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Leading the Way

Beginning in 2020, all new residential construction in California must include photovoltaic systems. If the site isn't suitable for solar, investment in community solar projects or implementing extra efficiency measures will be required.

California has once again lived up to its reputation of leading renewable energy into the mainstream and fighting climate change. The California Energy Commission (CEC) decided in May 2018 that all new residential construction will have to include PV systems beginning in 2020. This is the first such state mandate in the United States.

These new additions to California's robust Title 24 standards will affect most of the estimated 117,000 single-family homes and 48,000 multifamily buildings to be built in 2020. This is an amazing step forward for renewable energy, and is a key part of California's efforts to slow human-caused climate change.

Some buildings will be excluded from the mandate, such as those shaded by other buildings or without enough roof space to accommodate solar modules. Excluded buildings will be required to participate in community solar projects or employ additional efficiency methods.

The Commission is also requiring improved building envelope efficiency standards, lighting efficiency standards, and indoor air quality standards, which are necessary as building envelopes get tighter. As *Home Power* readers know, saving energy is every bit as important as how your energy is made. Production methods become irrelevant when kilowatt-hours are not needed in the first place.

These 2020 standards also encourage battery storage systems and other technologies designed to make solar homes more responsive to the grid's needs. Overall, the new standards are expected to result in 30% less energy consumption for the new residences. They will add an estimated average of $40 a month to a 30-year mortgage, but they are expected to produce $80 a month in energy savings.

If you're in a state other than California, hopefully your energy officials and legislators will be following California's leadership in RE and efficiency. It's up to your citizenry to demand these sorts of standards. What can you do to help make them a reality where you live, too?

—Michael Welch,
for the *Home Power* crew

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—Amory Lovins, efficiency expert

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Photos courtesy: Mary & Ken Baker; Simple Construct; Clean Energy Group

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On the Cover

A student from State University of New York-Morrisville climbs the 120-foot guyed lattice tower supporting a Bergey Excel 10 wind turbine.

Photo courtesy Jason Robertson

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Up Front

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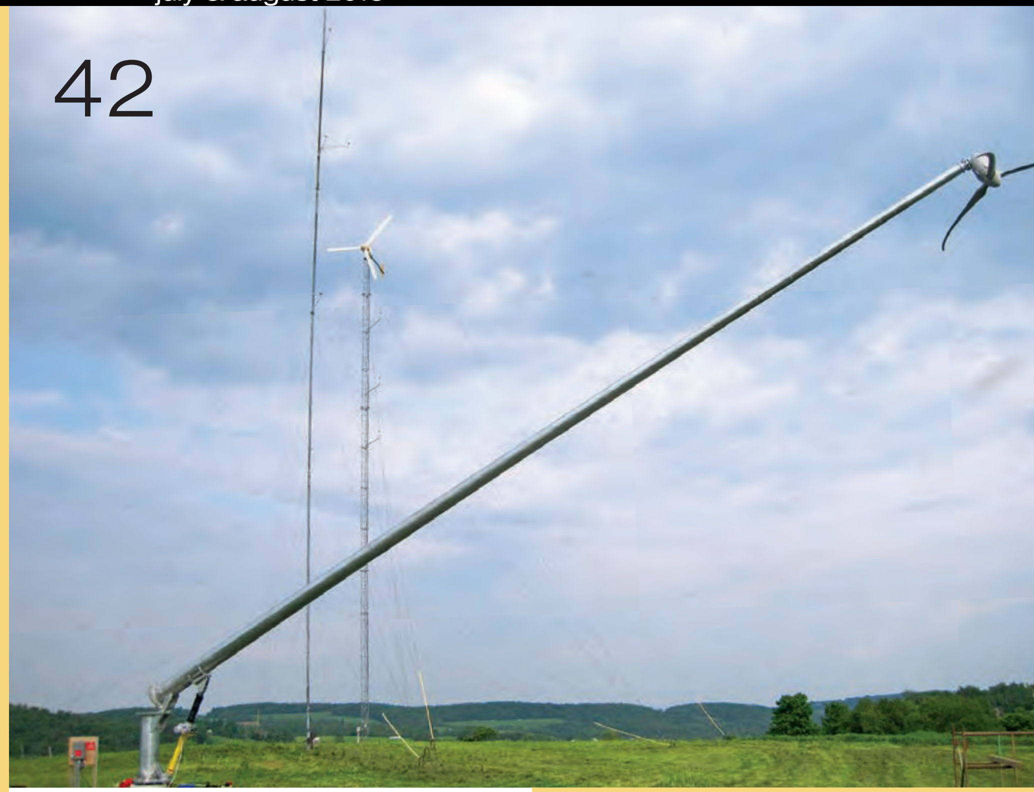

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Photos: Phil Hofmeyer; courtesy IOTA Engineering

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contributors

this issue's experts

James Dontje directs the Johnson Center for Environmental Innovation at Gustavus Adolphus College in southern Minnesota where he supports campus renewable energy sustainability efforts. He also does solar thermal installations as well as energy efficiency and renewable energy consulting.

Sarah Galbraith is a project assistant with Clean Energy Group, where she supports the work of the Resilient Power Project. Prior to joining CEG, Sarah worked for 10 years in renewable energy, including solid biomass, liquid biofuels, and energy efficiency. She is also a freelance writer and communications consultant. Sarah holds a bachelor of science degree in biology from Eastern Connecticut State University.

Phil Hofmeyer lives with his family in a net-zero-energy home powered by PV and a solar hot water/wood gasification combisystem. He teaches courses in PV, small wind, and microhydro-electricity at SUNY Morrisville State College in central New York.

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.

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

Ryan Mayfield is the principal at Mayfield Renewables, a design, consulting, and educational firm in Corvallis, Oregon, with a focus on PV systems. He also teaches online courses in conjunction with *SolarPro.*

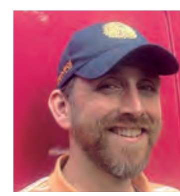
Khanti Munro is the director of development and technical design at Same Sun of Vermont. He is a NABCEP-certified PV installation professional and a PV instructor for Solar Energy International. Munro holds a degree in Renewable Energy Applications from Green Mountain College, and was formerly a technical trainer for SunEdison.

As project director for Clean Energy Group and Clean Energy States Alliance, **Todd Olinsky-Paul** directs the Energy Storage and Technology Advancement Partnership project, a federal-state funding and information sharing project that aims to accelerate the deployment of electrical energy storage technologies in the United States. He also works on Clean Energy Group's Resilient Power Project, which focuses on behind-the-meter solar-plus-storage for critical infrastructure energy resiliency.

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

Rebecca Tasker is a general contractor and co-owner of Simple Construct, a design-build construction company specializing in strawbale building and other forms of carbon-positive building. Simple Construct has been involved in the construction of more than 12 strawbale buildings in San Diego, including the complex at the Deer Park Monastery.

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



Vaughan Woodruff is the president of Insource Renewables, a NABCEP Accredited PV Installation Company based in Pittsfield, Maine. Woodruff has been involved in a variety of efforts within the solar industry, including as an instructor for Solar Energy International and the Department of Energy's Solar Instructor Training Network, as a volunteer on committees with NABCEP, IAPMO, and IREC, and as a technical consultant for various state energy offices.

Home Power senior editor **Ian Woofenden** has lived off-grid in Washington's San Juan Islands for more than 30 years, and enjoys messing with solar, wind, wood, and people power technologies. In addition to his work with the magazine, he spreads RE knowledge via workshops in Costa Rica, lecturing, teaching, and consulting with homeowners.

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IOTA Engineering

IQ Smart Charge Control Modules

Courtesy IOTA Engineering

IOTA Engineering (iotaengineering.com) offers six new "smart" charge control modules to be used with its DLS (Dual-State, Line-Load Control, and Switch-Mode) battery chargers. Different modules are compatible with different battery types or needs—the IQ-LiFePO is suitable for use with lithium iron phosphate batteries; the IQ-AGM and IQ-Gel are designed for absorbed glass mat and gel batteries, respectively. The IQ-Turbo provides rapid charging, the IQ-Equalizer is for equalizing batteries, and the IQ-40hour is for extended bulk charging. These devices connect to the battery charger through a phone-jack-style port. They automatically adjust voltage and current settings for specific battery type or function.

—Justine Sanchez

Eguana Technologies

Evolve Energy Storage System


Courtesy Eguana Technologies

Eguana Technologies (eguanatech.com) introduced its Evolve energy storage system for residential PV systems. It's designed for maximizing self-consumption of on-site PV energy; taking advantage of available time-of-use rates; and providing backup power during utility outages. Evolve integrates a power control system, smart inverter (UL1741-SA listed), battery management system, and LG Chem lithium batteries within two enclosures (NEMA 3R and 4 rated for indoor or outdoor wall-mount installation). The Evolve power rating is 5 kW and its energy storage is 13 kWh, and is expandable up to 39 kWh with two added battery cabinets. Output is 120/240 VAC to be AC-coupled with new or existing grid-tied PV inverters. Online system monitoring via a web browser displays household energy usage and system production data, along with battery state of charge. Battery reserve capacity can be altered through programming—for example, to prepare for expected utility outages due to incoming storms. This product carries a 10-year warranty.

—Justine Sanchez

"Daylight Drive"

I have built a number of houses, and worked a lot with renewable energy systems. *Home Power* has long been one of my go-to sources for inspiration and information. Over the years, numerous friends have asked me to help them install off-grid systems. Some of those systems are on their third, financially painful battery replacement. It seems that off-grid design has standardized around a very poor energy management approach.

Battery degradation costs of $1,000 per year are common in full-power off-grid systems. But our batteries are costing us about $25 per year. My family lives at Living Energy Farm, a community designed to operate without fossil fuel. Our house stays warm in the winter and cool in the summer. I can surf the 'Net, take a hot shower, or drink a refrigerated glass of lemonade anytime I want. Our power has stayed on for eight years now, without interruption, even as our neighbors lose power over and over again in big storms.

Modern off-grid systems try to imitate AC grid systems by having a robust power supply traveling down a single wire to many uses. We have redesigned our relationship with energy at our farm. There is no good reason to treat solar electricity (PV) like AC power. We have tied many needs for energy directly to specific PV power supplies in a mutlilinear system that is inexpensive, effective, and failproof.

Right: Homemade solar hot air collectors on the roofs of the main house and kitchen provide free heat during the wintertime.

Facing: A modern DC motor powers a vintage drill press, PV-direct.

Courtesy Alexis Zeigler (2)

By far, our biggest use of electricity is what we call "daylight drive." We run high- and low-voltage DC motors directly from PV arrays when the sun is out. Sun comes up, motors run; sun goes down, motors quit. It's that simple. The amazing thing about DC motors is that they float wonderfully as power input fluctuates. We can't overload the system. The motors simply speed up and slow down as power fluctuates.

With daylight drive, we cut firewood, process food, and grind grain. We have a fully equipped shop with saws, grinders, a compressor, a drill press, and all of the tools we need to keep the farm running. We also leverage our high-grade energy (electricity)

to store lots of low-grade thermal energy. During the day in winter, our daylight-drive heating blowers pull hot air from the cheap, homemade hot air collectors on the roof and pass it under the floor. Heat stored under the floor keeps the house warm when there is no sun.

We can take all the late-night showers we want (because of our solar water collectors and backup wood-fired heating system). Our well pump is daylight drive, and so are the water-heating pumps and our refrigerator. We have a daylight-drive system for charging electronics. A PV module is tied to a $30 voltage regulator that is tied to a half-dozen cigarette-lighter plugs. We use "car chargers" to charge laptops, smartphones, DVD players, and whatever electronic entertainment our guests may bring. Like our other systems, it all floats with the changing weather. None of these systems are dependent on a centralized battery bank.

