets all the energy it uses with a rooftop PV system—and it offers remarkable comfort, requiring very little upkeep.

Maximum Gain

Heating this northeastern home without relying on fossil fuels became a major focus, and it primarily uses the sun. The home's long axis sits along an east-west orientation and has lots of south-facing windows to take advantage of the sun's rays throughout the heating months, while offering stunning views of the creek and wetlands.

The polished concrete floors on the first floor provide thermal mass to absorb, store, and then gradually release the sun's heat when indoor temperatures dip during the night or on cloudy days. During the winter, the sun sits lower in the sky, and sunlight streams in through south-facing windows. In the summer, when the sun is higher in the sky, a 4-foot-deep overhang blocks sunlight from entering directly. The home's open floor plan and an energy recovery ventilator help circulate the air for even temperatures throughout.

Passive House Standard

Although Lubberland's Edge isn't certified as such, it was built to the Passive House standard, meeting its criteria for energy use and airtightness. Passive House Planning Package computer modeling was used to examine the impact of different design modifications on the home's energy consumption. This software also helped the architects estimate the required size of the PV system needed to be a net-zero energy consumer.

The open, modern living space defies the farmhouse-style exterior. The well-insulated, passive solar home rarely requires supplemental heat from the wood heater.

The kitchen takes advantage of energy-efficient technologies, including an induction cooktop. The range hood is ducted through the HRV.

Courtesy Chris Smith, Oceanexposure (4)

To minimize heat loss, generous amounts of insulation were used. The home features double-stud framing that results in 12-inch-thick walls. Insulated with dense-pack cellulose, these walls are rated at about R-45. Because the studs are spaced apart, this construction method also minimizes thermal bridging.

The roof sections have two different constructions—the pitched truss roof is insulated with loose-fill cellulose to R-70, while the lower roof is 5-inch-thick structural insulated panels on 14-inch I-joists with 1 inch of spray foam insulation and full-depth dense-pack cellulose, also for R-70. The interior slab-on-grade was insulated with 6 inches of rigid expanded polystyrene for R-26.

The home was constructed with durable materials and methods, for lower maintenance costs. A continuous air barrier helps eliminate condensation, promoting durability. The metal roof is designed to last 40 to 70 years. The home features two different types of siding. The bleached, oil-dipped cedar shingles should last 50 years or more, and the James Hardie cement siding has a 35-year product warranty and a 15-year warranty on the finish.

Almost Airtight

Most homes have air infiltration from numerous gaps and cracks. Although these can provide ventilation, they are also paths for conditioned air to exit and moisture and unconditioned air to enter. They can also cause winter comfort issues, when drafts can chill the occupants and create uneven temperatures throughout the home.

"Who wants anything that leaks?" says Matt Silva, general manager for Futuro Construction. "A tight home is a comfortable home because you don't have the drafts."

Lubberland's Edge was tightly constructed for comfort, energy efficiency, and quietness. This was achieved by an air barrier with taped seams, and sealing other gaps or penetrations. European Internorm-brand doors and its Home Pure KF 500 line of triple-pane windows help seal the house when closed. West- and east-facing windows (with U-factors as low as 0.107) provide daylighting, views, and some solar gain, without creating drafts and comfort issues. The HT 400 doors have U-factors as low as 0.13.

To meet the Passive House standard (see sidebar), the house must pass a blower-door test of 0.6 air exchanges per hour (ACH) at 50 Pascals negative pressure. This test uses a calibrated fan, a manometer to measure pressure, and a fan temporarily sealed into an opening of the home. Lubberland's Edge was tested twice—when only the outer dwelling shell had been finished—and both readings were less than 0.6 ACH. By contrast, the 2012 *International Energy Conservation Code* requires a maximum score of 3 ACH.

Advanced Performance

Norbert and Robin wanted a home that was comfortable throughout the four distinct New England seasons. The design and tight construction significantly reduce the dwelling's heating and cooling load but that also requires mechanical ventilation to exhaust stale air and excess moisture while supplying fresh air. Owing to its tight construction, exhaust

Second-story clerestory windows keep the landing well-illuminated, naturally.

Passive House Standard

Passive House (or Passivhaus) is a voluntary standard for ultra-energy-efficient design that can be applied to single-family homes and skyscrapers alike. Projects built to this standard are 80% to 90% more efficient for heating and cooling than a code-built project. This level of energy efficiency decreases the size of the renewable energy system needed to achieve net-zero energy use (see phius.org). It has five main principles:

- Continuous insulation throughout the entire envelope
- Virtually airtight construction and superinsulation
- High-performance windows and doors
- Continuous mechanical ventilation
- Maximization of solar gain in the winter and not in the summer

Water-efficient fixtures in the bathroom also provide some energy savings.

Courtesy Chris Smith, Oceanexposure (2)

Twelve-inch-thick, double-stud walls were filled with cellulose for an insulation value of R-45. Ceilings are insulated to R-70; the floor is insulated to R-26.

Innovative Filtration

To maximize energy efficiency and indoor air quality, the home features an innovative Zehnder ComfoHood range hood. Instead of venting conditioned air out of the home, the hood filters out grease and particles, then passes the air through the energy recovery ventilator. Heat from the exhaust air is transferred to the intake air in the winter and precools air in the summer. The design also eliminates the need for an envelope penetration, reducing air leaks.

fans were not an option. Such ventilation systems rely on gaps and cracks in the home envelope to supply the required makeup air for proper operation. Exhaust fans also vent conditioned air out of the home, without capturing energy, and require additional penetrations in the home envelope.

Lubberland's Edge features four high-efficiency systems for heating, cooling, and ventilating the home. Norbert, who works for heating and ventilation equipment manufacturer Zehnder America, designed the ventilation systems for the home, and Kaplan Thompson Architects designed the heating and cooling systems.

The Zehnder ComfoFond-L eco geothermal heating and cooling system uses near-constant ground temperatures to temper the air coming into the dwelling. The unit preheats the incoming air in the winter and precools and removes some moisture from the intake air in the summer before entering the energy recovery ventilator (ERV). A 150-foot-deep well was dug for the geothermal ground loop and the unit consumes between 5 and 70 watts.

The Zehnder ComfoAir 550 ERV continuously supplies fresh, filtered air while exhausting an equal amount of stale air from the kitchen and bathrooms, removing excess moisture, odors, and cooking fumes. It supplies fresh air to the bedrooms and living spaces after the air has been tempered by the ComfoFond-L eco. In the colder months, heat from the exhaust air is transferred to the intake air by the ERV's heat exchanger, saving energy. In the summer months, the ERV precools the intake air.

When summer temperatures spike, a control turns on the Zehnder ComfoCool, a heat-pump cooling system that consumes between 700 and 850 watts. Supplemental winter heat comes from a Zehnder towel warmer radiator in each of the two bathrooms and a wood heater in the living room. Norbert and Robin use the wood heater primarily for ambiance.

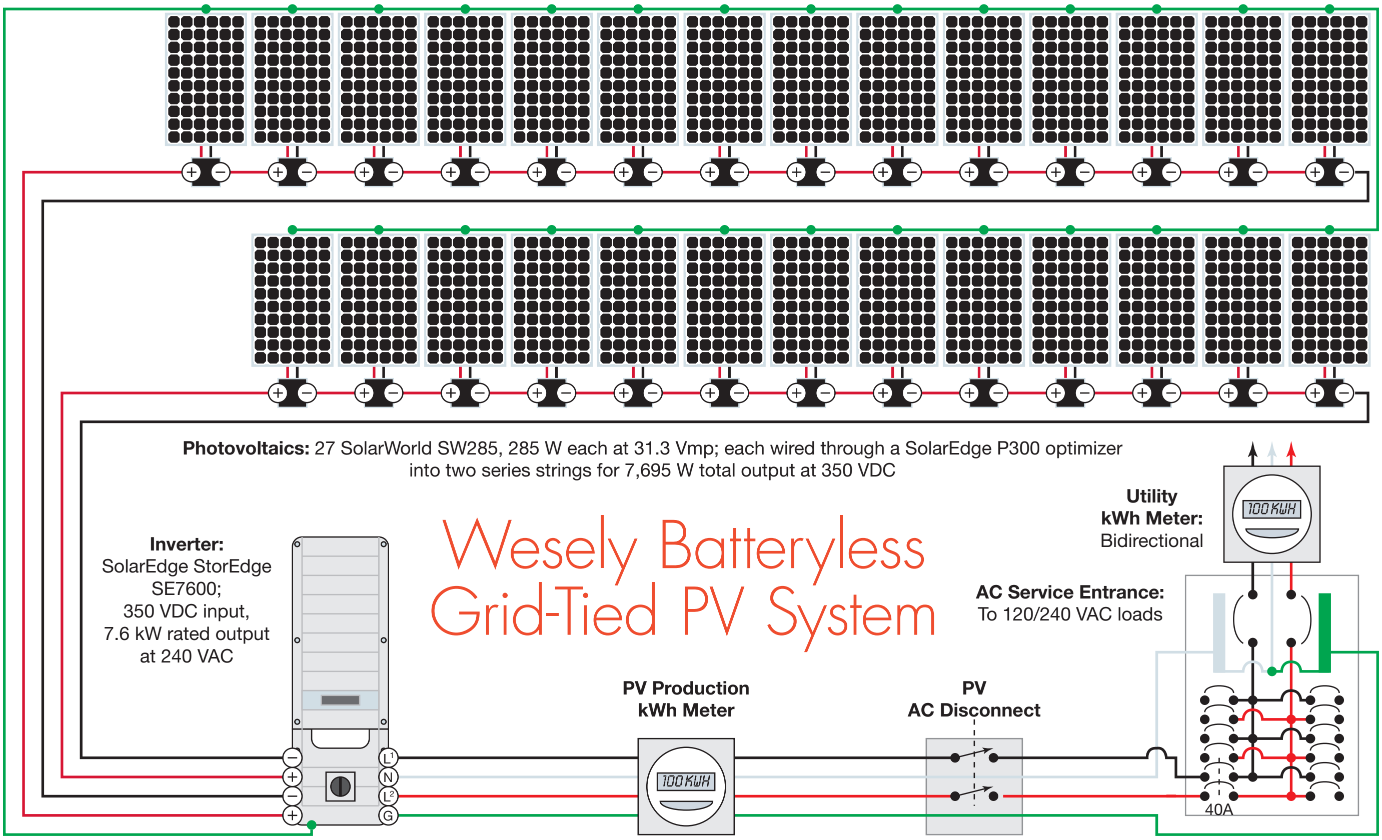
Lubberland's Edge has an induction range, LED lights, and a Whirlpool Hybrid Care dryer with heat-pump technology. It is ventless, which eliminates a penetration in the envelope, and the dryer is more energy-efficient than a conventional dryer.

"I was a bit hesitant about the ventless dryer, but am pleased to say that it works great!" says Robin. There's an ERV vent in the washer and dryer closet to avoid excessive moisture from the dryer. The drying time is similar to the drying time from the vented dryer in their previous home.

The Whirlpool Hybrid Care dryer, which has a heat pump, doesn't require an external vent.

The Zehnder ventilation system, from left to right: ComfoFond L Eco 550 ground-loop-based preheater; ComfoAir 550 energy recovery ventilation unit; and ComfoCool 550 cooling unit.

