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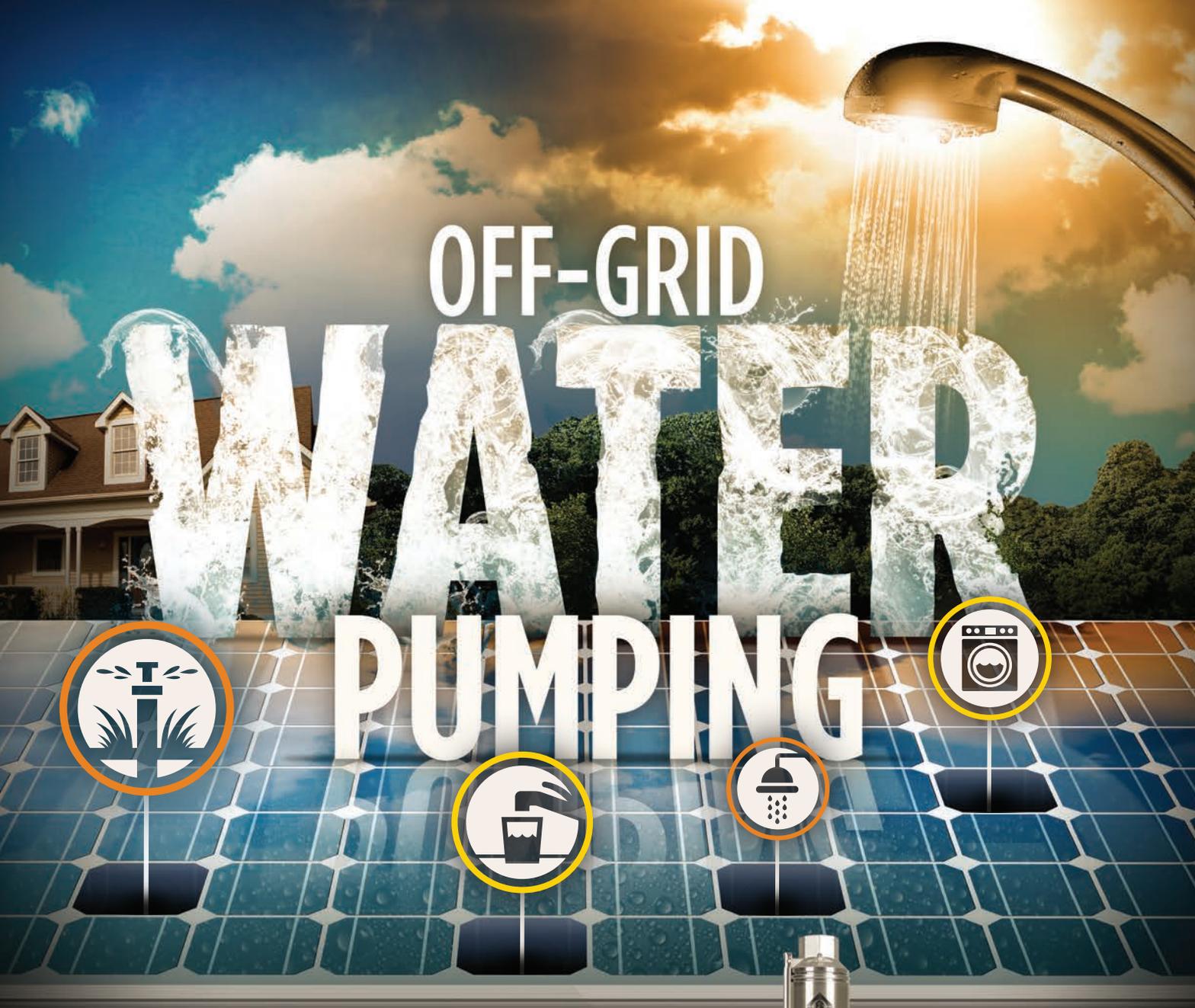


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Reclaiming & Recycling Solar

As I sorted through our recycling before hauling it out to the curb, I was not thinking about what we will do with our PV modules once they reach the end of their life. Our modules carry a 30-year warranty and our array is only four years old, plus there's a chance that most PV modules will outlive their warranties. *Home Power* founder Richard Perez said that there's no reason a well-made PV module won't last 70 years or more. Sometime down the line, however, we may be faced with replacing them—and figuring out a better place to retire them than the county dump.

In 2017 alone, more than 40 million PV modules were installed in the United States. These huge quantities will need to be dealt with in a constructive way. Even now, there are damaged PV modules that need to be properly disposed of—whether due to damage from hail, hurricanes, fires, accidents, or poor shipping and installation practices.

It's estimated that approximately 90% of decommissioned PV modules end up in landfills. However, recycling them—and reclaiming their valuable materials—is possible and important. In fact, in 2012, Europe's Waste Electrical and Electronic Equipment Directive mandated module recycling, requiring module manufacturers to collect and recycle modules at the end of their life cycle. The United States has no federal mandate, so in most locations PV module recycling is purely voluntary. Some states are tackling the issue, like Washington, which last year passed a solar stewardship bill requiring manufacturers selling PV modules in the state to offer recycling programs for their own products (effective 2021). New York is working on a similar bill. By California law, PV modules cannot be disposed of in landfills, but the state doesn't yet provide recycling guidelines.

According to the International Energy Agency and SolarQuarter, two-thirds of globally manufactured PV modules are crystalline silicon (c-Si), which are typically 76% glass (module surface); 10% polymer (encapsulant and backsheet); 8% aluminum (mostly in the frame); 5% silicon (PV cells); 1% copper (interconnectors); and less than 0.1% silver (contacts) and other metals. Thin-film modules, by comparison, are 89% glass, 7% aluminum, 4% polymer, and 0.02% other metals, such as copper, indium, gallium, and selenium.

Capturing some of these materials and keeping them out of the waste stream is now being tackled by a handful of companies. First Solar has its own PV recycling plants for its cadmium-telluride thin-film modules. The Cleanlites recycling plant in Cincinnati, Ohio, accepts crystalline modules. Both companies are part of the Solar Energy Industries Association's National PV Recycling Program. Industry veteran Sam Vanderhoof has launched Recycle PV Solar (recyclepv.solar) to help expand PV recycling. He recently announced that a solar recycling processing plant is being built in Arizona and will accept PV modules from across the United States. The PV recycling pilot program was scheduled to begin in August 2018. Plans include expansion to three other U.S. locations.

While our PV system's modules will be producing power for at least the next quarter-century, it's encouraging to know that solar industry players are taking the steps needed to ensure that our PV modules won't end up in a landfill, even after their lives are over.

—Justine Sanchez

Think About It...

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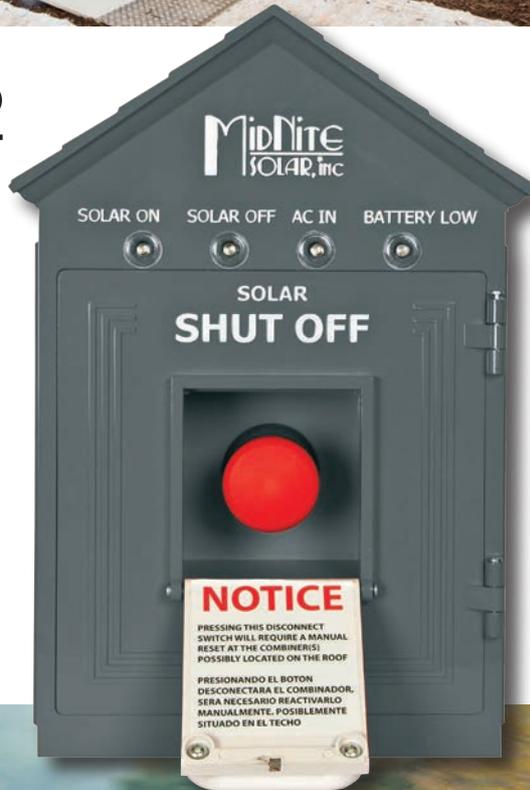
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On the Cover

The Mini Cooper Countryman Plug-In Hybrid is one of many new EVs and hybrids hitting the roads.

Photo courtesy MINI USA



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Rebekah Hren

In January 2019, the *National Electrical Code* will require newly installed PV systems to have rapid shutdown functionality within the array boundary itself. This article details the equipment necessary for compliance.

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Photos courtesy Dennis Schroeder/
U.S. Department of Energy Solar Decathlon; MidNite Solar; Chevrolet

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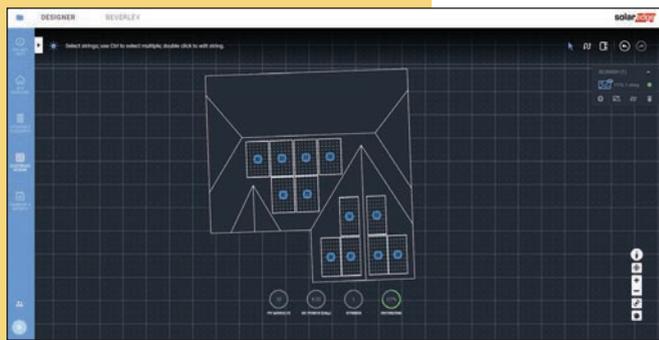
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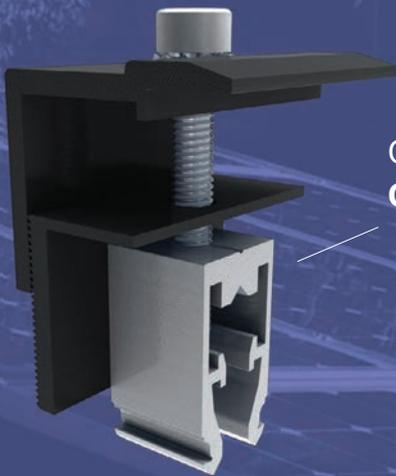
Photos courtesy Solaria; SolarEdge

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Brad Berman is the editor of PluginCars.com and HybridCars.com. Brad writes about alternative energy cars for *The New York Times*, Reuters, and other publications. He is frequently quoted

in national media outlets, such as *USA Today*, National Public Radio, and CNBC. Brad is the transportation editor at *Home Power* magazine.



Several decades ago, **Kathleen Jarschke-Schultze** answered a letter from a man named Bob-O who lived in the Salmon Mountains of California. She fell in love, and has been living off-grid with

him ever since. *HP1* started a correspondence that led Kathleen and Bob-O to *Home Power* magazine in its formative years, and their histories have been intertwined ever since.



Michael Welch, a *Home Power* senior editor, is a renewable energy devotee who celebrated his 28th year of involvement with the magazine in 2018. He lives in an off-grid home in a redwood forest in

Humboldt County, California, and works out of the solar-powered offices of Redwood Alliance in nearby Arcata. Since 1978, Michael has been a safe-energy, antinuclear activist, working on the permanent shutdown and decommissioning of the Humboldt Bay nuclear power plant.



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.



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.



Vaughan Woodruff is the president of Insource Renewables, a NABCEP-accredited PV installation company based in Pittsfield, Maine. Woodruff has been involved in a variety of efforts within

the solar industry, including as an instructor for Solar Energy International and the Department of Energy's Solar Instructor Training Network, as a volunteer on committees with NABCEP, IAPMO, and IREC, and as a technical consultant for various state energy offices.



Environmental writer **Juliet Grable** lives in southern Oregon, where she writes about sustainable building, renewable energy, and issues related to water conservation and watershed restoration.

This year, she completed training to serve as an Ambassador Presenter for the Living Building Challenge.



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

also installs hydro and PV systems, and writes about off-grid renewable energy systems.



Home Power senior editor **Ian Woofenden** has lived off-grid in Washington's San Juan Islands for more than 30 years, and enjoys messing with solar, wind, wood, and people power technologies. In addition

to his work with the magazine, he spreads RE knowledge via workshops in Costa Rica, lecturing, teaching, and consulting with homeowners.



Rebekah Hren is a licensed electrical contractor in North Carolina and a NABCEP-certified PV installation professional. Her focus is system performance, quality control, and Code

compliance. Rebekah currently works for Solar Energy International and for solar farm developer O2 Energies.



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 and develops and updates curriculum. 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.

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Solaria PowerXT AC Module (with Enphase microinverter)



Courtesy Solaria (2)

Solaria (solaria.com) and Enphase Energy (enphase.com) teamed up to release an AC module—the Solaria PowerXT 355R. It has a pre-installed Enphase IQ7+ microinverter, rated 290 VA at 240 VAC. Up to 13 modules can be paralleled per branch circuit, and the Enphase IQ Envoy communications gateway and Enlighten software provide module-level monitoring.

AC modules meet the 2017 *National Electrical Code* rapid-shutdown requirements for both inside and outside the array boundary (see “New Solutions for Rapid Shutdown” and “Code Corner” in this issue), without installing additional module-level power electronics. The IQ7+ microinverters meet California’s Rule 21 requirements for smart inverters, which support the grid by including voltage and frequency ride-through (see “Get Smart—Advanced Inverters” in *HP185*). Module efficiency is listed at 19.6%, and the black backsheet and frame provide a uniform appearance. It has a 25-year power and product warranty.

—Justine Sanchez

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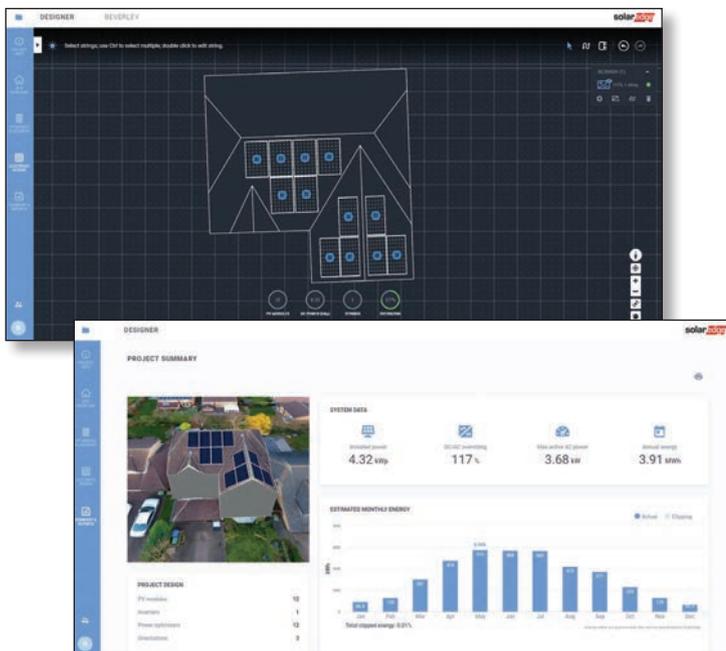


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SolarEdge (solaredge.com) introduced its free Designer tool to simplify creating customer proposals and the electrical design process for residential PV system installers. It utilizes satellite imagery to provide 3-D site modeling. Designers can “drag and drop” virtual PV modules onto a potential client’s rooftop. Module spacing and portrait or landscape orientation can also be specified. Designers can add required setbacks or access pathways into the design. Once the array layout has been established, Designer offers SolarEdge product recommendations, monthly energy output projections, and a list of materials report. Designer is web-based and accessible from any computer.

—Justine Sanchez



Courtesy SolarEdge (2)

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Rainbow Power

I captured this photo on the afternoon of June 27, 2018. If you want to do this, here's how. After a thunderstorm has passed, stand facing your wind turbine or PV array. The sun must start to appear at your back with the rain moving out and skies clearing.

