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Past Thanks, Future Pioneering

Courtesy Louis Woofenden

Dogged determination and altruistic business practices are primarily responsible for the renewable energy revolution that we are now enjoying. Renewable energy business owners of the '70s, '80s, and '90s paved the way—and continue their efforts—for the amazing solar presence that we have today.

Data for the United States shows about 15,000 annual solar installations, more than 260,000 workers in the industry, and 47.1 gigawatts (GW—a billion watts) of installed PV capacity as of the second quarter of 2017. That's amazing growth, all begun by a few eager believers.

Solar Pioneer Parties (SPPs) have celebrated this sentiment, as reported in some of Kathleen's recent "Home and Heart" columns, and as shown by *Solar Roots: The Pioneers of PV*, an upcoming documentary that is nearing completion. The attendees of the first solar pioneer party were a "who's who" of the early PV industry. The next two SPPs saw industry newcomers in addition to the pioneers—new PV folks understood that they could benefit from the old guard (and how exceptional they are). There are maybe 200 industry pioneers—including our own Richard and Karen Perez—who put their futures on the line for something that they believed in strongly. It certainly wasn't about getting rich (though it seems that a handful of them did)—it was more about doing the right thing for people and the planet.

But it wasn't just running businesses that increased solar's status within our energy world. Many solar pioneers spent hundreds and even thousands of hours lobbying in state capitols (primarily California) and in Washington, DC, to push forward the industry that they and others kickstarted. Many pioneers found themselves helping out in "developing" nations, spreading the renewable energy spore to those who, arguably, needed it even more than those in industrialized countries.

The pioneering spirit of the '70s and '80s found its way to Japan and several European nations, which quickly became international leaders in the newly developing world of grid-tied solar. In the United States, we became enthusiastic champions of that blossoming technology, with our pioneers working hard, and mostly succeeding, to increase regulatory support—and even new equipment—for grid-tied solar. And now, as evidenced by this issue's article on newly emerging inverters, our pioneers have paved the way toward smarter solar systems, complete with a new generation of batteries.

We continue to benefit from the successes of our pioneers, and we owe them many thanks. But most of all, we need the next generation to keep pioneering the future of renewables forward, one module at a time, one system at a time, one energy-efficiency upgrade at a time.

—Michael Welch, for the *Home Power* crew

Think About It...

"I am not afraid to be a pioneer. When a door is ajar, you need to open it fully. And once you are in that room, you need to see what other doors there might be and where they might lead."

—Gurinder Chadha, film director

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This home in a historic neighborhood in Lawrence, Kansas, draws on the local farmhouse vernacular, but brings it into the 21st century.

Photo Studio 804

Photos courtesy: Studio 804, SolarEdge

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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. She has completed training to serve as an Ambassador Presenter for the Living Building Challenge.

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

Michael Welch, a *Home Power* senior editor, is a renewable energy devotee who celebrated his 27th year of involvement with the magazine in 2017. 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.

Phil Hofmeyer lives with his family in a net-zero-energy home powered by a PV system and a solar hot water/wood gasification combisystem. He teaches courses in PV, small wind, and microhydro-electricity at Morrisville State College while doing energy consulting and installations on the side.

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.

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

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

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

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Courtesy Discover Battery

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—Justine Sanchez

Courtesy Magnum Energy

Magnum Energy

MagWeb GT Monitoring Kit

Magnum Energy's (sensatapower.com) MagWeb GT product offers integrated monitoring for a PV-plus-storage system in one dashboard. The monitor is designed to work with Magnum's MicroGT microinverter system, which is AC-coupled to an MS-PAE inverter/charger with a battery bank. The MagWeb GT collects module and microinverter data and inverter/charger status, along with battery state-of-charge from the ME-BMK battery monitoring kit. The MagWeb uses PLC communications and is plugged into a dedicated 120 VAC outlet and connected to a cabled or wireless router.

—Justine Sanchez

Pleased with EVs

I enjoyed the recent update on electric cars and thought I would reinforce the message. I have an Kia Soul EV, and it is the best car I have ever owned! I'm driving about 600 miles a month, and just plug it into an outlet in my garage every couple of days—with virtually no maintenance. It seems to cost about $1 of electricity per 100 miles of driving. My PV system comes online soon and becoming more self-contained and reducing my use of petroleum pleases me to no end.

Mac Zirges • Newport, Oregon

Courtesy Mac Zirges

Minisplit Maintenance

Home Power has been running articles on minisplit heat pumps (MSHPs) for the last few issues. When plugged into a central power station, the actual thermal efficiency is 95%—comparable to a condensing gas furnace.

We use minisplits for well-insulated small houses and apartments. We've installed about a dozen over about as many years and I also live with one. But as Vaughn Woodruff's article "Pairing Grid-Tied Power with a Minisplit Heat Pump" in *HP182* shows, the great potential for solar-coupling with MSHPs side-steps most, if not all, fossil fuels.

Many of the products we buy for efficiency are rated "out of the box." However, these efficiencies change with use. For example, an EV battery loses capacity with miles; the efficiency of an MSHP drops as lint builds up in the unit, internally blocking airflow. The air filters need to be washed periodically, but less understood is how lint can also build up inside the cylindrical fan. The indoor units placed high on the wall are pretty much built the same regardless of the manufacturer. Behind the fin tubes and electronics sits the fan. Earlier models had a problem with DC arcing from the motor to the shaft, pitting the ball bearings, so the fan had to be replaced with a motor with better grounding. I've pulled apart a few of these. It is a real pain—you have to disassemble the housing and louvers, and disconnect the electronics and condensate connections.

Some manufacturers, Fujitsu for one, offer a "floor-mounted" indoor unit. It still attaches to the wall but is closer to the floor. I installed one, and being able to reach the fans for cleaning by removing only a dozen fairly intuitively placed screws and avoiding having to disassemble all the unit's workings was a pleasant surprise. This unit costs about $100 more than the high-wall-mount unit, but I found that it's worth the small difference in upfront cost. I remain a devoted reader and hope this tip helps. Thanks for the good work.

Bill Dorsett • Manhattan, Kansas


Courtesy Fujitsu

As you have mentioned, indoor units have filters that are somewhat analogous to the lint screens in a clothes dryer. The fine screen catches larger particles to keep various contaminants—dust, pet hair, smoke particulates, etc.—from reaching the fan and the heat exchanger. Much like a clothes dryer, when this screen fills up, it reduces airflow and the unit's efficiency. It is important to keep these screens clean by washing or vacuuming them periodically. The frequency will depend upon indoor air quality.

However, these screens don't catch everything and, over time, the fan and heat exchanger may become coated with dust, smoke residue, or even mold. Since heat pumps cycle the home's air, they tend to accumulate contaminants from the house that you might otherwise breathe. If mold is present or the unit needs to be deep-cleaned, there are several methods that can be used. HVAC suppliers have mold inhibitors that can be sprayed into the unit. There are also degreasers available that can be sprayed on the fan and coil without disassembling the unit. HVAC professionals also have access to low-pressure washers made specifically for deep-cleaning these units. SpeedClean's Mini-Split Bib Kit ($90) goes around the indoor unit, keeping walls protected while the indoor unit is pressure-washed. It's designed to channel rinse water to a 5-gallon bucket (included with kit).

Vaughan Woodruff • Insource Renewables

write to:

mailbox@homepower.com

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

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Clogged Solar Water Heating Collector?

My technician inspected an antifreeze-based solar water heating system about nine months ago in which the heat-transfer fluid (HTF) wasn't circulating. He measured the temperature at the collector, which was 180°F. The pump and control were located in a pump station and appeared to be OK. The pressure gauge indicated 10 psi, indicating a loss of some fluid. When he tried to pump HTF through the collector with his charge pump there was no circulation. This pump can develop 50 psi of pressure, which has always been sufficient to blow all the air out of the system, so I doubt that it is the problem. Can the antifreeze in a system get "cooked," clogging the collectors' piping?

Phil Parkinson • Austin, Texas

I have never seen a glycol solution (even with a decade or so of no flow through a collector) become so viscous that it stops flowing altogether. I have seen solutions that are dark brown, or black and gunky with a viscosity similar to old engine oil and with an accompanying burnt smell, but the solution still flowed enough to drain—though it's a nasty job changing fluid like that!

I know you have confidence in your technician, but we can all make mistakes. I had a really great service guy (who had more than a dozen years of experience) once put in a pump backward on a large system. It took awhile to figure that one out since I thought he was too good a hand to do something like that.

My first suspicion would be that the charge and return hoses were connected to the wrong fittings in the pump station. I have done this myself a few times in my career. The result is no flow, since, no matter how large the pump, it is pumping against a check valve.

I would suggest checking the system again. First, ensure that the charge and return lines are correctly connected—only then should a technician try to flow the HTF solution through the collector. If there is no flow, they should check the valves—in particular gate or check valves—for being closed or not functioning. I've seen gate valves with the stem broken, and check valves stuck open or closed depending on whether it is a spring or swing type. Although it is a rarity, a check valve could be stuck closed by a really gunky antifreeze solution, but a large charge pump should open it.

The oddest clog I ever encountered was a silicone plug in a header pipe. It was left in at the factory, but not visible on installation. If you've exhausted all the other possibilities, look for this. Over many years, the plug had worked down the one-inch header tube on the collector to block the outlet or return connection.

It's tough to troubleshoot a problem like this remotely, and all of these no-flow conditions can be tough to diagnose if you've eliminated the pump as the cause. Good luck!

Chuck Marken • *Home Power* solar thermal editor

Replacing 30-Year-Old Batteries

I have a 360-square-foot cabin with a 12-volt off-grid PV system and a Trace 612 inverter. There are three balcony-mounted 40 W Kyocera PV modules charging the system. The 30-year-old reconditioned nickel-cadmium batteries are pretty well shot at this point, and I am considering a new set of Iron Edison industrial nickel-iron to replace them.

If I have either 100 or 200 amp-hours with the new batteries, would you recommend replacing the charge controller? If so, which one would work best in this small, simple system? Should I replace the PV modules, too? I'd like to know what other considerations (and costs) there might be with new batteries. Thanks very much. I have been loving *Home Power* all this time!

Mary Jensen • Twisp, Washington

First, congrats on keeping your system working for 30 years! The simplest thing would be to replace just the batteries with new nickel-iron batteries—you can expect another 30+ years from them. If the old inverter is meeting your needs, and the old panels and old charge controller were still working with the old batteries, there is no reason that they shouldn't work with the nickel-iron batteries. While the manufacturer recommends a bit higher charge voltage for the nickel-iron batteries (16.5 V), which your old controller may not do and your inverter may not like, the batteries can be used at lower voltages, just with a little lower capacity.

The Trace U-series inverter was a very good inverter in its day. However, in the last 15 years, sine wave inverters have become the norm. Switching to a modern sine-wave inverter gives you the possibility of serving more AC loads.

If you're running more loads, you may also need more solar-charging capacity—especially if the cabin is in full-time use. When those 40 W Kyocera modules were new, having only 120 W of charging on a 200 Ah battery bank was pretty normal. However, it also meant that recharging took longer after a cloudy period. In some cases, it could take a full week of sunny days to recharge the battery bank.

With reduced PV module prices (a 270 W to 300 W module is about $200), it is now affordable to put in much larger arrays. Doing so in your location will allow for significant charging—even on cloudy winter days. With a 12 V, 200 Ah battery bank, 600 W of solar-charging capacity could charge as well on a mostly cloudy day as the old 120 W array did on a fully sunny day. This can be a big improvement in the winter. In the summer, surplus energy could be used for water pumping or running a small fridge.

If you upgrade the PV array, you'll also need to upgrade the charge controller. Most new module voltages aren't compatible with 12 V battery banks, so you'll need an MPPT controller that can step down the modules' voltage to battery voltage. Blue Sky Energy, MidNite Solar, and Morningstar all make small MPPT controllers that would be appropriate for your system. Ones with digital displays will help you monitor the system more easily.

Some of the charge controllers (such as MidNite's) can be intentionally overloaded; for example, you could use a 30 A controller on a 600 W array, which could potentially generate 50 A to the battery under certain conditions. This would be well-suited for cloudy conditions and limited under full-sun conditions. Not all controllers can current-limit to keep from overloading themselves, so verify before choosing this design path.

While you don't necessarily need to swap out balance-of-system equipment or upgrade your modules when you replace your batteries, equipment advances may lend to a more adaptable setup.

Zeke Yewdall • Ward, Colorado

PV Breaker Problem

In July 2017, I had a rooftop grid-tied PV system installed. It consists of 32 SolarWorld 290 W black modules connected to one SolarEdge SE7600A-US inverter. I also had my breaker box updated to a 200 A service box. Since it went live, the backfed 40 A breaker has tripped maybe six times. It seems to trip when the array is at or near its peak daily output. I have not tried anything other than resetting the breaker. What's happening and how can I fix it?