Courtesy Norbert & Robin Wesely (3)



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

PV System Tech Specs

Overview

Project name: Norbert & Robin Wesely residence

System type: Batteryless, grid-tied solar-electric

Installer: Harmony Energy Works

Date commissioned: June 2015; monitoring installed January 2016

Location: Newmarket, New Hampshire

Latitude: 43°

Solar resource: 4.3 average daily peak sun-hours

ASHRAE lowest expected ambient temperature: -2°F

Average high summer temperature: 88°F

Average monthly production: 945 (actual), 792 (projected) AC kWh

Utility electricity offset annually: 100%

Photovoltaic System Components

Modules: 27 SolarWorld SW285, 285 W STC, 31.3 Vmp, 9.2 Imp, 39.7 Voc, 9.84 Isc

Array: 1 string of 13 and 1 string of 14 modules; 7,695 W STC total. With the SolarEdge P300 optimizers, there is no string Vmp or Imp per se. String voltage is approximately 350 VDC while operational and 14 VDC (safe DC voltage) when disconnected.

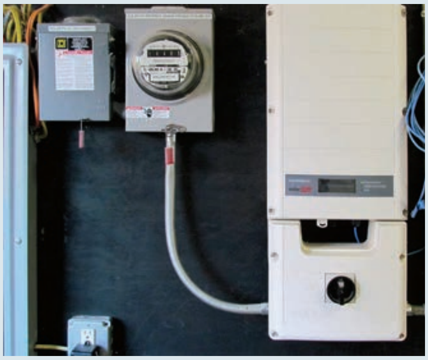
Array installation: IronRidge XR1000 rack with S-5! mounts, on south-facing roof, at 45° tilt (parallel to roof)

Inverter: SolarEdge StorEdge SE7600 with 27 SolarEdge P300 optimizers, 7.6 kW rated output, 500 VDC maximum input (nominal DC input to inverter from optimizers is 350 VDC), 240 VAC output

System performance metering: GE Ez-Read revenue-grade production meter

Left: The PV modules and DC optimizers during installation.

Right: The 7.6 kW SolarEdge StorEdge inverter.



Courtesy Norbert & Robin Wesely (2)

Courtesy Chris Smith, Oceanexposure

System Costs

Installed Cost: $16,822

Less Incentives, Rebates, Tax Credits: $3,750 state rebate and $5,046 for the 30% federal tax incentive

Net installed cost: $8,026

Smart Layout

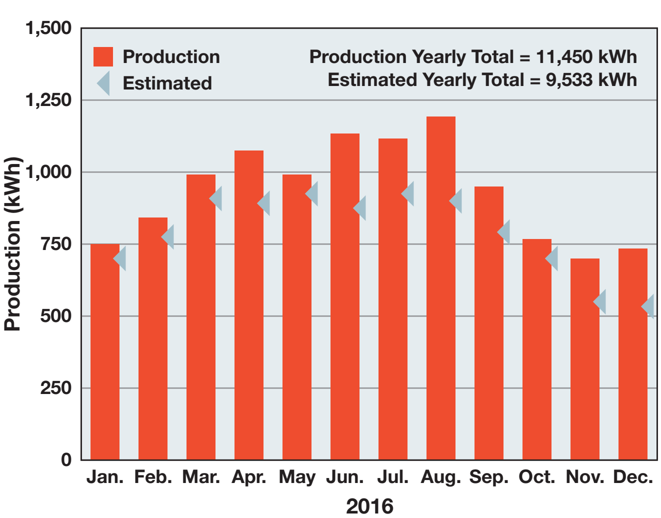
Norbert and Robin like the floor plan and layout of Lubberland's Edge. "We knew what we wanted going into the process and consequently didn't go through a lot of iterations during the design phase," explains Robin. "We like to entertain and have found this to be a great property for that. The open floor plan, with the living room, dining room, and kitchen area together, makes the most of the space. If the weather is nice, we're outside or in our screened-in porch."

The vaulted ceilings in the living and dining rooms, 11-foot ceilings on the second floor, and plentiful windows give the home an expansive feel without adding square footage. To minimize the heating and cooling load of the home, the exercise room, storage, garage, and mechanical room are all outside of the home's envelope. This keeps garage fumes and airborne pollutants from entering the living space.

As of mid-November 2016, the system had produced almost 14.5 MWh.

Courtesy Norbert & Robin Wesely

PV System Production



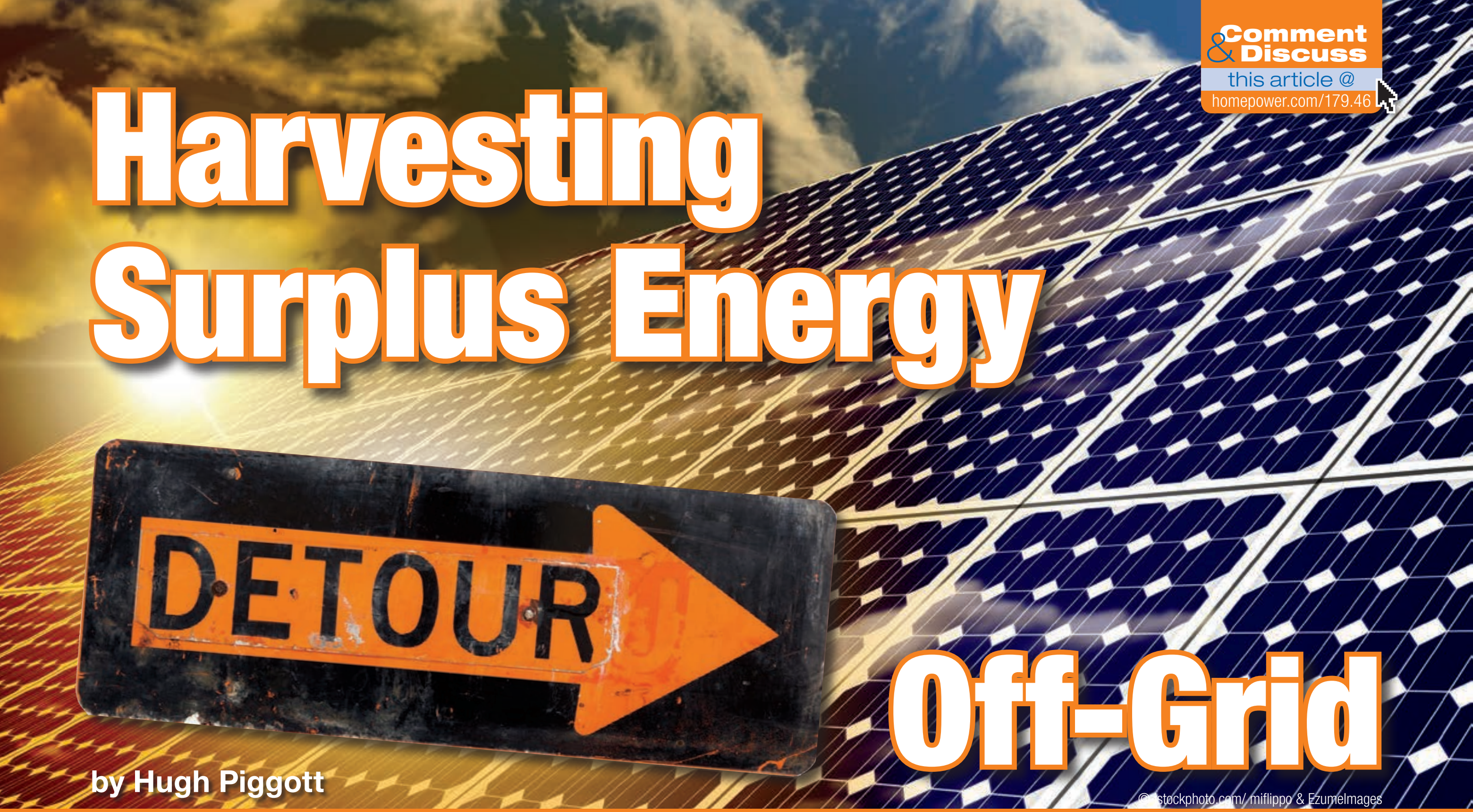
Active Energy from the Sun

Because Norbert and Robin wanted to live in a net-zero home that uses no fossil fuels, the PV system was sized to produce all of the energy the home uses for heating, cooling, cooking, water heating, and plug loads. The south-facing rooftop was the ideal location for the grid-tied 7.7 kW system. The roof's steep pitch (45°) is good for maximizing the system's production in the winter.

As soon as the roof and the electrical panel in the garage were in place, the PV system was installed to offset energy used during construction. The PV system's energy production has been much greater than the estimates, especially in the summer. During August 2016, it was about 25% greater than forecast. The system's power optimizers are helpful, since the array is partially shaded by trees to the west.

Harmony Energy Works designed the system for compatibility with the Tesla PowerWall by using the SolarEdge 7.6 StorEdge inverter, for future battery backup. The system also includes monitoring capabilities, so both Harmony Energy Works and the homeowners can keep an eye on the PV's system production.

Norbert and Robin have created a unique retirement home. They appreciate that Lubberland's Edge offsets it energy use with solar. This also helps protect the surrounding ecosystem that they cherish. "It's a really special home that integrates numerous innovative technologies," explains Norbert.



Harvesting Surplus Energy Off-Grid

by Hugh Piggott

Many off-grid users of renewable energy abhor wasting energy. We obsess about load efficiency, switching off lights, and putting phantom loads on plug strips. But few people realize how much energy is wasted by charge controllers. This article can help you use most of your system's available energy.

A PV system generates electricity during the sunny hours (as do wind turbines in windy hours), but much of this energy is needed at other times, such as evenings or periods of calm. The solution to this mismatch is to store energy in batteries.

RE sources will produce much more energy on one day than on another, depending on the weather and the season. Surpluses occur when the battery and the loads cannot absorb all the available energy. Also, the rate at which a battery can absorb current tapers off as the battery approaches its fully charged state. For a battery to remain healthy, this situation ought to be commonplace, but it often results in unused energy.

The principle of charge control is to regulate the battery voltage to an optimum level for the specific stage of the charging process. The installer must program the controller with the correct voltage "setpoints" for each stage—absorption, float, and equalize. At first, the battery will need a high charging current, but this will taper off over time, even though the voltage is kept at its setpoint. A quality charge controller uses information from a temperature sensor to further adjust the charging, and it runs a timer to determine when the absorption stage is complete and the battery is "charged." After this, it will limit the current to a very low trickle that maintains the float voltage.

A PV charge controller limits the current going into the battery bank based on the setpoints. This prevents the battery from charging too fast, which can result in damage. The downside is that it also reduces the system's efficiency by using less energy. Wind and hydro sources are not as easy to control. If their generated output is not used, turbines can be damaged by overspeed. For these sources, we must use a diversion controller that shunts unwanted energy into a load. This "protective diversion load" or "dump load" protects the battery from overcharging and the turbine from overspinning, but it can waste energy. The key to improved efficiency is using "opportunity diversion loads" instead of, or as well as, protective diversion loads.

With wind and hydro systems that can't be allowed to operate at open-circuit, dump loads, like these resistance air heaters, are necessary—but they usually don't do useful work.

Hugh Piggott

Lifestyle Adjustments

Most off-gridders try to get the laundry done and the floor vacuumed when the sun is shining (or wind blowing) and the batteries are full. Just as we switch off loads as the battery voltage falls (due to reduced RE), we try to use electricity when the voltage is high. We're taking advantage of energy that would otherwise go to waste.

In my home, for example, we have a single-burner induction cooktop that does most of our cooking when there's ample electrical energy available. It's a great feeling to use free, clean energy and to avoid the cost and pollution of using propane that is also likely derived from fracking.

While there are aspects of this that are satisfying, constantly having to monitor system energy can be irksome. Most of us have other priorities in our lives, and that's where "opportunity diversion" comes in. A diversion relay can often do our job better than we can because it has no other purpose in life than switching things on and off automatically. Don't ask a relay to make your breakfast, but it can heat your water tank, pump your irrigation, or switch on air conditioning.