This is my homemade 100-foot tilt-down tower with a 16-foot-rotor turbine. The 4 kW PV array is configured for a 150 V, 60 A OutBack MPPT charge controller. I upgraded my 48 V hybrid (wind and solar) system to the Schneider Electric Conext XW 6048 inverter for grid-interactive and off-grid use. I operate it in the load-sharing mode, consuming energy from sun and wind when available. The hybrid system charges 16 deep-cycle Trojan lead-acid batteries that provide us with at least 24 hours of backup with no wind or sun energy input. At times, I've seen the system generate more than 5 kW. The 6048 seamlessly powers my home when energy is available; otherwise, it pulls power from the grid.

I went with this design because it's simple and it works, but I'm always enhancing it and making it better. Anyone handy with tools who has patience to learn can create a similar system, even if at a lesser hub height or capacity. The turbine is a simple homemade alternator, using a six-stud

trailer-wheel hub with two bearings. I used 32 rotating rare-earth magnets next to a three-phase fixed stator, wound by hand with two strands of #14 copper coils, with 60 turns each. I constructed the lattice tower from thin-wall steel tubing (chain-link top rails) and electrical metallic conduit.

I use a dry contact on the Davis Instruments' Vantage Pro2 weather station and programmed it to apply emergency dynamic braking at winds of 35 mph or greater; it's just not worth all the extra wear and tear on the blades and furling system to allow it to continue running over this wind speed. As soon as the wind speed drops, blades start up automatically. The contact is wired to drop out a standard relay, using the normally closed contacts, to short out the alternator's three phases. With this setup, if the main system power is lost or a fuse is blown, the relay will still drop out and the normally closed contacts will still apply dynamic braking. I also programmed the relay driver to apply a dynamic braking relay if overspeeding occurs due to full batteries, or if the Morningstar diversion controller or a load resistor fails. Spending a little extra time on emergency shutdown circuits is well worth it. I've had my share of learning experiences over the years.

Roger Beale • Evington, Virginia

Renewable Energy Rights

Modern rooftop PV systems are a simple and an efficient way to generate electricity. Modern PV inverters are designed to match the grid and will only generate electricity when connected to the utility. My electric company in Kansas (Westar Energy, which has almost 700,000 ratepayers) declares these systems as a "significant advancement in technology" but, in their annual report to the stockholders, list rooftop solar as a "risk" to their business since people can generate electricity as cheaply as they can. To eliminate the competition, Westar has petitioned the Kansas regulatory agency to add fees onto distributed generators (rooftop solar). Their desire is to put all solar customers into a rate class which could add \$30 or even more to the monthly bills.

Can the utility companies kill rooftop solar or do we have the right (or duty) to put a few panels on our roof? The founders of *Home Power* magazine, Richard and Karen Perez, coined the term "guerrilla solar." Here is the guerilla solar manifesto: "We, the solar guerrillas of this planet, resolve to place energy made from sunshine...on the utility grids with or without permission...or financial compensation. We further resolve that our renewable energy systems will be safe and will not harm utility workers..."

Mark Cooper, chairman of the Consumer Federation of America, provided legal precedence for this right when he cited the 1968 Federal Communications Commission's decision against AT&T. The Carterfone decision allowed the public to plug into the phone lines, thereby ushering in an explosion of technological innovation.

Placing a few PV modules on your roof may not eliminate your electric bill, but it will help lower your purchased consumption of coal-generated electricity. Even if your local utility generates renewable electricity, rooftop solar has the major advantage of not requiring additional land; utility-scale PV installations usually destroy agricultural land or wildlife habitat.

Rooftop solar can be a benefit to all rate payers when it is efficiently incorporated into the modern grid. If utility companies choose to stifle rooftop solar, then we have the right and the moral obligation to put panels on our roof without permission, guilt, or fear of reprisal.

Robert Rosenberg • Manhattan, Kansas

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Courtesy: Roger Beale

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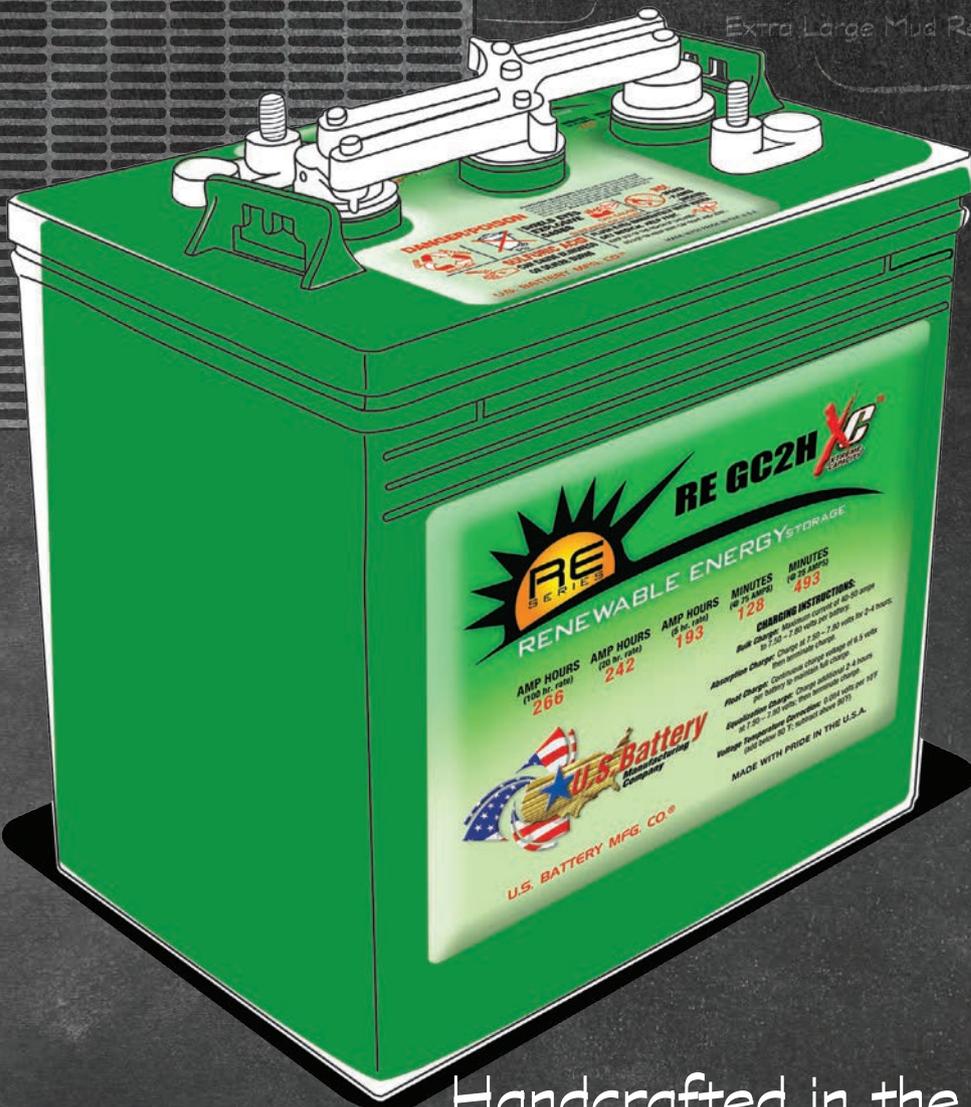
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A GEM of an Energy Monitoring System

I recently read the article on “Home Energy Management Systems” and thought I would put a plug in for BrulTech’s GreenEye Monitor (GEM) system. Based on what I have reviewed and conversations with owners of these systems, I opted to go with the GEM and DashBox. The GEM is the system’s brains, collecting all of the sensor inputs (32 current transducers for AC circuits, eight one-wire temperature probes, four pulse counters, and AC-line voltage readings). The DashBox provides data storage and real-time energy consumption information. It allows storing 13 GB of “minute” data and creates a web page for reviewing the information. The database can be accessed for reports and be useful in troubleshooting electrical issues. For example, when my heat pump was acting up when the temperature dropped below 40°F, I compared the minute-by-minute data in a graphical format to the 5-minute data from my ecobee thermostat. I discovered that the heat-pump thermostat was set to shut down at 40°F and not 25°F, the temperature at which I had it originally set it. I don’t know why it reset, but I reprogrammed the thermostat and it worked perfectly after that. I can also review my house’s interior temperature and HVAC running time in the database, which has been logging information since 2009. It is easy to compare historical data to current data to see if the efficiency projects I implement are worth the effort.

While this system does an excellent job collecting data and storing, a home automation system—Universal Devices’ ISY994i Z Series—can interface with the GEM (and other energy monitors). Data from the GEM can be used in other ways, too. For example, we have a 15-year-old washer and dryer pair that are still working perfectly, but it’s difficult to tell from outside the room when the cycle is done. With the ISY994i, I monitored the electrical usage while the dryer went through its cycles, and found that it used more than 1 kW while running, but would drop to less than 10 watts when it finished. I used a very basic program in the ISY994i Z by selecting a few options, and it now notifies me by text when the dryer finishes.

The ISY994i’s uses are many: Set up a vacation mode and let it monitor your water main; coupled with a flow sensor, the ISY994i will alert via text if there is any water flowing. If your refrigerator is using more energy than normal, you can set the unit to text you a notification. You can even add temperature sensors to your fridge and freezer, and couple this to the ISY994i, which can alert you if the temperatures go above or below their presets. Plus, the ISY994i interfaces with all the major voice-activated systems.

Don Houdek • how-to-doit.com



Courtesy Benjamin Root

United, Under the Sun

On June 23, 2018, my sweetheart Sarah and I married in a beautiful backyard ceremony on our property in southern Oregon. Draped with decorations and wired for sound, our PV array and its supporting pergola provided shelter from the afternoon sun as well as a beautiful backdrop for the ceremony.

I described the 5.3 kW PV system in the cover story (“Sun & Shade With a Double-Duty PV Pergola” in *HP182*). Besides announcing our marriage here, I’d like to also update readers on the system’s performance. From July 2017 through June 2018, the system produced 8,124 kWh—about 7% more than we originally estimated with the PVWatts calculator. This could be due to microvariables in the calculation parameters; additional bifacial production of the Lumos Solar PV modules; or having a sunnier-than-average year. That year’s worth of PV production accounted for about 78% of our total energy use, with 34% of the PV energy used on-site and 66% sent to the grid as a credit for later use (whether that same evening, or during the colder and darker months).

January was our lowest production month, with an average daily production of 8.1 kWh. (During that time, we bought an average of 39.5 kWh per day from the utility.) While January’s PV production covered only 16% of our loads, we still “sold” about 2 kWh to the utility each day, even if we “bought” it back that same evening. This shows that there are times—even on winter days—when the PV array produces more energy than the home is using. Our best production month was June, with an average daily production of 36.6 kWh (while “buying” back about 10 kWh daily). Summer loads are affected heavily by an irrigation pump, swimming-pool pump, and (rarely) air conditioning.

In the article, I talked about energy-efficiency upgrades I had planned in hopes of reaching net-zero energy use. Alas, we spent much of our free time and “extra” money last year preparing for the wedding. But now, especially after seeing the 78% figure, I feel like our net-zero goal is within range and plan to revisit my efficiency upgrade to-do list.

The wedding was perfect, with many family members and friends attending from across the country. The PV array and pergola structure performed as planned, providing energy (of course!) but in an aesthetically pleasing and shade-producing structure right in the middle of everything. While many of our guests knew about the PV structure, others didn’t even notice that our beautiful wedding backdrop was also producing 5 kW of PV power. While we tried to “disguise” the ugly aboveground swimming pool, the PV array was beautiful as designed. We even used the patio beneath for our first dance and into the evening, lit by an LED chandelier and twinkle lights.

We are blessed by what the universe has to offer us, if we are wise enough to accept and apply it, in appropriate and cherished doses.

Ben Root (*Home Power* art director)
& Sarah Elvington • Southern Oregon

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

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

RAPID SHUTDOWN



The MidNite Shut Off Box system is a simple to install, low cost rapid shut down system designed to comply with 2014 as well as 2017 NEC.

The system uses a receiver at the module that wires in just like an optimizer and a transmitter that is installed in or near the inverter. The installer is not required to install any additional wiring between the components as the communication is done using power line carrier. The system is fail safe. If the receiver does not sense the signal from the transmitter, it turns off and opens the circuit. All SOB's are listed to UL1741 and are NEC 2014, 2017 690.12 compliant.

BLEED DOWN UNIT

Not all grid tie inverters meet the NEC 2017 690.12(B)(1) requirement that states:

"Controlled conductors outside the Array Boundary need to drop to 30V or less within 30 seconds of initiating Rapid Shut Down". Our Bleed Down Unit addresses this issue and ensures that all systems comply with that requirement.

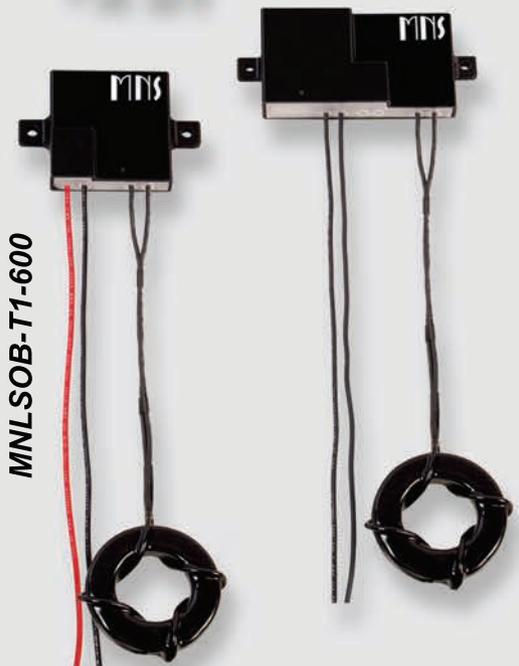


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MNLSOB-R1-1000



MNLSOB-T1-600



Aluminum or Copper Wire?

I need to run a cable between my MidNite Solar combiner box (with breakers) and my EPSolar 60 A PV controller. The cable run is about 150 feet. I would like to use ACWU cable (aluminum) since it is much cheaper than NMWU cable (copper). Can I use the ACWU with DIN rail combiner terminals, and the controller terminals?

If not, could I use ACWU for the majority of the run and then, at each end, use copper wire in junction boxes at the combiner box and at the inverter? The Cu and Al wires would connect in the junction boxes.

Pierre Levasseur • via email

Aluminum wire has one big advantage over copper, and a few minor ones. It also has major disadvantages; in most solar applications, these negatives outweigh the positives.

The primary reason people consider aluminum wire for PV systems is the significantly lower cost compared to copper. Other minor advantages include lighter weight for long wire pulls, flexibility, and price stability—copper prices fluctuate widely on the commodity markets.

However, the disadvantages of aluminum wire include that:

- It must be sized larger than copper wire, commonly one or two American Wire Gauge (AWG) sizes larger. As such, it requires a larger raceway and more space inside electrical boxes. The additional cost of upsizing wire size is also a factor.
- Aluminum oxidizes more quickly than copper, especially when exposed to moisture and humidity, and in contact with dissimilar metals like copper. This appears as a white, powdery substance on the metal and will result in a high-resistance connection, potentially causing overheating and posing a fire hazard. All aluminum wire connections must be treated with an anti-oxidization compound during installation.
- Splices joining aluminum to copper wire must be made with special (and expensive) connectors rated Al/Cu, such as Alumiconn, Burndy, and Polaris. These connectors are filled with antioxidant compound. Filling standard wire nuts with antioxidant is not safe, and does not meet *National Electrical Code* requirements. Crimping lugs to aluminum wire must be done with special crimps and a special crimping tool.
- Thermal expansion and contraction of aluminum wire is significantly higher than copper, so connections can gradually loosen over time. These connections need to be inspected and retorqued on a regular basis.
- Aluminum wire is not as malleable as copper, and is susceptible to breakage from repetitive bending. Any nicks to the wire made while stripping the insulation can cause breakage very easily, so great care or special strippers must be used.
- Most PV equipment lugs are not rated for aluminum wire, so an Al/Cu pigtail (terminating in an enclosure) must be used.