Steven Hambacher • via email

I'm sorry to hear you are having problems with nuisance tripping of that breaker, which is correctly sized for that inverter—at 240 VAC, it has a maximum output of 32 A at 7,600 W. Including the 125% safety factor required by the *National Electrical Code*, it's sufficient (32 A ×1.25 = 40 A).

Is the breaker tripping when ambient temperatures are high? Is your breaker panel installed in a location that's exposed to heat? Breakers can be affected by the ambient temperature, and high temperatures may cause them to trip at lower current.

Another possibility is that the breaker is faulty and needs replacing. There may also be a poor connection along that circuit or a slightly damaged conductor, which can cause an intermittent short-circuit. Call your system installer about the situation. They should be able to troubleshoot this for you. If you figure it out, let us know!

Justine Sanchez • *Home Power* senior technical editor

The breaker trips on hot and cool days, and when it trips—during peak production time—the sun is overhead and the breaker panel is located on the north side of the house, so high temperature or heat exposure is not likely the issue.

I replaced the 40 A breaker myself so I could eliminate that as a cause. The black-wire contact from the inverter had a stuck screw and may have been loose. I could back out the red wire screw easily, but I could only get half a turn on the black screw. It may have never been seated tightly. The new breaker is in place and both contact screws are seated, and the problem appears cured.

Steven Hambacher • via email

write to:

asktheexperts@homepower.com

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Net-Zero in the Heartland

Students enrolled in Studio 804—a graduate-level architecture design course—build net-zero-energy homes from the ground up.

by Juliet Grable, with Dan Rockhill

Three new houses stand out in the older, tree-lined neighborhoods of Lawrence, Kansas—and not just because of their decidedly modern style. These high-performance, PV-powered homes were designed and built by students enrolled in Studio 804, a practicum for aspiring building professionals in their final year of the Masters in Architecture program at the University of Kansas.

Dan Rockhill, professor and owner of the design-build firm Rockhill and Associates, started Studio 804 in the 1980s after recruiting students to help him finish restoring an old schoolhouse. "I was stunned by their enthusiasm," he says, recalling how students would park their cars strategically outside the building so they could work at night by the headlights' illumination. "These students were hungry for that kind of hands-on experience."

After a second similar project, he petitioned the university to implement a formal program into the curriculum, giving rise to Studio 804. Since the schoolhouse restoration, Studio 804 classes have completed 22 projects, 10 of them Leadership in Energy and Environmental Design (LEED) Platinum-certified, and three Passive House-certified.

The projects have ranged from modular and site-built homes to research centers and campus facilities. But, says Rockhill, homes are ideal because of their smaller size, and because they give opportunities to design features that aren't always included in commercial projects.

Net-Zero for Empty Nesters

Common between the three most recent projects is that they target a specific demographic: downsizing empty nesters with enough equity to afford the homes, which sell for between $250,000 and $350,000. The Studio 804 homes occupy well-established neighborhoods characterized by large, mature trees and small, older homes. They're within easy walking distance to grocery stores and other amenities in Lawrence's thriving downtown, which gives them extra cachet toward the goal of greater sustainability.

The Studio 804 homes range from 1,300 to 2,000 square feet. They include built-in flexibility, with spaces that can function as bedrooms, dining rooms, or offices as needed, and ADA-compliant bathrooms. The homes must sell at enough of a profit to fund the following school year's project, including the acquisition of land and the costs of construction. Studio 804 receives no university funding, though the program does accept donations—such as the discounted bamboo flooring featured in the 1301 New York Street project and donated microinverters for the home's PV system.

In a mixed-humid climate zone, the Lawrence area experiences cold winters and muggy, hot summers. While each project is different aesthetically, all share strategies to ensure superior energy performance in a tough climate. The homes' high energy performance translates into low utility bills—a plus for retirees on fixed incomes. For example, the average monthly bill for the New York Street house is $17.58 per month, which includes the $14 flat-rate base charge.

Promoting Sustainability

Rockhill salvages a lot of materials himself and encourages students to research and acquire salvaged materials. This stretches the budget and demonstrates responsible resource use. "We live in a throwaway culture. I've come back to the job Dumpster and pulled out two-by-fours," says Rockhill. "When students see that you can repurpose materials, it opens their eyes. I think [the salvaged materials] also add to the uniqueness of projects." For example, the red cedar siding that defines the Pennsylvania Street project was salvaged from old railroad bridge trestles.

A 70,000-square-foot warehouse serves as storage for materials that might be used later. "I end up with a lot of commercial materials," explains Rockhill, who says he likes to bring a commercial architecture aesthetic—flat roofs and the use of metal, for example—to the residential sector.

All images courtesy Studio 804

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Studio 804 students design and build a project from start to finish in the course of a single school year. The goal is to have the project's roof in by the winter holiday. They work six days a week, and usually during most of their winter and spring breaks. They perform every aspect of construction, from foundation to finishing. The plumbing, electrical, and HVAC contractors supervise the students, who pull wire and install appliances. Not only do students struggle with the physically demanding labor and long workdays, they face real-world design constraints and the limitations of schedule and budget while attempting to meet the rigorous design criteria and net-zero goals.

Studio 804 designs emphasize using simple materials, and renewable and durable products, such as the Alaskan yellow cedar and standing-seam metal roof featured in this Passive House.

A vaulted ceiling and inset porch give this home's simple rectangular footprint more visual appeal.

1301 New York

The 2015 Studio 804 class built the LEED Platinum- and Passive House-certified home at 1301 New York Street, the first of three net-zero energy homes. The exterior is distinguished by a single gable and long south-facing façade. The students chose simple exterior finishes, such as a standing-seam metal roof and Alaskan yellow cedar shingles for the siding.

"Throughout the design process, [besides the LEED and PH initiatives] we were also targeting aging-in-place goals," says Pia Westen, part of the design cohort. "Low-maintenance materials were a big part of that."

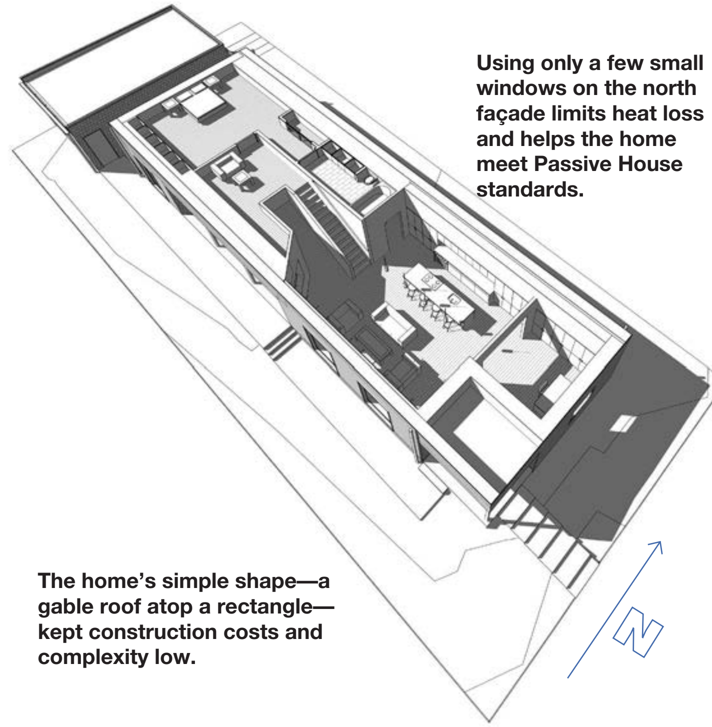
The long, thin envelope is on an east-west axis for good solar access. Openings on the north side are minimal, while the south side includes porches with deep overhangs, which limit the amount of summer sun that can enter.

The home features double-wall construction, with 2-by-4 walls on the interior and 2-by-6 walls on the exterior. The 12-inch cavities are filled with blown-in cellulose. Three inches of foil-faced polyisocyanurate rigid foam on the exterior adds insulation and reduces thermal bridging. With the exception of the roof, the entire building was sprayed with Prosoco R-Guard air and water barrier. Insulation values are three times that required by local code. Triple-pane windows from German manufacturer Intus also help minimize unwanted heat transfer through the envelope.

The all-electric house uses a Samsung minisplit system for heating and cooling, which consists of one outdoor condenser connected to multiple indoor heads. An energy recovery ventilator (ERV) supplies the tight house with a constant

Bamboo flooring and LED lighting work with the modern environmental aesthetic.

A 6 kW PV array comprised of 20 Renogy 300 W PV modules enables this home to produce more energy than it consumes.



Using only a few small windows on the north façade limits heat loss and helps the home meet Passive House standards.

The home's simple shape—a gable roof atop a rectangle—kept construction costs and complexity low.

Tech Specs

Location: 1301 New York Street

Interior: 2,000 sq. ft. (3 bedrooms; 2.5 baths)

Construction method & materials: Double-stud construction

Insulation & Airtightness Details

Conditioned crawl space/foundation: R-58

Wall: R-67

Roof: R-71

Airtightness: 0.28 ACH50

Passive Solar Attributes

Windows: Triple-glazed Intus windows; U-factor: 0.16; SHGC: 0.49

Appliances

Heating/cooling: Air-source heat pump, 30.5 SEER

Water heating: Heat-pump, 2.90 EF

PV array: Batteryless, grid-tied, 6 kW; 20 Renogy RNG-300P 300 W polycrystalline modules

Annual PV production: 8,160 kWh

Lighting: LED lighting

Ventilation: ERV, 150 cfm, 134 W

stream of fresh, conditioned air, ensuring good indoor air quality.

A 6 kW batteryless grid-tied PV system meets the homeowner's yearly electricity needs. The homeowner, Marc Epard, has been tracking the home's performance. Utility bills have averaged just $17 per month. From July 2016 to July 2017, the home produced a surplus of 2,273 kWh.

All of Studio 804's homes built in this mixed-humid climate include tight, superinsulated envelopes.

In addition to designing the home, Studio 804 students perform all aspects of construction—from foundation to finishing.

1330 Brook

Located in an established urban neighborhood, the house at 1330 Brook Street is convenient to the vibrant cultural district of downtown Lawrence and to public transportation and bike trails. It is less than a block from the East Lawrence Recreation Center, which offers a wide variety of services, and sits across from Brook Creek Park and its open green spaces, playgrounds, and mature trees.

The design uses some passive strategies to minimize energy consumption. Five-foot overhangs and steel-tube screens on the south and west elevations mitigate the direct summer solar gain, while still allowing filtered light to enter, reducing or eliminating the need for artificial daylighting. In the winter, when the sun is lower in the sky, direct sunlight can enter the house's floor-to-ceiling glass on the south and southwest faces, where it's absorbed by the polished concrete floors. The bedrooms, kitchen, and living room are arranged along the south wall, where they can be directly heated by passive solar gain.

To maximize use of every square foot—and in addition to an outdoor room that "notches" into the interior living room space—the plan includes a "flex space" that can be partitioned off with a curtain system to function as a study, dining room, or even a guest room.

Floor-to-ceiling glass blurs the lines between the living room and protected outdoor space.

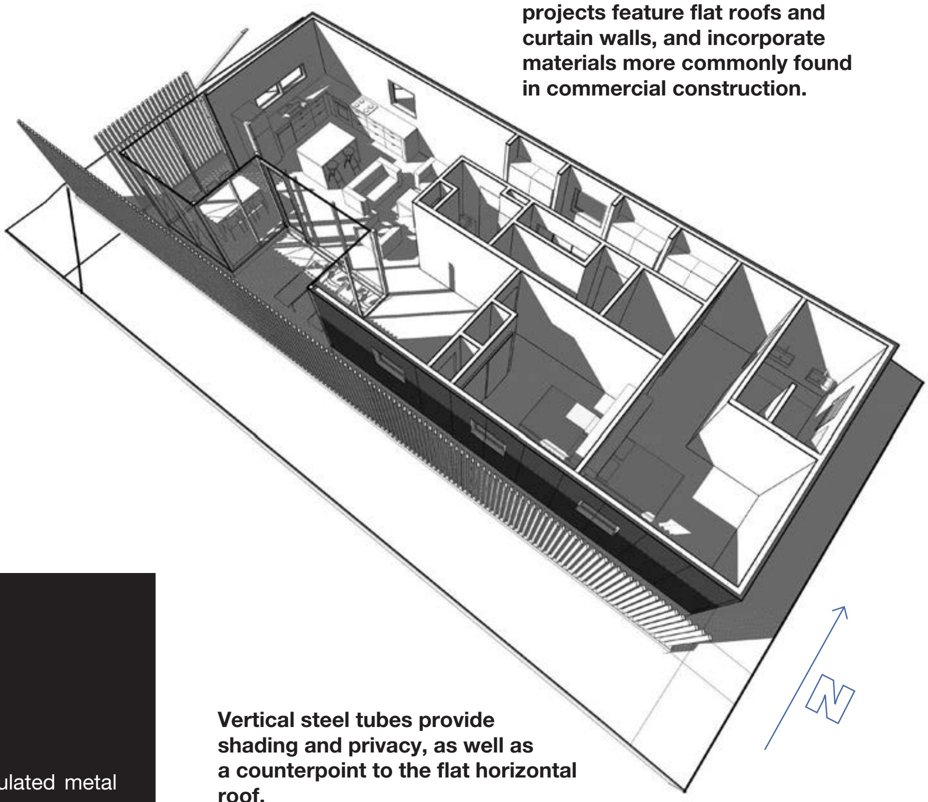
Constructed with repurposed insulated metal panels and floor-to-ceiling glass, this modern-style house is tucked into an older established neighborhood.