With most of our electrical load shifted to daylight drive, including basic needs like heating, cooling, and water supply, we store electricity in a centralized battery bank only for DC LED lighting. The problem with conventional design is that it demands powerful, disposable batteries. With a much-reduced need for electrical storage, we are free to use very durable nickel-iron (NiFe) batteries. Miraculously, this ancient battery still works! Since we put in NiFe batteries, our lights have never faded, even when we go through weeks of cloudy weather in the winter. The NiFe batteries tolerate huge voltage swings—and even full discharge—with no damage to the battery. The comparative amp-hour ratings between different kinds of batteries, so we have learned, are essentially meaningless. Our NiFe battery set is seven years old. With little attention, they are showing no signs of fatigue.

We live well with an off-grid design that is cheap, effective, and durable. We hope that in the years to come, we can help more and more people do likewise.

Alexis Zeigler • Living Energy Farm,
Louisa, Virginia

write to:

mailbox@homepower.com

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

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

Microhydro Flow

My family is considering installing a microhydro-electric system to power our remote cabin. We plan to use a 3-inch penstock (approximately 900 feet long) with 85 feet of head. Can a theoretical flow rate be calculated from these figures? The upper end will be submerged in a pond/creek and the water returned to the same creek.

We would prefer a batteryless AC system. This is a joint project with a neighbor. His part of the deal is installing the penstock; ours is selecting a hydro turbine. I keep telling him that the penstock has to come first so we can measure the pressure and flow. He wants me to "just buy a turbine" and says we'll make it work. Can these figures be estimated given the information above, or should we install the line first and measure directly?

Rob Day • via email

Measuring head and flow are critical design jobs that should be done before any equipment is specified or purchased. Deciding on the penstock diameter without solid head and flow measurements could lead to wasted money or lost power. While both these measurements are more easily done with an installed pipeline—a pressure gauge for head, and a bucket and stopwatch for flow—you really need to know them in advance to choose the right pipe and size. Buy a pipe that's too small and you could lose most or all of your power to friction loss; buy one that's too large and you will waste money.

Once you have determined head, flow, and pipe length, consult friction-loss tables for the pipe type you choose. Next, you need to decide if the pressure (head) loss is acceptable. People typically accept a head loss between 15% and 25%. I personally favor lower losses, since the pipe cost is a one-time purchase, and the head loss is forever.

Ben Root

Measuring flow, one of the two key components of determining available hydro power.

So instead of starting by specifying a pipe diameter, get some data and examine possible scenarios: "With 3-inch pipe, we'll spend $X,XXX and lose YY% of the potential from friction loss. With 4-inch pipe, we'll spend $X,XXX but only lose XX% of the potential."

See our many microhydro articles for more on this and other aspects of system design. For instructions on how to measure your hydro resource, see **homepower.com/104.42**.

If you're providing electricity for a conventional house or two, I'm doubtful, with that head and pipe size, that you'd get the power necessary for a stand-alone AC system. Your system would need to produce more than 2 kW of power to provide for the loads of a typical house. Stand-alone AC systems are limited in peak power, which equates to how many loads you can run simultaneously. Again, do the math first, and decide what system configuration is most appropriate.

Ian Woofenden • *Home Power* senior editor

Drainback Pumps

Thanks for James Dontje's article about his home drainback solar water heating system ("Designing a PV-Powered Drainback Solar Hot Water System" in *HP120*). Along with that information, Gary Reysa's affordable drainback systems at builditsolar.com have inspired us to implement a similar project at our home.

Our grid power has been reliable, but it's getting pricier, and we also recognize its myriad externalized costs. Before we install the solar thermal system, we're planning to install a PV system with battery backup to cover crucial loads (2 kWh per day) and reduce our fossil-fuel footprint.

One of those crucial loads would be the drainback pump, which would likely need to be AC to handle 25 feet of head. Could you recommend an energy-efficient variable-speed or low-flow AC pump that would meet this need? Also, how could we estimate the watt-hours needed to run an AC pump with 25 feet of head? Or should we consider piggybacked DC pumps to get the job done?

Jonathan Bentley • Bryson City, North Carolina

To make a lower-power (and lower-cost) drainback system, one strategy is to strategically locate your drainback tank to reduce the pump's head requirements. The system in the article served a two-story house—the hot water storage tank was a little below first-floor level, in the garage, and the drainback tank was suspended from the ceiling in a second-floor bathroom, which reduced the pump head by more than half. The pump was located at the level of the storage tank in the garage. The pump needs to be low enough that it can never pull in air when the drainback tank fluid is low. At a minimum, it needs to be at least a couple of feet below the bottom of the drainback tank.

Piggybacking either DC or AC pumps is an effective strategy to achieve the required head and to reduce energy use. In a drainback configuration, once the fluid is "over the top" and flowing out of the collector, pumping head requirements drop. The fluid on the down leg creates suction that balances the force needed to lift the water to the collectors. At that point, the pump only has to overcome pipe friction losses. If two pumps are piggy-backed, both pumps are run together for only a minute or so—long enough to get flow established—then the second pump is turned off. A delay timer relay will power the second pump for the user-adjustable time interval before shutting it off and letting the main pump carry the load.

Measuring the pumping energy required is a little tricky. Pumps have a rated power, but depending on the configuration, may use a bit less power than their rating. For sizing your power source, use the rating, but remember that there will be a current surge at startup. Your PV system's inverter will need to handle this surge. Most inverters can operate at double their rating for a short period of time—long enough for a motor to start up—but you'll need to verify this specification (usually called "peak" or "surge" power). For overall daily energy consumption, multiply the pump's rating by its run time during a 24-hour period. Pump run time can be hard to estimate for a solar thermal system as it depends on both the amount of sun and the temperature in the storage tank. You can use a location's average daily sun-hours to estimate the high end of a pump's energy consumption.

To choose a pump with suitable fluid flow capacity, examine its performance or pump curve, which shows flow versus pressure or head. For example, the pump curve for the Taco 009 pump shows it that can pump 5 gallons per minute at 25 feet of head. Be conservative in your choice—do not ask a pump to perform at its maximum—its "operating point" should be in the middle of the curve.

European energy-efficiency standards have pushed the U.S. market, too, driving the development of efficient pumps with lots of onboard adaptive electronics that can vary pressure and flow. For example, my home heating system (which heats a 2,400-square-foot house) runs on a very efficient 45 W pump. While this pump is a bit underpowered for rapid response, it can deliver enough heat to maintain comfortable indoor temperatures, even at outdoor temperatures of -20°F.

One key pump-choice consideration is whether your drainback loop is sealed or open to the atmosphere. Most circulating pumps are made of cast iron, which can introduce corrosion to the system. As long as the pump loop is sealed, the supply of oxygen is limited and corrosion is low. But with a constantly refreshed oxygen supply in an open-atmosphere situation (for example, a system draining into an unpressurized, open tank), corrosion is a concern. In that case, select a brass or stainless-steel pump housing. If your drainback loop is sealed (and many are), you can stick with the cast-iron pumps.

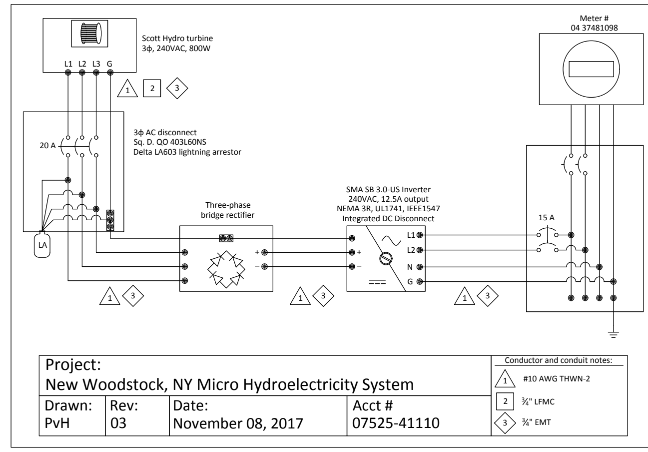
James Dontje • Johnson Center for Environmental Innovation, Gustavus Adolphus College

Microhydro System Permitting

I read "Grid-Tied Microhydro in New York State" (*HP183*) and am curious about required permits for microhydro systems in New York, where I live, and your dealings, if any, with local building inspectors, as well as state and federal regulators. The stream on my property is apparently too small to be of concern to state environmental authorities, but what has been your experience dealing with regulators?

David Noland • via email

All energy systems require permits from government agencies. Even off-grid systems are held to *National Electrical Code (NEC)* standards and are subject to inspections from local authorities having jurisdiction (AHJs). I've found that obtaining permits for microhydro-electricity systems can be particularly difficult. Because of these challenges, many renewable energy installation companies shy away from installing microhydro systems (and many DIYers fly under the radar, hoping to avoid being caught). Here are some tips for navigating a smooth path through a successful permitting process.



Courtesy Phil Hofmeyer

Unlike PV systems, hydro permitting can require a three-line (rather than one-line) wiring schematic.

My experiences permitting microhydro systems have been limited to New York State. Other state and local guidelines may differ, but there are enough similarities to draw parallels. Because microhydro systems are custom designs, you may experience a different permitting process for each system.

- Draw a site plan and three-line electrical diagram of the system
- Obtain an electrical permit from the town or county building or planning department
- Submit information for other required permits and applications. These may include: an application to your local utility for interconnection, state environmental permits, and Federal Energy Regulatory Commission permits.

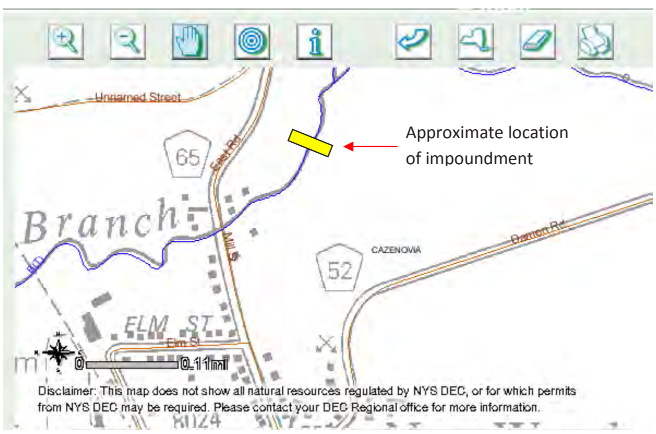
Electrical Permits. Because these are electrical systems, all raceways, conductors, power electronics, and balance-of-system components must be installed according to *NEC* guidelines. The first four chapters of the *NEC* apply to all electrical installations; the later chapters address special scenarios. There are specific sections for PV (Article 690) and wind (Article 694), but none specific to microhydro systems. Since microhydro systems function similarly to small wind systems—with diversion controls and loads for turbine control—Article 694 can be used as a working document for *NEC* compliance.

Because microhydro systems are rare, I generally spend more time during an inspection explaining the system and how it operates than defending some particular nuance of the installation. At the inspection, I hand the inspector an "as-built" three-line diagram—and wait for questions to arise.

The three-line diagram may also be submitted as part of a packet for the local utility, if you intend to grid-tie your microhydro system. In New York, the Public Service Commission (PSC) regulates interconnected devices operating in parallel with the grid. Form K and Appendix B of the Standard Interconnection Requirements require a line diagram, inverter commissioning procedures, the inverter's UL 1741 compliance documentation, a site map, a disconnect plan, and specification sheets for the inverter and microhydro turbine. Many of these documents will be used for obtaining environmental permits as well.

Environmental Permits. In New York, streams fall under the purview of the New York Department of Environmental Conservation (NYSDEC). Under the State Environmental Quality Review (SEQR) Act, the NYSDEC requires an Environmental Impact Assessment for

Aerial image of a site, with the existing dam, wheelhouse, and location of the proposed turbine.



Phil Hofmeyer (2)

Environmental Resource Mapper image of the site.

all microhydro systems. During the project's design phase, I generally contact the NYSDEC and speak with their wetlands permitting staff. Like me, they are interested in preserving water quality, but many also have a bent toward sustainability and renewable energy. I have found them to be willing to walk a site with me to discuss intake and tailrace locations, as well as identify potential penstock corridors. Immediately after walking a site, I complete an Environmental Assessment Form (EAF), using NYSDEC's GIS-based online EAF mapping tool. The output from this mapping tool is a three-page EIA form that provides information regarding the site's threatened or endangered biota, wetland status, and other critical environmental variables. Completing the form requires property tax map parcel data, a project narrative, and the project's interactions with the water body (e.g., water extraction, discharge, and excavation activities).