MidNite Solar products are *not* rated for use with aluminum wire. Equipment terminals must be specifically labeled Al/Cu to be compatible with aluminum wire.

To avoid the hassle and potential risks of using aluminum wire, first reduce the amperage (and therefore the wire size) of your PV home-run

Copper vs. Aluminum Cable

Characteristics	Copper	Aluminum
Specific resistance (ohms-cir/mil ft. at 20°C)	10.6	18.52
Cross-sectional area for equal conductivity	1.0	1.56
Tensile strength (lbs/in. ²)	50,000	32,000
Tensile strength for equal conductivity (lbs.)	50,000	50,000
Weight for equal conductivity (lbs.)	100	54
Coefficient of expansion (per °C x 10 ⁻⁶)	16.6	23

Data courtesy borderstates.com

by wiring the modules into strings of the highest voltage possible for your controller—in this case, an open-circuit voltage (Voc) of 150 VDC. Apply PV module temperature corrections before choosing the string voltage; most likely your maximum will be between 130 and 135 volts per string, but, in cold climates, it could be as low as 120 V. Then, you could run standard THWN copper wire in conduit. The reduced wire size may make the copper more affordable, especially considering the extra maintenance, the cost of special connectors, and the extra junction boxes you'd need to transition from copper to aluminum and then back to copper. I would not recommend NMWU wire for your application, as buried wires not in conduit or metal sheathing are vulnerable to damage from burrowing animals, even when at proper depth.

Aluminum wire does have its place in PV systems, including long PV home runs at high amperage; long well-pump runs; and utility service entrances. But, in most cases, the extra installation hassle, inspection, maintenance, and cost of special connectors don't add up to much cost savings.

Dan Fink • Buckville Energy Consulting

Wind Generator Governing

I used centrifugal feathering with my wind generator. It starts at 30°, then goes to 0° at high speeds. However, I've seen the feathering used in some big wind systems go the other way—starting at 7° and stalling at 30°. Could you tell me which system would be most convenient with a three-blade, 7-meter-diameter wind turbine?

Erik Barney • Misiones, Argentina

Changing the angle of wind turbine blades, usually called “pitching,” is a good strategy for protecting the turbine from high winds that could otherwise overload and damage the machine. The wind's angle of attack on the blades determines both lift and drag forces, so pitching can be used to optimize a turbine's performance—or to spoil it when needed.

Pitching a blade changes its angle relative to the plane of rotation. This blade angle is not the same as angle of attack. Changing the blade angle has the opposite effect on its angle of attack to the relative wind. The angle of the relative wind itself depends on the blade's speed and on the air velocity reaching it, which will already be slowed and diverted by the lift and drag forces.

For maximum working efficiency, start by optimizing the blade's geometry. (Optimum angle depends on the “tip-speed ratio;” how to

continued on page 20

Solar hot water

Solar Thermal

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- › Lowest carbon footprint

SOLkit 2

SOLKits are complete packages of 1, 2, or 3 collectors



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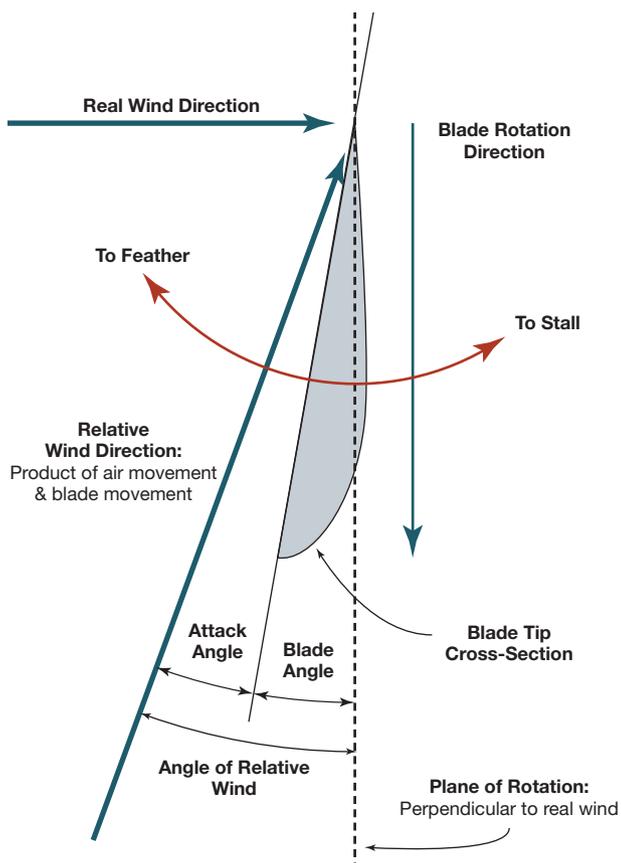
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continued from page 18

Blade Pitch: Stalling vs. Feathering



find it would require a much longer explanation.) In high winds, you can pitch the blades to “spoil” this optimum setting.

Most designers choose to govern by changing the pitch to a smaller angle. This increases the angle of attack, and brings on stall. This is the simplest strategy because stall creates drag, slowing the blades’ motion and further increasing the angle of attack. Once stall is started, the wind angle increases, pushing the machine deeper into stall. While a small pitching movement is sufficient to do this, making the mechanics easier, the downside is that the thrust loads remain quite high in stall and the blades and tower are not completely protected from the violence of a storm.

Pitching the blades the opposite way—by increasing blade angle—is known as feathering. This reduces the angle of attack, which slows the turbine by reducing the lift forces that drive it. In this case, the range of angular motion needs to be much larger, because the wind angle tends to increase as the blades move into feather. This approach is the better one for extreme winds (provided the blades can pitch far enough) as the loads on the turbine are reduced. But it is harder to engineer a larger angle of movement and its control, so it is more common to see blades that are designed to pitch into stall.

Blade pitching is a great way to control wind turbines, provided the mechanism itself is correctly designed and robust. The pitch mechanism can be a weak point in the turbine’s design, leading to poor power output or maintenance issues as the moving parts (springs, bearings, etc.) wear out and fail. Careful design and experimentation can find the right balance, and lead to long-term performance.

Hugh Piggott • Scoraig Wind-Electric

Expansion Tank for a Thermosiphon System?

I read with great interest Vaughan Woodruff’s article on the use of expansion tanks with solar water heating (SWH) systems in *HP162*. My SWH system is a Chromagen thermosiphon—an 80-gallon electric heater/reservoir tank paired with a 33-square-foot flat-plate collector—located on the roof of my house. The tank is located above the collector, which circulates a glycol solution that passively transfers heat to the water in the reservoir tank. The piping between them is about 3 feet long.

The pipe coming from the street water main, which serves the reservoir tank, has a pressure-reducing valve that is creating pressure problems in the potable water system. The manufacturer has suggested using a thermostatic mixing valve between the hot and cold sides of the reservoir tank to eliminate the problems created by the existing configuration.

I am considering placing an expansion tank in the system, but I am unsure if this would require a pump. What do you think about locating an additional expansion tank immediately after the pressure-reducing valve to buffer any water-volume expansion issues in the house piping?

Eric Kosak • via email

There are some important differences between the indirect thermosiphon/solar portion of the system that you describe and the pressurized glycol system that I detailed in “Protecting Water Heating Systems with Expansion Tanks” in *HP162*.

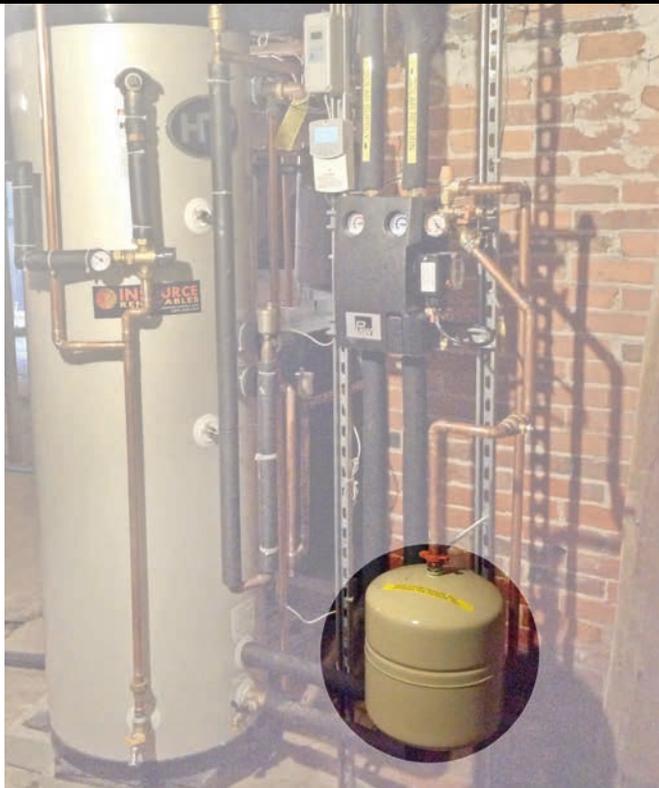
Your system is passive—it doesn’t rely on a pump to circulate the glycol in the system because the storage tank is above the collector; the fluid circulates by convection as it is heated in the collector. The heat from the glycol is transferred to the potable water in the reservoir/storage tank through a heat exchanger. This cools the glycol, which sinks into the collector to be heated again.

The glycol-based system described in my article is an active system, which requires a circulator pump to move the glycol through the collectors and the heat exchanger. In many of these systems, the collectors are located above the water heater. Without a pump, the heated fluid would stay at the top of the system, failing to provide usable heat that can be transferred to potable water. This is exactly what happens during stagnation, which occurs when the circulator pump is unable to circulate fluid due to a power outage or an issue with the controls, or if the water in the water heater has reached its maximum temperature and additional heat from the SWH collector would damage it.

Thermosiphon systems do not require an expansion tank on the solar loop (the piping in the system that contains glycol). Fluid expansion is much more predictable in these systems and can be readily planned for during the design process. A pressure-relief valve, which will open and release some glycol, is used to protect the system components from pressures exceeding their rated capacity. In some cases, the system is designed to release some glycol as it is heated for the first few times until pressure equilibrium is reached.

In contrast, active indirect glycol systems are pressurized upon commissioning. Excess glycol is pumped into the solar loop during startup to increase the pressure to the system specifications. These systems are designed with a properly sized solar expansion tank that helps regulate the system pressure at a level below the rating of the pressure-relief valve. In these systems, if the pressure-relief valve opens and releases glycol, air may be introduced into the system. If

Vaughan Woodruff



this occurs, the circulator pump may become air-locked and unable to move heated glycol from the collectors to the heat exchanger.

Since you have a thermosiphon SWH system, you do not need a solar expansion tank (nor a pre vessel) in the solar loop. The potable water system may be another story. Thermal expansion occurs in the potable water system as the water in the tank is heated by the solar loop. As discussed in my article, pressure issues will arise if there is a device between the water heater inlet and the city water supply that does not allow the water to expand as it is heated. If a pressure-reducing valve is preventing the public water system from absorbing the thermal expansion occurring in your water heater, an expansion tank is commonly required. Without one, the potable water pressure can vary significantly. The water heater's temperature- and pressure-relief valve alone is not a safe means by which to control pressure in the system. There are significant safety hazards associated with pressurized hot water. If in doubt, it may be time to call a plumber.

Vaughan Woodruff • Insource Renewables

A solar expansion tank (highlighted here) is a critical component of a closed-loop, pumped solar water heating system. The one shown is sized to maintain system pressure if system stagnation occurs.

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Long-Range, Big-Battery EVs

by Brad Berman

Courtesy Chevrolet

When the Nissan Leaf electric car first went on sale in late 2010, I immediately jumped on the electric vehicle (EV) bandwagon. Even though the first Leaf offered only 84 miles of driving range on a single charge of its 24 kWh battery, that was fine for me—I knew that this EV was intended for local driving. When I needed to push the range, I kept one eye glued to the dashboard, praying that I could make it home. With a little planning, I never ran out of juice.

When my Leaf's three-year lease was up, I swapped it for a 2014 Toyota RAV4—a speedy SUV with a Tesla powertrain and a 42 kWh battery that provided about 120 miles of range. The jump in battery capacity expanded my EV driving to regional trips.

I upgraded again in 2017 when my second lease was up. Leasing EVs, instead of buying, allows taking advantage of the improvements in battery capacity and range that have continued with each model year. My 2017 Chevrolet Bolt provides an estimated 238 miles of range. And after a federal \$7,500 tax credit and a \$2,500 rebate from the State

of California, the sticker price dropped to an affordable \$27,500—the base priced used to calculate the monthly lease.

In just six years, my EVs went from 84, to 120, and then to 238 miles of range. I no longer worry about the driving range—days go by that we don't bother to plug in the car because our daily average of 25 miles barely puts a dent in the pack.

With the steady drop in battery costs, the range of nearly all EVs has increased, as evidenced by the second-generation Leaf now offering a range of 151 miles. The all-electric distance of today's plug-in hybrids—the number of miles they can travel before relying on the gasoline engine—has similarly expanded on models like the Chevrolet Volt (53 miles), Honda Clarity Plug-in Hybrid (48 miles), and Chrysler Pacifica Hybrid minivan (33 miles).

Here's a quick rundown of today's electric—both pure EVs and plug-in hybrid electric vehicles (PHEVs)—focusing on the 10 most notable models of 2018. My selection is based on top sellers with class-leading driving range combined with what I personally consider to be the most attractive design and desirable features.

Pure EVs

BMW i3

Range: 114 miles

Battery capacity: 33 kWh

Size: Compact

Seats: 4

Base price*: \$44,450

*Base price listings may not include a "destination charge," which can commonly add \$1,000



Courtesy BMW (2)

At 114 miles of range, BMW's i3 might be lagging behind in the big-battery EV race. But the electric Beemer is one of the best-selling electric cars for several reasons. At a base price of \$44,450, it's the most affordable luxury EV with decent range. The sporty-yet-funky exterior styling, well-equipped interior, and 170 hp motor are unique in the EV market. It's the only EV available with a backup generator—the i3 REx model has a 650 cc engine and 2.4-gallon gasoline tank. In a pinch, the gas engine can be used to extend the battery's 114-mile range to 180 miles until you can recharge or refill the tank. The BMW showroom also offers plug-in hybrid versions of its 3 Series, 5 Series, and 7 Series cars, and its X5 SUV.

Chevrolet Bolt

Range: 238 miles

Battery capacity: 60 kWh

Size: Compact

Seats: 5

Base price: \$37,500

Unlike Tesla's Model 3, which requires a several-month wait after ordering, the 238-mile Bolt is readily available at dealerships. The 200 hp, five-passenger hatchback is fast, comfortable, and provides more battery capacity per dollar than any other EV on the market. *Motor Trend* named the Chevy Bolt as last year's Car of the Year. Building on its success, General Motors said it would introduce four new EVs by 2020.



Courtesy Chevrolet (3)

Nissan Leaf

Range: 151 miles

Battery capacity: 40 kWh

Size: Compact

Seats: 5

Base price: \$29,900



This popular five-passenger hatchback became more useful in 2018 when its driving range expanded to 151 miles. The slightly bigger second-generation model also took on a mainstream look and feel—replacing bulging headlights and a wide rear-end with narrower lines and wrap-around lights. At the same time, power output increased from 107 to 147 hp. While the increase in range from 107 to 151 miles is great—especially considering a \$700 drop in base price compared to its predecessor—Nissan no longer carries the mantle as the EV leader. The 40 kWh Leaf is still highly capable and popular, and a 200-mile version is rumored to be in the works.