Insulation includes both rigid foam board at the foundation wall and blown-in cellulose; insulation levels exceed the LEED standards. The home was constructed of salvaged insulated metal panels (IMPs) previously intended for a tennis club. Typically used in warehouses, IMPs consist of two metal faces sandwiching a 3-inch-thick core of polyiso insulating foam. The panels had suffered some cosmetic damage, but were repairable.

The north wall is insulated to R-37 by virtue of its IMP skin and an interior 2-by-4 wall insulated with blown-in cellulose. It has only minimal openings needed for cross-ventilation and daylighting. It acts as a shield against the cold north winds to which the site is exposed.

Sixteen 300 W PV modules mounted on the roof generate enough electricity to operate the house at net-zero energy use over the year. The Italian-made Bertazzoni kitchen appliances are Energy Star-qualified. The light fixtures are fitted with LEDs.

A 4.8 kW ballasted PV array comprised of 16 modules offsets utility electricity use.



Some of Studio 804's residential projects feature flat roofs and curtain walls, and incorporate materials more commonly found in commercial construction.

Vertical steel tubes provide shading and privacy, as well as a counterpoint to the flat horizontal roof.

Tech Specs

Location: 1330 Brook Street

Interior: 1,460 sq. ft. (3 bedrooms; 2 bathrooms)

Construction method & materials: 3 in. thick insulated metal panels plus insulated 2-by-4 wood studs on an insulated concrete slab

Insulation & Airtightness Details

Slab: R-10, perimeter

Wall: R-38

Roof: R-52

Airtightness: 1.65 ACH50

Passive Solar Attributes

Windows: Double-glazed, low-e, argon-gas-filled windows with U-PVC frames; U-factor: 0.21

Appliances

Heating/cooling: Air-source heat pumps, 14.8 & 16.0 SEER

Water heating: Conventional tank-style electric

PV array: Batteryless, grid-tied, 4.8 kW; 16 Hanwha Q-Cell Q.PEAK G4 300 W polycrystalline modules

Annual PV production: 5,782 kWh

Lighting: LED lighting

Indoor air quality: ERV, 56 cfm, 87 W

An open plan promotes daylighting and accessibility in this 1,460-square-foot home.

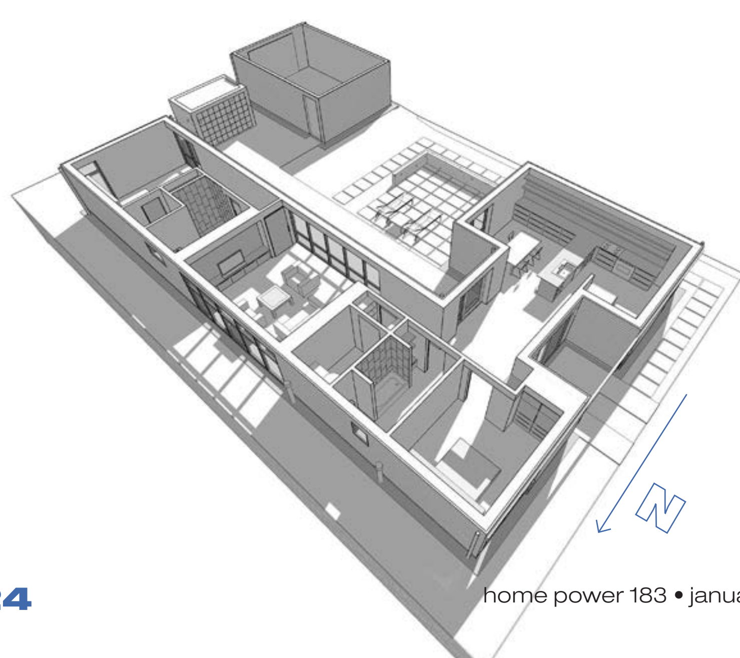
The house wraps around a south-facing courtyard that serves as the focal point—nearly every room connects to it visually through full-height windows.

1200 Pennsylvania

Located on a north-facing corner lot in the historic east Lawrence neighborhood, this design draws on the local farmhouse vernacular, but takes it into the 21st century. The two-bedroom, two-bathroom, 1,620-square-foot home features an air-tight, highly insulated envelope, efficient lighting (all LED) and appliances, as well as a high-performance mechanical system. A 5 kW batteryless grid-tied PV array on the roof and the home's overall orientation take advantage of the sun, assuring the homeowners low or no energy costs.

Sliding exterior panels give flexibility to manage the daylight quality, heat gain, and the level of privacy in the house. The dark epoxy-coated concrete floors absorb direct gain from the sun through the large south-facing windows that open to the courtyard. At night, when the home's interior temperature is lower than the floor temperature, this heat is radiated into the space, providing free heating. Operable windows located strategically throughout the house allow fresh air to circulate when the weather accommodates.

The siding is low-maintenance, 100-year-old western red cedar reclaimed from dismantled railroad bridge trestles.



Unlike most Kansas homes, the 1200 Pennsylvania home has no crawl space or basement for residents to escape to if a tornado threatens. Instead, there's a separate 72-square-foot concrete tornado shelter and a 400-square-foot one-car garage.

Salvaged marble slabs from the lobby of a demolished 1920s office building serve as kitchen countertops and backsplash.

Clean, spare design and large expanses of glazing lend a visual spaciousness to Studio 804 homes.

Tech Specs

Location: 1200 Pennsylvania Street

Interior: 1,620 sq. ft. (2 bedrooms; 2 bathrooms)

Construction method & materials: 2-by-6 stud-framed walls with 2 inches of exterior rigid-foam insulation

Insulation & Airtightness Details

Slab: R-21

Wall: R-32

Roof: R-52

Airtightness: 0.97 ACH50

Passive Solar Attributes

Windows: Triple-glazed Peerless windows with U-PVC frames; U-factor: 0.20; SHGC: 0.25

Appliances

Heating/cooling: Air-source heat pump, 16.0 SEER

Water heating: Heat-pump, 3.25 EF

PV array: Batteryless, grid-tied, 5 kW; 20 American Solar 250 W polycrystalline modules

Annual PV production: 7,483 kWh

Lighting: LED lighting

Indoor air quality: ERV, 100 cfm, 46 W

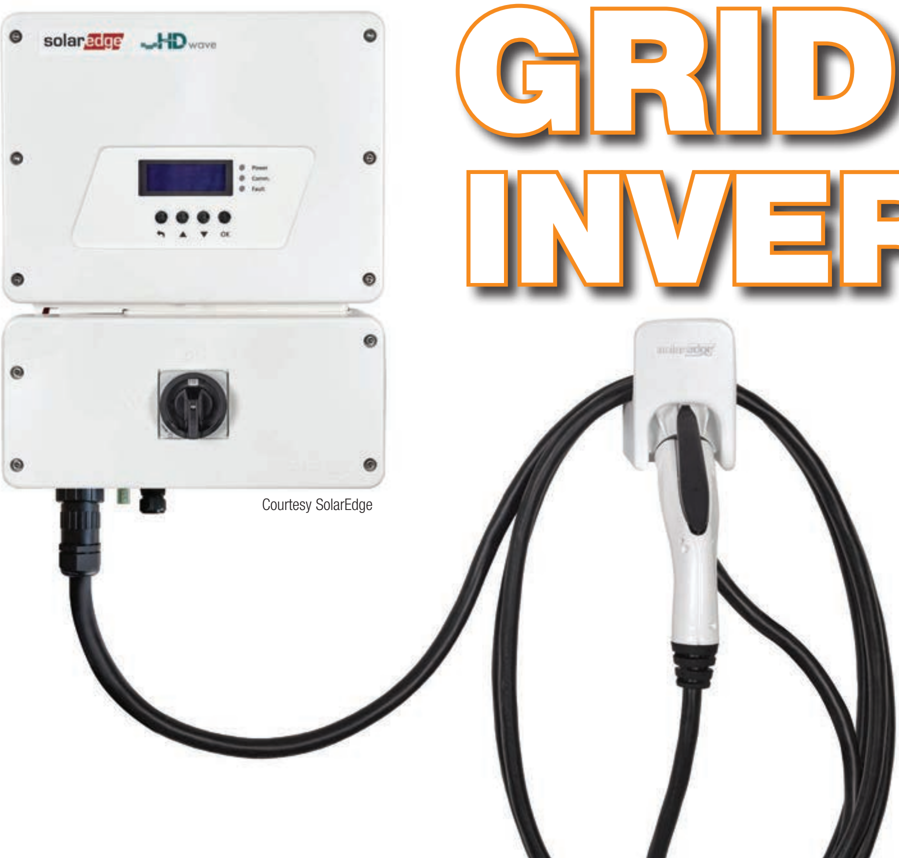
Measured at ACH50, the house has very little air infiltration. An energy recovery ventilator filters and conditions outdoor air, ensuring adequate air exchanges in the home and good indoor air quality. The combination of thermal mass, superinsulation, and low air infiltration means little need for mechanical cooling. All of the paints, flooring, sealants, and adhesives used were selected to contain few or no volatile organic compounds.

While the framing is conventional 2-by-6 lumber, it was harvested under the control of and certified by the Forest Stewardship Council. Three inches of rigid polyiso board on the roof and 2 inches in the walls help limit thermal bridging. The house uses high-efficiency light fixtures with LEDs, a Samsung minisplit system, and low-flow plumbing fixtures to minimize resource use. High-performance Peerless triple-pane doors and windows are used to ensure air-tightness and minimize thermal bridging.

The 1200 Pennsylvania home's batteryless grid-tied PV system.

Next-Generation GRID-TIED INVERTERS

by Justine Sanchez



Courtesy SolarEdge

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Inverter technology is progressing with the growing needs of the market. This SolarEdge HD Wave unit is listed to UL 1741-SA and has an integrated electric vehicle charger.

Before 1998, when a generous grid-tied PV rebate program was launched in California, the off-grid (battery-based) market dominated renewable energy installations, because they were often cost-competitive with bringing in utility power to remote sites. However, with the establishment of incentive programs for on-grid RE systems that tied into utility power and eliminated the need for batteries, a new market for batteryless grid-tied (GT) inverters emerged.

The first residential batteryless GT inverters were bulky (~200 pounds) and used low-voltage DC input. In 2001, German-owned SMA entered the U.S. market with its 600 VDC Sunny Boy inverters. Higher DC voltage inverters cut costs by allowing longer series module strings, fewer fuses, (sometimes) no combiner boxes, smaller-gauge wires, smaller and lighter inverter boxes, and higher efficiency. Soon DC and AC disconnects were integrated into inverter packages, again reducing installation time and equipment needed. The next evolution was integrating combiner boxes into DC disconnects and adding remote system monitoring.

Two decades later, new influences—such as more PV grid penetration (and thus the need to better support the grid), changes to net-metering programs, and renewed interest in backup power—are driving the latest developments in GT inverters.

Adapting to Greater Grid Penetration

Previously, with such a small amount of PV capacity on the grid, inverters were designed to simply shut down anytime there was a utility disturbance to ensure lineworkers' safety. With U.S. PV installations now reaching more than 47 gigawatts of capacity, having PV systems go offline due to brief fluctuations in grid power isn't desirable—it decreases grid stability. In some places with high concentrations of PV systems, such as California and Hawaii, new rules about how PV systems need to work with those grids have been established.

"Smart" PV inverters are designed to support the grid, including benefits like voltage and frequency "ride-through" (which allows PV systems to stay online during brief power fluctuations) and regulation; specified power factor; and soft-start ramp control. Rule 21 has been under development for California (and HECO Rule 14H for Hawaii) to address these smart inverter designs.

The first requirements address minor utility issues, such as voltage and frequency fluctuations that normally cause inverters to trip offline. Large-scale PV arrays can exacerbate the problem, affecting voltage and frequency even more. Voltage and frequency "ride-through," which allow PV systems to stay online during brief fluctuations, is on the list of grid-support functions included in Phase 1 of Rule 21.