Morningstar TriStar (right) can be configured for stand-alone PWM diversion using simple DIP switches that also select the battery type. ProStar MPPT charge controllers (below) can switch diversion loads directly (based on a fixed battery setpoint), using LVD mode with a rather high setpoint.

Courtesy Morningstar (2)

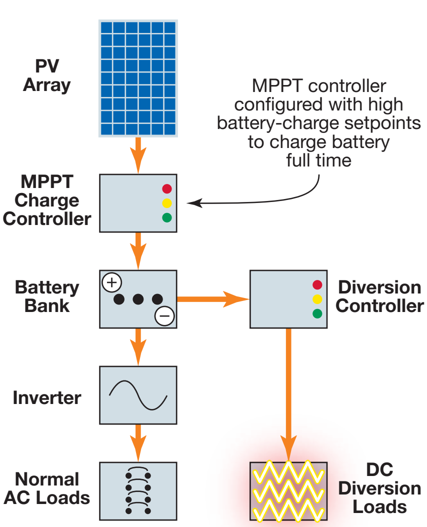
Diversion Controllers & Relays

One way to set up an opportunity load is with a separate controller. Use a second pulse-width modulation (PWM) controller, such as Morningstar's TriStar or the Xantrex C-40, configured for diversion mode, to do the job of controlling the battery voltage. Keep your solar controller for the sake of its maximum power point tracking to maximize energy capture. Set the MPPT controller's charging setpoints slightly higher than the PWM unit's setpoints, so the PWM is activated first by rising voltage. If your MPPT controller has no means of driving a relay, then adding a second controller is a good way to set up opportunity DC water heating.

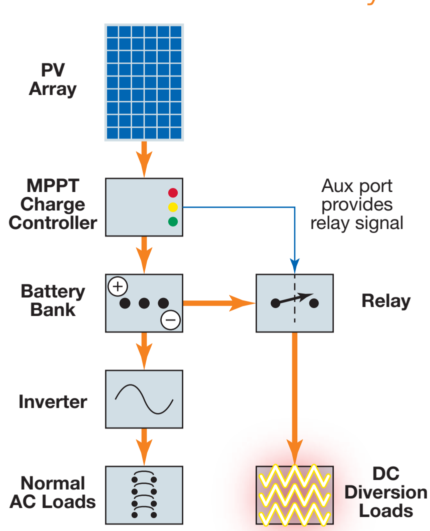
Often, your MPPT controller will "know" when there is excess power. MidNite Solar's KID charge controller can be set to "PWM Divert" and run a DC load (like a heating element) directly on its load output. Many of Blue Sky Energy's SolarBoost controllers can also switch loads using an internal 20 A relay, while its DUO upgrade option contains a PWM diversion control function. Most other makes of MPPT controllers offer an auxiliary output or "aux port" that can produce a 12 V signal (or close some switch contacts) when a battery voltage setpoint is reached. Connect this to the coil or input of a relay and it will switch on a load to make good use of the surplus energy.

Aux ports need to be configured for a particular "mode" that determines the criteria for switching. MidNite's Classic

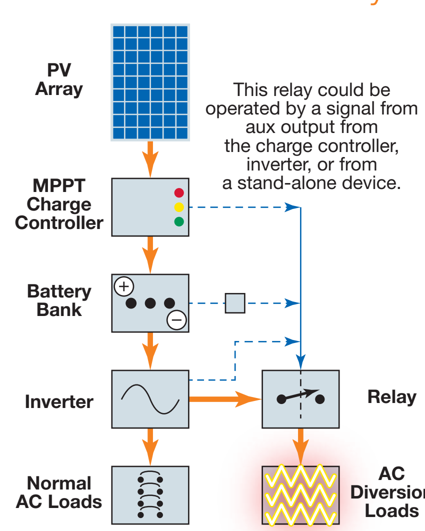
DC Diversion Using a Diversion-Load Controller



DC Diversion Using a DC Diversion-Load Relay



AC Diversion Using an AC Diversion-Load Relay



Courtesy Blue Sky Energy

Left: Blue Sky Energy's charge controllers (left) mostly contain a 20 A load relay that can be used for diversion. Also, the DUO Option software upgrade converts the Solar Boost 3024 controller's auxiliary output into a 20 A diversion-type PWM charge controller.

Courtesy MidNite Solar

Right & below: MidNite Solar's Classic controller has two aux outputs, one of which can divert PWM current to loads via SSR. The KID controller offers PWM diversion directly (without SSR) from its load terminals. In both cases, control can be based on prevailing battery-charging voltage setpoint.

Courtesy OutBack Power Systems

Right: OutBack Power's FLEXmax series can divert PWM current to loads via SSR based on prevailing battery-charging voltage setpoint.

Courtesy Schneider Electric

Left: The Schneider Electric C-series of PWM charge controllers can be configured for stand-alone PWM diversion using jumpers. Two potentiometers and a multimeter are used for adjusting the battery-charging setpoints.

and OutBack's Flexmax charge controllers offer modes that energize their aux ports when the battery voltage setpoint is reached for the prevailing stage of charging—absorption, float, or equalization—just like a dedicated diversion controller. If you plan to use diversion whenever possible, then you should use these modes. In other MPPT controllers (and inverters), the aux port modes offer only fixed voltage setpoints. A fixed voltage setpoint for diversion will either be too low to allow proper absorption or too high to be activated during the float stage of charging. It may work well for relatively low power loads or for heating a small water tank with a thermostat that opens after an hour or so, but otherwise it will prevent your RE system from properly charging the battery.

Some controllers offer Aux port modes that signal when charging has reached the float stage. Several offer modes for a certain percentage state of charge (SOC). These modes may be worth considering for operating motorized opportunity loads, such as irrigation pumps that can only work at full power. But they will miss out on the gradually rising surplus of power that occurs during the absorption stage.

High-array-voltage triggers are another possible mode to use for diversion. If the controller is rejecting surplus PV power, then the array voltage will rise beyond the maximum power point. You can choose an Aux port mode to trigger diversion as the array rises a little above its normal, observed MPP voltage. This should not interfere with the battery's ability to achieve absorption voltage setpoint, but your trigger point may be a moving target. This mode is ideal for hydro turbines, but less so for PV arrays, as the energy capture drops fast as the array voltages rises above MPP voltage and the MPP voltage will vary with array temperature.

Relays

A relay is a switch for high current that is operated by a tiny current. Older mechanical relays use an electromechanical solenoid to close physical contacts. They can open and close many thousands of times but will eventually wear out. Choose these relays for modes that cycle on/off over periods of minutes—for example, driving motorized loads. Use a "plug-in" relay that is easy to replace every couple of years.

For more rapid cycling (many times per second) conditions, choose a solid-state relay (SSR) that uses semiconductor technology. SSRs are more costly and they need a heat sink, but they can be driven fast enough to implement pulse width modulated (PWM) switching that ramps the average diverted current up and down smoothly.

Use a solid-state relay (SSR) when you need frequent, rapid switching. For example, an OutBack or MidNite controller's Aux port in PWM mode linked directly to the input terminals of a Crydom D1D40 SSR can reliably modulate a DC load up to about 25 A at 60 V (2.4 ohms, 1,500 W). Mount it on a heat sink rated for less than 2°C temperature rise per watt. You can also use an AC SSR to switch AC loads via the inverter, but a heavy load may cause your lights to flicker as it pulses.

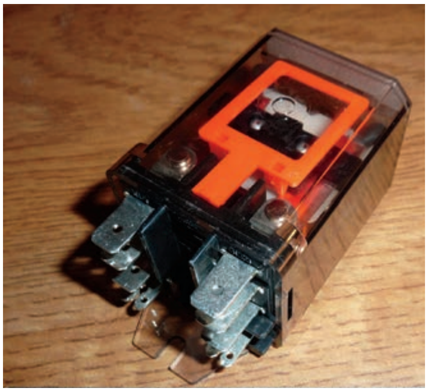
When choosing a relay, make sure the is rated well above the working voltage and current. As with most products, they have a higher failure rate when pushed to their limits, so good safety margin, such as a factor of two, is wise. Some relays are designed for AC, and some for DC—which require heavy-duty contacts due to arcing potential. Aux ports typically provide 12 V, which will work for most SSRs. If you only have aux contacts switching 48 V battery power, it would need to somehow be stepped down below 30 V to be usable for SSR input. Mechanical relays can be found with many different coil voltages, including 48 V DC.

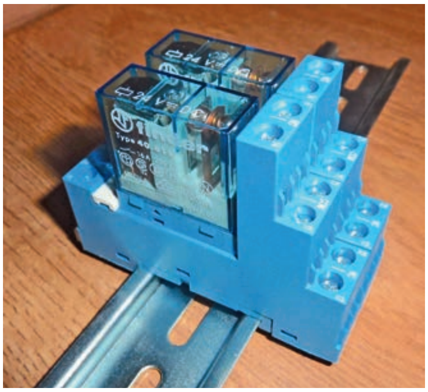
You can set your relay to operate a DC heater that draws current directly from the battery. But if your inverter is large enough, you may prefer to divert to an AC load, which has the same effect. The Aux ports in OutBack inverters have an "AC diversion" mode that prevents overloading the inverter. Irrigation pumps and air conditioning are among the possible loads, along with AC water heating elements. (Note that 120 V or 240 V heaters are easier to find than battery-voltage ones, and most thermostats are not designed to switch high DC currents.)

Courtesy Morningstar

Above: Morningstar products can operate relays based on a variety of parameters via the optional Relay Driver module. Their MSview software has many advanced tools for customizing relay drivers and charge controllers.

Right and below: Mechanical relays are simple, inexpensive, and efficient, but they switch more slowly than solid-state relays. They have a limited service life, so it's wise to buy a relay base that you can plug them into for easy replacement (as shown in the lower photo).





Solar converters offer low-cost stand-alone circuit boards that you can build into your own control cabinet. The LDR is a PWM load controller, whereas the VCS is a mechanical relay that switches on and off based on battery setpoints configured with a screwdriver.

Solid-state relays are ideal for PWM or rapid, frequent switching, as they will not wear out, but they do generate some waste heat and need a heat-sink to prevent damage.

Hugh Piggott (4)

Diversion Control Options

Manufacturer	Charge Controller or Inverter	Hardware Format of Output Port: Stand-alone (No Other Function)	Aux Contacts	Aux DC Output	PWM Capable	Direct Load Output
Blue Sky Energy blueskyenergyinc.com	Solar Boost CC		✔		DUO	20 A
MidNite Solar midnitesolar.com	Classic CC		✔	✔	✔	
	KID CC		✔		✔	30 A
Morningstar morningstarcorp.com	Relay Driver	✔		✔		
	TriStar PWM CC	✔			✔	45, 60 A
	Prostar MPPT CC					25, 40 A
OutBack Power outbackpower.com	FlexMax CC			✔	✔	
	FX inverter			✔		
	Radian inverter			✔		
Schneider Electric schneider-electric.com	Conext XW CC			✔		
	Conext XW inverter			✔		
	C-series PWM CC	✔			✔	35, 40, 60 A
Solar Converters solarconverters.com	VCS relay	✔				✔
	LDR CC	✔			✔	✔

Water-Heating Elements

The most popular opportunity diversion load for off-grid PV systems is an electric heating element in a large hot water tank. Heaters do not care whether they get AC or DC, but they are sensitive to voltage. For example, a 1,600-watt 110 V heater will only give 400 W at 55 V as a diversion for a 48 V battery system. Half the voltage means half the current, and thus only one-quarter of the wattage.