Courtesy Nissan (3)

Tesla Model 3

Range: 220 or 310 miles

Battery capacity: 50 kWh for the 220-mile version; 75 kWh for the 310-mile version

Size: Compact

Seats: 5

Base price: \$35,000

The sleek and upscale Model 3—if ordered today—requires a likely wait of about six months. The price for the model that Tesla is producing in 2018 commonly exceeds \$50,000. The wait for a \$35,000, 220-mile Model 3 could put you well into 2019. The Model 3 is a coveted high-tech design marvel. It offers all the acceleration and handling of a luxury car, with numerous design flourishes such as an expansive panoramic windshield and the replacement of all dashboard knobs and buttons with a single large touchscreen.



Courtesy Tesla (3)

Plug-in Hybrid EVs

Chevrolet Volt PHEV

Range: 53 miles in pure-electric mode; 42 mpg gas engine; 420 miles total range

Battery capacity: 18.4 kWh

Size: Compact

Seats: 5

Base price: \$34,095

Since the Chevy Volt plug-in hybrid was introduced in late 2010, the field of PHEVs has expanded to about 25 models. But the Volt continues to be the leader in all-electric range with its 18.4 kWh battery. After those electric miles, its 1.5-liter gasoline engine provides 42 miles per gallon. The second-generation Chevrolet Volt, introduced in 2017, is a nice-handling commuter car—with a long list of high-tech features.



Courtesy Chevrolet (3)

Chrysler Pacifica PHEV

Range: 33 miles in pure-electric mode; 32 mpg gas engine; 566 miles total range

Battery capacity: 16 kWh

Size: Minivan

Seats: 7

Base price: \$40,000

Besides being the industry's first PHEV minivan, the Pacifica plug-in has the biggest interior storage space among today's minivans. The Pacifica is also praised for its 3.6-liter V6 engine and two electric motors, which combine to produce 260 horsepower. Its pure-EV range is usually enough for everyday errands.



Courtesy Chrysler (3)

Honda Clarity PHEV

Range: 47 miles in pure-electric mode
42 mpg gas engine; 340 miles total range

Battery capacity: 17 kWh

Size: Midsize sedan

Seats: 5

Base price: \$33,400 (PHEV model)

The Honda Clarity comes in three varieties: a hydrogen fuel cell, pure battery-electric, and a plug-in hybrid. The fuel-cell version is sold only in California and requires finding an H₂ station to refuel; the EV-only model has limited range (89 miles) and availability, as it is sold only in California and Oregon. The PHEV is available in 50 states, and its 17 kWh battery provides 47 miles of all-electric range—the only PHEV to come close to the Volt's 53 miles. After the battery is drained, the Clarity achieves 42 mpg via its 4-cylinder gasoline engine. The Clarity is a full-size sedan, with a trunk and plenty of room for five passengers, compared to the compacts and hatchbacks that make up the majority of PHEVs.



Courtesy Honda Motor Co. (4)



Kia Niro PHEV

Range: 26 miles in pure-electric mode;
46 mpg gas engine; 560 miles total range

Battery capacity: 8.9 kWh

Size: Crossover SUV (front-wheel-drive only)

Seats: 5

Base price: \$27,900

Small, station-wagon-like, crossover SUVs are very popular, and Kia used that format for its latest PHEV. While its price and EV range are nearly identical to the Prius Prime, the Kia Niro provides a more-engaging 139 hp system and six-speed automatic gearbox that feels more like a conventional car. After its 26 electric miles, the Niro sips gas at a rate of 46 mpg. With its upscale cabin, it is one of the nicest among all of the cars in the same price range.

Courtesy Kia Motors America (3)



Mitsubishi Outlander PHEV

Range: 22 miles in pure-electric mode; 25 mpg gas engine; 310 miles total range

Battery capacity: 12 kWh

Size: Crossover SUV (AWD)

Seats: 5

Base price: \$34,600

After five years of promising, Mitsubishi finally started selling the plug-in SUV in North America in late 2017. It's the most affordable plug-in AWD SUV option in its class—handily beating the price of sport-utility PHEVs from BMW, Mercedes, Tesla, and Volvo. Strictly a two-row, five-passenger vehicle, the Outlander's 12 kWh battery provides a modest 22 miles of all-electric range before the car reverts to its gasoline engine.



Courtesy Mitsubishi (3)



Gone Missing

If you're looking for the Ford C-Max Energi Plug-in Hybrid, Mercedes-Benz B-Class Electric, or the Mitsubishi I-MiEV, you're out of luck. Those plug-in vehicles were discontinued so their makers could focus on longer-range electric models.

Toyota Prius Prime PHEV

Range: 25 miles in pure-electric mode; 54 mpg gas engine; 640 miles total range

Battery capacity: 8.8 kWh

Size: Midsize (but back seat is limited to two passengers due to a middle console)

Seats: 4

Base price: \$27,300



Courtesy Toyota (2)

The Prius Prime has been the best-selling plug-in hybrid in the United States for more than a year. That's despite offering less than half of the Volt's all-electric range, about 40% less power, and room for only four passengers. But the Prius has brand, quality, and reliability recognition. It's a highly affordable plug-in hatchback and a great car for long-distance commuters because, after the first 25 miles of all-electric driving, its engine achieves 54 miles per gallon.



On the Horizon...2018

Hyundai Kona EV

The gas-powered Hyundai Kona is considered one of the best compact SUVs on the market. If Hyundai introduces its promised 250-mile-range, all-electric version in late 2018, it will take the lead in EV range among EVs priced less than \$40,000. It will only be available in California until about mid-2019, when sales are planned in other states.



Courtesy Hyundai

Jaguar i-Pace EV

The low-slung 240-mile-range Jaguar i-Pace will be the British company's first battery-electric vehicle. At about \$70,000 before incentives, the all-wheel-drive i-Pace is due by the end of 2018. This luxury EV will deliver 392 hp and a top speed of 124 miles per hour.



Courtesy Jaguar

Subaru Crosstrek PHEV

The all-wheel-drive Crosstrek compact SUV will become the company's first PHEV in late 2018. Subaru has not yet confirmed details, but it appears it will use Toyota technology to offer about 20 miles of all-electric range before its four-cylinder engine is called into service.



Courtesy Subaru

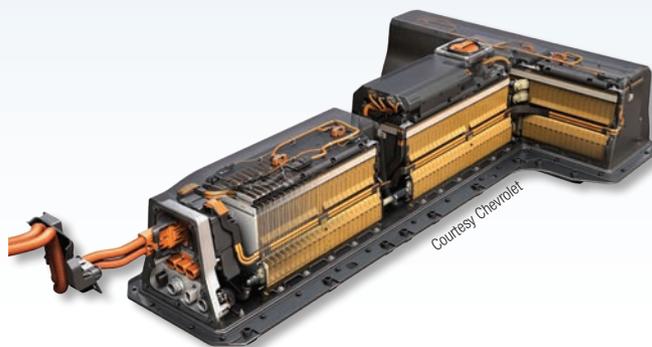
Battery Cost & Electric Cars

Many experts say that the price of a single kWh of energy storage in an EV battery needs to drop to roughly \$100 before long-range electric cars become competitive with gasoline-powered vehicles. Analysts believe we will hit this mark by 2025—if not a couple of years sooner. In a virtuous cycle, increased adoption of electric vehicles will dramatically increase the volume of battery production. The resulting economies of scale will further reduce the price per kWh.

A few years ago, a range of more than 200 miles would have been cost-prohibitive. In 2010, a fully installed EV battery was estimated to cost \$1,000 per kWh, according to a report from the Union of Concerned Scientists (UCS). UCS says the battery in a Chevy Bolt or Tesla Model 3 today costs about \$200 per kWh. Automakers could then either drop the sticker price of their EVs or add even more driving range.

Navigant Research, a clean-technology market research firm, forecasts that lithium-ion battery pack prices for EVs will continue to fall by 7% annually, reaching \$160 on average by 2026. This is for the full pack, including thermal management system and battery housing, not just the cell price.

Based partly on declining battery prices, Bloomberg New Energy Finance expects global sales of electric cars to accelerate from 1.1 million in 2017 to 11 million in 2025 and to 30 million by 2030. Some automakers warn that the rate of reduced battery cost will flatten in a few years based on shortages of materials such as cobalt, which comes from remote parts of the world with questionable labor practices. Engineers are seeking alternatives, such as new variants of lithium-ion chemistry or those that rely more on magnesium and sodium. Meanwhile, solid-state batteries—seen as a quantum leap in both energy density and power—are reportedly only a few years away. Both Toyota and Dyson, better known as a maker of vacuum cleaners, say they will introduce an electric car using solid-state batteries by 2022.



Courtesy Chevrolet

EV Incentives

For a rundown of EV and PHEV incentives, both federal and state, see bit.ly/EVIncentives

...2019

Audi e-tron quattro EV

Audi will launch production of a 250-mile performance-oriented SUV in late 2018. The fast 430-hp e-tron quattro will use one motor on the front axle and two separate motors at the rear for precise handling at high speeds.

Mini Cooper EV

Last year, Mini confirmed that an all-electric version of the Mini Cooper will go into production in late 2019. It might not look as cool as the minimalist concept version that Mini unveiled, but the youthful, urban Mini Cooper will make a fun, small EV—especially if it offers 200 miles of range, as the rumor mill suggests.



Courtesy Audi

...2020

BMW iX3 EV

The BMW iX3 appears to be aimed at competing with Tesla. The iX3, due in 2020, is a 270 hp, all-electric small SUV with an expected 270 miles of range. Based on the preview of the iX3 in Beijing in May, the iX3 looks just like the brand's conventional crossovers.



Courtesy BMW

Chevrolet Bolt Crossover EV

General Motors revealed in late 2017 that the company plans to introduce a new long-range crossover using the same drive system and battery as found in the Chevy Bolt.



Courtesy Chevrolet



Courtesy Mini USA

Electric Robotaxis Are on the Way

In the future, our cars and trucks will likely be powered by batteries, and will increasingly be self-driving, networked, and shared (rather than privately owned). The industry acronym for the combined force of these trends is ACES—autonomous, connected, electric, and shared.

Onboard advanced sensors—such as radar, lidar, and sonar—in concert with cameras, image recognition, and machine-learning, may remove human beings from the driver's seat and eventually render steering wheels unnecessary. Because these networked cars could provide service 24/7, there'd be no reason to keep them parked in a garage or driveway—where today's automobiles remain dormant for more than 90% of the time. They could freely roam and meet us when and where we call them, even autonomously driving themselves to a wireless charger before taking the next ride hailed from an app. The shift to autonomous EVs will likely happen first with fixed-route, long-haul trucking before coming to designated urban areas. Toward that end, companies like Uber, Lyft, Google, and China's Didi—as well as legacy automakers getting into mobility services—are deploying tens of thousands of EVs in self-driving pilot programs across the globe.

...2020 continued

Ford Electric SUV

Ford promises seven new pure-electric vehicles by 2022. The first one, due in 2020, will be a 300-mile sport utility that Ford says will have Mustang-like levels of performance.

Porsche Mission-E EV

Porsche's outrageous all-electric sedan, the Mission-E, will be sold for about \$80,000. It is expected to accelerate from zero to 60 mph in about three seconds while offering a range close to 300 miles. Actual specs will be confirmed closer to its 2020 launch.

Tesla Model Y EV

Slated for production in 2020 at the earliest, the Model Y small crossover will be built on the Model 3's drivetrain and is intended to provide the same range and features as Tesla's small sedan.

Tesla Roadster EV

The numbers being teased about a new version of the Tesla Roadster are off the charts. Tesla CEO Elon Musk says it will accelerate to 60 mph in less than two seconds while carrying a 200 kWh battery for a driving range of more than 600 miles. The Roadster, with a small back seat to squeeze in two additional passengers, is expected to sell for \$200,000.



Courtesy Ford



Courtesy Porsche

Courtesy Tesla



Courtesy Tesla

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The Solar Decathlon

Innovation Incubator

by Juliet Grable

Since Solar Decathlon's inception in 2002, this U.S. Department of Energy-sponsored collegiate competition has been an incubator for residential solar home innovation. Solar Decathlon teams have integrated and demonstrated technologies well ahead of market adoption.



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All photos courtesy Dennis Schroeder/U.S. Department of Energy Solar Decathlon

The 2017 competition was no exception to the rule of innovation common to all past Solar Decathlon events. Eleven collegiate teams spent two years designing solar-powered homes, which they built, disassembled, transported, and rebuilt at the Solar Village in Denver, Colorado. There, the teams' homes were compared in a series of 10 contests—that's the "Decathlon" part—some based on measured data; others juried by a panel of experts.

New to this competition were the Innovation and Water contests. The Innovation contest encouraged teams to go beyond off-the-shelf solutions and come up with unique and thoughtful solutions for their particular project. Teams were evaluated on research, sustainability, innovation, and

durability and safety. Although previous Solar Decathlon entries often included water-saving features and innovations, the Water contest was the first competition that scored teams on how they integrated appropriate landscaping and solutions that conserved and reclaimed water.

Many teams in 2017 used market-ready products and systems and incorporated them in innovative ways—for example, the University of Maryland's home used heat harvested from an adjacent glazed courtyard to improve the efficiency of the heat-pump compressor units. Some of the products and systems may not yet be household names, but if past Solar Decathlons are any indication, some soon may be.

Innovative Products

DecoTech Solar Roofing • gaf.com

GAF manufactures roofing and DecoTech integrated PV roofing panels. They have 60-cell SolarWorld 285 W Sunmodule Plus modules, set into black aluminum frames. The interlocking panels install directly onto the roof deck, integrated with the surrounding roofing. Step- and counter-flashing prevent moisture and pest intrusion. Flashing is similar to that used around skylights. The result is a low-profile solar roof that utilizes conventional PV modules.

Installation can be by certified GAF contractors. The 25-year warranty covers power generation and manufacturing defects, and if installed by a certified contractor, workmanship.

Solar Decathlon 2017: Northwestern University's team used DecoTech panels for its 6.5 kW PV array, creating a sophisticated, modern aesthetic. The array was paired with a Schneider Electric Conext XW+ 6848 NA inverter/battery charger and a 25 kWh bank of Sun Xtender AGM batteries.

Cost: Similar to other premium rack-mounted PV systems.

BamCore • bamcore.com

The BamCore hollow wall system consists of two laminated load-bearing panels made with bamboo from Latin America. Structural wall panels have four layers of bamboo with a formaldehyde-free binder and are finished on both sides with a veneer made from Douglas fir for a thickness of 1 1/4 inches. Thinner partition wall and ceiling lid panels are also available.

The standard panel is 4 feet wide and between 8 and 10 feet tall; custom sizes are available. The panels mount into steel tracks and are connected using stainless-steel splines, and can be spaced apart four to 12 inches. This studless system significantly reduces thermal bridging and insulation can be blown into the cavities once the walls are in place.



Northwestern University's Enable House featured DecoTech integrated PV roofing panels.

The panels can be prefabricated with openings and penetrations for windows, doors, plumbing, and electrical. Interior faces can be sanded and stained or painted, or can be covered with drywall.

Timber bamboo grows rapidly and can be harvested in four to six years. According to the company, one-fourth of a crop can be harvested every year, leaving the rest of the stand to continue retaining water and sequestering carbon.

BamCore's manufacturing facility is in Windsor, California. Most of BamCore's projects have been regional, but the company has projects on the East Coast and will deliver anywhere in the United States.

Solar Decathlon 2017: A low carbon footprint was important for the University of California-Davis team. They used BamCore panels in the exterior and interior walls. Structural BamCore panels were used to create 12-inch-thick exterior walls, which were then filled with 9.6 inches of blown-in mineral wool for R-45. Conventional SIPs were used for the roof.

Cost: \$15 to \$28 per square foot.

Right and below: The UC-Davis house used structural BamCore panels on both the interior and exterior. Panels were separated by 9.6 inches of insulation for an R-value of 45.