Another grid-support function allows inverters to vary their power factor to stabilize grid voltage. The inverters absorb reactive power if the grid voltage is high or inject reactive power if the grid voltage is low. Additionally, adjustable, normal "ramp rates" (how quickly a PV power plant increases output due to power changes) and "soft-start" capability (desirable for a smoother transition back to full power after a shutdown) are also requirements of this phase that inverters must meet.

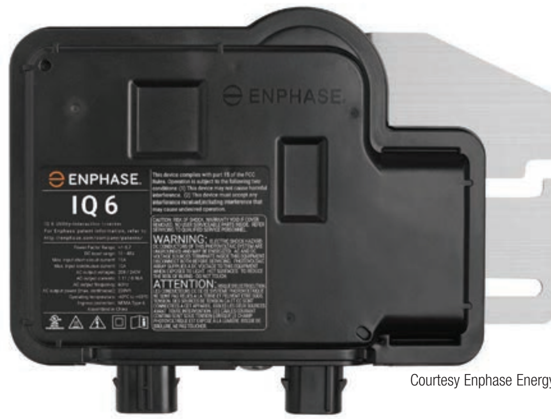
As of September 9, 2017, new GT PV systems installed in California had to comply with Phase 1 of Rule 21 and be listed to UL 1741-SA. A list of UL 1741-SA compliant inverters can be generated from the California Energy Commission website (bit.ly/CAeligInv). When you download the list, you need to filter for only those that have the UL 1741-SA listing. HECO 14H has required ride-through and specified power factor since January 2016, but may delay implementation of the full suite of functions until sometime in 2018.

The second phase of Rule 21, which begins in 2018, establishes IEEE 2030.5 communications protocols that will enable remote control of the inverters' grid-support functions and provide a common language between the utility and products by different manufacturers. Phase 3, slated for future development (possibly in 2019 or beyond), will build on the previous phases, adding even more advanced functionality to UL 1741-SA-compliant inverters. While California and Hawaii are the first states to require smart inverters, other U.S. utilities are starting to move in this direction as well, including National Grid, which services parts of Massachusetts, New York, and Rhode Island; PPL, which supplies electricity to parts of Pennsylvania; and ComEd and Ameren in Illinois.

SMA was one of the early leaders in the batteryless GT inverter market and has continued to adapt to new requirements, with products like this UL 1741-SA listed Sunny Boy inverter.

Courtesy SMA America

Enphase Energy was an early adopter of microinverter technology and continues to develop next-generation GT inverters, such as this Rule 21-compliant IQ 6 microinverter.



Courtesy Enphase Energy

Self-Consumption

Changes to net-metering and incentive programs have altered the financial equation for PV systems in some locations, making it more advantageous to directly use on-site-generated PV electricity rather than send it to the grid. These systems require load-shifting strategies, energy storage, or both. New inverter options have been developed that offer hardware and programming modes to prioritize "self-consumption," allowing system owners to adapt to these changing net-metering and incentive programs.

Backup Power Focus

With stronger storms and longer power disruptions, and grid vulnerability to other forms of disruption like cyber attacks, locally produced energy with storage has taken on new urgency. With Puerto Rico and other islands struggling to re-establish grid power after the 2017 hurricane season, resiliency is becoming a priority. Since backup grid-tied systems need energy storage, this requires inverters that are designed to work with batteries. Historically, multimode inverters have been used for this application, but some new hybrid inverters work with the grid and household loads at a more sophisticated level; are designed for newer battery technologies; and, like traditional multimode inverters, are able to operate independently during outages.

web extras

"Net Metering & Beyond" by Carol Weis and Christopher Freitas in *HP 177* • **homepower.com/177.44**

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

Types of GT Inverters

There are several types of GT inverters, and each type has models from various manufacturers either already released or to be released as "smart inverters" as they will have to be listed to UL 1741-SA, if installed in California or Hawaii. Each of these inverter types (and models within those types) will have a different combination of features, programming options, and design advantages to address the various influences discussed above.

Microinverters

Microinverters were first available in the 1990s, but it wasn't until 2008 that they began being installed in large quantities. Perhaps their two greatest benefits are module-level maximum power point tracking (MPPT), which maximizes each module's output independent of the others, and module-level monitoring, to pinpoint performance and problems with each module. Increasingly important, as we get closer to 2019 when the 2017 *National Electrical Code (NEC)* 690.12 rapid-shutdown rules within the array boundary becomes effective, microinverters also offer *module-level* rapid shutdown.

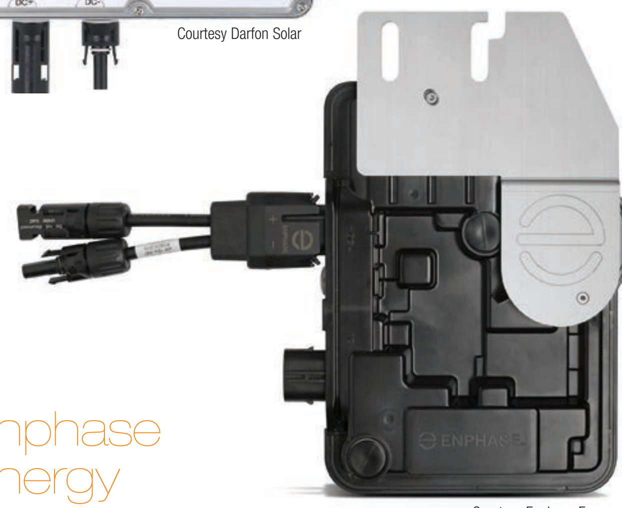
Microinverter input power has grown to accommodate higher module output, and most can accept input from either 60- or 72-cell modules. Some microinverters are now designed to work with two modules while still offering module-level MPPT, reducing system installation time, but still offering the same benefits. And some microinverters are already listed to UL 1741-SA; see "Microinverters" table.

Darfon Solar

Courtesy Darfon Solar

AP Systems

Courtesy AP Systems



Enphase Energy

Courtesy Enphase Energy


Magnum Energy

Courtesy Magnum Energy

MICROINVERTERS

Manufacturer	Model	Output (kW)	No. of Modules	MPPT Channels	No. of Cells Per Module	Recommended PV Module Range (W)	Rule 21 Compliant	Availability
AP Systems apsystems.com	YC500	0.50	2	2	60 & 72	280 - 310	No	Now
	YC600	0.60				200 - 365	Yes	
Darfon Solar darfonsolar.com	G700R	0.66	2	2	60 & 72	200 - 400	In devel.	Q3 2018
	G640	0.60	2	2	60 & 72	200 - 350	No	Q2 2018
	G320	0.30	1	1	60 & 72	200 - 350	No	Now
Enphase Energy enphase.com	IQ 6	0.24	1	1	60	235 - 330	Yes	Now
	IQ 6+	0.29			60 & 72	235 - 400		
Magnum Energy, Sensata sensatapower.com	ME-MGT500	0.50	2	2	60 & 72	180 - 310	No	Now

String Inverters

String inverters are used for series strings of modules and, due to lower pricing and ease of installation, have been the most common type of batteryless GT inverter installed. Over the last few years, the industry has moved away from transformer-based inverters to transformerless (TL) and "smart" TL string inverters. Additionally, rapid shutdown requirements that will be in effect in 2019 are necessitating new features. Some string inverter manufacturers are betting on the likelihood of intelligent devices (i.e., solid-state chips) being deployed in module junction boxes that will communicate with inverters (via "SunSpec Communications Signal for Rapid Shutdown, for example) to enable *module-level* rapid shutdown.

Other enhancements include being smaller and lighter, having easier mounting systems, offering greater efficiency, having a secure power supply (to provide backup power without batteries, if the sun is shining), and integration of an EV charger. See the "Smart Residential String Inverters" table.

ABB

Courtesy ABB

Fronius

Courtesy Fronius

SolarEdge

Courtesy SolarEdge

Ginlong

Courtesy Ginlong

STRING INVERTERS

Manufacturer	Model	Output (kW)	MPPT Channels	Additional Features	UL 1741-SA Listed	Availability
ABB abb.com	UNO-DM-Plus-US	3.3, 3.8, 4.6, 5.0, 6.0	2	Integrated power supply for rapid shutdown; plug-and-play connectors	Yes	Now
Fronius fronius-usa.com	Primo	3.8, 5.0, 6.0, 7.6, 8.2 10.0, 11.4, 12.5, 15.0	2	SnapInverter hinge mounting system	Yes	Now
Ginlong ginlong.com	Solis-4G MiNi	0.7, 1.0, 1.5, 2.0, 2.5, 3.0, 3.6	1	Compact, light (16 lbs.)	Yes	Now
	Solis-4G Single Phase	2.5, 3.0, 3.6, 4.0, 4.6, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0	2 or 3	Export Power Mgmt.		
SMA sma-america.com	SB-1SP-US-40	3.0, 3.8	2	Secure power supply (up to 2 kW)	Yes	Now
		5.0, 6.0, 7.0, 7.7	3			
SolarEdge solaredge.com	HD with EV charger	3.8, 7.6	N/A	Integrated EV charger	Yes	Q1 2018
	SE-H-US (HD-Wave)	3.0, 3.8, 5.0, 6.0, 7.6		Works with SE power optimizers for module-level MPPT & rapid shutdown	Yes	Now
	SE-A -US	3.0, 3.8, 5.0, 6.0, 7.6, 10.0, 11.4				

Multimode Inverters

Multimode inverters have been in use for many years to accommodate batteries in a GT system, primarily for backup purposes. Currently, OutBack Power is the only battery-based inverter manufacturer to have the majority of its existing line of multimode inverters listed to UL 1741-SA. In addition to backup power, OutBack's multimode inverters have historically offered backup generator support and several diverse operating modes, such as GridZero (maximizes self-consumption) to accommodate utility interconnection restrictions. Because they can work with various battery chemistries, such as lead-acid and lithium, they are employed in some packaged energy storage systems like sonnen's Eco series.

Delta

Courtesy Delta

Ginlong

Courtesy Ginlong

OutBack Power

Courtesy OutBack Power

HYBRID INVERTERS

Manufacturer	Model	kW Options	MPPT Channels	Maximum PV Array Input (kW)	Compatible Battery Types	Batteryless Operation	Optional Integrated Battery Package; Capacity	Connection to PV Array	Rated Power for Backed-Up Loads (kW)
Darfon darfonsolar.com	H5000	5	2	6.5	AGM, Gel, Lithium	Yes	Yes, several; 5 - 20 kWh	AC- or DC-coupled (built-in MPPT charge controller)	5
Delta delta-americas.com	E-series	6, 8	3	7.8, 10.4	Lithium	Yes	No	DC- or AC-coupled	5.0, 6.5
	E7U	7		8			Yes; 6 kWh		3.6
Ginlong ginlong.com	RHI	3.0, 3.6, 5.0	2	Unknown	Lithium	Unknown	No	DC-coupled	3
OutBack Power outbackpower.com	Skybox	5	1	6	AGM, Lithium	Yes	Developing	DC-coupled	5
Pika pika-energy.com	X7600	7.6	N/A	10	AGM, Lithium	Yes	Yes-Harbor Flex or Plus; 13.5-20.3 kWh	DC-coupled (with Pika optimizers)	8
SMA sma-america.com	Sunny Boy Storage	3.8, 5.0, 6.0	N/A	N/A	Lithium	No	No, but has secure power supply (up to 2,000 W)	AC-coupled (requires a separate PV inverter)	3.8, 5.0, 6.0
SolarEdge solaredge.com	StorEdge	7.6	N/A	10	Lithium	Yes	No	DC-coupled (with SolarEdge optimizers)	5

Hybrid Inverters

Generally speaking, hybrid inverters integrate a transformerless string inverter and a multimode inverter into a single feature-rich "smart" inverter package, commonly designed to work with lithium battery banks. These inverters often offer flexibility—such as the ability to add batteries to the system later, without having to purchase and install a second inverter. Many hybrid inverter manufacturers are developing optional integrated battery packages. These inverters usually