When choosing the heating element, there is no need to aim for high wattage. Diverting low power steadily works better than a very powerful heater. The big load will switch on and off frequently when there is only a small excess, cycling the battery and creating power quality issues, such as flickering lights. Higher power loads also need heavier wiring. If the controller's aux mode works at a fixed voltage setpoint, then it is preferable to use a lower-wattage diversion so that the battery can still reach full absorption voltage later in the day, even with the heater active.

If you cannot find a standard AC water-heating element that works at your battery's voltage, then you can buy DC elements online. Often, these have multiple subelements that can be configured in series or parallel to match your system's battery voltage and optimum power. For safety's sake, put a notice next to the drain valve to remind you where to turn your heater off before you drain the tank!

Hugh Piggott

Specialty water heating elements often come with several subelements. Use them in series for higher voltage or for lower power. Use in parallel for operation at nominal voltage, switching as many as needed, using one or more relays.

Safety & Thermostats

Even a small heater operating over a long period can produce dangerously hot water. The conventional solution is to use a thermostat to turn the heater off. But switching high DC current may damage a standard thermostat.

One solution is to use an AC water heater that draws power through the inverter. Another is to use a very large tank which, due to the greater volume of water, will be less likely to reach scalding temperatures. A third option is to wire the relay-control signal through the thermostat, so that when it opens, the relay turns off the heater or diverts the current to another load.

If you use a PWM diversion controller to run your water heater, then various strategies are possible. The TriStar has a battery-voltage-sensing circuit that can be wired via the thermostat. When the contacts open, the sensing is diverted through a diode string. A couple of diodes step the voltage down by a volt or so, making the controller think the voltage has fallen, and it turns off the heater. As the actual battery voltage rises further, the MPPT controller starts to limit the charging rate, so the TriStar is defeated. Be aware that a voltage difference exceeding 5 V will produce an error in the controller.

Criteria for Diversion (Names of Modes)							
Fixed Voltage	Absorb, Float, EQ Setpoint Reached	SOC%	Float Stage	Computer Can Connect	Needs Separate Relay	Needs Separate Control Panel	Notes
"Lod" volts		Amp Hours				✔	Products vary. IPN-ProRemote needed for most.
Diversion	Waste Not Hi	SOC%	Float	✔	✔		2 Aux ports
Diversion	PWM divert		Float				Direct load control output plus Aux.
Threshold	Duty			✔	✔		Linked to CC products or stand-alone
	Diversion			✔			Configured with DIP switches
LVD				✔			Configure with display or computer
	Diversion		Float		✔		For PWM option, choose "solid state"
DC divert, AC divert					✔	✔	Use the Mate control panel. Overloaded inverter cancels AC divert
DC divert, AC divert					✔	✔	Use the Mate control panel. Overloaded inverter cancels AC divert
Load control					X		Configure with its own display
LowBattV		SOC			X	X	Battery monitor required for SOC
	✔						Configured using multimeter
Only option							Configured using multimeter
Only option							

The Generator Paradox

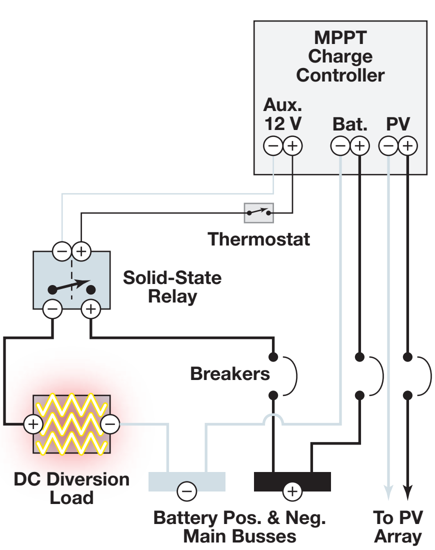
A minor challenge arises when a generator is connected to an inverter-charger, as the inverter-charger attempts to push the battery voltage up to its own charging setpoint. Often, this is coordinated with the MPPT controller's setpoints in a control system common to both. If the diversion controller has a lower setpoint, it will divert generator power as if this were another opportunity to harvest excess PV energy—but it is not. You can defeat the diversion load using a relay that opens its (normally closed) contacts when its coil is energized by the generator's AC voltage. The relay may simply interrupt the heater circuit, or again be used to distort the battery sensing of a TriStar controller (as before).

Wiring Examples

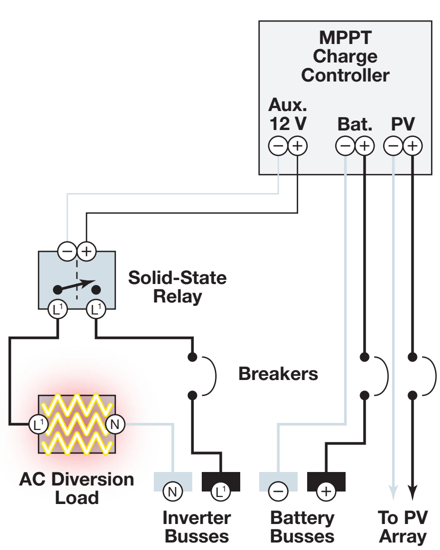
Choose wire with suitable ampacity and temperature rating, and also check that the voltage drop is acceptable. You need appropriate wire terminals, circuit breakers, and a heat sink or relay socket. Conform to all local codes, and hire a professional electrician if necessary. Read the manuals and plan how to program your controller(s) to optimally charge your particular battery type. In some cases, you may find useful videos on YouTube.

The diagrams show some of the possible wiring configurations for using relays to drive diversion loads based on signals from aux ports in MPPT controllers. Before you start, shut down any turbines and turn off all circuit breakers,

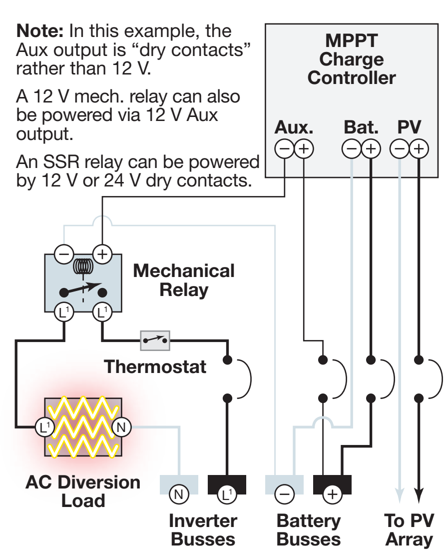
Wiring a DC Diversion Using a Solid-State Relay



Wiring an AC Diversion Using a Solid-State Relay



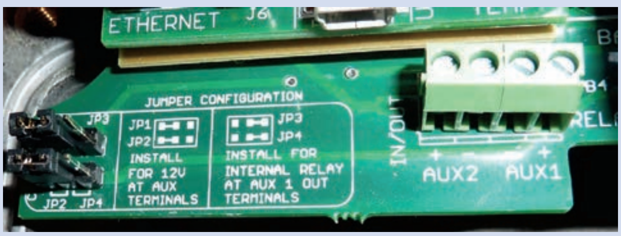
Wiring an AC Diversion Using a Mechanical Relay



Programming a MidNite Classic Charge Controller for Diversion

Use "AUX 2" for PWM control of a load via SSR.

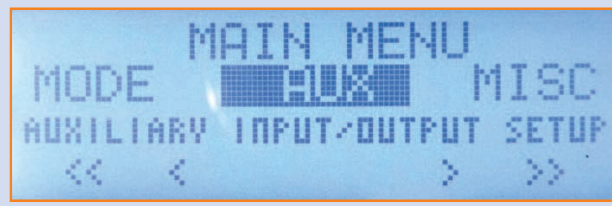
Use "AUX 1" for slower switching, or if AUX 2 is already used for the WBjr (MidNite's "Whiz-bang junior" current sensor shunt). If using AUX 1, it must be correctly configured using the jumpers. As shown, it is configured as a "12 V source" to drive an SSR. If the jumpers are moved to the right, you have "dry contacts" (without power) instead. Use this to switch battery power to the 48 V coil of a mechanical relay.

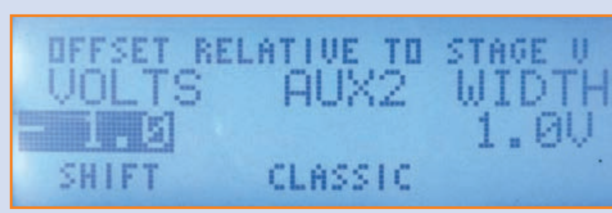


Example: Using the controller's own display to configure the AUX 2 port for PWM diversion (suitable for driving an SSR):

- Push the Main Menu button (bottom-right of keypad).
- Use arrow keys to scroll left or right to highlight "AUX," and push the Enter button.
- Scroll right to highlight the AUX 2 port.
- Push the top right-hand "soft" key (now labeled "SETUP" on the screen).
- Scroll up or down to change the relay mode to "Waste not hi." This mode energizes the load (via an SSR) using PWM when the voltage approaches the setpoint for the current battery charging stage (absorb, float, or equalize).
- Push the right soft key again to set the voltage offset. Set a small negative voltage offset for this mode so that diversion will operate before the controller regulates the PV array current. I suggest VOLTS= -1.0 and WIDTH = 1.0.
- When finished with parameters, push the ENTER button to save the changes.
- Use the Main Menu button to move back up a level in the menus. If the screen shows "manual on" or "manual off" under AUX 2 then scroll vertically to choose "Waste not hi" and press ENTER.

Using this mode can prevent the absorption setpoint being reached. If so, you may wish to adjust the battery setpoints slightly higher. You should also go into the Tweaks menu and press the soft key three times to find "DvrtCnt" and turn it on. The diversion timer will now run when the load is on, and the battery will be able to reach float stage. Press ENTER to save your changes before leaving any screen.





Hugh Piggott (4)

starting with your PV array. Take note of the polarity of the wiring between the aux port and the SSR input, connecting positive to positive. Connect the positive of the SSR output to the battery positive busbar through a suitable breaker that is rated above the heater current and below the wiring ampacity. Double-check that everything is correct before powering up the system.