Ductal Concrete

• lafargeholcim.com

Ductal is cement reinforced with quartz or silica and is used for casting into lightweight panels for a variety of architectural applications. Ultra-high-performance concrete (UHPC) can achieve the same structural strength with less thickness and weight without rebar reinforcement. With compressive strengths up to 29,000 pounds per square inch (psi) and flexural strengths up to 7,000 psi, UHPC is six times stronger than traditional concrete, which provides an average of 5,000 psi compressive strength.

Solar Decathlon 2017: The team from Washington University–St. Louis used UHPC in the outside face of the precast concrete panels for their project. The panels consist of a four-inch layer of standard concrete, five inches of expanded polystyrene insulation, and 1.25-inch layer of UHPC on the exterior. The panels were constructed in a factory and assembled on-site. Advantages include strength, longevity, insect- and rot-resistance, and aesthetics. The versatility of the UHPC allowed a dynamic façade with integrated exterior LED lighting, and reveals and ridges.

Cost: Custom-designed; varies.

Nanawall Sliding Glass Wall

• nanawall.com

Nanawall provides folding, sliding, and frameless glass walls that enable entire walls to open. Narrow frames surround each panel; the glass walls meet Passive House standards.

Nanawall folding door systems can accommodate openings up to 39 feet; some systems can go even wider. The aluminum design is manufactured in the United States and is considerably less expensive than similar options. It incorporates a thermally broken insulation barrier into the frames. The SL60 system is 2.4 inches thick; the double-paned, argon-filled glazing has a U-factor between 0.26 and 0.32 and a SHGC of 0.21 to 0.23. The product can be specified with triple-paned glass. FoldFlat is available with SL60 Nanawalls, enabling a door to hinge open against an adjacent pane; then the entire assembly pivots to lie completely out of the opening.



Washington University's CRETE House used ultra-high-performance concrete as structural and aesthetic architectural elements.

Solar Decathlon 2017: The team from Missouri S&T incorporated Nanawall into SILO, their modern farmhouse-style home, for an indoor-outdoor connection and expansion of living space. SILO incorporates SL60 systems into the kitchen and the master bedroom. The south-facing kitchen wall opens up to a patio. A mobile “green curtain” of plants can be rolled in front of the open wall, providing shade in the summer while allowing fresh air in.

Cost: An SL60 system starts at \$700 per lineal foot.

The Missouri University of Science and Technology's SILO House utilized a Nanawall to transition from cozy solar gain to outdoor living.





Courtesy LG (2)



Efficient Appliances

LG Multi F Minisplit Heat Pump & Therma V Air-to-Water Heat Pump

• lg-dfs.com

LG's Multi F minisplit can serve up to four indoor units, up to 40,000 Btu. It has a SEER rating of 22. It can provide heating down to a -4°F outdoor temperature, making it a viable choice for many climate zones. It also uses a safer, chlorine-free R-410A refrigerant.

LG's Therma V air-to-water heat pump can be used for water heating, space heating and cooling, or all three; it can also be coupled to an existing boiler to improve its efficiency. With a DC motor and Class A water pump, the company claims Therma V is up to four times as efficient as other heating sources.

Solar Decathlon 2017: The University of Maryland's team chose the 3 kW LG minisplit system for space heating and cooling, and the air-to-water heat-pump for domestic hot water. The minisplit compressor and the outdoor unit of the split-type air-to-water heat pump are both located in an unconditioned space above the kitchen. In winter, both units take advantage of warmer air from the adjacent glazed unconditioned central courtyard. This raises air temperatures in the attic by an estimated 10°F, boosting the efficiency of both compressors. In summer, when the minisplit compressor is in cooling mode, the heat pump extracts heat from the attic air, and the precooled exhaust air is directed to the compressor unit, so it doesn't have to work as hard. The water heater's heat pump cools the attic air, reducing the need for the MSHP to work in cooling mode.

Cost: LG Multi F (outdoor unit only): \$1,800-\$2,100; Therma V Heat Pump (outdoor unit only): Not currently available in the United States.

Above: The University of Maryland's reACT House integrated a minisplit heat pump and an air-to-water heat pump for space and water heating. The units gained efficiency from a preconditioned sunroom space.

Nature's Head Composting Toilet

• natureshead.net

This dry composting toilet is compact, lightweight, and self-contained. A diverter routes urine to an easily removed 2.2-gallon compartment, which must be emptied every two to five days, assuming full-time usage by two people. The solids compartment can accommodate 60 to 80 uses and must be emptied every three to four weeks. The 12-volt exhaust fan can be used with a transformer to plug directly into a standard 120 VAC outlet. Nature's Head can be suitable for boats, RVs, cabins, and small homes.

Solar Decathlon 2017: This composting toilet is easy to install, according to the University of Maryland team, which included one in their house. One of the team's goals was to maintain a closed-loop system, recycling and reclaiming "waste." The home included a series of composting bins in which human manure could be transformed into nutrient-rich compost through a hot composting process that renders any disease-carrying organisms harmless. The team also planned to dilute and use captured urine to irrigate plants, although the urine can also be applied to the compost pile.

Residential Energy-Storage Options

The 2017 Solar Decathlon showcased several different residential energy-storage systems, as teams sought to meet the rigorous requirements of the Energy contest, in which the homes were judged by how much energy their systems produced and the energy's value at the time of use. All of the homes were connected to a microgrid that mimicked a utility's time-of-use rate structures—with higher rates during times of high demand. Teams had to manage the energy produced by their homes' PV arrays and, to score big, take advantage of lower rates during periods of lower demand (usually at night). Most homes included battery storage and energy-management software.

Teams earned full points for the production component if their homes produced at least as much energy as they consumed. The value component was more complicated. Teams began the competition with a \$5 charge to their accounts, which represented the fixed cost of grid connection. Throughout the competition, teams "bought" and "sold" energy from and to the grid at different rates, which were determined by hypothetical demand during those periods. Teams with at least \$10 in their accounts when the contest ended earned the maximum points. The Swiss team earned a perfect score for this contest, although the team from the University of Maryland and the joint team from the University of California-Berkeley/University of Denver both had positive balances in their accounts.

The RISE Home used Tesla's Powerwall 2, a sleek unit that incorporates an inverter and battery, for energy storage.



Courtesy Tesla



Swiss NeighborHub House

Tesla Powerwall 2 • tesla.com

Three teams, including the University of California-Berkeley/University of Denver team, relied on Tesla's Powerwall 2 system for energy storage. The UC Berkeley/University of Denver team used an eGauge data logger and student-designed system to monitor and manage the energy produced by the home's 20 Panasonic 235 W modules.

Tesla's second-generation residential battery stores surplus energy produced by a home's PV array, enabling energy management for time-of-use rates and providing backup power during grid outages.

Capacity: 13.5 kWh

Peak output power: 7 kW

Chemistry: Lithium-ion

Round-trip efficiency (ratio of energy put in to energy retrieved from storage): 90%

Dimensions: 44 × 29 × 5.5 in.

Installation: Indoor or outdoor; wall or floor mount

Cost: \$5,900 (plus \$700 supporting hardware, according to website); installation runs between \$1,000 and \$3,000

Berkeley/Denver RISE House



Missouri S&T SILO House



Courtesy Enphase

Enphase 1.2 kWh battery with integrated microinverter

• enphase.com

Missouri University of Science and Technology's team chose six Enphase 1.2 kWh AC storage batteries for the "plug-and-play" ease of installation. The system can be connected directly to the electrical panel, saving time and labor. The Enphase AC Battery is the first residential storage battery to be UL 9540 listed as a home energy-storage system. The home's system included 24 LG NeON 355 W PV modules with Enphase IQ 6+ microinverters and the Enphase combiner box with an IQ Envoy communication module. The team managed energy using Enphase's energy-monitoring program.

Specs: Enphase's AC batteries maximize self-consumption of surplus solar power and manage energy to take advantage of time-of-use rates. These AC-coupled batteries do not serve as a backup or off-grid power source, as they require the grid to operate.

Capacity: 7.2 kWh

Chemistry: Lithium iron phosphate

Peak output power: 1,620 VA (270 VA each)

Round-trip cell efficiency: 96%

Dimensions: 15.4 x 12.8 x 8.7 in.

Installation: Indoors; wall mount

Cost: \$13,500

Sunverge Energy AC-Coupled Solar Integration System

• sunverge.com

The University of California-Davis team installed two separate PV arrays on Our H2Ouse. Both utilized SunPower X22 360 W modules. The 12-module array was connected to a Sunny Boy inverter, while the 15-module array was linked to a Sunverge Energy Solar Integration System. This system includes an AC-coupled 7.7 kWh battery, a bidirectional inverter, and power electronics in the enclosure. A cloud-based energy-management system collects data, monitors the system, and determines, based on utility rates, when to charge the battery and when to switch from grid-based to stored electricity.

An all-in-one battery storage, inverter, and energy management system, this can be installed with new or existing PV systems.

Capacity: 7.7 kWh (also offered in 11.6, 15.5, and 19.4 kWh)

Chemistry: Lithium-ion



UC-Davis OUR H2Ouse

Dimensions: 34 (W) x 75.5 (H) x 14 in.(D)

Installation: Indoors or outdoors

Courtesy Sunverge Energy

Beko Appliances' Tumble Dryer • beko.us

Although Beko is a new name in major appliances in the United States, more than 90% of its products, including washers, dryers, refrigerators, and dishwashers, are Energy Star-qualified. Blomberg, a sister brand, provides energy-efficient appliances optimized for smaller urban spaces. Beko and Blomberg have distributors in about two-thirds of the states.

One of the company's products is a tumble dryer that combines condensing and heat-pump technology. This appliance has earned Energy Star's Most Efficient label, with an estimated energy use of 208 kWh per year, which is at least 20% more efficient than conventional models.

Air passes through a heat exchanger before entering the drum, where it absorbs moisture from the clothes. Next, the air passes through an evaporator, where the water condenses. The heat moves through the heat exchanger again, starting the process over. The condensed water collects into a small reservoir, which must be emptied periodically. The ventless tumble dryer offers more placement flexibility than a conventional dryer. Another benefit is that the air temperature inside the drum is lower compared to conventional dryers, making it gentler on fabric. The dryer uses moisture and temperature sensors to reach a set dryness level, rather than a prescribed time.

Solar Decathlon 2017: Several teams incorporated Beko and Blomberg appliances into their projects, including the team from University of California–Berkeley/University of Denver, which won the Appliances contest.

Cost: \$1,200



Several teams used the washing machines and condensing dryers made by Beko.

Energy, Water & Air-Quality Management

SolarEdge Power Optimizers • solaredge.com

Optimizers improve a PV system's production by tracking the maximum power point (MPPT) of each PV module—modules in the same string can experience different conditions without compromising neighboring modules' performance. Optimizers send the electricity to a central inverter. When SolarEdge optimizers are installed with SolarEdge inverters, the optimizers automatically maintain a fixed string voltage. This allows greater flexibility in the installation, accommodating longer series strings and strings of different lengths.



Several teams used SolarEdge power optimizers on their PV arrays.

Courtesy SolarEdge

SolarEdge power optimizers are compatible with c-Si and thin-film modules and have a 25-year warranty. They can be added to existing modules, but some module manufacturers have the optimizers embedded. The optimizers also automatically reduce DC voltage if an inverter or grid outage is detected. Sensors and transmitters are built into both the SolarEdge optimizers and the inverters; if the PV system is connected to the SolarEdge monitoring platform, the optimizers collect performance data for each module, and the system can detect a problem at the system, string, or module level.

Solar Decathlon 2017: Several Solar Decathlon teams used SolarEdge optimizers and inverters, including the Swiss team, which not only won the overall competition, but earned perfect scores in both the Energy and Engineering contests. The Swiss team used 29 SunPower 335 W modules paired with SolarEdge optimizers, and three SolarEdge single-phase inverters (two model SE2200H units and one SE3500H unit). The University of Maryland team used the optimizers with the SolarEdge StorEdge inverter, a DC-coupled inverter that can also manage battery power and provide backup power during grid outages. They also used an LG Chem 9.8 kWh, 63 Ah, 400 V lithium-ion battery.

Cost: \$40 to \$70 per optimizer

Ark Labs DRiY • thearklabs.com

DRiY is a water-usage monitor that uses cloud-based software and frequent ultrasonic monitoring to “learn” a household’s water-use patterns. Installed at the water main, it also includes a shutoff valve. If it detects an anomaly in water usage, it will send an alert to the homeowner, who can choose to remotely turn off the water. If after three alerts there has been no response, DRiY will automatically shut off the water. Occupants can also track their water use over time, and use the data to implement water conservation efforts.

Solar Decathlon 2017: The University of Alabama-Birmingham’s team used DRiY to address possible leaks, which can account for up to 12% of a home’s water use, as well as occupant water-use habits, which can be influenced by the data and feedback provided by DRiY.

Cost: \$299 to \$449 (plus cell connection fees)



Courtesy Ark Labs

The University of Alabama team implemented water monitoring and leak detection with DRiY.

Awair • getawair.com

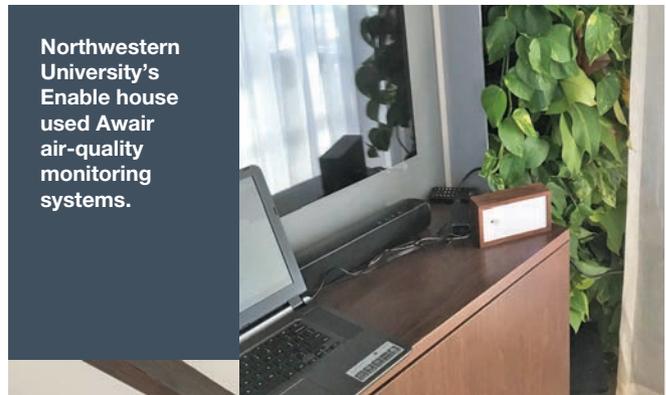
Awair and Awair Glow are “smart” devices that monitor indoor air quality (IAQ). Sensors track temperature, humidity, carbon dioxide, volatile organic compounds (VOCs), and particulates. The display has LED indicators for each factor and an overall IAQ score between 0 and 100. Awair works with other smart home devices, such as the Nest thermostat, Amazon Alexa, or HVAC appliances. For instance, it can coordinate with a humidifier or can be programmed to activate a ventilation system if pollutants reach certain thresholds.

Awair Glow is a plug-in device that uses a color-coded scale to indicate air quality, though it does not track particulates. It includes a nightlight and a receptacle so a non-connected device such as an air purifier can be plugged into Glow, which can set schedules for the device or activate it when air quality reaches a certain threshold.

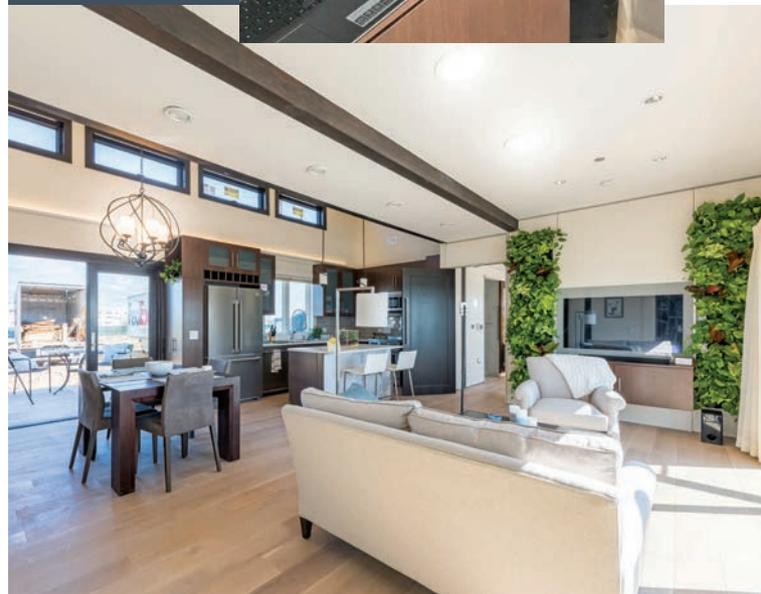
Awair and Awair Glow can be accessed through a smartphone app. Based on readings, the app provides recommendations for improving IAQ, and users can also track trends over time.