SMA America

Courtesy SMA America

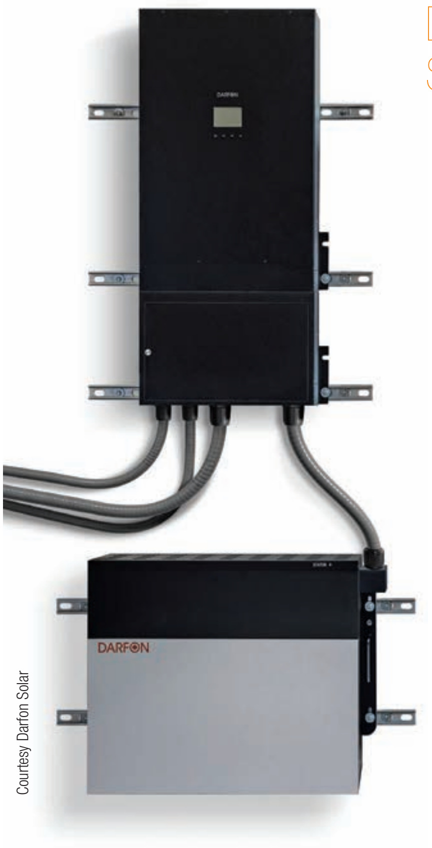
Pika

Courtesy Pika

	Surge (kW)	UL 1741-SA Compliance	Outdoor Enclosure	Expected Availability	Battery Input (DC Volts)	Input for Generator
	7.5	Yes	No, NEMA1	Q4 2017	48	Yes
	6.5, 8.3	Pending	NEMA 3R	Q2 2018	360 - 480	No
		In development	NEMA 4X	Q3 2018	380	No
	4	In development	NEMA 4X	Mid-2018	Unknown	Unknown
	8.4	Pending	NEMA 3R	Mid-2018	48	Yes
	12	Pending	NEMA 3R	Now	380	Pending
	4.8, 6.25, 7.68	Pending	NEMA 3R	Q1 2018	360	No
	6.6	Yes	NEMA 3R	Now	400	No

SolarEdge

Courtesy SolarEdge



Courtesy Darfon Solar

Darfon Solar

As battery storage becomes popular again, either for load management or backup, some companies like Darfon are offering integrated battery packages.

have multiple operating modes for time-of-use rates, using only solar power to charge batteries, and have the ability to easily shift modes should conditions change (for example, reserving more battery capacity for backed-up loads in anticipation of incoming storms and potential utility outages). Some hybrid inverters are designed to accommodate backup generators. Several inverter manufacturers are developing hybrid inverters; however, only a few of these inverters have actually completed the UL 1741-SA listing process and are actively shipping; see "Hybrid Inverters" table.

Full Circle

With year-after-year record-breaking GT PV system deployment, inverters have greatly improved from those early days and continue to evolve, with new advantages and features. It also seems that PV systems are coming full circle, with batteries being added back into the equation for an increasing number of systems designed with self-consumption and backup requirements. What was once old is new again, and for those of us who have been in the industry long enough to see this full cycle, it is somewhat gratifying, as it seems like we are returning to our roots. Where in addition to green energy aspirations, those RE systems made financial sense, and energy reliability and home resiliency were key motivators for early adopters.

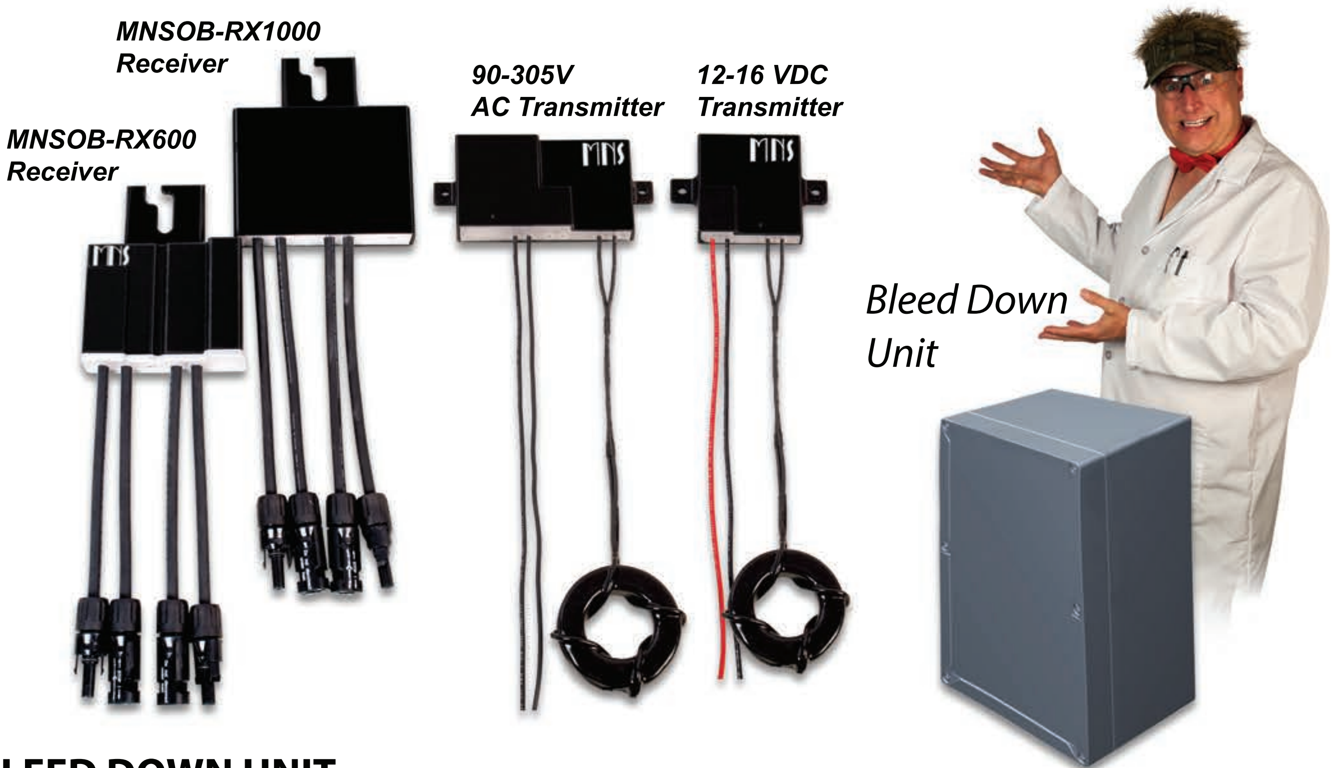
MidNite Solar

SOB's

Shut Off Box (SOB)

The MidNite SOB is a simple to install, low cost, rapid shut down system solution. It has been designed to comply with NEC 2014 and NEC 2017.

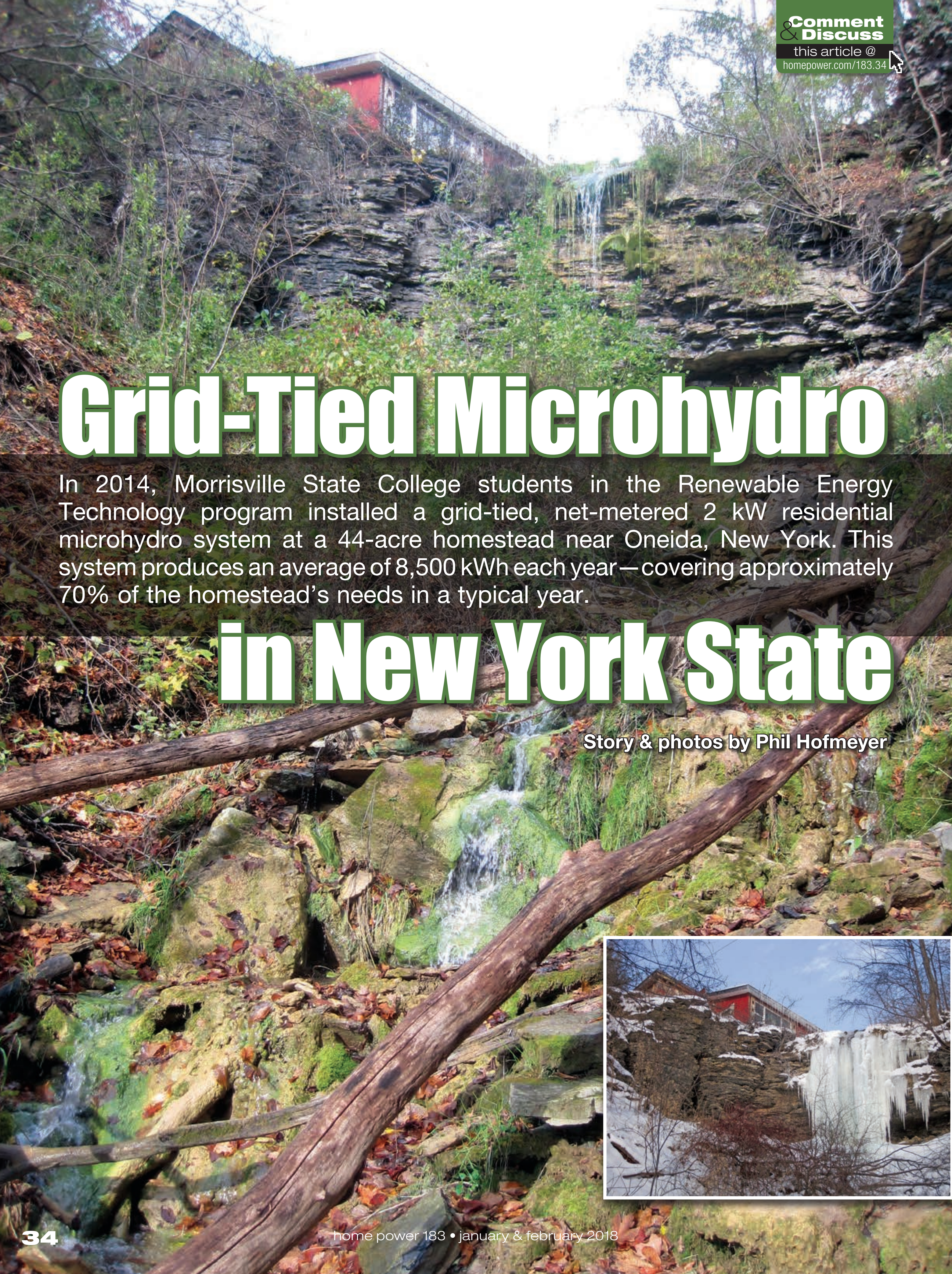
The system uses a receiver at the module that wires in just like an optimizer and a transmitter that is installed in or near the inverter. The installer does not need to install any other wiring between the transmitter and receiver. The system is fail safe. If the receiver does not sense the signal from the transmitter, it turns off and opens the circuit. All SOB's are TUV listed to UL1741 and are NEC2014, 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.

www.midnitesolar.com
17722 67th Ave. NE., Arlington, WA. 360-403-7207 FAX: 360-691-6862



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Grid-Tied Microhydro in New York State

In 2014, Morrisville State College students in the Renewable Energy Technology program installed a grid-tied, net-metered 2 kW residential microhydro system at a 44-acre homestead near Oneida, New York. This system produces an average of 8,500 kWh each year—covering approximately 70% of the homestead's needs in a typical year.

Story & photos by Phil Hofmeyer

In 2012, I gave a presentation about microhydro-electric systems at a small conference on renewable energy and efficiency options for local farms. At the end of the seminar, a tall man with a rough farm-built handshake asked me about the process of installing a net-metered microhydro system at his homestead. This is how I met Bernie Wootten, and how we came to install his hydroelectric system.

When I first pulled down his long driveway, I was greeted by guinea fowl, chickens, sheep, and Scottish Highland cattle. His homestead sprawls across 44 acres outside of Oneida, and his hand-built house is perched at the brink of a 40-foot waterfall on a small, unnamed stream. Bernie has long had a love of water; he has paddled whitewater with the best boaters in the world and holds several records for flatwater kayaking time trials. He works on weekends as a rescue kayaker for a whitewater-rafting outfitter on the Black River in Watertown, New York. While he always dreamed of using water to create electricity for his home, he was unsure how to go about it.

Permitting, Contracting & Incentives

If you're interested in a grid-tied PV system in New York state, companies will show up within 48 hours to give you a free assessment, can have the permitting paperwork submitted within a week, and your system can be installed within a month. Though small wind has permitting challenges in this part of the state, companies are at the ready for a client with a promising wind site. But microhydro specialists are few and far between—Bernie had been trying, unsuccessfully, to find a company who would take on his project.

I had been working on and teaching about residential and farm-scale hydro projects since 2008 through SUNY-Morrisville, a small agriculture and technical college in upstate New York. Though most of the courses I teach are about solar electricity, solar water heating, and small wind systems, I have had a strong interest in residential hydro systems. We have abundant rainfall (approximately 36 inches) that's well-distributed throughout the year, and topography amenable to hydro (rolling, forested ridges with 100 to 200 feet of relief). Additionally, I enjoy the challenge of designing and installing hydro systems. These systems require integration of assessment, analysis, electrical, mechanical, and on-site fabrication skills. Many lean companies cannot afford to take on hydro systems and stay profitable, so hydro systems are relegated to the few.