Looking Beyond

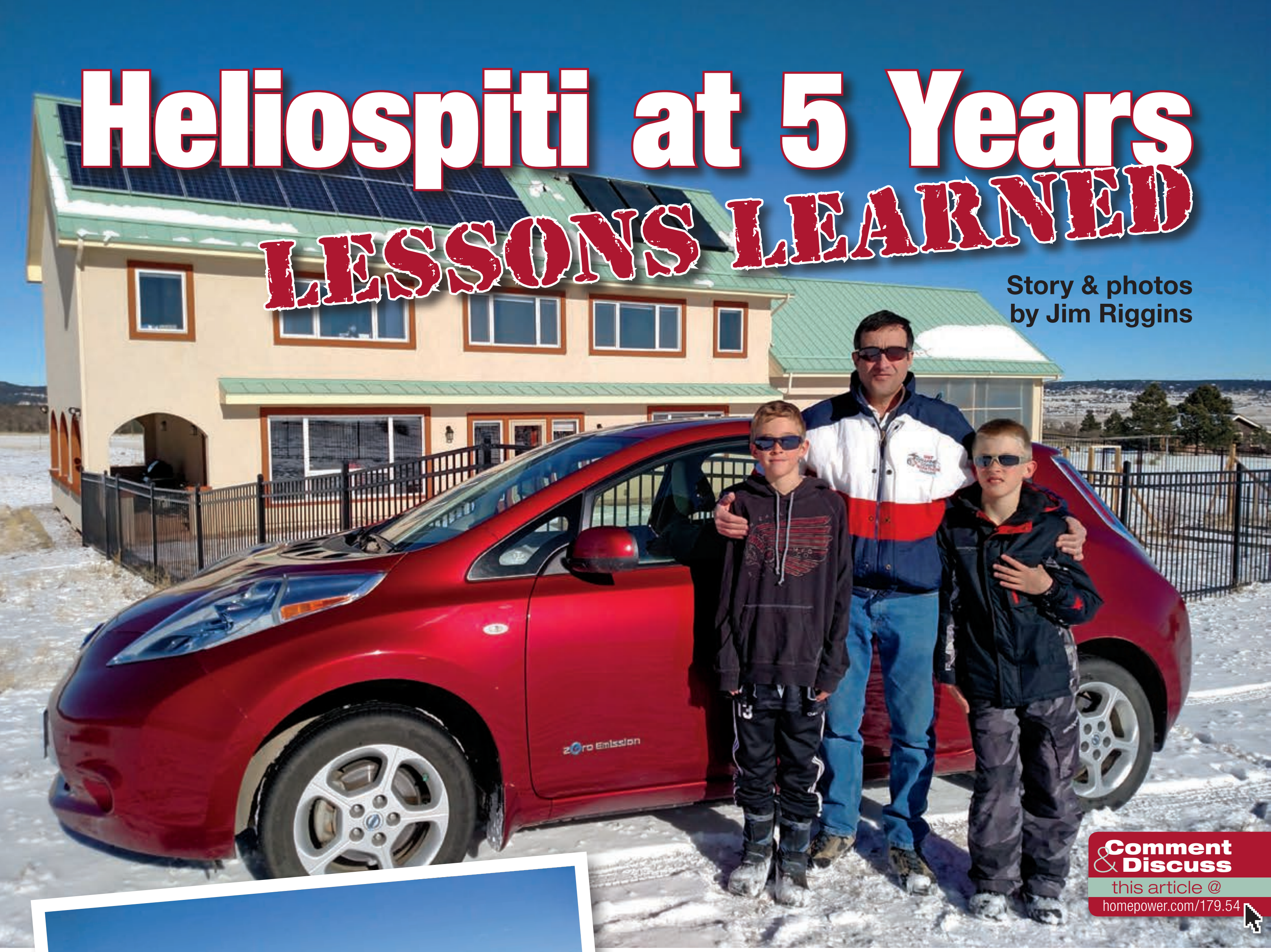
There are other techniques for harvesting surplus PV energy. For example, Morningstar's Relay Driver can be networked with charge controllers and programmed with a computer to operate diversion loads according to a wide range of criteria. Another method uses the diversion controller's DC load output as a signal to trigger a special type of SSR that modulates the inverter's current to an AC heater using phase-controlled switching. This combines the convenience of a conventional AC heating element with the smoothness of PWM control—but it's a component-level project beyond the scope of this article.

This is a fascinating arena for creative homebrew, but "turnkey" products are rare. It's sad to think of all the solar energy that is wasted because manufacturers and installers consider it such a low priority.

Courtesy Nunatak Alternative Energy Solutions

Heliospiti at 5 Years
LESSONS LEARNED

Story & photos
by Jim Riggins



After five years in their passive solar, solar thermal, and PV-powered home, the Riggins family is assessing their home's systems and their solar lifestyle.

With the December temperature plunging to -11°F and snow outside, our central Colorado home's interior temperature was a comfortable 71°F, and rose to 76°F as the storm passed and sun came out in the afternoon. Even after five years in our net-zero energy Heliospiti ("Sun House"), my family and I still marvel at achieving these temperatures—with no mechanical heating.

In two previous *Home Power* articles, I described the design (*HP141*) and one-year performance (*HP150*) of Heliospiti. With five years of experience, this article answers the common question I'm asked when showing the house: "Knowing what you do now, what would you have done differently, if building today?"

The house was built with the Passive House focus of extreme airtightness and super-insulation. Passive solar gain satisfies the bulk of the space-heating load, while a combination of extreme efficiency, plus active PV and solar water heating (SWH) systems meet the full energy requirements for this all-electric house and our electric vehicle.

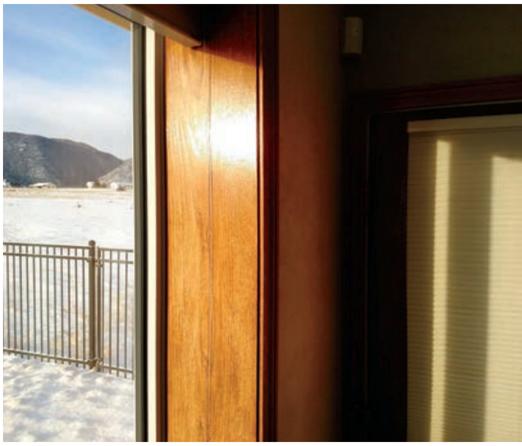
An all-electric net-metered house makes it easy to determine net consumption and production. Based on the initial meter reading upon moving into the house, and the reading on the five-year anniversary in May 2016, the net excess production of our 4.5 kW PV system was 8,829 kWh, an average of 4.8 kWh of surplus electricity per day. This includes powering the house—plus refueling our Nissan Leaf since April 2012. The house did indeed perform as a net-zero energy home—with energy to spare.

Passive Solar Resolutions

The passive solar plus Passive House design has met or exceeded our computer modeling results. Even with temperatures as low as -25°F, we put less than five hours on the air-source heat pump during the first five years. It's clear that the three concepts of ultra airtightness, super-insulation, and passive solar design (which includes ample interior thermal mass) will achieve high heating and cooling performance. All three elements work in harmony to capture winter solar gain, hold it within the house at night and on cloudy days, and provide comfortable, even temperatures throughout the house without the typical cold spots or drafty rooms.

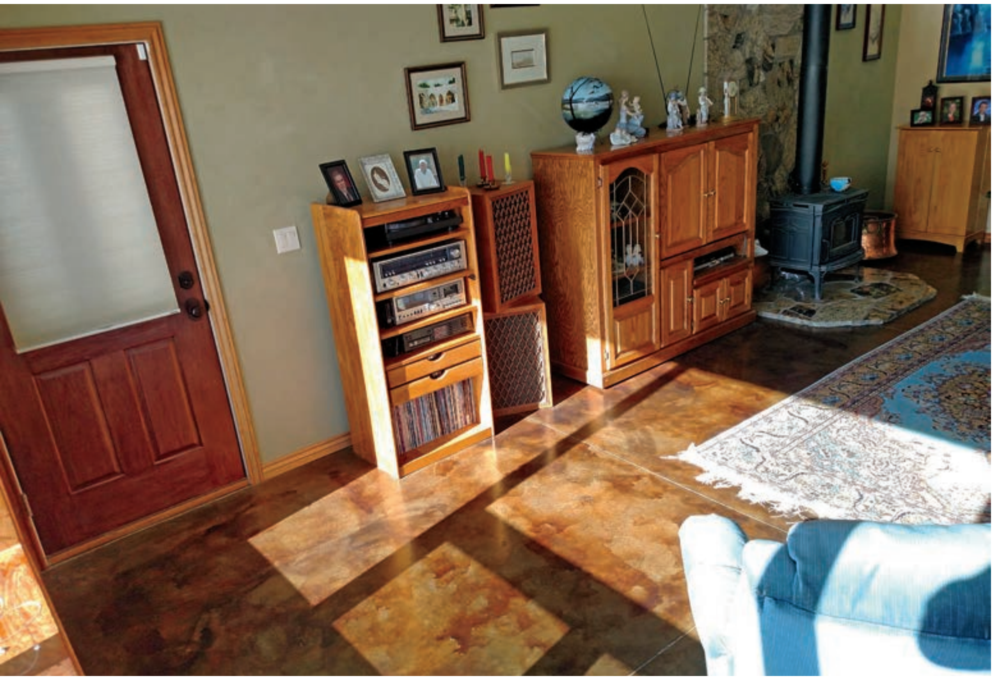
The first passive solar lesson learned was failing to account for 12-inch-thick walls limiting the effective aperture of the south-facing, solar-collecting windows. The thick window wells narrow our solar exposure, reducing the amount of sunlight reaching our concrete slab floor and 1 1/4-inch-thick gypsum wall thermal mass. This is especially a factor with low sun angles early in the morning and late in the afternoon. This solar energy is not lost but it strikes the window well material, not the high thermal mass areas. Building today, I would replace the oak window trim with drywall. Although oak has an 85% greater specific heat value than gypsum drywall, the gypsum is 116% more dense, giving it greater thermal mass value.

Another advantage to removing the wood window trim relates to our choice to use low-iron glazing in the south-facing windows. Although this glazing results in a higher solar heat gain coefficient (SHGC), which is fantastic for improved solar gain, it also increases ultraviolet (UV) transmission by approximately 25%. This UV transmittance created significant fading on the wood trim, cabinets, and second-floor's cork flooring. The fading was so significant on the window trim after just one year that I had to sand and refinish the trim using a UV-protecting exterior polyurethane.



Twelve-inch-thick walls slightly block solar gain at the south-facing windows.

Pulling back a throw rug reveals the degree of fading on the cork flooring due to ultraviolet light exposure.



At winter sun angles, most of the thermal mass floor is exposed to sunlight.

web extras

"Heading for Zero: Smart Strategies for Home Design" by Jim Riggins in *HP141* • **homepower.com/141.88**

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

Three SunEarth 4-by-10-foot solar thermal collectors provide a substantial portion of domestic hot water needs, even during cold and cloudy periods.

Water Heating Solutions

Our nonpressurized, drainback SWH system has worked well in spite of reluctance and warnings from the local installers we spoke to during our design phase. When properly installed, nonglycol-based drainback systems do indeed have a very low risk of freezing in cold climates. We like the simplicity and lower maintenance of the simple drainback system, and avoiding the need to build a dump circuit to extract excess summer transfer-fluid heat.

Our key problem with the SWH system, which was easily remedied, stemmed from my lapse in basic high-school-level science: At 7,000 feet elevation, unpressurized water does not boil at 212°F—it boils at 198°F. We initially programmed our Caleffi iSolar Plus controller to shut down the circulation pump when the collector temperature reached 205°F. But this allowed the heat-transfer fluid—distilled water—to flash boil, creating violent vibration in the copper pipes. It sounded as if the system was ripping itself apart in our attic. Air was getting trapped near the circulation pump and bubbles were moving up to the roof. As the transfer fluid heated and expanded, it compressed the air pockets so that when they shot into the drainback tank, it was at high pressure and vibrated the pipes. The key was to bleed the system both high (at the drainback tank in attic) and low (inlet to circulation pump) after the distilled water was partially heated from the sun. Bleeding air from the system and setting the upper shutoff temperature to 190°F solved this problem. The lower shutoff temperature reduced the efficiency of our SWH system by sometimes shutting down on clear days before the storage-tank water reached its maximum temperature. However, it was still an acceptable trade-off for us to have the benefits of a simple drainback system.

A final SWH lesson learned occurred with the premature failure of the thermal expansion tank. Our original tank was a 4.4-gallon unit, standard for a typical 120-gallon water heater. We are drawing 40°F water from our well and heating to a maximum of 170°F. This temperature difference creates a thermal expansion in excess of 7 gallons, and caused the internal diaphragm of the original tank to fail. I replaced the tank with a 10.3-gallon unit, and moved it from the hot side of the water storage tank to the cold side to increase the diaphragm's life.

The substantial temperature difference between the 40°F incoming well water and 120 gallons of 170°F stored solar-heated water required replacing the original 4.4-gallon pressure tank with a 10.3-gallon unit.

The solar thermal differential controller's high-temperature setpoint was lowered from 205°F to 190°F to prevent vaporization at the 7,000-foot elevation.

Before the addition of a second electric car (purchased in August 2016), the 20-module PV array provided an average surplus of 4.8 kWh per day.