In addition to the EIA form, the Environmental Resource Mapper (ERM), another GIS-based interactive tool, must be used to create a report that provides an overview of the water body standard and classification, the site's National Wetlands Inventory categorization, and identification of rare or endangered biota. If the site is designated a "C(T)" or higher (designated as "protected streams"), a Joint Application Form (JAF) must be completed. The JAF must include site photos and detailed narrative describing stream bank disturbances, fill or excavations, erosion mitigation plans, and sequence of construction activities. Using the proper terminology is important (for example, "banks" may have a very specific definition related to high water lines). The JAF is concurrently submitted to the NYSDEC, the Army Corps of Engineers, the Office of General Services, and the Department of State.

FERC Permits. The last hurdle for microhydro permitting also tends to be the highest. The Federal Energy Regulatory Commission (FERC) regulates all hydropower installations, with little distinction between multi-MW and sub-kW systems. FERC has jurisdiction over navigable waters and their tributaries (which translates to every stream in the United States) and grid-interconnected systems. FERC's Low Impact Hydro program is partitioned into several regions of the United States, with a single contact for all correspondence within the region. Visit the FERC "tips" website to find your region's contact person. There are many documents on the FERC page that provide permit process information. At a minimum, you'll need to submit:

- State fish and wildlife permitting documents
- A complete civil drawing and narrative that details the intake, penstock, power house, and tailrace, including dimensions and materials
- A full electrical diagram with a narrative describing the system's overspeed control and operation at varying water levels
- Full engineering drawings (both plan and profile) of any impoundments affected by the project
- Civil and electrical site maps.

Many of these materials have been produced during the previous steps—you'll just need to assemble them all together. FERC often takes months to issue permits—microhydro systems are not simply shrugged off and FERC staff must work with you to make sure their requirements are satisfied.

Phil Hofmeyer • Associate Professor of Renewable Energy, SUNY, Morrisville, New York

web extras

NYSDEC • **dec.ny.gov**

NYSDEC EAF mapper • **dec.ny.gov/eafmapper**

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

NYSDEC Joint Application Form • **bit.ly/JointForm**

FERC information on small hydro systems • **bit.ly/SmallHydroFERC**

FERC application tips for microhydro system s • **bit.ly/TipsFERC**

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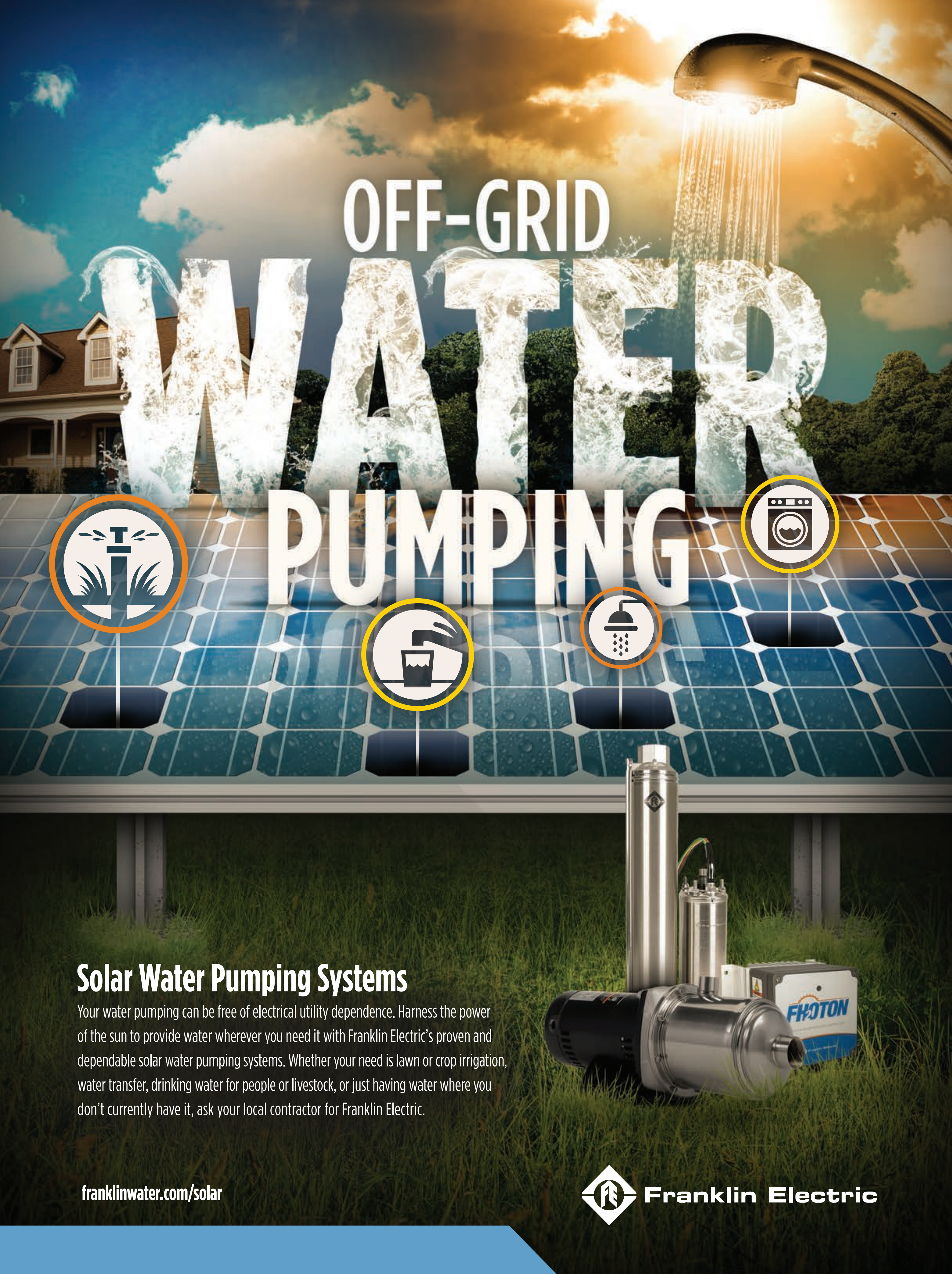
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Home, Business & Grid RESILIENCY

BATTERIES REQUIRED

by Justine Sanchez

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According to Eaton's *Blackout Tracker—United States Annual Report 2017*, the number of people affected by utility outages more than doubled from 2016 to 2017, from 17.9 to 36.7 million. The report details the causes of these blackouts—from large-scale disasters, such as hurricanes and wildfires, to much smaller incidents, involving bees, bears, and chickens. But no matter what the cause, the events illustrate the vulnerability of our grid to outages.

Impacts of power outages range from being inconvenient to life-threatening. Outages at home may result in dark nights, lost communications, and, depending on the climate, overheated occupants and spoiled food, or frigid rooms and frozen water pipes. For businesses, power loss can mean significant lost revenue, whether due to unsellable spoiled products or lack of operating phones and computers to process orders and shipping. Utility outages can jeopardize the operations of hospitals, schools, fire and police stations, and even water systems and wastewater treatment plants.

Having a PV system—whether that's on a home or a business's roof, or out in a field—doesn't necessarily provide protection against losing power. The majority of PV systems are batteryless grid-tied that rely on utility power to operate. Grid-tied solar-electric systems are great for reducing utility bills and generating clean energy, but unless there are batteries integrated into the system, they will not be able to store solar energy for backup during utility outages—even during sunny weather.

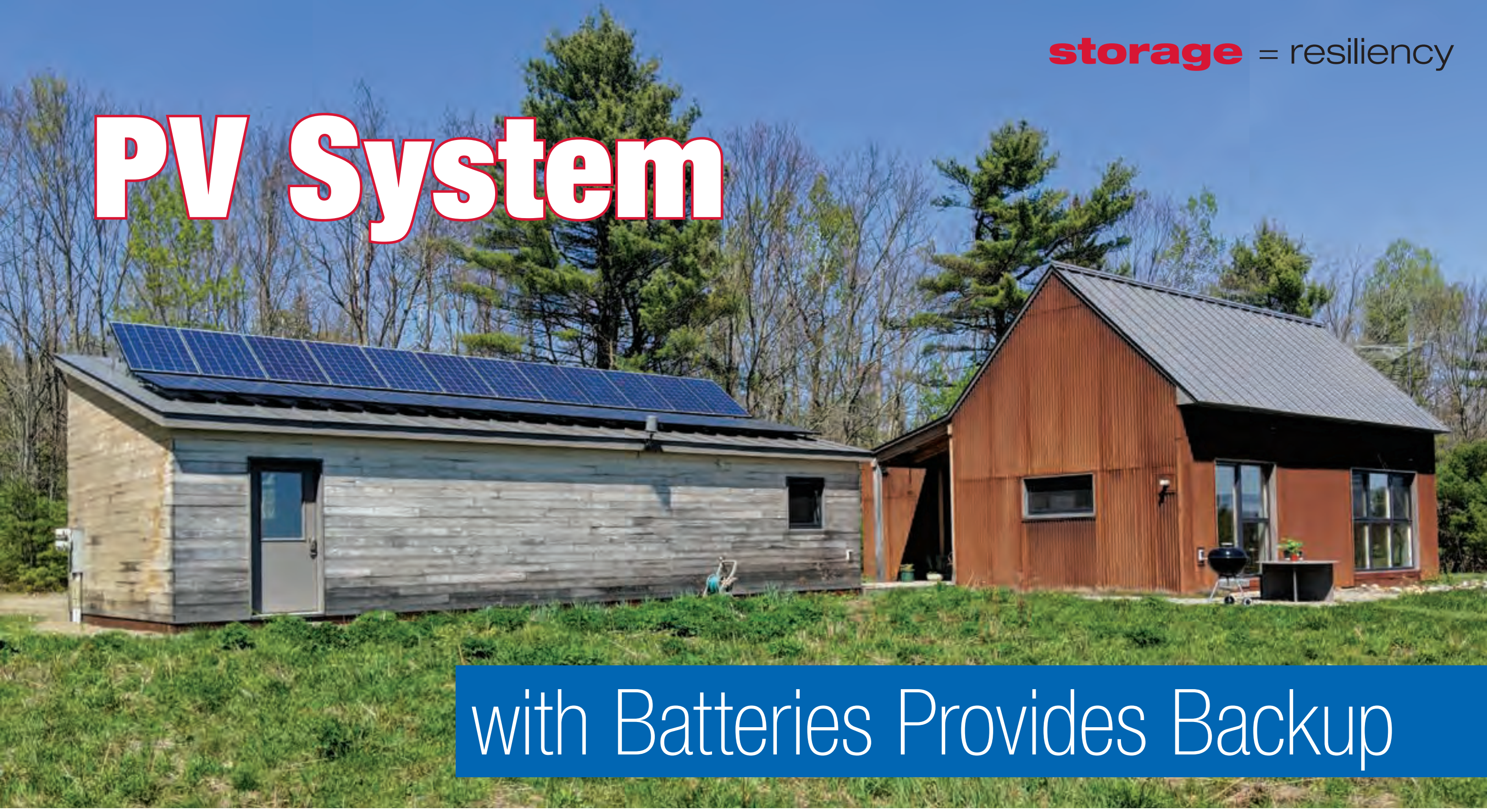
This article illustrates how battery-based PV systems for residential, commercial, and utility-scale markets are addressing resiliency for each of these sectors.

Financial Incentives for Energy Storage

Energy storage adds backup capability to our RE systems, but it also adds cost. In addition to batteries, other costs are incurred, such as for power electronics (inverter/chargers and charge controllers), battery containers, cabling, disconnects, overcurrent protection, metering, shipping and taxes, and installation labor. A 30% federal tax credit can be claimed if the energy storage equipment is installed as part of a PV system. The catch is that the PV system (not the grid) must be charging the batteries to apply the full tax credit. You cannot just charge those batteries from the grid (say during a low rate period) and then discharge back onto the grid when rates are high if you want to claim the tax credit. Stipulations allow charging from the grid to account for up to 25% of the battery's total capacity, but the tax credit will be reduced proportionately.