In New York, there are excellent state incentives—both tax credits and grant funds—for solar electricity and small wind systems. However, no such incentives exist for microhydro systems—though small hydro can be cost-competitive without incentives. To help offset the expense, I applied for a grant through the Research Foundation of SUNY. I used this grant fund, along with free student labor, to help Bernie get his dream hydro system installed.

Opposite: About half of the system's total head comes from a waterfall just below the house. Access for building the powerhouse and maintaining the system was a challenge.

Inset: Flow fluctuates significantly throughout the seasons, and depends on rain events and temperatures.

The retention pond, built for the project, holds approximately 520,000 gallons and helps temper runoff to a usable, steady flow. The perforated intake is visible near the overflow drain.

Site Assessment

Estimating power from a hydro site is not terribly complex. Since the base physics equation is derived from potential energy, potential hydro system power can be determined as:

Power = Water Density × Acceleration Due to Gravity × Flow × Head

Since density and acceleration of gravity can be considered constants at a given site, you need only measure head (the vertical drop between the intake and the turbine) and flow (volume per unit time) to estimate the resource's power.

Head (ft.) × Flow (gpm) ÷ 12* = Power (W)

***For this system, 8 was used; a range of 8 to 12 is typical.**

After our initial meeting, Bernie had a retention pond constructed to raise fish and to water his animals and gardens. At the time the pond was constructed, he sistered a perforated 4-inch-diameter PVC pipe next to the overflow culvert for an intake, and capped the end that punched through the berm.

There's a valve and vacuum break at the top of the 4-inch penstock where it enters the dam, next to the overflow culvert. The pipe had not yet been connected to the elbow.

During the site assessment, we discovered that there was 100 feet of vertical drop between his retention pond and where the turbine could be installed. Water has a relationship between vertical distance and static pressure—there is 1 psi for every 2.3 feet of vertical drop (for every 10 vertical foot of water in a pipe, there are 4.3 psi). Since Bernie's site had 100 vertical feet, this would give a static pressure of 43 psi. To get the water from the intake to the turbine, it required about 800 linear feet of pipe.

System Design

It is possible to calculate the power delivery of a given pipe diameter and length, assuming a certain flow. Larger pipe costs more, so finding the ideal pipe size saves money without losing much power potential. This sweet spot generally occurs when dynamic head pressure is approximately 70% of static head pressure. As water moves through the penstock, friction from the interior pipe surface extracts pressure energy from the system, as does turbulence from fittings and valves. These frictional losses reduce pressure from the maximum of static conditions to a lower dynamic (net) head pressure. Many turbine manufacturers provide head loss tables to help with estimating frictional losses. If net head is greater than 70% of static head (i.e., too close to static head pressure), the pipe diameter may be larger and more expensive than necessary. If net head is less than 70% of static head, the pipe may be undersized (i.e., too much frictional loss). In this case, it may be cost-effective to install the next larger pipe size, since more power will be the result.

We calculated head loss for water flowing through a 4-inch high-density polyethylene (HDPE) pipe, since that was the largest diameter we could afford through the grant. We determined that maximum power through the pipe would occur at approximately 32% head loss, yielding a net head of 68 feet (30 psi). To net 68 feet of head, we would expect a maximum flow of 230 gallons per minute (gpm) through the penstock, which would, in theory, provide 2,400 watts. From this, we needed to subtract the system inefficiencies from the runner, the generator, and the electrical system. The realized maximum power output from the machine would be likely be between 1,800 and 2,000 W.

The next task was estimating annual energy output. Energy is equal to power multiplied by time—for a hydro resource, then, which fluctuates depending on the season,

Students weld 20-foot sections of 4-inch HDPE pipe into the 800-foot-long penstock.

Advanced Math for Microhydro

Power extraction = $\eta \rho g Q H$

Where:

η is efficiency

ρ is water density (about 1,000 kg/m^3)

g is 9.81 m/s^2

Q is flow in m^3/s

H is vertical head in m

Efficiency (η) accounts for *all* of the energy conversions once water has left the pipe:

- Nozzle efficiency—0.8 to 0.95 is common depending on the nozzle shape.
- Runner efficiency, which follows typical curves based on runner type, head pressure, and percent of maximum flow—about 90% for turgo runners at high head.
- Alternator efficiency, which varies wildly depending on rpm—up to 80% or so.
- Wiring and power electronics—2% to 3% for line losses; 3-5% each for controllers and inverters.

When these are multiplied together, the water-to-wire-efficiency is about 60%.

H has to be adjust for dynamic conditions, following Bernoulli's equation. In microhydro systems, both major losses (pipe friction described by the Hazen-Williams equation) and minor losses (valves and fittings, a function of pipe velocity) must be accounted for. A typical pipe should aim to keep dynamic head to about 70% of static head.

Assuming a small microhydro system with 100 feet of head (gross) and 100 gpm, we can estimate power output as 100 × 100 ÷ 12 (range could be 8–12) = 833 W.

Working backward (and converting feet to meters and gpm to cubic meters per second), this gives:

833 W ÷ (1,000 kg/m^2 × 9.81 m/s^2 × 0.00631 m^3/s × 30.4 m) = 44% efficiency

The easiest way to increase efficiency (from 44%) is to properly match the nozzle to the runner and the alternator rpm to the jet velocity and flow, and slightly oversize the pipe (if funds allow for it). This is how we improved the efficiency of Bernie's system.

The gauge at the power shed shows 43 psi of static pressure. At maximum flow, pressure loss due to friction will reduce net pressure to about 30 psi.

flow must be measured at various times throughout the year. Though the power of a 4-inch HDPE penstock is maximized at 230 gpm, there was nothing suggesting this could be achieved year-round. The small stream was fed from only about 0.8 square miles of watershed area, flowing from a low of 40 gpm in the autumn to more than 1,000 gpm through the spring. We turned to the U.S. Geological Survey's National Water Information System (NWIS) real-time database for further data.

The NWIS database (see "Web Extras") includes long-term flow information for rivers and streams. With a Swoffer 3000 flow meter, we measured the stream's flow over a six-month period, and determined the range to be 25 to well over 3,000 gpm, depending on the season. We then took real-time data from four nearby streams on the same dates that we measured stream flow at Bernie's site. A regression analysis was used to predict monthly and annual stream flow from the streams in the NWIS database. We used this to estimate his system's annual energy production to determine cost-effectiveness of his net-metered hydroelectricity.

web extras

USGS NWIS database • **bit.ly/USGSwaterdata**

Hydro Induction Power • **hipowerhydro.com**

Central Plastics pipe welder • **bit.ly/FusionWelder**

Banjo Liquid Handling Products • **bit.ly/BanjoProducts**

NYS DEC Environmental Resource Mapper • **dec.ny.gov/gis/erm/**

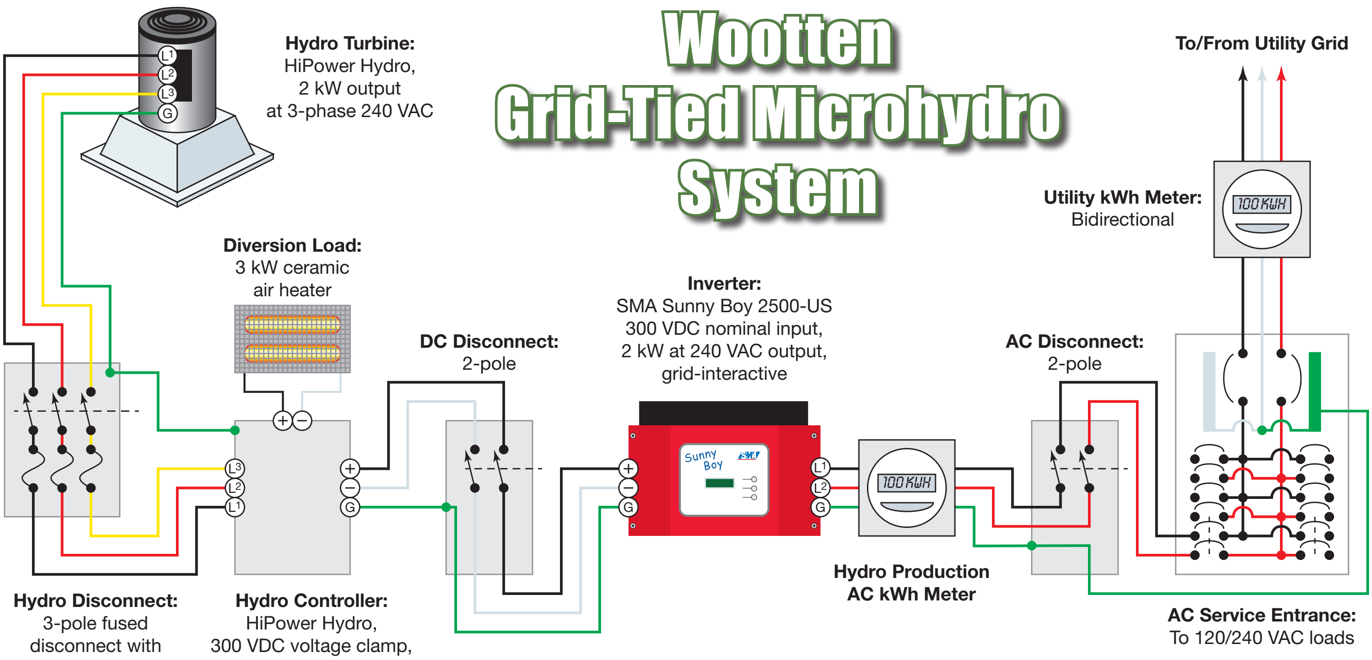
System Permits

Permitting is often a daunting requirement for microhydro systems. Bernie's system was installed in compliance with the New York State Department of Environmental Conservation (DEC). The pond's construction required completing a Joint Application Form (JAF), a state permitting package that describes the scale of stream disturbance and the nature of the impoundment. To aid with this aspect, the NYS DEC provides web access to the Environmental Resource Mapper, a geographic information system specifying stream classification, presence of rare or endangered biota, and wetland classification. This tools aids in completion of the JAF, which is completed once and submitted for review by the DEC, Army Corps of Engineers, the Office of General Services, and the Department of State.

Getting a small hydro system approved through the Federal Energy Regulatory Commission (FERC) can also be a challenge. This involved several phone calls and email chains to resolve. After quite some time, we applied for and received a "small hydro" exemption. However, this required submitting all civil and electrical plans for the system, including estimates of maximum power production and annual energy exports onto the grid.

In addition to DEC and FERC permitting, local permits were required for the civil and electrical work. This necessitated submitting an electrical diagram, and a site plan depicting power sources and disconnects for system shutdown. These documents, along with inverter testing procedures, were also submitted to the electric utility for grid interconnection. Both the township and utility permitting process required an electrical inspection from an independent inspection service. Letters of completion and copies of the inspection were sent to the utility and to the local town's codes enforcement officer.

A Morrisville State College student with the (L to R) DC disconnect; SMA Sunny Boy 2.5 kW batteryless grid-tied inverter; hydro production kWh meter; and AC disconnect. From there, the input backfeeds a 15 A breaker in the main distribution panel.



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

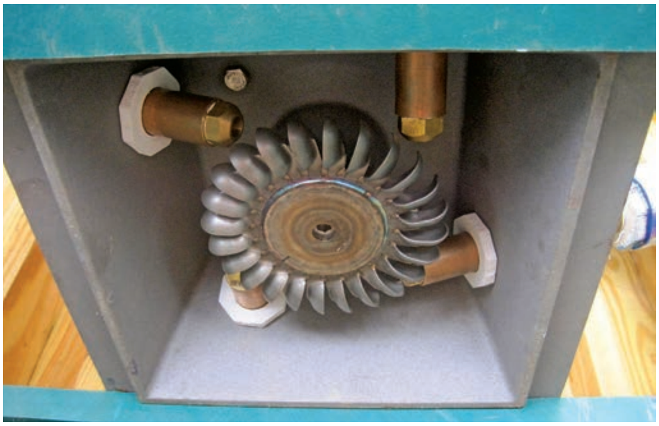
Gear & Installation

Since we knew the maximum output would be around 2 kW, we purchased a 2 kW grid-intertied system from Hydro Induction Power. This package includes a four-nozzle turbine with a turgo runner and a 2 kW alternator, AC and DC disconnects, a controller and ceramic air-heater diversion load, and a 2 kW Sunny Boy grid-tied inverter. Turbine design and runner efficiency are strongly linked to vertical head and available flow. Because this system is characterized by its relatively high head and low flow, it is ideally suited for either a turgo or Pelton runner. Alternatively, high flow and low head sites are best suited for propeller, Kaplan, or Francis runners. To convey the water from intake to turbine, we purchased HDPE pipe in 20-foot lengths from a local geothermal supply company.