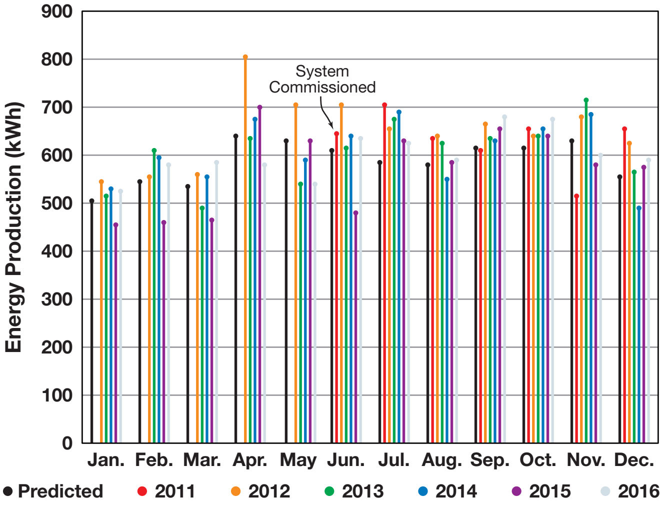
PV System Fixes

Contrary to initial expectations, we have not been as lucky with the reliability of our PV system as we have with the SWH system. Our largest trouble spot was with our Enphase M190 microinverters. As of this writing, seven of 20 microinverters have failed, and others are showing intermittent output. While the Enphase warranty provides replacement microinverters, it does not cover the labor cost of hiring a solar contractor to replace the equipment, nor the expense of the boom lift necessary to service modules on a second-floor, 38° metal roof. Replacement of the failed units is averaging $180 per unit. The graph illustrates the decline of our PV production due to the periodic inverter failures, which began in 2012.

Our takeaway? Scrutinize published reliability claims, and always plan maintenance and accessibility into the house design. We had the space on our property to install a ground-mounted PV array, which would have allowed replacing the microinverters myself (and also easily clear snow from the array). Instead, we are exploring the costly and difficult decision of continuing to replace the M190 inverters, or to replace all microinverters with a string inverter mounted in our garage. The efficiency gain that microinverters offered when we were designing the house has largely been negated with the availability of more efficient transformerless string inverters. We will, though, lose one very useful microinverter advantage—the ability for the array to start producing partial power as snow melts from even one module. A second option would be to replace the failed M190 inverters with Enphase M215 microinverters, as there is an adaptor that allows the M215 microinverters to work with the original M190 cabling system, but this would not improve our maintenance accessibility issue.

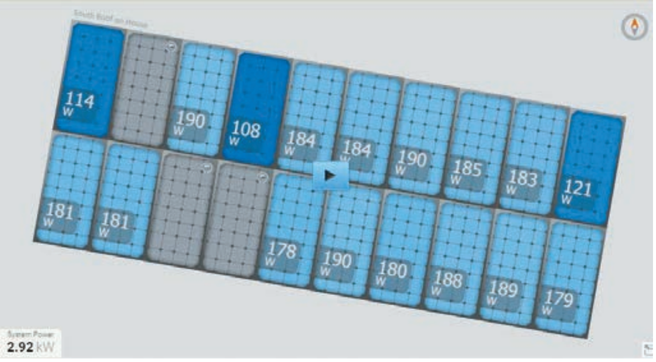
We would also like to address another PV lesson learned. When the grid goes down during winter storms, and our grid-tied PV array shuts down, the house can stay comfortable for days through passive solar heating. We also have battery-based phones and lighting for backup. However, what we find difficult to live with is the loss of our well pump and running water. We are considering reconfiguring the system to include a small battery bank to back up a few essential circuits, such as for the well pump, refrigerator, and one or two wall sockets.

PV Production History



The Enphase Envoy monitoring screenshot shows the lower performance of three modules (dark blue) and complete failure of three microinverters (gray).

Possible solutions include a piecemeal or full-array upgrade to more reliable microinverters or switching to a string inverter.



A water-to-air heat exchanger (left) was planned to move heat from the solar thermal system (below) to the input of the HRV air handler. However, passive-solar direct-gain performance is so good that the system was never hooked up.

Mechanical Heating & Cooling

Our passive heating and cooling have performed better than expected. Our Mitsubishi Mr. Slim air-source heat pump has run less than five hours in the past five years.

My not fully trusting my computer modeling results and engineering calculations led me to add a redundant heat source—which turned out to be a waste of money, as it has gone unconnected. This is a water-to-air heat exchange coil installed in the inlet duct to our energy recovery ventilator (ERV) at the point where the 10-foot-deep earth tube enters the house prior to the ERV unit. The water-to-air heat exchanger was to be connected to an upper heat exchanger in our 120-gallon solar hot water storage tank.

But the earth tube has been successfully preheating winter air to no less than 49°F, even with outside air temperatures as low as -25°F, and the passive solar, insulation, and air-sealing strategies have led to such low peak heat loads that the additional heating source has not been needed.

The handful of days we could have used this hydronic space heating usually occur in April or May, when our south-facing window overhangs are starting to limit solar gain, and we are faced with four consecutive days of fog and snow with highs in the 30s. But, by the end of day four, our storage tank water temperature is down to 115°F, and all of this hot water is needed for showers and dishwashing, with no excess available for space heating. If our heating loads did actually require support from the water-to-air exchanger, the answer would be to increase our hot water storage capacity to 300 gallons or greater. This is a costly alternative compared to installing a minisplit heat pump larger than our 9.7 kBtu unit. This would also be contrary to the Passive House philosophy of simplicity.

Water Conservation

With a 640-foot-deep well, water conservation is also electricity conservation. Our approach of zero outdoor irrigation, WaterSense plumbing fixtures, and Energy Star appliances has worked very well. We average less than 7 gallons of water per person per day, as compared to 49 gallons per person per day in the typical American household.

One design concept that has worked well, but could be improved upon, is the use of a hot water recirculation loop combined with an on-demand recirculation pump. When activated by a bathroom or kitchen push button, the demand pump circulates hot water in a closed loop until it senses a 15°F temperature rise in the return water at the storage tank.

My design error with this loop was an attempt to give hot water priority to bathroom showers over the kitchen sink, dishwasher, and clothes washer by connecting the latter three items to the end of the recirculation loop. This was not only unnecessary due to the excellent performance of our SWH system, but it also caused delayed or lower-temperature water in the kitchen, due to radiant losses through our insulated hot water loop.

The result is frustration waiting for hot water at the kitchen sink, but also wasted energy at the dishwasher. The high-performance SHX series Bosch dishwasher eliminates the electric resistive heating element. For drying, it sprays high-temperature water on the dishes at final rinse and allows it to evaporate. If the incoming water is not hot enough, the unit will internally heat the water. By connecting a Watts Up! power and energy meter to the dishwasher, I measured 1,340 watts at the start of the drying cycle as the unit heats the cooler incoming water. In hindsight, I should have plumbed the kitchen and laundry rooms to the output side of the hot water recirculation loop. Additionally, I should have run a separate, dedicated, insulated line from the hot water outlet to just the dishwasher, before it is mixed down from 170°F to 130°F by the antiscald mixing valve installed at the storage tank. This would have minimized or eliminated the need for internal dishwasher water heating.

A push-button switch in the bathroom activates a pump that circulates hot water through the distribution system to avoid wasting water.

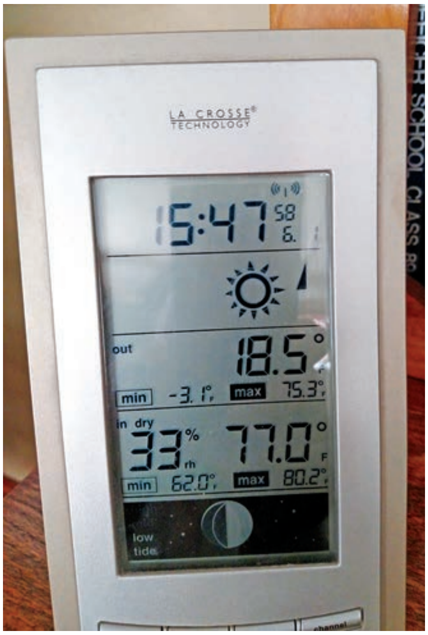
Electricity Conservation

The largest category of energy consumption in the average American house—about 41%—goes to space heating. Since passive solar and efficiency measures drive this category close to 0% for us, what quickly dominates energy consumption is appliances, lighting, and electronics. With a focus on Energy Star appliances, high-efficiency lighting, and eliminating phantom loads, we have held our electrical consumption to an average of 330 kWh per month—or about 11 kWh per day. This does not include EV charging, but does include the well pump, SWH circulation pump, cooking, heating, and cooling. The average American household, by comparison, consumes roughly 920 kWh per month—30.6 kWh per day.

Our key lesson in this category is not so much what we would have done differently, as it is analyzing advances in technology. At the time of our home's construction, given the very high cost of LED lightbulbs, compact fluorescent bulbs and fluorescent T-8 tubes were the most cost-effective option. But since then, the price of LED bulbs has plummeted. We have begun swapping out fluorescent bulbs for LEDs. One of the most effective upgrades has been the removal of 32-watt, 48-inch-long T-8 tubes in the garage, workshop, and kitchen, and replacing them with 12-watt Philips InstantFit T-8 LED tubes. They work with existing lamp ballasts, so only the bulbs needed to be changed.

One of our favorite surprises that impacts electrical consumption came from the search for a way to fully cook rice and beans at high altitude. This led us to a stainless steel pressure cooker that would work on our magnetic induction stovetop. We quickly discovered that this appliance can cook grains, beans, vegetables, and meat in 2 to 10 minutes. We use it every day and have cut our cooking times (and cooking energy) by a factor of two to three.

At high altitude, a lower boiling point increases cook time and thus energy use. Using a pressure cooker on the induction range shortens cooking time, saving electrical energy.



Even on cold days (here, the weather station shows 18.5°F outside), the passive solar gain can raise interior temperatures to comfortable levels (77°F).

Lifestyle

Our final category of lessons is the lifestyle changes that come with net-zero living. It does take more occupant input to run a net-zero house, but we have found these requirements to be quite simple and not onerous at all. They are now just part of our daily routine to which we give little thought.

We raise and lower thermal shades to modulate interior temperatures. Our passive cooling in the summer requires opening windows at night and closing them during the day. We will turn on and off the ventilation system multiple times in a week depending on whether or not we are ventilating with open windows. And finally, we sometimes allow interior temperature swings in the winter if the extended forecast shows multiple days of snow, fog, or cloud cover combined with low temperatures. For example, in the sunny days prior to this weather moving in, we may allow the sun to heat the house to 77°F—what we call "banking Btu"—so that the house temperature won't drop below 66°F during the multiday storm.

Overall, we have been extremely pleased with the performance of Heliospiti. It has been a rewarding experience to take a project from concept through design and construction, and observe performance that is meeting (and exceeding) expectations and computer modeling. Even after five years, we still marvel when the SWH system will kick on in a storm or fog, or when we can sit in a 72°F house, with no heater on, with an outside temperature of -15°F. We are also pleased that through the National Solar Tour, and builder and school tours, we have been able to spread the word that extreme efficiency, primarily through passive means, is straightforward and cost-effective, and leads to a home with lower operating costs.

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An Earth-Shifting Change in Grounding

by Brian Mehalic

The sections of Article 690 that deal with grounding PV systems have changed significantly over the last several code cycles, but never so much as in 2017. This is primarily due to the introduction of a newly defined term—"functional grounded." The implications are extensive—a wholesale simplification and homogenization of grounding the DC side of PV systems, along with the shortening (and even elimination) of many parts of Article 690, resulting in a single comprehensive theory and methodology that works for all types of PV systems.