Solar Decathlon 2017: Enable House by Northwestern University used the Awair system as part of a comprehensive indoor air quality strategy that included air-filtering houseplants. The team used two Awair units and two Awair Glow sensors to monitor indoor air quality and raise awareness about the importance of good IAQ to people touring the house.

Cost: \$200 (Awair); \$119 (Awair Glow)



Northwestern University’s Enable house used Awair air-quality monitoring systems.

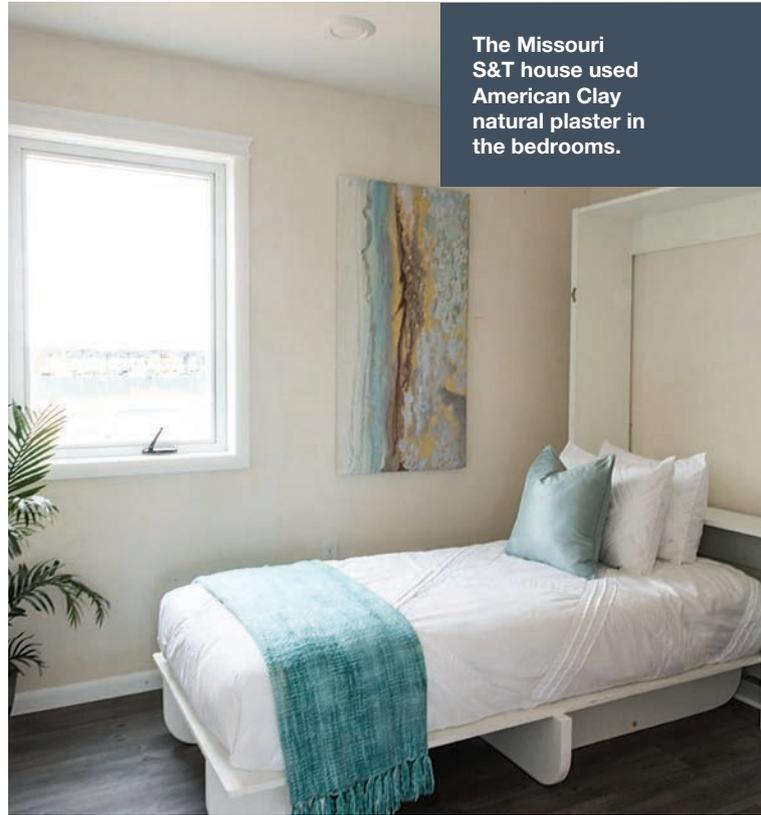


American Clay Forté Plaster • americanclay.com

American Clay produces natural interior plasters. Forté is their line of earthen plasters that have been amended to increase durability. It contains zero VOCs and is made in the United States, and helps regulate indoor environments by absorbing and releasing moisture.

Solar Decathlon 2017: Missouri S&T's team used American Clay Plaster to take advantage of the pollution-absorbing capacity of natural plaster. Guided by a professional painter, students helped apply the plaster in the two bedrooms of their farmhouse-inspired home.

Cost: Forté Base: \$1.41 to \$2.66 per square foot.; Forté Finish: \$1.47 to \$2.66 per square foot; Forté White: \$1.53 to \$1.61/ square foot.



The Missouri S&T house used American Clay natural plaster in the bedrooms.

web extra

"2013 Solar Decathlon" by Ryan Mayfield • homepower.com/160.35



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New Rapid Shutdown Solutions for Grid-Tied PV Systems

by Rebekah Hren

New standards in the 2017 *NEC* require that grid-tied PV systems have the capability of being quickly and remotely shut down, ensuring firefighter and first-responder safety. So what does this mean for new PV systems?

© istockphoto.com/Petmal & Altayb

Rapid Shutdown of PV Systems on Buildings—the requirement for quickly deployable voltage control of PV system circuit conductors in or on buildings—was first introduced in the 2014 *National Electrical Code (NEC)* as Section 690.12. Substantial changes to rapid shutdown (RS) requirements came in 2017 (see “Code Corner” in this issue).

RS systems allow first responders to expect consistency in the method for de-energizing PV system circuits on or in buildings, to help avoid shock hazards. RS requirements have caused a lot of hand-wringing in the solar industry about increased system cost due to the need for additional equipment, and reduced system reliability, since rooftop-mounted electronic equipment has to endure year-round temperature changes and all kinds of weather.

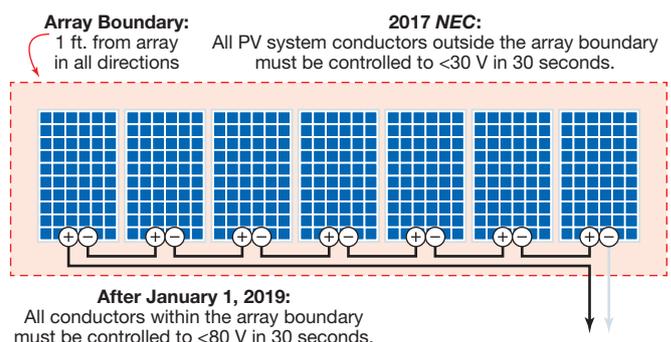
More than a decade of experience with rooftop-mounted module-level power electronics (MLPEs, such as microinverters and DC-to-DC converters) has shown the viability of well-designed, properly installed products. Different system types, including those with string inverters or MLPEs, all now have fairly straightforward RS solutions.

RS on the Horizon

Nearly half of the U.S. has already adopted the 2017 *NEC*, while the remaining states are enforcing older editions of the *Code* with different (or no) requirements for rapid shutdown. Subsection 690.12(B)(2) of the 2017 *NEC* requirements for module-level shutdown goes into effect on January 1, 2019. Until that date, there is no *NEC* requirement to control PV circuit voltage within the PV array boundary. But there are requirements for outside the 1-foot perimeter around the

array boundary—conductors must be limited to 30 volts or less within 30 seconds of RS initiation. For PV systems installed after January 1, 2019 (in areas that have adopted the 2017 *NEC*), there are three options for controlling voltage within the array boundary. (Options 1 and 3 allowed in 690.12(B)(2) are described in this issue’s “Code Corner,” but are not viable installation choices at this time.) Option 2—referred to as module-level shutdown—requires voltage within the array boundary to drop below 80 V within 30 seconds of RS initiation. A crystalline PV module’s typical open-circuit voltage (V_{oc}) is between 35 and 60 V, although that voltage may be higher as the temperature drops below 77°F. While a single module’s voltage is usually within the acceptable range, two or more modules wired in series could exceed the 80 V limit inside the array boundary.

2017 *NEC* Array Boundary



Batteryless Grid-Tied Systems

String Inverters

String inverters, which are connected to one or more series strings of modules (PV source circuits) at a maximum of 600 VDC on residences, have to transcend a particular issue when it comes to module-level shutdown. For 2014 NEC RS compliance, inverter manufacturers, such as ABB, Delta, Fronius, Ginlong, and SMA, offer roof-mounted devices listed for RS. These devices typically can handle one to four module strings and are installed as a pass-through box, junction box, or paralleling combiner box.

The rooftop device, mounted at the edge of or inside the array footprint, is connected to a power supply circuit. An initiator that opens or closes the string circuit triggers the device, bringing the output to 0 volts, but the string is still energized up to the point of connection with the device (inside the array boundary). The initiator can be installed to operate upon loss of AC voltage from the grid or to operate from a designated switch. For 2014 NEC compliance, third-party manufacturers such as Bentek, Innovative Solar, MidNite Solar, and SolarBOS also offer rooftop contactor-combiner or pass-through box solutions that can be paired with string inverters.

But without some electronic device that can disconnect each PV module from the series string, there is no possible way to bring the voltage inside the array boundary below the NEC 2017 limit of 80 V. This means that string inverters must be installed in conjunction with some type of MLPE to meet RS requirements. Manufacturers have had several years to figure out solutions, with some forming a working group through the SunSpec Alliance (see “SunSpec-Compliant Rapid Shutdown” sidebar). Wanting to avoid the cost of running an extra conductor for RS device functionality, in addition to the PV power circuit, the group created a certified

Fronius string inverters will be available this year with SunSpec-compliant RS communications. This Symo Advanced is a commercial product, but expect the residential line of Fronius inverters to follow.



Courtesy Fronius

An external initiation switch, such as this Bentek product, can be used for systems with string inverters that are not yet compliant with SunSpec protocols or are otherwise lacking RS functionality.



Courtesy Bentek

SunSpec-Compliant Rapid Shutdown

In June 2017, the SunSpec Alliance, a trade organization pursuing open information standards for distributed energy resources, published a multivendor, multidevice communication interoperability standard to support 2017 NEC module-level RS requirements. This working group, which includes many inverter, module, and MLPE manufacturers, created this standard so that different pieces of equipment—even from different manufacturers—installed in one PV system can communicate with each other to form an RS system. The SunSpec RS protocol details the manner in which a transmitter (the RS initiation device) sends a signal to the receiver (MLPE) via power line communications (PLCs).

There are two modes of operation: active mode and shutdown mode. During active mode, the RSS continuously monitors the initiation device for a change in system status; it must receive a “permission to operate” command for the PV power source to remain connected. During shutdown mode, the receiver (MLPE) lowers the voltage in the array circuits to less than 80 volts within 30 seconds. The transmitter (initiation device) can be inverter-integrated or a separate component. The initiation device can be triggered upon loss of AC voltage, which can be either from the main service disconnect or the PV system (AC) disconnect. Installers will need to use inverters, MLPE, charge controllers, and initiation devices (if external and not integrated into the inverter) that state they are SunSpec-compliant and listed to UL 1741 for RS functionality.



SUNSPEC
— ALLIANCE —



Courtesy Tigo Energy

Tigo Energy recently introduced its newest product for RS compliance. A single TS4-F is mounted at each module and receives a signal via a PLC from any external or inverter-integrated SunSpec-compliant initiation device.

power line communication (PLC) protocol that can be used by inverter, module, and MLPE manufacturers. Equipment from different manufacturers can be “mixed and matched” and still qualify as a Code-compliant, listed RS system. This SunSpec RS protocol can eliminate the cost of an external RS box and increase reliability as inverter manufacturers integrate initiation functionality that communicates with module-level shutdown devices.

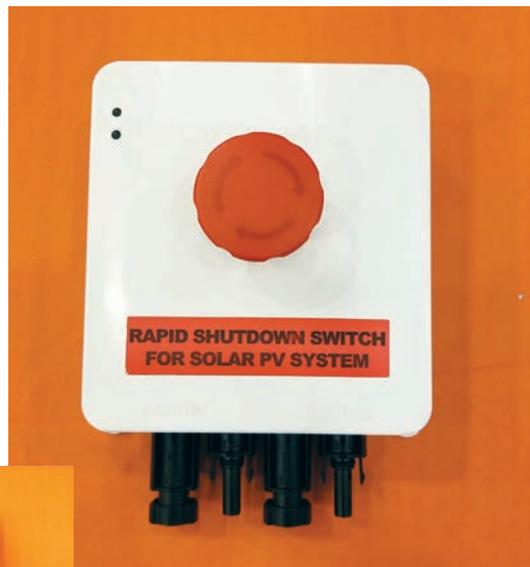
Tigo Energy’s TS4 line of MLPEs can provide RS functionality for string inverters as well as power optimization and module-level monitoring capabilities, depending on the device. Its lowest-cost RS device, the TS4-F, is UL-certified and can be factory-integrated into a PV module or retrofit as an add-on module junction-box cover. It can be paired with PV modules rated to 475 W STC, with voltage up to 90 V and current up to 12 A. Upon loss of utility power, it provides either automatic module-level shutdown or manual shutdown via a switch, which must be mounted at a readily accessible location on the exterior of the building.

The TS4-F works with SunSpec-compliant RS initiation devices. Tigo has tested compatibility with several inverters—including ones from Chint, Fronius, and SMA—and its compliant inverter list is expanding. The Fronius Symo advanced inverter will be available in the last quarter of 2018 and will meet all 2017 NEC RS requirements when paired with the TS4-F.

Tigo is also developing a stand-alone initiator—the TS4-S—that can be used if the string inverter manufacturer does not supply one. When installed along with Tigo’s Cloud Connect or Cloud Connect Advanced, which requires an AC power supply, and a Gateway device, which is mounted at the array, the TS4-S also provides data monitoring.

Northern Electric and Power (NEP) is now manufacturing a SunSpec-compliant MLPE receiver, the **PV Guard PVG-1**. Similar in functionality to Tigo’s TSF-4, which also provides module-level monitoring via proprietary software, the NEP device is listed to UL 1741 for RS equipment, and has been tested and listed to work with Chint’s larger-model string inverters via an initiation device integrated into the inverter. NEP also manufactures an external RS initiation device that can be used with SunSpec-compliant inverters lacking an internal initiator. NEP devices can either be installed by module manufacturers as a junction box replacement or field-installed as an add-on.

The NEP initiation switch is for use with string inverters that lack integrated RS initiation capability. When the button is pushed, PLCs signal the rooftop MLPE to reduce array voltage.



Left: The NEP junction box with RS receiver capability is designed for factory integration by module manufacturers. The junction box receives a power line signal from an initiation device.



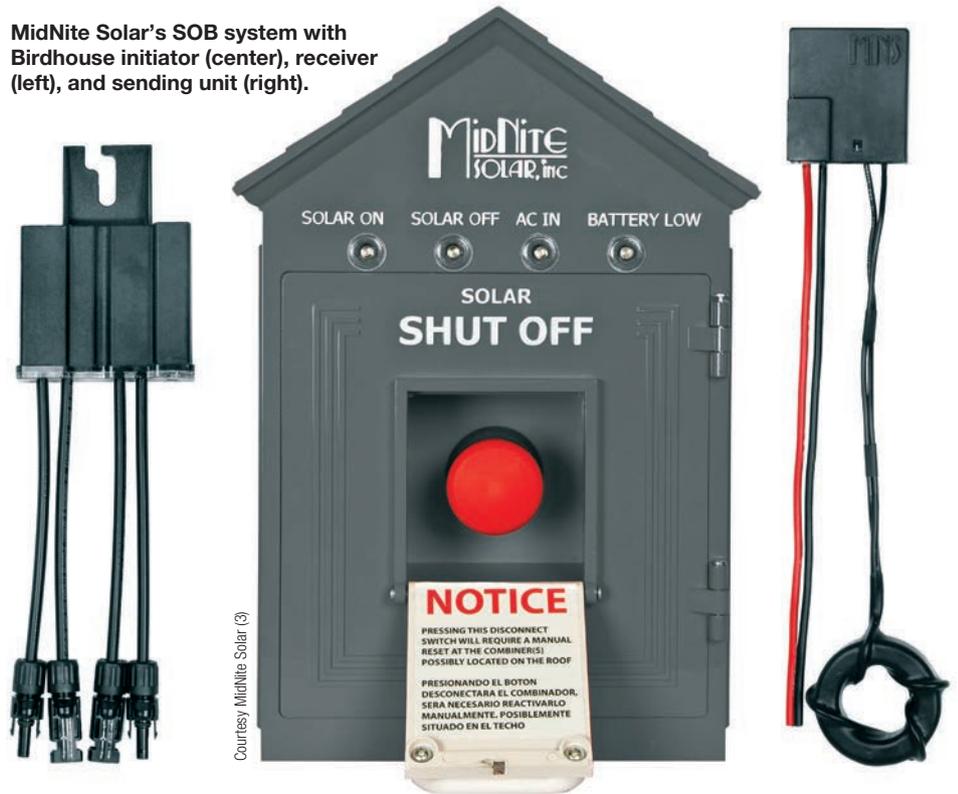
Right: The NEP receiver unit is made for field-installation on each module and for use with any SunSpec-compliant initiation device.