The students from my lab classes and I installed the system over five weeks. We started by hand-excavating a flat area at the base of the waterfall, and poured a concrete pad. A 4-by-4-by-8-foot shed was built on it to house the turbine and power electronics. The 20-foot HDPE pipe sections were fused with a Central Plastics BS-4 pipe welder; stainless steel fittings transition between the HDPE penstock and both the PVC intake and distribution manifold.

In the holding pond, the intake uses a vertical, screened, perforated PVC pipe to exclude debris, fish, and amphibians; a ball valve for flow control; and vacuum relief to drain the system for maintenance. At the power shed, four brass gate valves control flow to the nozzles, to adjust overall flow throughout the year. We put in two each of 1/2 and 9/16 in. nozzles so that Bernie can turn nozzles off and on to match the stream flow throughout the year. We connected the brass valves to the turbine with 1-inch braided, reinforced flexible PVC tubing to allow disconnecting from the penstock for maintenance and purging the pipe. Because braided PVC can be difficult to remove from barbed fittings, we used Banjo cam lever couplings at the turbine to disconnect the turbine from the manifold quickly and easily.

The turbine includes a 4-inch turgo runner and four nozzles.



A HiPower 300 VDC hydro controller and disconnect.

Water exits the bottom of the powerhouse onto the concrete pad. Several layers of fencing and large stones make up a gabion wall that forms a tailrace to return water to the stream. This reduces erosion of the stream bank, but still gives Bernie a small waterfall that he can see from his house.

The powerhouse contains a three-pole AC disconnect, a diversion controller, and a diversion load. We opted to mount these components inside the powerhouse in case a tree fell onto the aerial wire run to Bernie's house. Because of bedrock, buried conduit was not possible. From the controller, we ran the DC output conductors along the penstock and then back uphill in flexible liquid-tight metal conduit. We installed a utility pole to span aluminum SE cables across the stream to a weather-head on the house. The DC disconnect, inverter, analog production meter, and AC disconnect were put on the outside wall of Bernie's house (mostly so that students could access the electrical equipment without going into his house). The system backfeeds a 15 A breaker in the home's main service panel.

Tech Specs

Overview

System type: Grid-tied microhydro-electric

System location: Oneida, New York

Site head: 100 ft.

Hydro resource flow (dry season): 40 gpm

Hydro resource flow (wet season): 1,000 gpm

Production (dry season): 250 AC kWh per month

Production (wet season): 1,200 AC kWh per month

Utility electricity offset: 70%

Civil Works

Diversion: Vertical pipe intake in pond

Intake: 4 in. diameter PVC pipe

Penstock: 800 ft., 4-in. diameter, HDPE

Powerhouse: 4 x 4 x 8 ft. wood-framed powerhouse

Hydro Turbine

Turbine: 2 kW HiPower Hydro, 4 nozzles

Runner: 4 in. turgo

Rated peak power output: 2 kW

Balance of System

Hydro turbine controller: HiPower Hydro, 300 VDC, 7 A

Inverter: SMA Sunny Boy SB2500-US, 250–600 VDC nominal input, 240 VAC output

System performance metering: Form 2S, 240 VAC, 100 A EZ-read cyclometer

Diversion load: 3 kW passive ceramic air heater

A view into the power shed shows the component layout, including diversion resistor and 2 kW HiPower turbine and tailrace in operation. The fourth nozzle was not yet connected.

Site Challenges

A major issue was dealing with the steep terrain during construction. Working with students in this environment became an exercise in risk management. However, tower climbing and rescue are part of the RRT curriculum, and some of the students were already familiar with high-angle rescue and overhead rigging systems. We built a high line to bring all of the materials to the powerhouse, including bags of cement, building materials, and the electrical equipment. We also built a rock staircase and hand line for easier access to the turbine.

Microhydro electricity systems require more owner attention than PV systems. The first real eye-opener occurred when the perforated standpipe intake dislodged from the slip fitting we installed for maintenance purposes. The intake dislodged just as madtom catfish were spawning in the retention pond. Troubleshooting a loss of power, I found four

Bernie, with the microhydro system in full operation. By closely monitoring flow and adjusting nozzles appropriately, the system will product about 70% of his homestead's energy annually.

Wootten Microhydro System Costs

Item	Cost
HiPower kit: incl. turgo turbine, SMA SB2500 inverter, controller & 3 kW dump load	$6,000
Pipe: 800 ft. of 4 in. HDPE	2,945
Miscellaneous plumbing	1,077
Miscellaneous electrical	580
Disconnects, AC & DC	317
Cost	$10,919
SUNY RF STEM Grant	-$4,500
Total Cost	$6,419

Payback Period & ROI

Annual electricity consumption (kWh per yr.)	12,500	From utility bills
Annual electricity cost (w/o service charges)	$1,407	From utility bills
Energy value (per kWh)	$0.113	Cost ÷ consumption
Microhydro system production (kWh per yr.)	8,500	Average since 2014
Microhydro energy value (per yr.)	$957	Energy value × hydro production
Total microhydro system cost	$6,419	From cost table
Payback Period (Yrs.)	6.7	Total cost ÷ hydro energy value
Return on Investment	14.9%	Inverse of payback period

nozzles packed with little fish. Since then, we have secured the intake and have had no debris—or critters—entering the pipe.

In February 2015, we were gripped in a two-week cold snap, with temperatures never rising above 15°F and dropping to a low of -31°F. Worried, we drained the penstock to avoid pipe damage. Unfortunately, the ball valve at the intake then froze and split. In hindsight, it would have been better to crack the upper ball valve and allow flow through an open gate valve, disconnected from the turbine nozzle.

During a particularly wet spring in 2016, a stream on a neighboring property jumped its banks. Stream overflow rushed across a large pasture and into Bernie's valley, sending cascaded shale onto the penstock, distribution manifold, and powerhouse. The entire rock staircase was gone within a 3-hour period. One of the shale pieces took out the pressure gauge upstream of the valves, so water was shooting out of the pipe. The repair required draining the line and changing the manifold setup to better protect it from future rockslides.

The most challenging part of system operation is squeezing every kWh of energy from it. Because of rapid flow changes, capturing water from a two- or three-day storm event can boost the system's production by 60 to 80 kWh during that time. This need for hands-on interaction from the homeowner makes actual energy production nearly impossible to accurately predict. If Bernie were less willing or physically unable to traverse the steep terrain down to the turbine to adjust valves based on available flow, the system's annual energy production would be substantially lower.

Moral of the Story

Would we do it again? Yes. My students and I have designed and installed five residential and farm hydro systems through the years. In each case, success of the project was dependent upon a robust design; realistic expectations of system maintenance and operation by the homeowner; and funding through grants to keep systems cost-competitive with current utility rates.

Bernie was my favorite hydro "client" because of his willingness to help with the construction and his interest in seeing the project succeed in all weather conditions. He is exceptionally happy to fulfill his dream of using the stream to reduce his carbon footprint. Students are happy to get real-world experience in system design, installation, and troubleshooting. Outreach into the community with renewable energy education is the best thing I can think of for future generations, for environmental, economic, and social advancement.

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Stand-Alone Systems & the *NEC*

by Brian Mehalic

Major changes occurred in the 2017 *National Electrical Code* regarding PV system disconnects; where a PV system ends; and what constitutes separate systems, even though they were historically thought of as parts of a PV system (see "Simpler *NEC* Disconnection Rules" in *HP180*). Rules that previously resided in Article 690 were relocated within the *NEC* with the objective of stripping out requirements that were not PV-system-specific. One example is stand-alone systems.

Article 710

While Article 710—"Stand-Alone Systems"—is a new "Special Condition" in Chapter 7 of the *NEC*, the language is essentially the same as in the 2014 *NEC's* Section 690.10. One of the main additions is the scope of Section 710.1, which states that the article covers "power production sources operating in stand-alone mode." The information is applicable both to complete stand-alone systems as well as to the wiring on the stand-alone side of a multimode inverter, even though the system may normally be operating in parallel with the utility grid.

Also added is the general requirement that all equipment be listed or field-labeled for the intended use. This requirement works in conjunction with 710.15(F), which stipulates that the power supplied by a stand-alone system stays within acceptable voltage and frequency limits of the loads (as a listed product would).

Note there is still a drawing in Figure 690.1(b) showing a stand-alone system; this drawing also includes a PV system (covered by Article 690) and an energy storage system (Article 706). A stand-alone system is defined in Articles 100 and 690 as a "system that supplies power independently of an electrical production and distribution network" (aka independently of the grid or another primary source of power). Expect future editions of the *NEC* to further segregate different system types so that rules and requirements can be applied only to the relevant equipment and wiring of each.

Section 690.56(A) specifies a labeling requirement for stand-alone PV systems: a directory in a readily visible location on the exterior of the building must state the presence of the system, as well as the location of the system's disconnecting means. While there is no corresponding requirement in Article 710 (nor are there any rapid shutdown requirements for a stand-alone system without PV), providing this information is valuable to system users and first responders even for stand-alone systems that don't include PV.

General Requirements

In general, premises wiring systems for stand-alone applications must meet the same requirements for electrical systems that are supplied by a service (the utility). The load side of a PV system is basically the same as any other premises wiring system and should follow the rules of Chapters 1 through 4, with the few exceptions and additions outlined in 710.15(A) through (C).

While Article 220 covers load calculations for branch circuits and feeders, 710.15(A) allows stand-alone systems to have an output power less than the calculated load. However, the stand-alone system must be able to provide a level of power greater than or equal to the single-largest load it supplies. This ensures that the largest load, running on its own, will not overload the system. This allowance—if utilized in the system design—means that a combination of loads running simultaneously could still overload the system and likely result in an overcurrent/overload shutdown of the power electronics. To remedy this, load management systems may be installed; or it may be left to the end user to manually manage loads accordingly; or the system may be sized large enough to power all concurrent loads.

Section 710.15(B) addresses conductor sizing for the stand-alone system's source output and is based on the total ratings of the stand-alone source(s). This is an important allowance—it is common for a stand-alone system's output to be much smaller than the rating of the distribution equipment to which it is connected. An example would be two 3,600 W inverters providing 120/240 VAC to loads—essentially 30 A per phase (or 60 A at most on a single phase depending on the equipment and inverter stacking configuration), with the load breakers in a 100 or 200 A panel. Instead of having to follow rules for conductor ampacity in Section 310.15(B)(7) for single-phase feeders or services in dwellings, the conductors on the output of the stand-alone system can instead be sized based on the current the system can provide.

Because a stand-alone system is a voltage source (unlike a grid-direct PV system that shuts down without the presence of grid voltage), Section 710.15(E) requires that plug-in, backfed circuit breakers must have an additional fastener so that the device cannot simply be pulled off a busbar. This is because, similar to a breaker on a generator's output, the breaker on a stand-alone system's output can remain energized when removed from the busbar. Also note that breakers are not permitted to be backfed by stand-alone systems if marked "line" and "load."

Single 120 VAC Supply

Historically, many of the inverters used in stand-alone systems only provided a 120 VAC output, and they were often connected to distribution panels designed for 120/240 VAC split-phase, but with only 120 VAC loads (single-pole breakers installed on all branch circuits). This is allowed by 710.15(C), provided that there are not any 240 VAC loads—this would violate 710.15(F) regarding supply voltage—and that there are no multiwire branch circuits.

Multiwire branch circuits are circuits in 120/240 VAC systems where the hot Line 1 and Line 2 conductors are supplied by a double-pole breaker and share a common neutral conductor. Circuits are sometimes installed in this manner in interior wiring lighting and outlet circuits. A common example is 12/3 Type NM or NMC ("Romex"), which has two hot conductors (one black and one red), a single neutral conductor, and an equipment grounding wire, used to supply two different circuits, one on each phase of a 120/240 VAC split-phase system. If both "phases" are in fact the same phase (as when both are supplied by the same 120 VAC inverter), then the shared neutral conductor will carry the sum of the currents on the two lines, potentially exceeding the ampacity of the neutral conductor and resulting in a fire hazard. When two truly separate phases share a neutral conductor, the current on the neutral is minimized because one phase is positive, while the other phase is negative—and they effectively cancel out each other.

When installing a stand-alone system that only produces single-phase 120 VAC, it is critical that existing wiring is examined to ensure that there are no common-neutral branch circuits (multiwire branch circuits). If there are, then four options are available:

- Use an inverter that can produce 120/240 VAC.
- Stack two (or multiples of two) 120 VAC inverters in series so they provide 120/240 VAC.
- Add an autotransformer to produce both phases from a single-phase inverter.
- Rewire branch circuits so that they each have their own neutral conductor.

Additional Notes

A stand-alone system does not inherently include energy storage or have backup power, so Section 710.15(D) also applies to PV-direct systems, such as a ventilation fan system installed in a greenhouse that only runs during daylight hours. Systems like these may also be subject to the requirements in Article 720, "Circuits and Equipment Operating at Less Than 50 Volts." When energy storage is connected to a stand-alone system, it must follow the requirements of Articles 480 and 706.