Grounding Electrical Systems

"Grounded, solidly" is defined in the *National Electrical Code (NEC)* as "connected to ground without inserting any resistor or impedance device." Most of the AC systems that PV systems are connected to—especially in residential applications—are "solidly grounded." This is accomplished in a 240/120 VAC split-phase service by the main bonding jumper, which connects neutral to ground in the service equipment. This is a solid bond, and the connection is usually made with equipment supplied by the enclosure manufacturer. It may be a wire between the neutral and grounding bus bars; a strap that bonds the neutral bus to the chassis of the box; or a green screw that runs through the neutral bus bar and into the chassis.

Historically, there have been some solidly grounded PV systems in which one of the DC conductors—often, but not always, the negative—is mechanically connected to ground, using means similar to those described above for AC systems. However, with growth in PV system installations and realizations of some of the associated risks and hazards they present, requirements for DC ground-fault protection appeared in the *NEC* in the 1990s. One common way to implement DC ground-fault protection is with inverter-integrated systems, which typically consist of a fuse that acts as the main bonding jumper, forming the connection between the grounded and grounding conductors.

However, it's hard to consider a fuse, which can melt open in a ground-fault scenario, a solid connection to ground. It makes more sense to call them "functional grounded PV systems" in that they have "an electrical reference to ground that is not solidly grounded." Further clarification in the definition's Informational Note states that in a functional grounded PV system, the connection to ground is often through a "fuse, circuit breaker, resistance device, non-isolated grounded AC circuit, or electronic means that is part of a listed ground-fault protection system." This list essentially covers 99.9% of all PV systems installed in the last 10 years or more. Grounded or ungrounded—whatever we used to call them—they are "functional grounded" now.

Now, the only type of PV system permitted to be solidly grounded has only one or two PV source circuits, and no DC circuits on or in a building. This limits these applications to small, load-focused, PV-direct systems and perhaps some smaller battery-based systems.

Related Changes

Don't go searching for Ungrounded Systems in Section 690.35—it's no longer part of the 2017 *NEC*. That means that some differences that existed between various system configurations in the 2014 *NEC* are gone, too.

Prior to 2017, "ungrounded" systems had particular (and more stringent) requirements for PV wire or other wiring methods compared to their "grounded" counterparts. Now, 690.31(C) allows the use of USE-2 or PV wire for any exposed outdoor PV source-circuit wiring within the PV array, eliminating an issue that arose when installers had to replace an older inverter with a modern transformerless (TL) inverter, but still had to deal with an existing array of modules with USE-2 (rather than PV wire) leads.

Since Section 690.31(B)(1) permits only solidly grounded conductors to have a white- or gray-colored insulation (in accordance with Section 200.6), it is very unlikely that any newly installed residential PV system will have any field-installed white or gray wiring on the DC side. However, in many cases the industry has already moved forward—many residential systems were already being installed with TL inverters ("ungrounded") or with module level power electronics (MLPEs—which reduce or eliminate field-installed DC wiring), so the transition from white or gray conductors has already been going on.

A byproduct of the clarification in the PV system grounding definition is that fewer labels are required. For example, 690.5(C) and 690.35(F) in the 2014 *NEC* required ground-fault warning labels for "grounded" and "ungrounded" systems; these requirements are now gone. Even though the label is no longer required, conductors at ground potential during normal operation (for example, in a functional grounded system using fused-based GFP) may have voltage to ground during a fault, and this risk is still stated in the Informational Note to the definition of functional grounded. Additional labeling requirements related to "ungrounded" systems in the 2014 *NEC* were also removed.

Overcurrent protection device (OCPD) requirements have been simplified as well—only a single OCPD is required for a PV source or output circuit per 690.9(C). Previously, "ungrounded" systems required OCPDs on both conductors. This stands in contrast to the requirement in 240.15(A), which specifies an OCPD be placed in series with each ungrounded conductor (as is still required on the AC side of the system). Expect to see combiners and inverters with fuses on both the positive and negative circuits disappear—though this may take some time as some jurisdictions use earlier versions of the *NEC*. (Note: Language previously in Sections 690.3 and 705.3 regarding Chapter 6 and 7, which supplements and modifies the earlier parts of the *NEC*, now resides in Section 90.3.)

A future "Code Corner" will discuss the significant changes in the sections of Article 690 pertaining to disconnects. Briefly, without any solidly grounded conductors, both the positive and negative poles of DC circuits need to be switchable or isolated per 690.15.

Equipment Grounding & the Grounding Electrode System

At first glance, it may appear that there were significant changes to Section 690.43, since there is a lot of highlighted, gray text. But most of this is related to reorganization and small changes for clarity—actual requirements did not substantially change.

What is most surprising is how short Section 690.47 has become. The target of wholesale changes in several of the last few versions, it has again been reworked considerably—primarily due to the newly defined concept of functional grounded systems, and essentially with the premise that if there already is a grounding electrode system, connect to it. If there is not, then install one.

Section 690.47(A) clearly states that any building or structure supporting a PV array must have a grounding electrode system. As with all other electrical systems, it should be installed in accordance with the part of the *Code* that governs all other grounding electrode systems—Article 250, Part III. Article 100 defines structure, and it is a pretty wide-ranging definition—"that which is built or constructed, other than equipment."

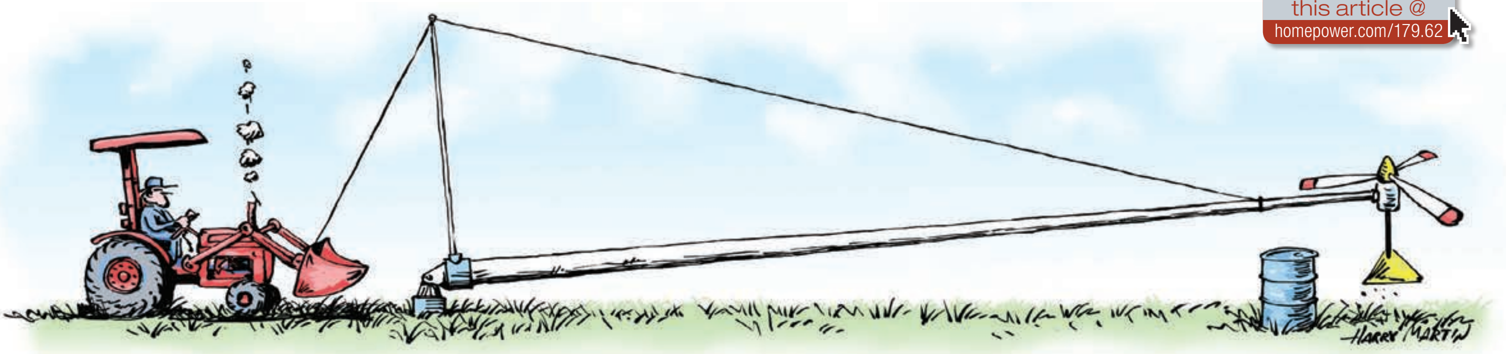
This section specifies that equipment-grounding conductors (EGCs) from the PV array must be connected to the grounding electrode system. Again, the idea is make PV systems follow the rules that apply to other electrical systems. As such, the connection between the EGCs and the grounding electrode system must follow the rules in Part VII of Article 250, which defines "methods of equipment grounding."

Section 690.41(A) is a new list of the most common PV system grounding configurations, including the (increasingly rare) solidly grounded systems, which must comply with 690.41(B) and 690.42, strictly limiting their applications. Section 690.47 states that for non-solidly grounded systems, the EGC for the PV system's output, connected to the associated distribution equipment, will serve as the connection to ground for ground-fault protection and equipment grounding. In fact, all requirements related to DC grounding electrode conductors (GECs) for non-solidly grounded PV systems have been removed from the 2017 *NEC*. This means that PV system grounding conductors do not have to be continuous and are not sized per 250.166 requirements, but rather in accordance with 250.122—as they are all EGCs. Only solidly grounded PV systems are required to have a DC GEC.

Pilings, ground-screws, and other metal foundations used as supports for ground-mounted systems may now be able to meet the new definition in Section 250.52(A) as metal in-ground support structures. To do so, they must have least 10 feet in vertical contact with the earth (either directly or encased in concrete). When there are more than one of these support structures—as is usually the case in a ground-mount system—the *Code* allows installers to bond only one of them to the grounding electrode system. This is an allowance that contrasts the typical requirement in Section 250.50 that all grounding electrodes must be bonded to any other electrodes present at a building or structure to form a grounding electrode system. While PV rack components have to be bonded together to meet equipment grounding requirements, this allowance in 250.52(A)(2) means only that one piling out of the total needs to be connected with an appropriately sized bonding jumper to any other pilings or to other types of electrodes present in the grounding electrode system.

The somewhat onerous requirements for additional auxiliary electrodes have been renumbered as 690.47(B) and are permissive, not mandatory—electrodes can be installed at the location of ground- and roof-mounted arrays but do not have to be. This section specifically references 250.66 for sizing GECs. Changes in 250.66 regarding the concept of a "sole connection" now clarify that the GEC connected to a specific type of electrode only need to be larger than the maximum stated in 250.66(A) through (C) if they are continuing on and connecting to another type of electrode that requires a larger GEC. For example, if a GEC was connected to a ground rod (maximum size = 6 AWG), but also to 1 AWG ground ring, the GEC would have to be 1 AWG.

While additional auxiliary electrodes are not required to be bonded to an existing grounding electrode system by a bonding jumper, they can be—and this is still typically a best practice. It provides a superior path for lightning-induced surges as opposed to the grounding electrodes only being bonded together by ECGs.



Trucks, Trailers & Tractors

by Kathleen Jarschke-Schultze

If you have a homestead, you either have a truck or you are pining for one. Depending on the size of your holdings, you also may have a tractor (or that may be second on your wish list). These two tools rival any Swiss Army knife for versatility.

Truckin'

My husband Bob-O and I have always had a four-wheel-drive truck at our homestead, which sits 1.8 miles from the nearest paved road. We have owned a couple of gasoline-powered trucks, but when we started acquiring trailers, we switched to diesel-powered pickups.

Bob-O believes a 3/4-ton truck is a good size for an all-round work truck. He prefers diesel trucks because of their longevity and their torque for pulling loads. Here in the mountains, we need the torque. A diesel engine seems to last much longer than a gasoline engine. They are competitive on fuel mileage, and they can haul or pull most anything.

We use the pickup pulling a dump-bed trailer to pick up our firewood. Using the bed and the trailer, we can haul two cords of wood per trip.

Our gardens also benefitted from the truck-trailer setup, since we used it to pick up two truckloads of rabbit manure each year from a friend of ours who was a 4-H leader. She's retired now, but luckily, we live in the land of horses and rodeos. By either perusing Craigslist or placing an "in search of" ad there, we find people more than happy to have us come with our truck and trailer and carry off the wonderful mixture of horse manure and bedding straw. As we age, we have gotten picky. Whomever we get the manure from has to have a tractor for loading the manure into the trailer—no more shoveling by hand for us. The 7-by-10-foot dump trailer holds about 7 cubic yards of dry manure. Bob-O made sturdy wooden sides that raise its height by 11.5 inches, making it 40 inches deep. We take the sides off when we haul gravel for the road. As heavy as rock is, we cannot fill the trailer to its capacity.

Tractor Beams

We saved up for our first tractor and told ourselves it was an investment, and it was. Tractors aren't cheap, and you need a reason to buy one. We needed a four-wheel-drive version with at least 30 hp, as well as a three-point hitch and power takeoff for attachments. Bob-O is enthusiastic about power steering. And, if you are considering using your tractor anywhere but home, you will need to invest in a trailer big enough to haul it.