California's investor-owned utilities—Pacific Gas & Electric, Southern California Edison, and San Diego Gas & Electric—offer cash rebates via the Self Generation Incentive Program (SGIP) for energy storage. While rebates can approach $400 per kWh for the first 10 kWh of capacity, the exact amount depends on which utility and which program "step" they are at. Maryland offers state tax credits for energy storage—up to $5,000 for residential systems and up to $75,000 for commercial systems. And a few other states such as Nevada and Massachusetts are in the process of developing energy-storage incentive programs, as well.

PV System with Batteries Provides Backup



by Sarah Lozanova

The Rectors' passive-solar, energy-efficient home, with a 6.48 kW PV system and battery backup, weathers power outages with grace and comfort.

In January 2018, Maine homeowners Eric and Alison Rector learned that a "bomb cyclone" was pummeling much of New England. The couple was on vacation in Mexico, and they soon discovered that many people in their home region were without power. Yet Eric and Alison took comfort that their high-performance house in Monroe, Maine, was protected from freezing pipes and would continue to have running water for the pet sitter. Their home features a dynamic combination of energy efficiency and a grid-tied 6.5 kW PV system with 20.5 kWh of battery backup.

The Rectors' PV system also provided the support they needed during a six-day power outage last October. "Our 48-volt battery bank gives us running [well] water, space heating, ventilation, lights, and electricity for some appliances," says Eric. "If our PV system didn't have batteries, we would be stuck with no power during grid outages."

Weathering the Storms with PV Power

Sundog Solar of Searsport, Maine, designed the PV system in 2014 to work both on and off the grid. Twelve Canadian Solar PV modules wired to a Schneider Electric charge controller charges a Surrette battery bank and the Conext XW 6048 inverter/charger sends surplus electricity to the grid. "I call the Conext XW 6048 'the magic box' because it seamlessly transitions between being on- and off-grid," says Eric. "The 'magic box' keeps the battery bank full at all times when there is grid power. During outages, there is no need to switch anything manually. All of our critical loads stay powered and, during a sunlit day, the PV system charges the batteries until the grid power returns."

When a second array of 12 Canadian Solar PV modules was added to the array last year, the system started generating enough electricity to power the home throughout the year and charge their 2017 Chevy Volt plug-in hybrid-electric vehicle (PHEV). Eric and Alison can drive the car about 50 miles on a solar charge before it has to utilize the gasoline engine.

A Conext XW6048 inverter and eight Rolls Surrette S-550 flooded lead-acid batteries provide more than 10 kWh of backup at 50% depth of discharge.

Courtesy Eric & Alison Rector (2)

Courtesy Eric & Alison Rector

The recently added 3.3 kW of PV capacity help charge the Rectors' Chevy Volt for more sustainable transportation.

On sunny days, the PV array produces more than enough electricity for Eric and Alison to use in their home. On cloudy days and at night, during an outage, they are conservative and limit their consumption to about 8 kWh from the batteries to keep the batteries well above a 50% depth of discharge.

Efficient Design Saves Energy

The Rectors' home was designed and constructed by GO Logic and is built to the Passive House standard, a stringent German certification for energy efficiency. Passive House homes typically use 90% less energy for heating and cooling than a conventionally built home.

The 1,100-square-foot home is heated by a combination of electric baseboard heaters and one through-the-wall propane heater, an Empire direct-vent, 20,000 Btu-per-hour model. That heater is connected to a Nest thermostat that tracks its use. Despite living in a cold climate, the couple used fewer than 1,000 kWh and about 35 gallons of propane to heat their home last year. An on-demand propane water heater is used for heating domestic water.

The house features passive solar orientation and south-facing glazing to maximize heating through solar gain. There are generous amounts of insulation in the slab, walls, and ceiling. Triple-pane windows and doors and meticulous air-sealing minimize air exchange between the interior and exterior of the home, eliminating drafts and wasted heating and cooling energy. Because the home is nearly airtight (a requirement of the Passive House standard), a Zehnder heat recovery ventilation system supplies fresh, filtered air to the living room, office, and bedroom.

An Unstable Power Grid

Maine ranks a dismal 49th in power grid reliability, according to the U.S. Department of Energy. As long-term residents of rural Maine, the Rectors are no strangers to power outages, even multiday ones. "The power goes off monthly, perhaps for just an hour or so," says Eric. In the 1998 ice storm, when the Rectors lived in a neighboring house, the power went out for 11 days.

With a home office, even a short power outage can be highly disruptive. And when the grid is down, Eric and Alison still have to forgo a few luxuries, such as use of the wall oven, stovetop induction range, ice-making half fridge, and washing machine. But in a pinch, they know they can hand-wash and line-dry clothes, and use the patio grill or a portable gas burner for cooking meals. Outside of those constraints, the home and office are unaffected by outages—the priorities are space heating, lights, hot and cold running water, and air circulation. If the couple is away from home, a Nest thermostat alerts them of power outages and monitors indoor temperatures and will turn on the electric baseboard heat that can be powered from the batteries for greater peace of mind.

Residential Tech Specs

Overview

Project name: Rector home

System type: Grid-tied PV with batteries

Installer: Sundog Solar

Date commissioned: September 2014 (original array); May 2017 (second array)

Location: Monroe, Maine

Latitude: 44.6°N

Solar resource: 4.7 average daily peak sun-hours

Average monthly PV production (estimated): 660 AC kWh

Utility electricity offset annually: 100%

Photovoltaics

Modules: 24 modules: 12 Canadian Solar 265 W; 12 Canadian Solar 275 W STC, 31 Vmp

Array: Two series strings: 12 modules each; 6,480 W STC total, 372 Vmp

Array installation: IronRidge mounts installed on south-facing roof; 20° tilt (lower array), 35° tilt (upper array)

Energy Storage

Batteries: 8 Rolls Surrette flooded lead-acid S-550 batteries, 6 VDC nominal, 428 Ah at 20-hour rate

Battery bank: 48 volts VDC nominal, 428 Ah total

Balance of System

Charge controller: Two Schneider Electric MPPT, 80 A, 600 V

Inverter: Schneider Electric Conext XW6048, 48 VDC nominal input, 120/240 VAC output

System performance metering: Schneider Electric Conext meter

Vermont Solar Plus Storage

by Khanti Munro

Above: The Same Sun storefront with a 4.1 kW PV array awning.

Below: The Pika X11400 Islanding Inverter with Pika/Panasonic Harbor Smart "Flex" lithium-ion batteries provide 11.4 kWh of usable backup.

Courtesy Same Sun (2)

As Same Sun of Vermont, a solar design and installation company, approached its seventh anniversary, it was clear the business had outgrown its offices. The headquarters were moved to another location, three to four times larger, in downtown Rutland. The larger space allowed more offices and a conference room, and an equipment and showroom space.

In addition to featuring existing products and installation techniques—PV modules, inverters, racks, and wire management—the Same Sun team also wanted to showcase new technologies and their custom applications, in a real-world application. The new building did not have a viable south-facing rooftop, so Same Sun engineered and fabricated a façade-mounted PV awning. The south-facing 4.1 kW array provides an aesthetically pleasing covered entryway and blocks the high summer sun from overheating the offices through the large south-facing windows. To help mitigate surrounding shade from utility poles and city buildings across the street, Pika Energy's string-level optimizers were used.

With steady customer inquiries about battery storage and an increasing frequency of severe weather-related outages, testing one of the emerging lithium-ion batteries at the new headquarters seemed like a win-win solution. The system would provide backup power to the company's essential loads, while also demonstrating a new solution for homeowners interested in backup power.

Left: The custom PV awning serves two functions: providing shade for the lower windows and generating energy.

Right: The Pika Energy inverter display showing backup power being used during a grid outage.

Courtesy Same Sun (2)

The financial argument for battery storage—especially in Vermont with its relatively progressive net-metering policy—is still difficult to justify for the typical homeowner. The reality is that both the climate and net-metering policy are changing, and not necessarily in a positive way. Compared to an engine generator, a "solar battery" has a potentially unlimited fuel supply, is quiet and automatic, and can help with both backup power and net-metering limitations, as is now becoming common in other states.

Same Sun chose the 11.4 kWh Harbor Smart "Flex" Battery by Panasonic, paired with the Maine-manufactured 11.4 kW Pika Energy Islanding inverter. The design goal was a full eight-hour "office day" of backup power for core company operations, even if the sun wasn't shining on the array. "Essential loads" were determined based on office-utility and employee preference—phone and Internet devices; computers; conference room LED lights and outlets for laptop recharging; the refrigerator and microwave' LED lighting above the battery; and a double-sided illuminated company sign. The selected circuits were rewired into a backed-up loads subpanel, which is fed by one of the Pika Inverter's AC outputs. Current transducers were added to the main distribution panel to enable the advanced inverter functions, such as self-consumption and zero-export.

In the first three months of the system's operation, all has worked smoothly. At the first company event in the new space—a local "Young Professionals Mixer"—the battery system provided electricity for the three-hour evening event in self-consumption mode, using only the day's stored sunshine. In May, a four-hour-long power outage shut down the city block. Thanks to the battery backup, the Same Sun offices remained open. With the phones still ringing, and computers up, the lighted conference room accommodated a new customer who came in during the outage to sign a contract for a new PV system.

Commercial Tech Specs

Overview

Project name: Same Sun of Vermont Headquarters

System type: Grid-tied with battery backup

Installer: Same Sun of Vermont

Date commissioned: March 2018

Location: Rutland, Vermont

Latitude: 43.6°N

Solar resource: 4.41 average daily peak sun-hours

Average monthly production: 425 AC kWh

Utility electricity offset annually: ~75%

Photovoltaics

Modules: 13 Panasonic N315K black, 315 W STC, 70.2/58.4 (Voc/Vmp), 5.83 / 5.4 A (Isc / Imp)

Array: Three DC optimizer output circuits (4, 4, 5), 4.095 W STC total; array installation: custom-fabricated awning mount installed on 174°-facing wall at a 30° tilt

Energy Storage

Batteries: Pika/Panasonic Harbor Smart "Flex," 380 VDC, 11.4 kWh (usable), lithium-ion (NMC)

Balance of System

Charge controller: N/A

Inverter: Pika X11400 Islanding Inverter, 380 VDC nominal input, 208 VAC three-phase output, 120/240 VAC 1PH backup output

System performance metering: Pika Review Dashboard

Sterling Municipal Light Department

Energy Storage System

Courtesy Sterling Municipal Light Dept.

by Sarah Galbraith & Todd Olinsky-Paul, Clean Energy Group

Adapted from "Resilient Power Project Case Study: Sterling Municipal Light Dept."

Sterling Municipal Light Department (SMLD) is a municipal utility serving the small New England town of Sterling, Massachusetts, with 3,700 residential, commercial, municipal, and industrial customers. In 2013, with a total of 3.2 megawatts (MW) of PV array capacity installed, SMLD had the most solar watts per customer in the country, with PV power accounting for approximately 30% of SMLD's peak load.

At this high level of grid penetration, the variable nature of PV generation began to cause problems (such as clouds and snow cover reducing system output). Additionally, the costs of capacity and transmission services, based on SMLD's power purchased from the grid operator, were rising dramatically, increasing from $500,000 in 2010 to $1.2 million in 2017. SMLD needed a new strategy to smooth the output of its PV generation and control rising costs linked to the utility's share of regional demand peaks.

PV-Plus-Battery System

The Town of Sterling was considering adding a natural gas peaker plant to avoid rising capacity costs at its Municipal Light Department. But this idea was abandoned when the

Here, 3.9 MWh of lithium-ion batteries provide load balancing and emergency backup for municipal services.