Rebekah Hren (3)

MidNite Solar offers its SOB system for RS compliance, an MLPE product for string inverters that includes a receiver (which is installed at each module or string) and a transmitter (installed in or adjacent to the inverter). The transmitter (MNSOB-TX) is available in 12 to 16 VDC or 90 to 305 VAC, so it can be powered from nearly any residential or commercial voltage source. The receivers are available in 600 or 1,000 VDC models. A “keep-alive” signal is sent to the receivers, which are mounted at the modules. Loss of AC or DC power to the transmitter opens each module’s or string’s connection. Using a single receiver on each module string complies with 2014 NEC requirements; and a receiver at each module is required to meet the 2017 NEC. For non-RS-listed inverters with input capacitors that keep DC circuits energized (above 30 V for longer than 30 seconds), a MidNite Solar MNBLEEDER bleed-down unit must be installed near the inverter to remove capacitor voltage.

MidNite Solar’s SOB system with Birdhouse initiator (center), receiver (left), and sending unit (right).



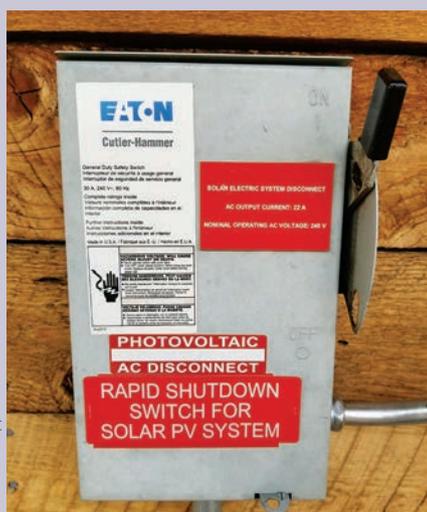
Initiating Rapid Shutdown

Regardless of what system topology and equipment provides control of the voltage of PV circuits, every system must include an RS switch (aka “initiation device” in the NEC). This switch, which can be the utility service disconnect, the PV system disconnect, or a switch that indicates “on/off,” must be at a readily accessible location outside the residence. The switch must be labeled “RAPID SHUTDOWN SWITCH FOR SOLAR PV SYSTEM” per NEC 690.56(C).

If the main circuit breaker and the PV backfed breaker(s) are located in an electrical panel inside a garage, the RS switch must be installed

on the garage’s exterior. This switch could be as simple as a 240 VAC disconnect switch (fused or unfused) on the inverter AC circuit, prior to the backfed breaker. The switch would be labeled as the RS switch and could also be labeled as the PV system disconnect. If the house’s main service panel and main breaker are located on the home’s exterior, the main breaker or the PV system backfed breaker could be used as the RS switch. Up to six RS switches are allowed per service. The initiation switch does not have to be NRTL-listed for providing RS functionality. However, the inverters or MLPEs must be listed for RS functionality.

RS can be initiated by one or more different devices in a system, including: a dedicated AC disconnect (left); an AC main breaker (center); or a PV backfed breaker. Only one should be labeled as the RS switch unless multiple switches must be activated.





Courtesy SolarEdge (2)



SolarEdge string inverter and optimizer systems are listed for RS. The RS initiation device can be the AC PV system disconnect or the main service disconnect.

Microinverter Systems

Microinverter systems including APsystems, Darfon, and Enphase are 2017 RS-compliant as long as the devices are mounted adjacent to the connected module and not outside of the array boundary. Loss of AC power in the system will lower AC output conductors to 0 V within milliseconds, while the microinverter's DC input will remain at the module's DC voltage potential. Various AC modules, such as those from LG Solar, Jinko, and SunPower, are similarly compliant, since AC modules integrate microinverter functionality.

It is important for installers to verify that the microinverter, AC module, or MLPE and inverter system has been listed as either RS equipment or as part of an RS system by a nationally recognized testing laboratory (NRTL) as part of the UL1741 testing of the device. The product should bear the marking: "PV Rapid Shutdown Equipment." For microinverters or DC-to-DC converters, several manufacturers make RS devices that connect to two modules. However, for modules greater than 40 VDC, each module must be connected directly to the device, meaning that the device has two positive and two negative inputs rather than a single set of inputs with the modules wired in series externally.



Rebekah Hren

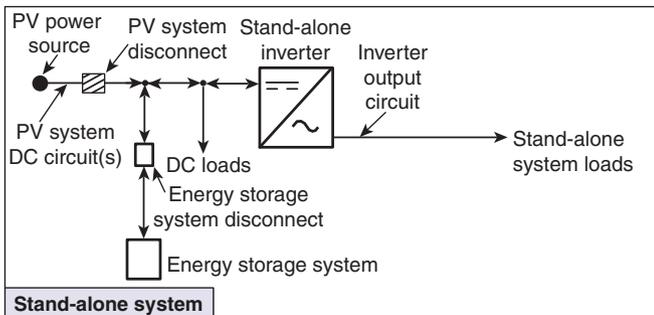
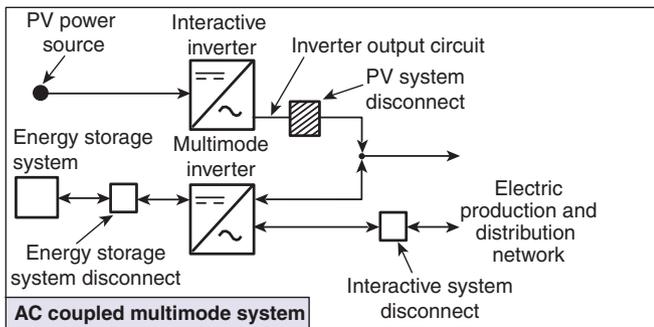
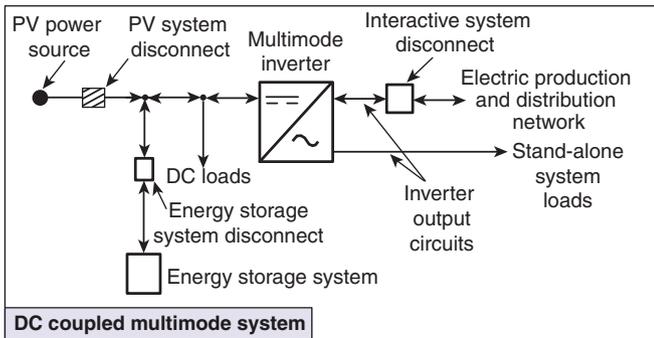
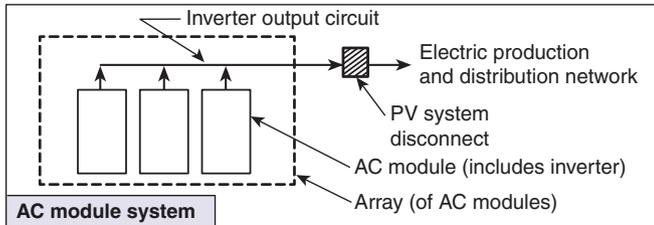
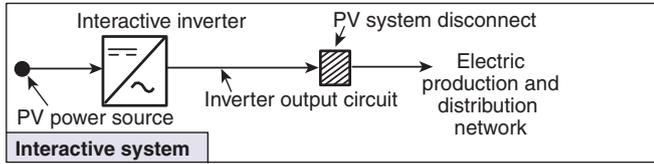
AC modules, such as this Jinko/Enphase combination, are a simple solution to comply with RS requirements. Any loss of AC power will cause a reduction in PV circuit voltage to below Code limits.

Battery-Based Grid-Tied PV Systems

2017 NEC Figure 690.1(B) clarifies which circuits are defined as part of the PV system, and thus which PV circuits are subject to RS requirements. Energy-storage systems, including battery circuits and multimode or stand-alone inverter input and output circuits, are not part of a PV system. AC-coupled battery-based PV systems will be able to rely on any of the equipment choices detailed above and can use the PV system disconnect or a separate initiator as the RS switch.

2017 NEC Figure 690.1(b)

Identification of PV System Components in Common Configurations



Notes:
 (1) These diagrams are intended to be a means of identification for PV system components, circuits, and connections.
 (2) The PV system disconnect in these diagrams separates the PV system from all other systems.
 (3) Not all disconnecting means required by Article 690, Part III are shown.
 (4) System grounding and equipment grounding are not shown. See Article 690, Part V.
 (5) Custom designs occur in each configuration, and some components are optional.



Magnum Energy, a manufacturer of battery-based inverters, supports an AC-coupled RS-compliant system using the Magnum-branded microinverter shown above.

MidNite Solar's transmitter and receiver solution is not yet compatible with charge controllers, but the company expects to add it soon for DC-coupled PV systems. OutBack Power's FLEXware ICS Plus is a listed RS system for DC-coupled and grid-direct systems, but it was designed to meet the 2014 NEC. Additional module-level functionality will be required for 2017 compliance. Magnum, a battery-based inverter manufacturer, offers Micro GT microinverters for installation in AC-coupled RS-compliant energy-storage systems.

Expect more RS solutions and listed equipment to appear on the market as January 1, 2019, nears and more jurisdictions adopt the 2017 NEC. Remember that NEC requirements are not enforced retroactively—any system permitted and installed before a jurisdiction adopts the 2017 NEC has to comply only with the Code edition that was used at the date of the permit. Thus, module-level shutdown will not be required for systems installed previous to adoption of the 2017 NEC. However, enforcement of 690.12(B)(2) is not delayed if the 2017 NEC is adopted after January 1, 2019.



web extras

SunSpec-compliant product list • bit.ly/SunSpecCerts

"PV System Rapid Shutdown" by Justine Sanchez in *HP175* • homepower.com/175.38

"Code Corner" by Ryan Mayfield in *HP178* • homepower.com/178.54

"Code Corner" by Brian Mehalic in *HP187* • homepower.com/187.48



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Rapid Shutdown

by Brian Mehalic

Section 690.12 of the *National Electrical Code (NEC)*, which was first introduced in 2014, governs rapid shutdown (RS) of PV systems on buildings. For the 2017 edition, this section has been expanded and clarified, including defining RS initiation devices. (See “New Rapid Shutdown Solutions” in this issue for more information on strategies and products to meet new RS requirements.)

Where RS Applies

Section 690.12 only applies to PV systems in or on buildings—ground- or pole-mounted systems are not subject to these requirements so long as none of the system circuits “touch” a building. An exception is when a building’s sole purpose is to house PV system equipment; then RS does not apply.

Wiring from the PV and within the PV array to the PV system disconnect is subject to 690.12—see the system schematics in Figure 690.1(b) for specific configurations on page 47 of this issue. This is an example of how clearly defining the location of the PV system disconnect adds clarity throughout Article 690. For instance, this shows that an energy-storage system in an AC-coupled multimode system is not part of the PV system, and thus not subject to RS.

Newly defined in the 2017 edition, the PV array boundary is described as 1 foot in *all* directions from the outer edges of the PV array. Section 690.12(B)(1) applies to PV system circuits *outside* of the array boundary, as well as to circuit conductors more than 3 feet from the point of entry into the building; 690.12(B)(2) covers circuits *inside* of the array boundary. While the RS voltage limit is higher inside the array boundary, the requirement to control PV system conductors inside the array boundary has in practice necessitated module-level RS, which has tremendous implications on system design and component selection.

RS is not a disconnect requirement—rather, it resides in Part II of Article 690, “Circuit Requirements.” As such, a variety of products—some of which may be disconnects—can be used and must be listed for the purpose per Section 690.12(D). However, this requirement for listing does not include disconnects, circuit breakers, or control switches that are used to initiate rapid shutdown.

Controlled Conductors

Outside of the array boundary, conductors must be limited to 30 volts within 30 seconds of RS initiation. This is not tremendously different than the 2014 *NEC* requirement, though the distance from the array to where the conductors

must be controlled has decreased due to the definition of the array boundary only being 1 foot.

Prior to the 2017 *NEC*, there was no requirement for controlling voltage inside the array boundary; now there is, and three options exist, though not all of them are practical or possible. (Note that this requirement does not go into effect until January 1, 2019, or immediately upon adoption of the 2017 *NEC*, if the jurisdiction adopts it after that date.)

To meet the RS requirement inside the array boundary (or for conductors inside the boundary and not more than 3 feet from the point of penetration into the building; for example, running parallel to the roof, inside the building, and underneath and within 1 foot of the array), the most common approach is to limit conductors to no more than 80 V within 30 seconds of RS initiation, as described in 690.12(B)(2)(2). In most cases, this voltage level equals “module-level” shutdown—the open-circuit voltage of two 60-cell PV modules in series will likely exceed 80 V at the expected low temperatures in many locations; two 72-cell modules definitely will. Module-level power electronics (MLPEs), such as DC-to-DC converters, microinverters, or additional module-level devices specifically designed for RS, will be used to meet this requirement.

Another option—690.12(B)(2)(3)—is an allowance for PV arrays without exposed wiring methods or conductive parts that are installed more than 8 feet from grounded parts or ground. Since shock hazards are minimized by the nature of the system design, these types of arrays do not have to comply with RS inside the array boundary. While some types of building-integrated PV systems may fall under this allowance, they must still meet the 690.12(B)(1) requirements that apply outside of the array boundary.

Some PV arrays may be listed or field-labeled as being an “RS” PV array, thus meeting the requirement as specified in 690.12(B)(2)(1). However, standards for RS PV arrays have not been completed, and by the time a standard is fully developed, it is likely that it will be written to meet 2020 *NEC* RS requirements in the form of UL3741, “Standard for Safety for Photovoltaic Hazard Control.”

Initiation Devices

Section 690.12(C) is new and provides three options for the RS initiation device or devices. Regardless of the type of device, its “off” position must equate to RS having been initiated. For one- and two-family dwellings, the device (or devices) must be outside the building and readily accessible.

continued on page 50

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continued from page 48

One option for an initiation device is the service-disconnecting means, which will meet requirements for most load-side-connected interactive PV systems without energy storage. Shutting off power to the building shuts off the inverter and also causes associated, listed RS equipment—such as a contactor combiner and/or MLPEs—to open or otherwise operate, meeting the requirements for controlling conductors inside and outside the array boundary. When possible, this is the preferred initiation device, since first responders will already be using the service disconnect to isolate the building from utility power and this single switch can perform both functions.

The PV system-disconnecting means can also be used as the RS initiation device; this is a typical configuration for supply-side-connected PV systems that do not have energy storage. Connected to the primary source of power between the utility meter and the main service disconnect, a supply-side-connected PV system will not be impacted by shutting off the main service disconnect. Disconnecting means and overcurrent protection are required to interconnect on the supply side, and this device—either a fused disconnect or a circuit breaker—can double as the RS initiator.

The third option for initiation devices is a readily accessible switch that clearly indicates “on” and “off” (with “off” equaling RS initiation). As described in the Informational Note to 690.12(C)(3), this strategy could be employed for multimode systems, since a loss of utility power—and the system switching from interactive to stand-alone mode—is an expected operating condition and a strategy for initiating RS based on a loss of grid power would not work. Note that the PV system disconnect could still be the initiation device for multimode systems, and either of these options—meaning the PV system disconnect or an accessible on/off switch—could also be used for stand-alone systems.