We bought our first tractor from a dealer. It was used, but in good condition. The dealer dropped it off at the end of the road, but by the next day, after he had put it through its paces, Bob-O had them fetch it and replace it with a larger one, a Yanmar, he had been looking at. A former RE client had given Bob-O a random backhoe attachment he had in his boneyard. When Bob-O attached it to the first tractor the front wheels barely touched the ground. He could tell the first tractor wasn't big enough to do the jobs we needed done.

Our old Yanmar has been a faithful workhorse these many years. Being the only tractor in our neighborhood, its bucket and blade have maintained the dirt road in every season. Bob-O bought a 5-foot-wide rototiller attachment that does the job in one pass what our Troy-Bilt tiller does in several passes.

When we had a shop built, we had to prepare a level gravel pad for the base. Bob-O used the bucket and blade to build up, level off, and gravel the pad. The crew that was sent to dig the footings tried to auger through the rocks in our placer soil. After a whole day of digging, they told us they had to move to the next building site. Bob-O told them, "Give me two days." He used the backhoe and bucket to dig and remove a big pile of large rocks to get the prescribed depth. Because of the size of the rocks, the holes were somewhat larger than expected. Instead of the usual single cement truck payload, it required two full trucks to pour our footings. That building isn't going anywhere.

Bob-O bought forklift blades for the bucket, and we used it to load and unload pallets of PV modules for our former RE installation business. We use the Yanmar to raise and lower the wind turbine on its 63-foot tilt-down pole. I drive the tractor as Bob-O keeps the cables straight.

We still have the Yanmar, but as our gardens expanded and projects got more complex, Bob-O began looking for a bigger tractor. He found an excellent deal from a private seller. This man had a nice little ranchette where his wife kept a couple of horses. He had recently been offered a very lucrative job on the East Coast. He was going to ship the horses to their new home, but wanted to liquidate everything else. Bob-O got an excellent deal on a 36 hp Kubota with a four-in-one loader bucket that had an assortment of attachments. There was a deck mower, an auger, an arena harrow and water-filled roller, a box scraper, back blade, and forklift attachments.

I went with him when he took the trailer to pick up the tractor. Once we had it loaded and chained down, the man asked us if we could use any PVC pipe fittings. Why, yes we could! He took us into a workshop and emptied full drawers of various fittings into paper bags for us. He was very eager to be on his way. Soon, Bob-O purchased a chipper/shredder attachment that easily handles the brush and tree prunings we put through it. Since we do not have horses and don't plan on any (why get the horse when the manure is free?), Bob-O traded the arena harrow and roller for 12 cords of split madrone firewood. When our electrical lines from the microhydro turbine sagged across our lower road, I lifted Bob-O in the bucket high enough to raise and secure them.

Backhoe Beauty

When the opportunity arose, we bought a 4-by-4 Case backhoe. It has a four-in-one bucket in front. Bob-O cautions new backhoe owners that before you start digging you need to decide exactly what you want to achieve—and when to stop. Sometimes digging a hole or trench is way too much fun, and what was meant to be a 2-foot-deep trench turns out to be 4 feet deep.

When we replaced our old wood bridge, Bob-O moved the long log supports using the jaws on the backhoe bucket, and stacked them on a three-sided square to level a large, sloped garden area. When he used the backhoe to dig out a hillside for a shipping-container root cellar (see *HP140*), all of that excavated dirt was used to fill the new terraced garden. The backhoe also was pivotal in relocating the shipping container to the excavated site and in backfilling dirt around and on top of it.

With the equipment we have invested in, we can handle just about anything that comes our way. The older we get, the more we appreciate, and utilize, the old saying, "Let the horses (horsepower) do the work."

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Lead-Acid Battery Chemistry Basics

To understand what is happening inside a lead-acid battery, you need to look at the electrochemical reaction occurring on a subatomic level. A charged battery cell has atoms looking to form chemical bonds to reach greater stability. We can use the energy released when those bonds are made.

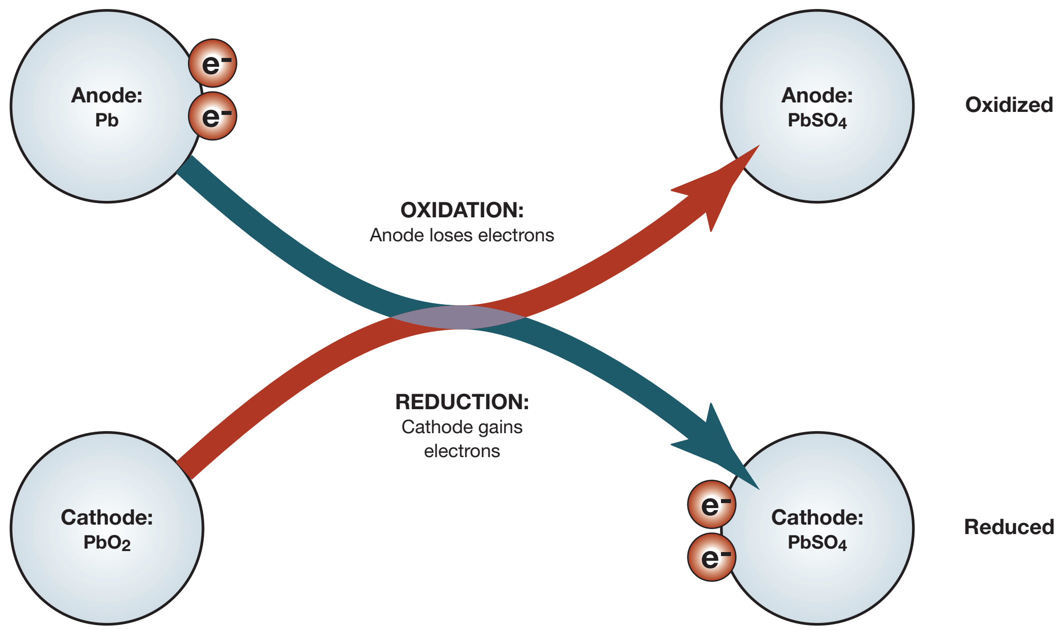
Most battery cells operate under multiple "redox" reactions—short for "reduction" and "oxidation." This is the transfer of one or more electrons from one atom to another. "Reduction" happens when an atom gains electrons, and "oxidation" is when an atom loses electrons.

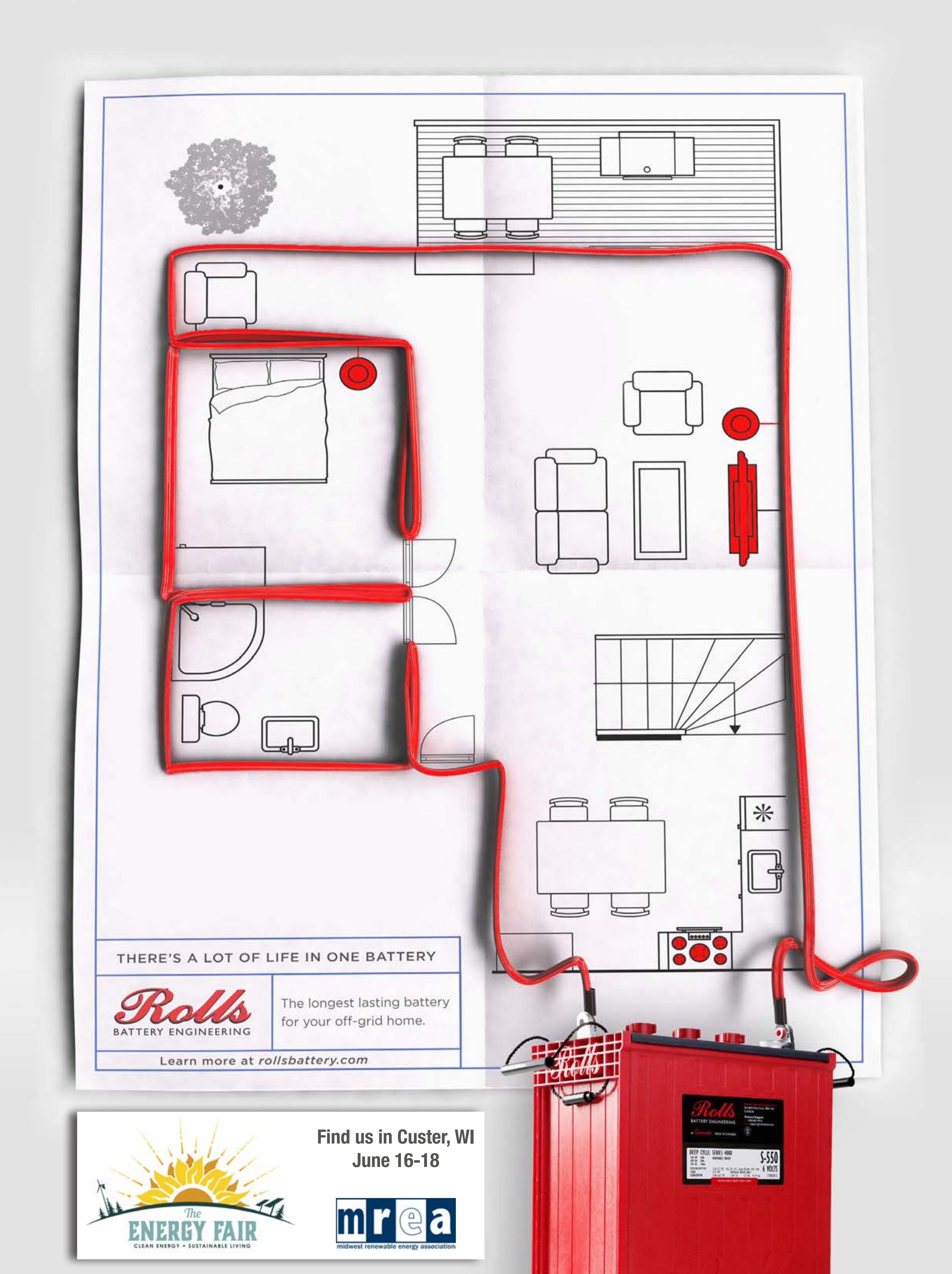
A charged lead-acid battery's electrolyte has sulfuric acid (H_2SO_4) dissolved in water (H_2O). The water and sulfuric acid are split into positive hydrogen ions and negative sulfate ions. Under discharge, for each chemical reaction, four positive hydrogen ions ($4H^+$) flow to the cathode (lead dioxide plate; PbO_2). A sulfate ion with a -2 charge (SO_4^{2-}) flows to both the anode (lead plate; Pb) and the cathode. Internally, this results in an overall +2 charge at the cathode (oxidation) and a -2 charge at the anode (reduction) per each reaction. This imbalance of electrons (a surplus at the anode and a deficiency at the cathode) creates a "pull" toward a level of stability. When an external electrical circuit is placed between these electrodes, electrons flow through that circuit, from the anode to the cathode. This energy can be used as it's released. The external circuit provides the opposite (rebalancing effect), with oxidation at the anode and reduction at the cathode.

During discharge, sulfate ions bond to the lead and lead dioxide plates, creating a lead sulfate compound ($PbSO_4$) until no more surface area is left for the reaction to take place. Then, the battery is completely discharged. Charging the battery reverses these processes—energy is pushed into the battery. Oxidation occurs at the lead dioxide plate and reduction happens at the lead plate. The chemical bonds of the lead sulfate are broken on both plates and the hydrogen and sulfate ions are returned into the solution.

—Justine Sanchez

External Redox Reaction in a Discharging Lead-Acid Battery





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