Courtesy Clean Energy Group (2)

The storage system is housed in a climate-controlled shipping container at the Chocksett Road substation.

Courtesy Clean Energy Group

Critical services, like the police station and emergency dispatch, are backed up by the system, which can detach from the greater utility grid during outages.

option of energy storage presented itself in the form of a grant program—the Community Clean Energy Resiliency Initiative offered through the Massachusetts Department of Energy Resources. The grant program, initiated after Hurricane Sandy hit the Northeast, was designed to support resilient municipal clean-energy systems. The town had also been hit by an ice storm in 2008, which left residents without power for about 14 days. Energy storage presented an attractive strategy for leveraging the town's solar resources, adding resiliency for critical infrastructure, and controlling rising energy costs. A 2 MW, 3.9 megawatt-hour (MWh) lithium-ion battery storage system was installed at SMLD's Chocksett Road Substation in October 2016.

The system is designed to "island" from the grid during a power outage and, with the support of an existing 2 MW of PV generation, can provide at least 12 days of backup power to the town's police station and dispatch center. The substation, the PV field, and the police department are all on the same electrical feeder, which can be isolated to create a microgrid in the event of a grid outage.

Energy Storage Economics

A key benefit of the project was to demonstrate and analyze the economic case for using battery energy-storage systems, and to identify potential benefits and value streams from electrical energy storage. A white paper analysis, "The Value Proposition for Energy Storage at the Sterling Municipal Light Department," was completed in early 2017, led by the DOE's Office of Electricity and Sandia National Laboratories. Economic benefits considered in this analysis included: energy arbitrage, frequency regulation, reduction in monthly network load, reduction in capacity payments to ISO New England, and grid resiliency.

Based on this analysis, SMLD expects the battery, which cost $2.52 million, to save at least $400,000 per year over the project's 10-year lifespan, which is significant for a small municipal utility with an annual budget of $8.2 million. The battery was commissioned in December 2016 and, in the first year of operation, savings came within $1,100 of the $400,000 annual projection. The economic case proven by SMLD's battery system has been noticed by other municipal utilities and electric cooperatives in New England, several of which are planning to install their own battery systems.

The financial value of "resilience" is difficult to estimate, since it depends on the severity of future weather events and grid outages. Using several assumptions, the DOE/Sandia report valued this benefit at $40,819 per grid outage event—based on the value of lost services for a typical commercial consumer due to grid disruptions and did not account for improved public safety or health, which the SMLD system will provide by supporting the town's police and dispatch services.

The value of renewable integration is also difficult to quantify. Approximately 35% of SMLD's generation comes from renewable sources. Prior to installing the energy-storage system, SMLD had declared a moratorium on additional variable generation, due to concerns about power possibly backfeeding onto the transmission system. Because the battery can buffer the system, as well as contribute to grid stability and reliability by providing voltage support to variable power sources like wind and solar, SMLD is now considering adding more variable renewable generation to its grid. Based on the success of its Chocksett Road Substation installation, SMLD is working on a new energy-storage project in conjunction with a community PV installation.

Utility Tech Specs

Owner: Sterling Municipal Light Department

Location: Chocksett Road Substation, Sterling, Massachusetts

Equipment: 2.2 MW, 3.9 MWh lithium-ion battery, installed on feeder with existing 2 MW solar electric system

Installed cost: $2.52 million

Payback: 2.5 yrs. (6.3 without grant funds)

Services provided: Capacity and transmission cost management, energy arbitrage, and backup power

Supported infrastructure: Police station and dispatch center for emergency response

Battery vendor: NEC Energy Solutions

Project partners: Sterling Municipal Light Department; Massachusetts Department of Energy Resources; U.S. Department of Energy: Office of Electricity; Sandia National Laboratories; Clean Energy Group; Clean Energy States Alliance; and Barr Foundation

PV & MSHP
A Case Study

All photos courtesy Mary & Ken Baker

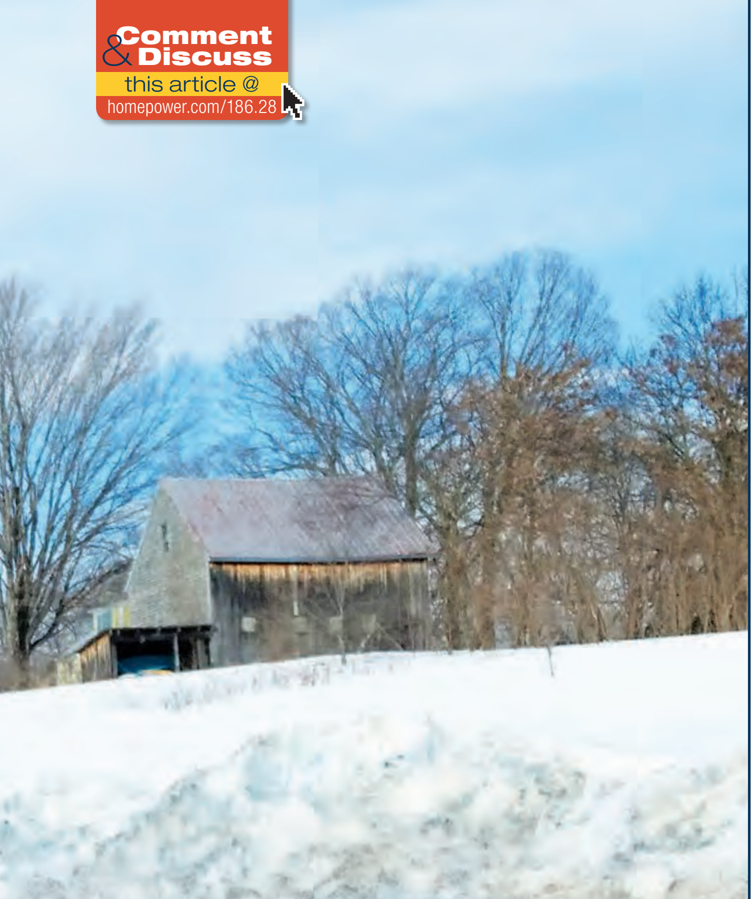
by Vaughan Woodruff

In 2016, Mary and Ken Baker of Norridgewock, Maine, constructed a new home intending annual net-zero energy use. The two-story, 26-by-30-foot timber-framed home was built with structural insulated panels (SIPs) on an insulated concrete slab.

This tight, well-insulated envelope included triple-glazed windows and high-effiency doors, and a heat recovery ventilator (HRV) to preheat fresh incoming air for good indoor air quality. In addition, other good efficiency choices such as LED lighting and Energy Star appliances were selected. Their previous home was an old farmhouse that required significant amounts of oil and wood to heat. After years of handling large quantities of cordwood, the Bakers' initial goal was to use no more than one cord per year to heat the home as they transitioned to a less labor-intensive lifestyle.

In the design process, several options were explored to generate the heat necessary to maintain comfort in the cold Maine winters. The south wall of the home was designed to collect passive solar heat. As the Bakers' understanding of indoor air quality and heating demands increased, it became clear that there might be alternatives to using their woodstove that would still accomplish their goal of carbon neutrality.

The home's floor plan allowed using a single-zone heat pump on the first floor. An open stairwell to the second floor distributes heat upstairs. Minisplit heat pumps (MSHPs) were not considered an acceptable primary heat source by their lending institution for home loan purposes, so electric baseboard heaters were placed in bedrooms, bathrooms, and in the kitchen to satisfy the lender. For homes in cold climates, smaller, dedicated heating appliances help maintain comfort in areas of the home where heat distribution from the MSHP may be challenging or in regions where the MSHP's capacity is lower than the winter heating demand.



Design Heat Loss

The design heat loss—how much heat a home requires given a specific outdoor temperature—was calculated via *Manual J*, which accounts for insulation; air infiltration; the surface areas of the windows, doors, walls, floors, and ceilings; and design temperatures. For this home, the design heat loss was estimated to be 16,800 Btu/hour at an outdoor temperature of -5°F. Design temperatures can be obtained for many locations from the "Degree Day and Design Temperature" table from the *International Plumbing Code* (see "Web Extras").

Heating Capacity

We wanted to ensure the selected MSHP would maintain comfort throughout the heating season. A Fujitsu 15RLS3H unit, which can effectively move heat at outdoor temperatures as low as -15°F and can maintain comfort in this home at outdoor temperatures below -5°F.

Analyzing the regional heating data from NOAA (see "Web Extras"), which documents the incidence rate of outdoor temperatures for nearby weather stations, we calculated that the estimated heating demand would exceed the capacity of the MSHP less than 1% of the time. During these short spells, the home's passive solar, plus thermal mass and internal heat gain, will likely provide a buffer.

Opposite page: Mary and Ken Bakers' home in central Maine is heated by the sun. A combination of passive solar gain and a PV-powered minisplit heat pump keeps the super-insulated home cozy through the northern winters.

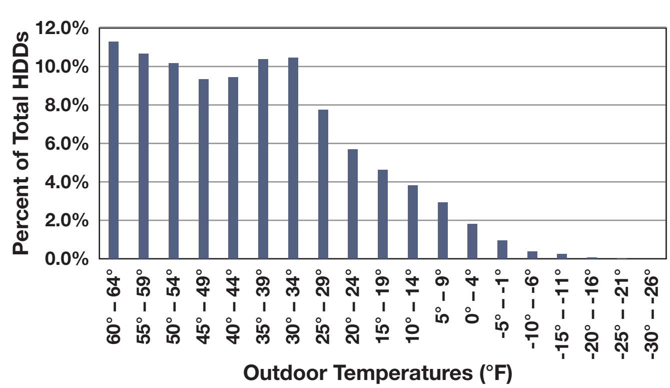
Left: To reduce heat loss, the east, west, and north walls have very few windows.

Fujitsu 15RLS3H Capacity at 65°F Indoor Temperature

Outdoor Temp. (°F)	MSHP Capacity (Btu/Hr.)	Heating Load (Btu/Hr.)
59	26,500	1,440
50	25,500	3,600
47	24,500	4,320
41	24,100	5,760
32	23,400	7,920
23	22,800	10,080
14	22,200	12,240
5	21,500	14,400
-5	19,100	16,800
-15	16,700	19,200

Data Fujitsu

Temperature Distribution in Central Maine



Source: NOAA's National Centers for Environmental Information

Above: The traditional post-and-beam frame was wrapped in structural insulated panels, giving the walls an insulative value of approximately R-40.

Left: Large triple-pane windows on the south face admit available solar gain, while limiting heat loss.

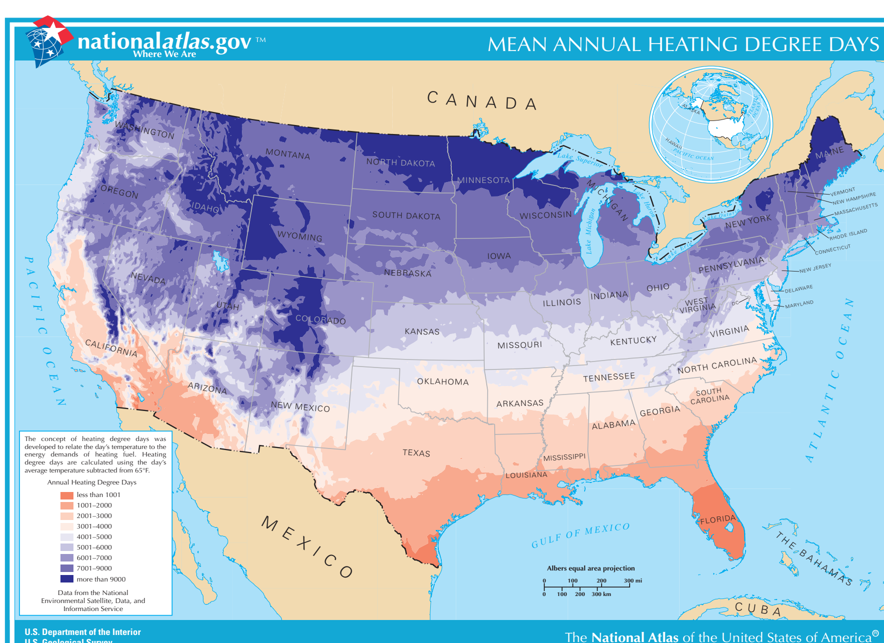
Annual Heating Demand & Heat Loss

Most heat-loss calculations are based on an outdoor temperature of 65°F, which represents the temperature below which the heating system will be turned on, and the design temperature. In this case, the temperature difference is 70°F (65°F minus -5°F). Dividing the design heat load of 16,800 Btu per hour by this temperature difference gives a heat loss per hour per degree of approximately 240 Btu/hr./°F. Multiplying this by 24 hours per day gives us the heat loss per degree over the course of a day. For this home, it's 5,760 Btu/day/°F.