Section 690.12(C) allows for multiple switches—up to six—per service, so long as the switch(es) act as the initiation devices for *all* of the PV systems on that service that are required to have RS. (Having two separate PV systems—which could mean a total of 12 switches—would not be allowed on a single service.)

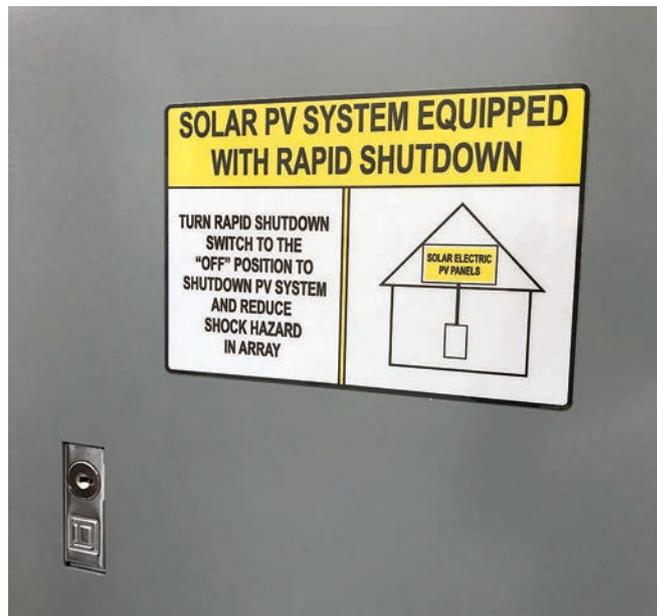
Labeling

Marking requirements for buildings with PV systems—which must have RS—and for the associated initiation device(s) are found in Section 690.56(C).

The initiation device, referred to as the “rapid shutdown switch” in 690.56(C)(3), must be labeled as such. As is the case with other labels primarily intended for first responders, there are specific requirements: all capital letters, white letters on red, and with a minimum letter height of $\frac{3}{8}$ inches. The label must either be on the switch or no more than 3 feet from it.

After January 1, 2019, there will only be one other label required for RS; until then, there are two, which distinguish between systems that have RS only outside the array boundary [see Figure 690.56(C)(1)(b)] and those that meet the 690.12(B)

RAPID SHUTDOWN SWITCH FOR SOLAR PV SYSTEM



Courtesy: Heilmann/Tyson (2)

Top: The required label at the RS switch. Bottom: This label must be located no more than 3 feet from the service-disconnecting means. These labels comply with NEC Section 690.56(C)(1) requirements for PV systems with rapid shutdown both inside and outside the array boundary. In jurisdictions that have adopted the 2017 NEC, this will be the only type of RS allowed after January 1, 2019.

(2) requirement for inside the boundary [Figure 690.56(C)(1)(a)]. Because of the enhanced safety offered by controlling conductors both inside and outside of the array boundary, the label indicating “module-level” RS has a requirement for black text on a yellow background. The increased hazard associated with RS only outside the array boundary is indicated by the requirement for white lettering on a red background, as well as different wording indicating that “conductors within the array remain energized in sunlight.” As with the label for the RS switch, font sizes are specified for both labels.

Finally, because there could be a case where there are two systems on a building with different RS requirements—for example, if a system is installed in 2019 on a building that has an existing system from 2014 or a pre-2014 system where no RS was required, 690.56(C)(2) provides details on labeling, including a requirement to delineate which arrays will remain energized inside the array boundary.



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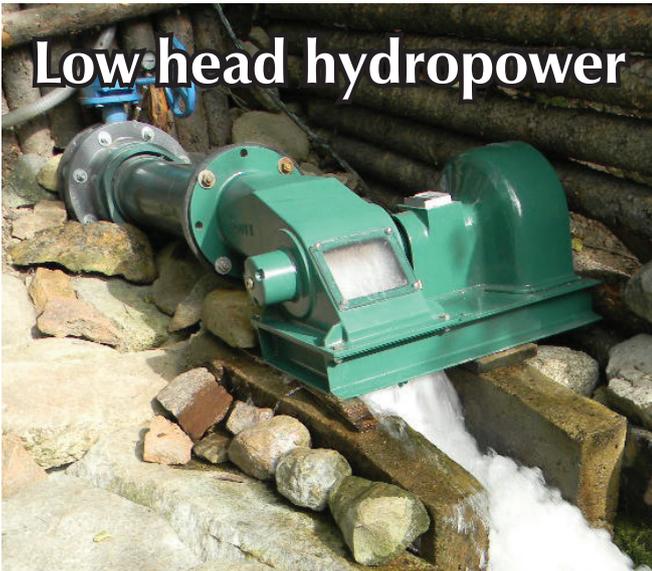
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Those Who Want More

by Kathleen Jarschke-Schultze

As my husband Bob-O has often stated, “There are two kinds of people who want solar energy—those that haven’t done it yet and those who want more.” The two of us fall into the latter category.

This spring, we upped the ante on our house’s solar input. Just as we were shutting down the microhydro system due to low creek flow, Bob-O finished our latest solar addition—a stout fixed-mount array on our windy hillside. This array adds 1,620 watts (a 56% increase) to our house’s PV system. We have six PV arrays—some tracking and some fixed—for house power and water pumping. Our PV capacity is 4,500 W.

Getting Drier

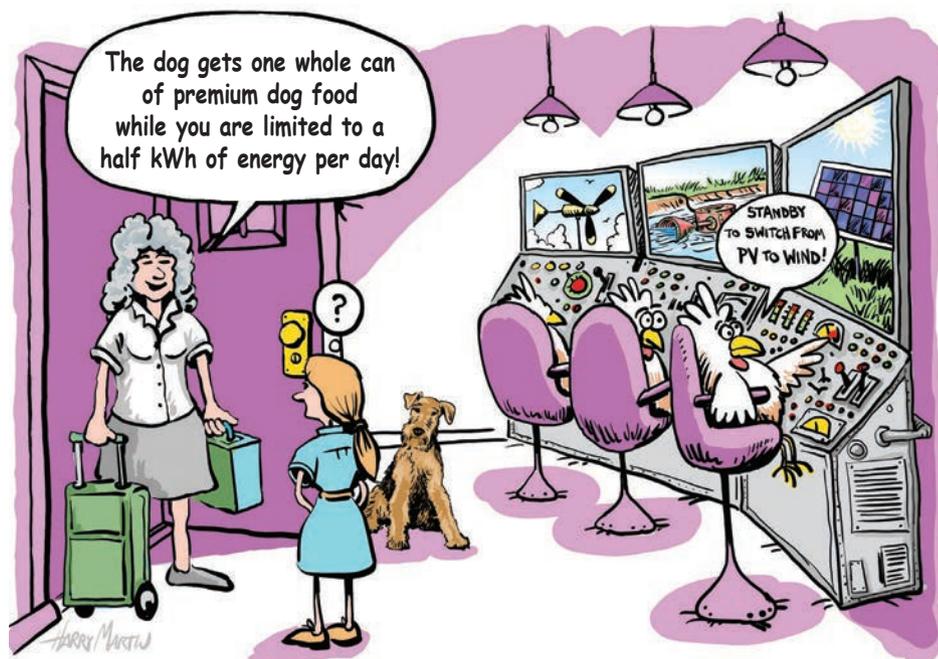
This past winter was the shortest, driest one we could remember. Whereas during the previous winter, the creek rose high enough to take out our small hydro-electric turbine, this past winter’s water level never reached our turbine, which we had relocated farther downstream and higher up on the granite bank.

Because of the drought conditions, I told Bob-O we should curtail some of our gardening this year. Having received only 57% of our normal rainfall, we would risk losing much of what we planted. He agreed with me. Despite this, we planted the lower garden, the upper garden, the main garden, and put three new raised beds in the front yard. I am not sure how this happened. Maybe gardening is like solar energy and we just want more.

Our cisterns store 5,700 gallons of automatically solar-pumped water from one well. This is used for gardening and fire protection—and it’s definitely not a good idea to deplete these tanks. Another solar-pumping system serves our other well and pumps to cisterns that can store 2,700 gallons of water for house use and, of course, additional fire protection.

More Renewable Diversity

At our homestead, we harvest three renewable resources—water, wind, and sun—to power our off-grid lifestyle. Our available resources change with the seasons and partly because of our land’s topography. We live in a small canyon



with a mountain at the upper north end and a human-made reservoir at the bottom. Spring through fall, cold mountain air moving down toward the warm lake gives sustained daily wind to our 1,000 W Whisper wind turbine. A seasonal creek runs through our property, and we capture the energy from its flow with a microhydro turbine, which runs late fall through early spring and, if we are lucky, into summer. The PV arrays round out our energy mix. Early on, we put some of our PV arrays on tracking mounts in an effort to capture every bit of sunlight we could. However, with the cost of PV panels less and the cost of tracking arrays still expensive, our most current array is on a fixed mount.

The shorter days and overcast skies during autumn affect both our wind and PV systems, decreasing output. By then the creek also has dried up, so we have no hydro input. In the winter, the sun disappears behind the western mountains at about 3 p.m., severely impacting solar production.

Annual Challenge

Our first PV array was made up of four Kyocera 45 W modules—that’s it. We were more frugal with our energy back then. Our cumulative PV array capacity is 25 times more than we had originally, but we still return to our old watt-saving habits in the autumn and winter. When our RE resources dwindle, I wash dishes by hand instead of using my dishwasher. If the weather allows, I dry clothes on the

clothesline. We also use the “one person, one light” rule. If you are in a room, only that light is on. When you leave that room, you turn off that light. We have all-LED lights now, so that maneuver only saves us a few Wh, but during our conservation season, every Wh saved adds up. We also do our best to eliminate phantom loads—putting small appliances on plug strips and switching the plug strips off to ensure the appliances are not drawing any electricity. We use the most efficient household appliances we can afford.

We have a backup engine generator to recharge our batteries when RE input isn't enough. However, we consider it a personal challenge to see if we can get through the meager RE input season without running the genny. The weather plays a big part in our annual success or failure. Even with all of our conservation efforts, we do have to run the genny sometimes. For the past 11 years, I have kept records of the generator's yearly gasoline consumption, which has ranged from about 7 gallons (in 2010) to less than 1 gallon (in 2007, 2011, 2013, 2016, and 2017).

Preventive Power

Before the creek dries up and we leave for our annual commitment to provide and set up PV systems at the Oregon Country Fair, we turn off our microhydro system. While we are gone for these nine days, we leave our house, dog, and numerous gardens in the hands of caretakers.

Some of our housesitters grok living on renewables; some don't have any experience with intensive energy-conservation methods. But it's best that any of our caretakers don't have to deal with our microhydro system or shutting it down. We hoped the additional electricity from the new array would make up for any deficiency of conservation practices from our off-grid newbie caretakers.

Bob-O has a standard instructional lecture on how to read the amp-hour meter, which is mounted on our living room wall. He likens the battery state of charge (SOC) to a bank account. When your account has lots of money in it (batteries are at 100%), you can write a lot of checks on that account (use some energy). When money (energy) gets low, you write fewer checks and are more frugal with it. And, until you deposit more money in your account (the sun shines on the PV array, transferring electricity to the battery bank as measured by the amp-hour meter), you cannot write as many checks.

There are so many ways that people used to living on the power grid unwittingly waste power. It is always a little nerve-racking to leave our home in the hands of the uninitiated. We like to think that at the end of their nine-day off-grid stint, they'll carry this new knowledge into their grid-connected lives. Maybe it will turn them into people who want solar—and then more solar!



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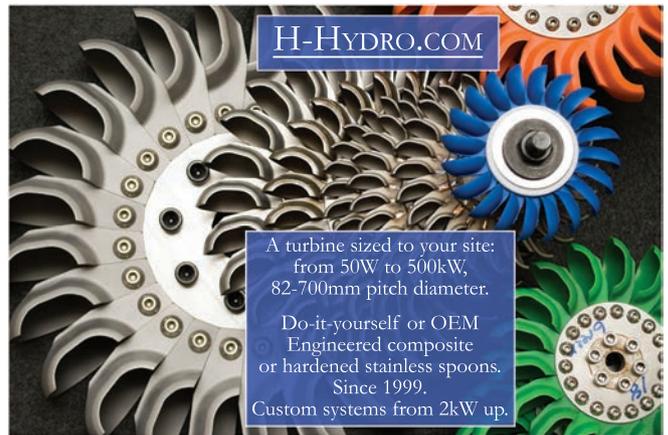
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Clean Energy Credit Union

I recall the circumstances during the construction of the Dakota Access Pipeline and the protests that took place at the Standing Rock Sioux Reservation in 2016. In pondering what I could do to voice my opposition to that pipeline, I examined the individual banks funding it and found out that our bank was one of them. We were unwittingly funding big oil and gas development (and its infrastructure) with our hard-earned savings! So my family moved all of our savings and checking accounts to the best option we had—a local credit union that keeps that money working for us within our community.

Now, there's a new option. The Clean Energy Credit Union (CECU) recently received its federal charter and officially launched this summer. CECU is focused solely on funding loans used for energy-efficiency and clean-energy

products and services, including PV systems, electric vehicles, home energy-efficiency retrofits, and net-zero-energy homes.

CECU takes sustainability and political ideals even further with their mission—"envisioning a world where everyone can participate in the clean energy movement"—with the goals of:

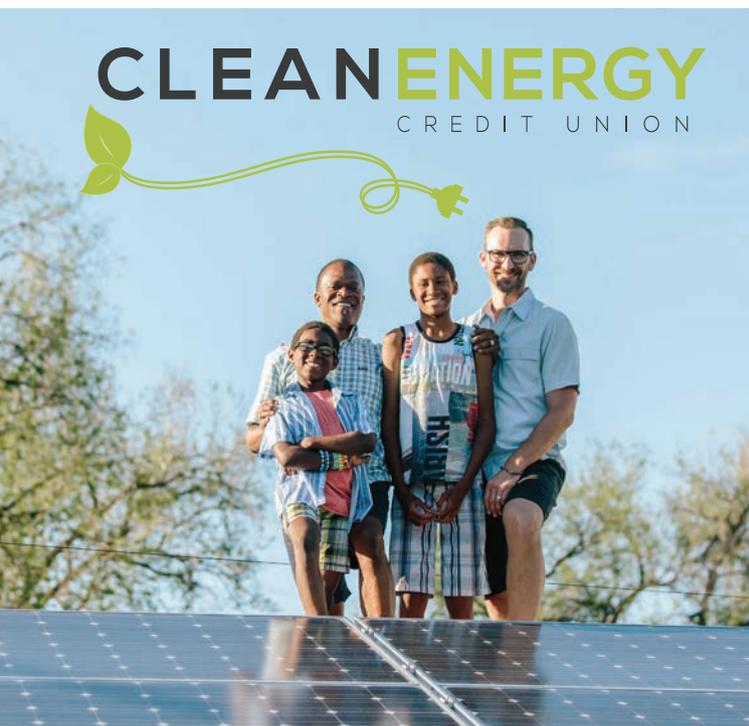
- Mitigating climate change
- Reducing pollution and improving public health
- Creating jobs and building community wealth
- Promoting democratic organizations
- Improving national security through increasing energy independence
- Promoting personal financial independence.

CECU provides two ways to participate:

- **Loans with competitive terms.** With no physical branches (it is an online-only financial institution), savings on overhead costs can be passed on to members as better loan terms.
- **Clean-energy investment opportunities** that are federally insured, and require a very low minimum buy-in.

In a conventional bank savings account, your money is used in a wide variety of investments by the bank—many of which you may not support—with the primary purpose of increasing the bank shareholders' profits. With the CECU, individual savings are pooled and then used to make competitive loans for clean-energy purchases and projects. In turn, if you are looking for a loan for a clean-energy project, the CECU may have the rates and terms you are looking for.

—Justine Sanchez



Courtesy: CECU

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