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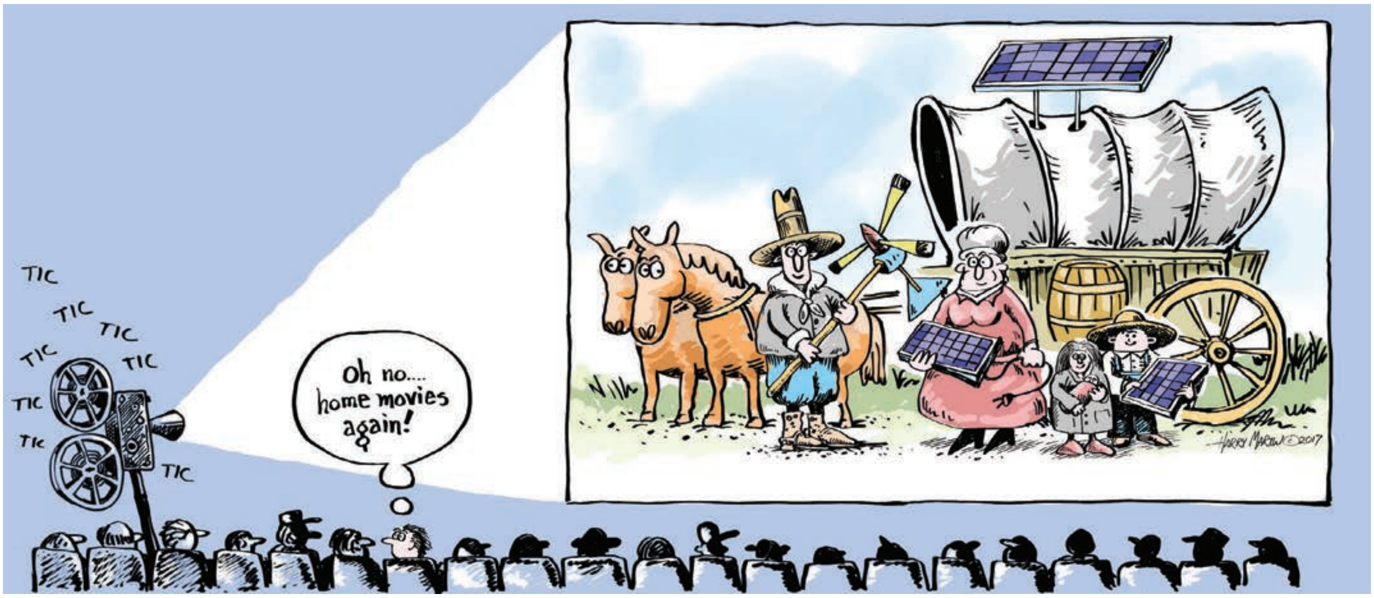
The Third & "Final" Solar Pioneer Party

by Kathleen Jarschke-Schultze



In November 2017, almost 300 solar pioneers and enthusiasts gathered in Willits, California, to celebrate the roots of the U.S. residential renewable energy industry, and to view the PV pioneers documentary that had been two years in the making.

The day before Solar Pioneer Party (SPP) III, Bob-O and I arrived in the late afternoon. We got situated at the Willits KOA, which was a clean, nicely run park. Although the park welcomed dogs, we were warned that a colony of wild black bunnies roamed the park. Our Airedale was intensely interested in them.

The first day of SPP III was devoted to visiting with friends we hadn't seen since last year's SPP and others we hadn't seen for decades. We gathered in the red barn at the campground. There was a warm fire burning in the barn's wood heater, and organizer Jeff Spies' wife Colleen served snacks and drinks. It was so good to be able to talk to friends without being interrupted by business. It used to be we only saw each other at trade shows and energy fairs. That evening's dinner was an array of Mexican cuisine served by Taqueria Ramirez food truck courtesy of Sequoya Cross of Backwoods Solar. During dinner, Jeff and his coworker and collaborator Jason Vetterli showed a memorial film they put together showcasing Richard and Karen Perez and *Home Power* magazine. Using footage from their interview with Richard in 2016 and old photographs, they paid homage to my dear friends and the work they did. Jeff said the most powerful of all the interviews he did for the documentary was with Richard at his home after the first SPP.

Solar Roots: The Pioneers of PV

Just over two years ago, Jeff began a journey to document the beginnings of the residential photovoltaic movement in the United States. He quickly enlisted the talented (and modest) Jason Vetterli, a coworker and fellow renewable energy enthusiast.

For the last two years, Jeff and Jason traveled the country, scouting solar pioneers to interview. The project encompassed thousands of miles and hundreds of hours of recordings. They were supported by myriad people who understood that *Solar Roots* was a story that needed to be told.

Solar Weekend

The next day, *Solar Roots* was unveiled at the Noyo Theater in Willits. There were several showings to accommodate all of the people at the gathering. Saturday morning's early showing was reserved for people who were going on the Skunk Train excursion toward the coast that day.

When it was our turn, we showed up at the theater—all somewhat giddy with anticipation. As the movie played, it was kind of surreal—we watched the story unfold from the very beginnings of solar power to the present-day boom. Back then, everyone in the business knew everyone else. If not face-to-face, for sure we had connected over the phone—a tight group of like-minded people. Jeff had put out a call for old pictures of pioneers, and seeing our younger selves on the big screen was pretty darn amusing and amazing. The thrill of being a part of that tribe never gets old.

Jeff and Jason used masterful editing to keep the story flowing. Historical vignettes, starring Jeff, sometimes in costume, are interspersed with interviews with the "back-to-the-landers" who pioneered residential solar technology. This documentary pulls no punches and tells it like it was. I laughed along with everyone else as Charlie Wilson's wife, Cietha, described his great idea of loading a garbage can half full of water, clothes, and laundry soap in the back of their pickup and driving to town. The agitation from the back roads cleaned them—replacing the wash water before the drive back was the rinse cycle. She shared that they had stopped that practice after a can rollover that spread wet clothes far and wide.

That evening, Tamarack Solar hosted a catered dinner at their warehouse in Willits. After dinner, half the tables were put away and people danced the evening away to the music of Midnight North, featuring Grahame Lesh (the son of Grateful Dead bassist Phil Lesh), and TJ Kanczuzewski of Inovateus Solar.

On Sunday morning after breakfast, we all caravanned down Highway 101 to the Solar Living Center in Hopland. Beautiful grounds, interesting buildings, and a very cool store were the backdrop for more visiting. Some folks pulled out a collection of—dare I say—really old PV modules. Some of the cell placements were downright artful.

We were ushered into a large event tent where we enjoyed a tasty catered meal and hot apple cider. It was afterward that I found out that the people who catered our meal had just lost their homes and business in the Mendocino Complex fires the preceding month. Very sobering.

That evening, back at the red barn at the KOA, any pioneers who had brought their instruments played music into the night. Windy Dankoff on flute, Kelly Larson on ukulele, Michael Hackleman on guitar, and Bob-O on a five-string bass had people up and dancing.

It was wonderful for me to have several people tell me they like my "Home & Heart" column. I am grateful. I will miss these gatherings, but Jeff worked his butt off making the event happen three years in a row, as did both he and Jason making the definitive film that documented so much of the magic before it disappears.

There was talk of coordinating a solar family reunion in two years. If it comes to pass, Bob-O and I will be there.

altE Store....................................1
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Backwoods Solar 12
Crown Battery ....IFC
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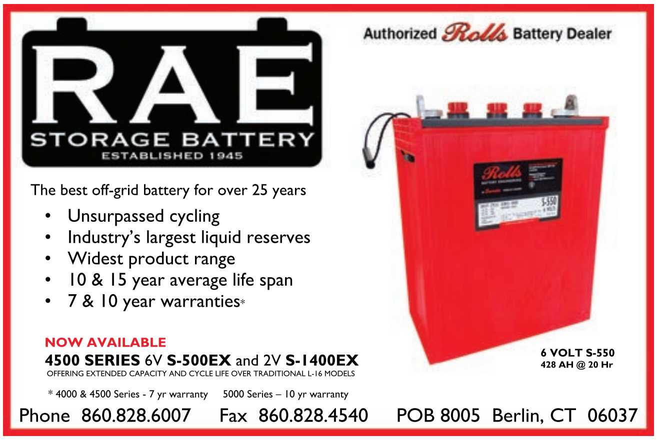
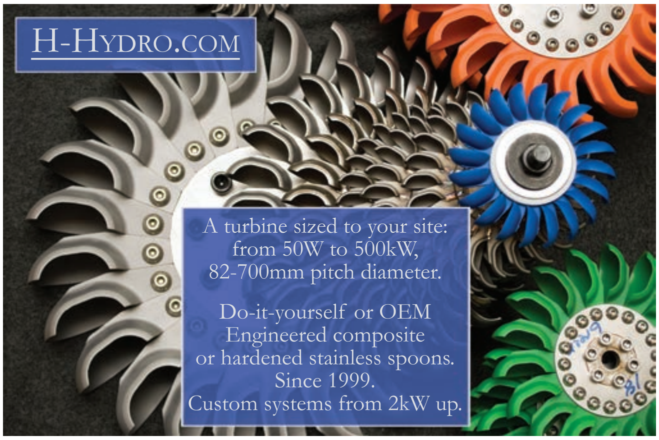
Trojan Battery 3
U.S. Battery.............................11





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Adding Backup to an Existing PV System

While batteryless grid-tied (GT) PV systems are a cost-effective and efficient way to use solar electricity, most cannot provide power for a home if there is a utility outage. This is because all GT inverters have an "anti-islanding" restriction, ensuring that the PV system cannot energize the utility lines for the safety of utility line workers who are working on restoring power. One exception is systems with a secure power supply (SPS) feature available with the SMA Sunny Boy TL-US series inverters, which can provide up to 2,000 watts via a dedicated SPS outlet—not to the grid—but only up to the amount of power from sunlight on the array.

If power outages are not a concern, batteryless GT systems work well. If access to power during a utility outage is important, new equipment and system alteration is needed. Several options are available, and the best fit will depend on the level of backup desired and your budget:

- A small uninterruptible power supply (UPS) can be an affordable option that can work to power small loads during short outages.
- Changing to an inverter with the SPS feature will provide a limited amount of daytime power and may be a workable option depending on how your existing array is configured.
- A backup generator is an option that can offer a range of capabilities and fit a range of budgets; if you don't mind dealing with generator noise, emissions, maintenance, and buying and storing fuel.
- Adding batteries and a battery-based inverter to an existing PV system via AC-coupling is a common solution. The battery-based inverter acts like the grid to trick the batteryless GT inverter(s) into staying live during an outage. This usually requires a significant investment—for the battery bank and a battery-based inverter. It also requires connecting the inverters to a backed-up loads AC subpanel, which becomes isolated from the main service panel during an outage for utility worker safety.
- New hybrid inverters will make the transition from batteryless to a battery-based system easier and more affordable. See "Next Generation Grid-Tied Inverters" in this issue.
- Depending on your goals during an outage (i.e., heating, cooking), non-electric options, such a wood-burning stove, may be more suitable.

—Justine Sanchez

Options for Adding Backup

Installation	Plug-In UPS	Sunny Boy Inverter w/ SPS	Battery-Based PV System	Portable Generator	Permanent Generator
Cost range	$150 – $500	$1,500 – $2,500	$3,000 – $100,000	$500 – $6,000	$5,000 – $20,000
Ease of installation	Easy	Moderate	Moderate to difficult	Easy to moderate	Moderate to difficult
System Operation					
Uses solar during outage	No	Yes, daylight	Yes	No	No
Quiet	Yes	Yes	Yes	No	No
Requires fuel storage	No	No	No	Yes	Depends on fuel
Ongoing fuel costs	No	No	No	Yes	Yes
Maintenance	Replace batts at 5 years	None	Depends on battery type	Engine	Engine
Outage Duration					
Automatic transfer	Yes	No	Yes	No	Yes, slow
Short	Good	Poor	Good	Poor	Poor
Hours-long	Poor	Good, daylight	Good	Good	Good
Weeks-long	Poor	Good, daylight	Good	Good	Good
Load Applications					
Whole-house	No	No	If large enough	If large enough	Yes
Lights & refrigerator	If large enough	Possibly; daylight only	Yes	Yes	Yes
Computer backup	Yes	No	Yes	Maybe	Yes
Personal electronics	Yes	Yes, daylight	Yes	Yes	Yes
Heating systems	No	No	If non-electric	Maybe	Yes

web extras

"Backup Power for Grid-Tied Systems" by Zeke Yewdall *HP 170* • **homepower.com/170.44**

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


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