This calculation enables using heating degree-days (HDDs) to estimate the annual heating demand. HDDs are a measure of one full day at 1°F below the outdoor base temperature (typically 65°F). For example, if the average temperature for a day is 30°F, this equates to 35 HDDs (65°F - 30°F). By multiplying HDDs by the heat loss per degree over the course of a day, we can estimate the heating demand for the full day. By using this approach—considering the number of heating degrees over the winter—we can estimate a home's annual heating demand.

In this particular example, the annual HDDs are 7,510. (This information can be obtained from the IPC or from degreedays.net.) To estimate a total annual heating demand, multiply the HDDs (7,510 day-°F/yr.) by the heat loss (5,760 Btu/day/°F). This results in an annual heating demand of approximately 43,260,000 Btu per year.

Heating Degree Days in the United States



The measurement of heating degree days (HDDs) helps quantify a building's heating energy demand.

Courtesy USGS

Passive solar gain and internal sources of heat also contribute to this home's heating, and engineering models are typically used to determine these values. In this case, the estimated gain from these sources during the heating season was calculated (through F-Chart Software) to be 23,450,000 Btu per year, which reduces the estimated annual heating demand to 19,810,000 Btu per year.

Estimating MSHP Electrical Demand

Since electricity provides this heat, it is beneficial to convert the heating demand into kWh. Dividing the estimated annual heating demand (19,810,000 Btu/year) by the number of Btu in a kWh (3,412 Btu/kWh) equals about 5,800 kWh per year. This figure represents the energy consumption using electric resistance heat, which has an efficiency of 100%.

The average coefficient of performance (COP) for a Fujitsu 15RLS3 installed in a climate like central Maine is roughly 3. This means that the unit averages 3 kWh of heat for each kWh used. Since the MSHP is expected to offset close to 100% of the heating demand, we can divide the heating demand (5,800 kWh/yr.) by the MSHP's annual COP to obtain an estimated electrical consumption of 1,935 kWh.

Reducing electricity usage by using energy-efficient appliances and lighting allowed the PV system to be smaller.

Sizing the PV Array

For this location, using PVWatts, and adjusting for shading from trees and snow, results in an estimated annual output of 1,245 kWh per kW of PV capacity. The PV capacity needed to offset the MSHP's electrical consumption is roughly 1.6 kW (1,935 ÷ 1,245).

We estimated the other electrical consumption for the home to be approximately 7,800 kWh/year, which included lighting, water heating, appliances, cooling, and a future electric vehicle. An additional 6.3 kW of PV capacity is required to offset the non-MSHP consumption.

The system we installed has 27 REC Twin Peak 290 W modules and a SolarEdge SE7600A-US inverter. The total system capacity is 7.83 kW and should result in the home being net zero in an "average" year.

Far left: The Fujitsu minisplit indoor unit is mounted high on a wall in the home's main room. Heat convects to second-story rooms up the open stairwell.

Left: The outdoor unit is mounted on the east wall, above the snow line.

Left: The 7.83 kW PV array.

Above: The SolarEdge grid-tied inverter.

Right: Ken and Mary.

Livability

The Bakers have been very pleased with the new home's performance. After decades of handling wood and coal, Ken reports, "The use of heat pumps and solar has made our home effortless to live in. When the kids come home, they no longer fight for the space near the heating vents and find home to be more relaxing."

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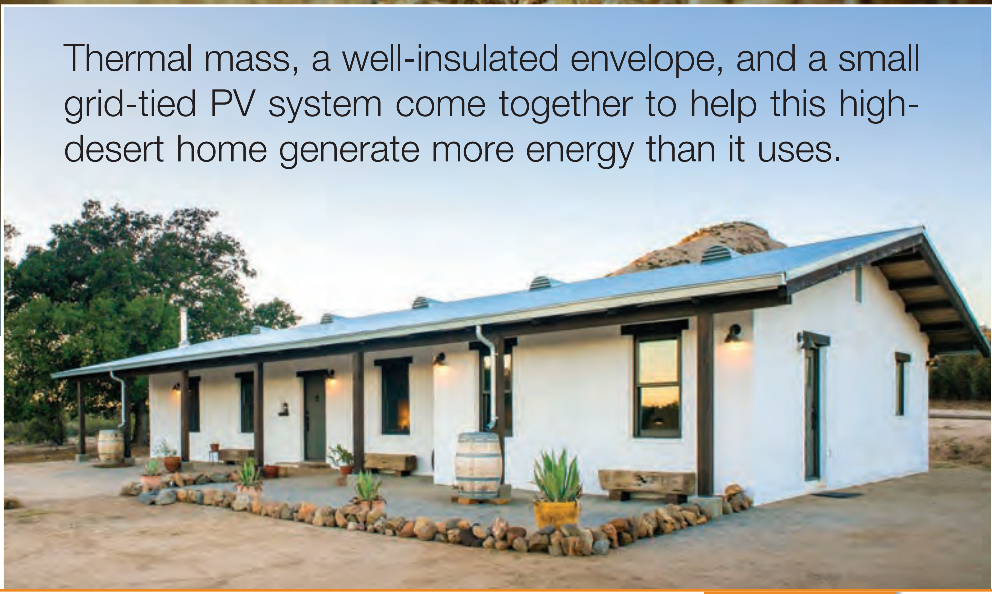
Net Zero, Naturally

The Fallgren Strawbale Home

Thermal mass, a well-insulated envelope, and a small grid-tied PV system come together to help this high-desert home generate more energy than it uses.



by Rebecca Tasker

All photos courtesy Simple Construct

Home Design

Brian and Sue Fallgrens' home, 60 miles east of San Diego, was inspired by traditional adobe ranchos. It uses time-tested natural materials—straw, clay, and wood—to create a well-insulated, high-performance envelope. Thoughtful design by Simple Construct, a design-build company specializing in strawbale homes, included incorporating passive solar orientation to maximize cooling; shading on the south face; and a compact size in a relatively simple footprint. Coupled with careful construction—well-detailed strawbale walls, ensuring an even distribution of mass, and attention to mitigating air infiltration—these strategies help this home maintain comfortable temperatures year-round, while using little supplemental energy for heating or cooling. A 4.1 kW batteryless grid-tied PV system provides almost twice as much electricity as this home uses each year, even though every system in the home is electric—there are no fossil-fuel-powered appliances. The only combustion that takes place is in the small woodstove that uses brush collected for wildfire prevention.

The shared ethic of simplicity between the homeowners and builders led the home's design—to try the lowest-tech solution; the most affordable off-the shelf choice; the refurbished/reclaimed option; and the passive technology first. It started by making the home as small as possible—a smaller building translates into fewer materials and less energy used.

The owners' desire to tread lightly on the land guided many of the design decisions, as did the commitment to achieving high performance by using natural, nontoxic, low-embodied-energy materials. Opportunities to design with salvaged and repurposed furniture and to use reclaimed materials were identified, such as refurbishing an old buffet for the bathroom vanity, using wood from collapsed sheds on the property for trim, and constructing the kitchen countertops from reclaimed vintage oak planks. Human solutions—such as opening windows for ventilation rather than relying on fans—took priority over mechanical options whenever possible.

The 1,600-square-foot interior (1,900 sq. ft. exterior footprint), two-bedroom, one-bath home was completed in the spring of 2016. It is one of only 27 to have achieved the International Living Future Institute's (ILFI) Net Zero Energy Building (NZEB) certification. ILFI, a nonprofit organization promoting ecological design, coordinates the Living Building Challenge, a rigorous green-building standard from which the certification draws (see "NZEB Certification" sidebar for more information).

Material Selection & Use

What distinguishes this house from most zero-energy homes is the use of natural, local, low-embodied-energy, carbon-sequestering materials, which consume less energy and emit less carbon pollution in their manufacture and transport.

The Fallgrens had planned to build an adobe home, but were disappointed to learn that obtaining a permit for adobe construction in this seismic zone is difficult. That's when they began examining strawbale building. What began as a compromise became an exciting opportunity as they learned about the benefits—good insulation, high fire resistance, humidity buffering, and sound isolation.

The three-string bales are an agricultural byproduct of wheat production in the Imperial Valley, about 50 miles from the project site. Laid flat and tightly chinked, these walls have an insulation value of about R-30. The clay for the plaster finish came from a mine about 125 miles away. Much of the wood used in the project traveled feet rather than miles: most of the nonstructural lumber was salvaged from old buildings at the job site. The oak countertops were fabricated from vintage timber purchased from a wood salvage company.

The adobe blocks were made on-site from the same clay, sand, and straw used to make the plaster finish for the walls. Nonstructural elements, such as the central bookcase, the dividing wall at the entry, and a bench in the great room, were constructed with the blocks, which provide additional thermal mass.

Energy-Efficiency Strategies

To meet the NZEB requirements, the Fallgren home relies on several energy-conservation and efficiency strategies:

- A well-insulated, well-sealed envelope
- Well-placed thermal mass for storing heat and “coolth” for reliance on passive heating and cooling
- Appropriate building orientation, plus ample overhangs and careful window placement for avoiding solar gain during the hot summer months and shoulder seasons (spring and fall)
- Energy Star appliances—Dishwasher, refrigerator, induction stove, chest freezer, clothes washer, and clothes dryer
- Fujitsu Slim Duct minisplit—12,000 Btu heat pump for cooling and heating; model ARU12RLF; SEER: 14.7; EER: 11.7
- GE Geospring 50-gallon hybrid heat-pump water heater
- All-LED lighting
- Passive ventilation through well-placed, operable windows

The NZEB certification verifies, through a third-party audit of performance data over a year of occupancy, that the building operates as claimed, harvesting energy from the sun, wind, and earth to exceed net annual demand.

- Annual energy use: 3,813 kWh
- Annual electricity generated: 7,023 kWh
- Total surplus: 3,210 kWh

Thermal Performance

The Fallgren home's most important energy strategy—thermal mass and ample insulation—requires no electricity. The 4-inch-thick concrete slab, the clay-plastered walls, and the adobe block pony walls provide well-distributed thermal mass, acting like a thermal battery—storing heat and then reradiating it. The R-30 strawbale walls and R-40 blown-in cellulose in the attic reduce envelope heat loss, and the influence of the mass—known as the thermal flywheel effect—minimize interior temperature swings for good comfort.

After a warm fall heated the mass—and before the minisplit heat pump or insulation in the attic had been installed—the unfinished home was able to maintain 62°F, even though the outside temperature fluctuated between 60°F during the day and 35°F at night. Even after the temperature dropped into the 20s for a week, the home's interior temperature dropped only one degree—to 61°F.

Summer performance was even more dramatic. During interior plastering, the doors and windows were opened to ventilate the space and disperse excess moisture. Within an hour, the interior temperature had risen from 75°F to 95°F. Once the windows and doors were shut, the ambient temperature returned to 75°F within an hour. The house had effectively cooled itself, with the thermal mass acting as a sink for the heat.

"Last winter," says Brian, "the house stayed about 70°F without turning on the minisplit. And this is in a climate with average lows of 33°F in December. Last summer, the house stayed about 74°F without running the air conditioning. Our average summer high is 94°F."

NZEB Certification

The Net Zero Energy Building (NZEB) certification was a program operated by the International Living Future Institute (ILFI) using the structure of the Living Building Challenge (LBC), a rigorous green-building program.

The Fallgren home was the 27th and final project to be certified under the NZEB program, which was retired at the end of 2017. Other projects are now being certified under the ILFI's Zero Energy (ZE) program, which simplifies and streamlines the certification of zero-energy buildings to create broader market adoption, codification, and standardization of ZE technologies in everyday buildings. ZE certification still requires a year of energy monitoring to verify that the building performs as designed, but does not require compliance with any other LBC imperatives.

NZEB was one of three certification paths under the LBC. Projects that met the requirements rely on exceptional energy conservation and on-site renewable energy systems to meet all of their heating, cooling, and electricity needs. The NZEB certification verified, through a third-party audit of performance data, that the building is truly operating as claimed, harnessing energy from the sun, wind, or earth to exceed the home's annual energy demand. In addition to requiring that 100% of the home's annual energy needs be met by on-site renewable energy, the NZEB certification differs from most net-zero certifications (and ILFI's current ZE certification) in that the project also had to meet three LBC imperatives:

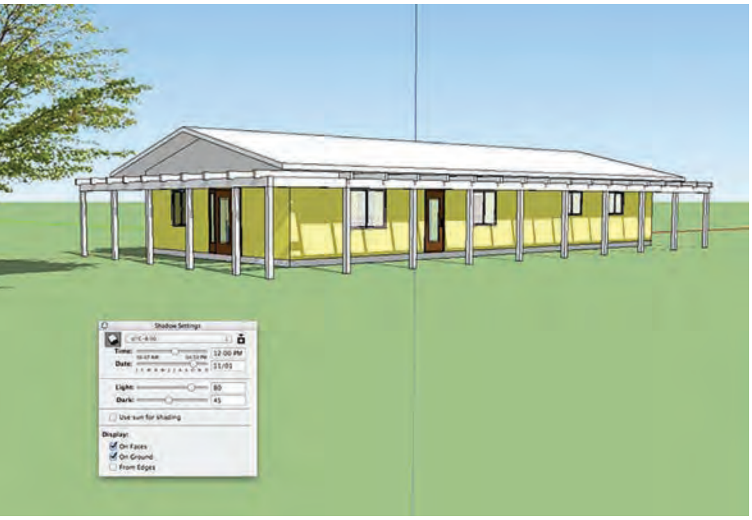
- **Limits to Growth** addresses sprawl and encourages sensitive land development. As a former dumping ground, surrounded by development on three sides, this was a fitting site for an environmentally sensitive home and landscape restoration.
- **Beauty + Spirit** explores the less-tangible goals of designing structures to create delight and foster well being. Beauty in this project centered on authenticity of design and materials as they relate to this location, which dovetails Simple Construct's focus on achieving a high-performance envelope with natural, local, carbon-sequestering materials.

  The project's aesthetic was grounded in the land and its rich history, native plants, and subtle color palette. Exploring the shapes and variations of local adobe buildings opened up dialogue about what looked and felt right. Themes emerged: being low and integrated with the landscape; simple lines; interplay of strong light and shadow; and a color palette of bright white, silver gray, and deep brown. Incorporating reclaimed wood from the site as trim further celebrated what was already there. A few scraps of brightly painted wood from Camp Lockett, a local abandoned WWII army base, were saved until their place in the home revealed itself.
- **Inspiration + Education** covers efforts to reach out to the public to share information about the project. The home was part of the U.S. Green Building Council's Green Homes Tour in 2016 and will be a featured home on its 2018 tour. It also received an Excellence in Energy Leadership award from San Diego Gas & Electric, who produced a promotional video about the project (see youtube.com/watch?v=JgsWMgs7TMs).

Nichos—shapes carved into the walls—are a tradition in both strawbale and adobe building, as pictured below in a historic rancho. Though they can serve specific functions, they often host objects of beauty.

Above: Besides providing good insulation, the two-foot-thick strawbale walls lend themselves to sculptural interpretation, especially around window openings. The flared window shapes in this home echo the window shapes at local historic ranchos (left) and missions (right). This technique minimizes glare by creating a light gradient—from the bright outdoors to the more subdued indoors.

Nichos throughout the home reference a traditional aesthetic and draw attention to objects of beauty and function.



Solar orientation is another important energy strategy for this home. Given the sunny location and very hot summers, the home is oriented with its longer face to the southeast (165° off north). A deep porch shades the home's south face to reduce solar gain and facilitate summer passive cooling. The porch depth and window height were designed so that almost no direct sunlight enters the windows at any time of year, yet views are maintained. A small amount of unshaded east-facing glass allows for solar heat gain in the mornings, which are generally cool.

In this climate, there is too much hot sun year-round. In the summer, the ambient sun and air temperature slowly heat the mass; night-time ventilation keeps the interior temperature comfortable. Well-insulated high-thermal-mass buildings are easy to overheat and, once overheated, require quite a bit of energy to shift the temperature back to the ideal comfort range, so controlling heat buildup from solar gain is a priority. The majority of heating and cooling for this home relies on the mass to maintain a steady temperature. Once the house is at a comfortable temperature, it is a matter of fine adjustments—a little bit of supplemental heating or cooling.

The Cost of "Green"

This home cost approximately $350,000 to build (which includes the cost of the appliances, but not the PV system). Keeping the building's shape and the systems simple allowed for more intricate finishes. The homeowners were very involved with the design and with certain parts of the construction, such as staining the wood for the porch ceiling and antiquing the tin wainscoting around the bathtub. The homeowners also shopped for their appliances and fixtures, finding some good deals.

A custom strawbale home can cost the same to build as a custom conventional home if it is well-designed and the builders have a good understanding of strawbale details. In general, the materials for a strawbale building cost less but more labor is required. It is important to compare apples to apples: Any well-insulated wall system will cost more than one that only has code-minimum insulation.

A ground-mounted 4.125 kW batteryless PV array—15 SolarWorld 275 W modules and 15 Enphase M250 microinverters—provides the home's energy generation. This array was sized to meet the anticipated needs of this all-electric home but has proven to be larger than needed. An electric car could easily be charged with the surplus electricity. Once energy-storage prices drop, a battery bank would be an asset to this remote rural home when the grid goes down.

A truth window is a small opening in the wall that reveals the substrate behind the plaster—straw-clay (above) and straw bales (below). A tradition in strawbale houses, truth windows are a source of surprise and delight as guests get a peek inside.

Beyond Net Zero: Embodied Energy & Carbon Sequestration

It wasn't long ago that few people understood what "net zero" meant in relationship to building design, and though there's still some dispute about exactly how to define it, it's broadly understood that a net-zero building generates as much energy as it uses on an annual basis. A net-positive building generates more energy than it uses over a year's time.

The energy a building uses—its operational energy—has been the focus of the green building industry. We now know how to dramatically decrease a building's operational energy use through building techniques (better and more insulation, building orientation, and more airtight building envelopes). But we can push the boundaries of sustainable building further, saving even more energy, by considering the energy that goes into making and transporting the building's materials. Known as embodied energy or embodied carbon, this is often referred to as the building's "carbon footprint."

If we're truly serious about saving energy and resources, embodied energy matters. And if we can build with materials that act as a carbon sink—a place to store compounds that contain carbon, thereby sequestering carbon dioxide from being released into the atmosphere— we make an even bigger, immediate difference. For an in-depth discussion of embodied energy in construction and why it matters, *The New Carbon Architecture* by Bruce King is an excellent resource.

The owners prefer to be smart operators of a passive home rather than passive owners of a smart home, so they open and close windows and doors to provide ventilation as needed for fresh make-up air and night-air flushing. Mechanical ventilation, required by code, is provided by a NuTone 742RBNT, 70 cfm exhaust fan in the bathroom and a Zephyr Tornado Mini AK8400AS exhaust fan in the kitchen. Unconditioned air exchanges like this have little effect on the interior temperature due to the home's high thermal mass. A Fujitsu minisplit, located in the attic above the central hallway and ducted to the master bedroom, provides supplemental heating and cooling.

web extras

"Straw Bales & Solar Energy—A Natural Partnership" by Rebecca Tasker in *HP175* • **homepower.com/175.46**

California Straw Building Association and conference • **strawbuilding.org**

Embodied carbon in the built environment • Carbon Leadership Forum • **clf.be.washington.edu**

Living Building Challenge • **living-future.org/lbc/**

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Lessons Learned from WIND LAB

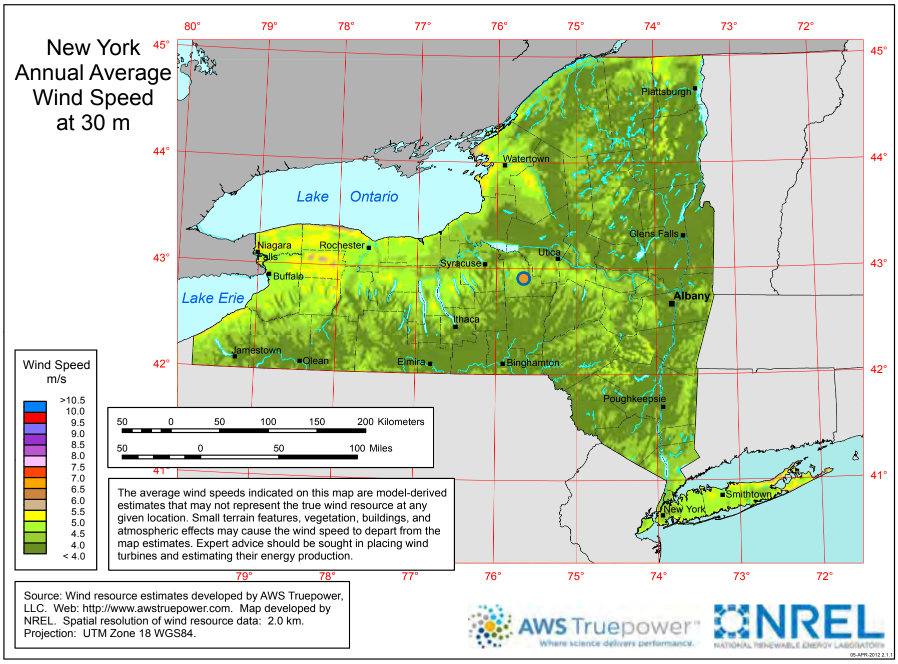
Courtesy Jason Robertson

by Phil Hofmeyer

In 2006, the State University of New York-Morrisville (SUNY-Morrisville) campus installed the college's first small wind system, a 10 kW Bergey Excel. A meteorological (met) tower was installed in 2009; a second system, a Xzeres Skystream 3.7, went up in 2013. Students in the Renewable Energy (RE) program were able to apply their classroom instruction in wind resource site assessment, and practice technical skills in wind system installation and troubleshooting.

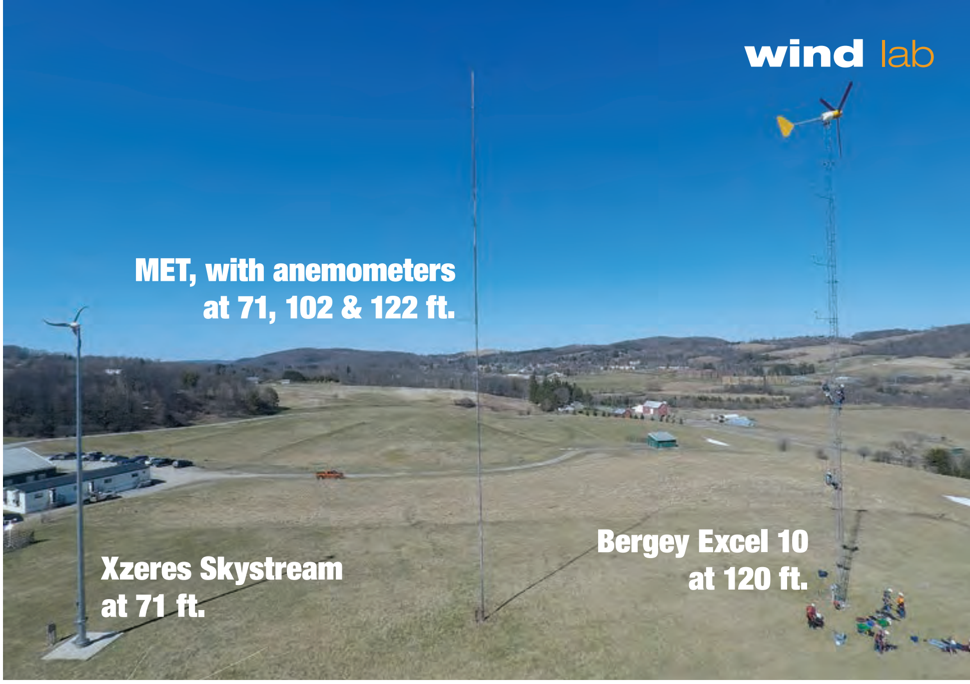
Assessing the Site

The campus sits at the geographic center of New York State, in a rural agricultural landscape with mountain ridges and a patchwork of cropland and forests. At the convergence of westerly winds from Lake Erie and Lake Ontario, there



is a strong wind resource at the ridge tops. However, due to the complex terrain, wind site assessment is challenging.

While most of the campus is in a valley, the Dairy Complex sits on a hilltop, and was chosen as the wind lab location. Only 0.5 miles south of the main campus, it is close enough for easy access during labs, and has a large enough electrical load to warrant RE systems. The site is on a hilltop within a bowl, with ridges to the northwest, west, and southwest that are 100 to 300 feet higher in elevation. This is particularly concerning because those are the prevailing wind directions. The ridge tops are all less than 1 mile from the turbine sites.



Courtesy Dylan Mathews

The SUNY-Morrisville wind energy site at the Dairy Complex.

Met-Tower Lessons

Installing an anemometer prior to installing a turbine is a good way to determine site suitability if you can measure wind speed for a fairly lengthy period of time (6+ months) as close to the proposed hub height as possible. A home weather station with an anemometer and wind vane will not be effective unless it is at least 30 feet above and 500 feet away from obstructions.

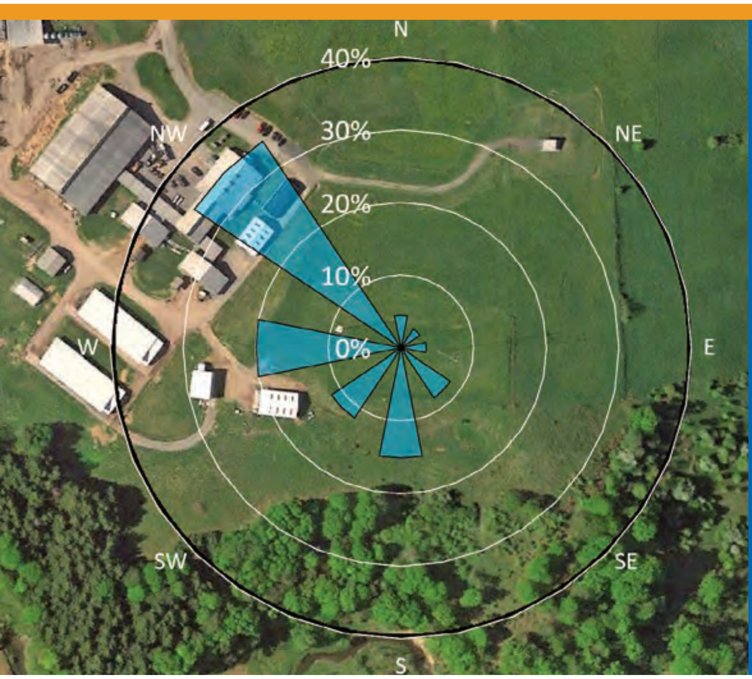
In 2009, to better understand the wind resource and its influence on energy production and long-term turbine maintenance, RE installation company Sustainable Energy Development and the students installed a guyed, tilt-up met tower. The tower is outfitted with anemometers—which measure wind speed at 71, 102, and 122 feet above ground level—and a wind vane for recording wind direction at 100 feet. Anemometers were also installed on the Bergey tower at 71 feet and 102 feet as control points for the met-tower anemometers.

At 122 feet above ground level, our site has a measured average wind velocity of 9.8 mph; at 71 feet, wind speed is 8.1 mph. While neither of these wind velocities is fantastic for energy production, they are adequate for teaching purposes.

The concept that describes nonlinear increases in wind velocity with respect to height above ground is called wind shear (see "Wind Profile" sidebar). Our site has a measured wind shear value of 0.385, which is fairly high, but not unreasonable for hilly, forested sites.

Wind power available to a machine has a cubic relationship to wind velocity.

Wind power potential = 1/2 × air density × area × wind speed^3



Left: A wind rose for the site shows the distribution of wind directions.

Right: Anemometers on a met tower measure wind speeds at 71, 102, and 122 feet, as well as wind direction (at 100 feet).

Phil Hofmeyer (2)

This Bergey Excel 10, installed in 2006, produces about 9 MWh of electricity each year.

If you assume air density and swept area are constant then, for example, a turbine on our site placed at 122 feet has 77% more wind power available than a turbine at 71 feet $((9.8^3 - 8.1^3) \div 8.1^3 = 0.77)$.

In addition to increased power available with increased height, there is also less turbulence. Turbulence is rapid changes in wind direction or speed (or both). It reduces aerodynamic lift of airfoil blades, putting a mechanical load on the blades that must be overcome. Turbulence intensity is the standard deviation of wind velocity divided by the average wind velocity measured each second over a 1-minute period (see "Turbulence Intensity" sidebar).

The Bergey Excel 10's output is grid-tied through a Powersync II inverter.

Phil Hofmeyer (2)

Flying without a Met

Using Maps & Tools to Estimate Wind Speed

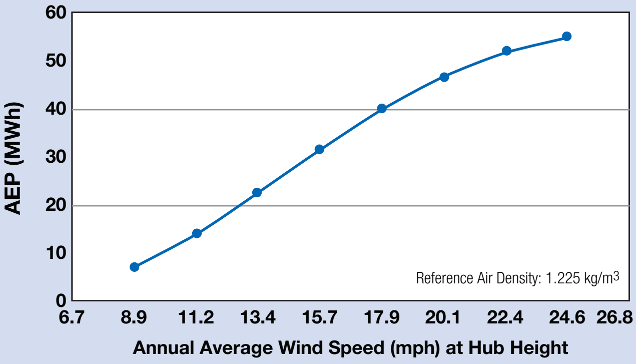
It is unrealistic to expect homeowners to use a meterological (met) tower's data-intensive wind analysis—it's too expensive and time-consuming. Instead, most rely on a wind-energy site assessor who is trained in interpreting the landscape and parsing a wind map to determine site suitability—part art, part science. It requires experience and understanding of wind speed, direction, frequency distributions, wind shear, and turbulence effects on turbine productivity, as well as being able to "read" the landscape.

However, some tools can help homeowners with their assessments. The GIS-based, interactive Wind Prospector online program is available from the National Renewable Energy Laboratory (NREL) at bit.ly/windprospector. Its tools and maps are available for each state at 30-, 50-, 80-, 90-, and 100-meter intervals. (Tower heights for small wind systems up to 100 kW are commonly 33 to 43 meters; 100 to 140 feet.) Interpolation of the wind speed measured at any two heights can be used to estimate hub-height wind speed. To estimate wind shear at the site, two wind maps can be used, or the Wind Prospector and the equation in the "Wind Shear" sidebar can be used.

Wind maps have a few challenges. The reported wind-speed range can be up to 1.1 mph and the map resolution may be over 1.5 square miles. Plus, wind maps do not account for local turbulence inducers, such as scattered trees and buildings, and do not account for local changes in elevation.

Once an average wind speed range is estimated, a homeowner can consider turbines that are certified in accordance with the American Wind Energy Association's 9.1 standards (such as the Small Wind Certification Council or Intertek). Every certified turbine has an estimated annual energy output for a given average wind speed. For example, if we assumed an estimated average wind speed between 12.3 and 13.4 mph at a turbine hub height of 120 feet, for a Bergey Excel 10, we might expect between 17,000 and 22,000 kWh per year. With a variable electricity rate of $0.12 per kWh for a grid-tied system, this turbine might produce between $2,040 and $2,640 worth of electricity per year. If wind speed is not accurately determined, annual production could be dramatically less than expected. Even a difference of 2.2 mph less than the above 12.3 mph results in half the production (11,000 kWh) and half the energy value ($1,320). This highlights the importance of good site assessment.

Bergey Excel 10: Annual Energy Production



Courtesy Bergey Windpower

Left: A Xzeres Skystream, installed in 2013, produces nearly 1.7 MWh annually. Here, it is being tilted down for turbine maintenance.

Phil Hofmeyer

Turbulence intensity proportionally reduces turbine output—as turbulence intensity increases by 1%, it reduces electrical output nearly 1% from ideal wind conditions. Because turbulence mechanically stresses the blades and drive shaft, more turbulent sites often need increased maintenance. On our site, average turbulence intensity was measured at 26.7% at 71 feet above ground level and 22.7% at 122 feet. Turbines mounted on tall towers capture higher wind velocities, greater wind-power input, with lower turbulence and lower mechanical stress from turbulence.

System Details & Production

The Bergey Excel 10 is an upwind, horizontal turbine with a rotor diameter of 23 feet and a swept area of 415 square feet. This turbine has a three-phase alternator that produces wild AC (variable frequency and voltage). It requires installation of a down-tower inverter for electrical signal conditioning to match the electrical grid. It can be configured to sync with either split-phase 120/240 VAC grids or three-phase 120/208 VAC grids. When connecting to three-phase grids, only two phases are backfed from the inverter into the main service panel. This turbine employs a hinged tail boom to passively furl the rotor in high wind conditions. It is certified by the Small Wind Certification Council to produce 13,800 kWh per year (in an 11.2 mph average wind speed) and has a peak power of 12.6 kW at 36.9 mph.

The Xzeres Skystream 3.7 is a downwind, horizontal turbine with a rotor diameter of 12 feet and a swept area of 116 square feet. This turbine has a three-phase alternator that immediately is conditioned for grid export by the integrated

Wind Profile

Wind profiles describe how wind speed increases as height above the ground increases. The shape of the wind profile is directly related to the surface roughness of the earth in that location. For example, smooth surfaces like water and ice have a lower surface roughness compared to forests and buildings. The higher the surface roughness, the more the lower tail of the wind profile is "held back."

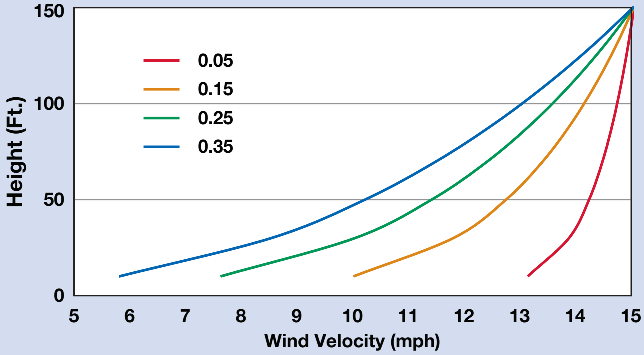
Surface roughness is described mathematically by alpha (α), which is a value between 0 and 1. As alpha approaches 0, the shape of the wind profile comes closer to vertical, suggesting very little surface roughness and little change in velocity in wind speed throughout the wind profile.

Alpha can be determined with anemometers logging wind speed at different heights using the equation:

$$\alpha = (\ln (V_1 \div V_0)) \div (\ln (H_1 \div H_0))$$

The wind shear (α) is determined by the natural log of the ratio between wind speed at a higher anemometer (V_1) over the wind speed at a lower anemometer (V_0) divided by the natural log of the ratio between the height AGL of the higher anemometer (H_1) over the height AGL of the lower anemometer (H_0).

Wind Profiles for Four Shear Values

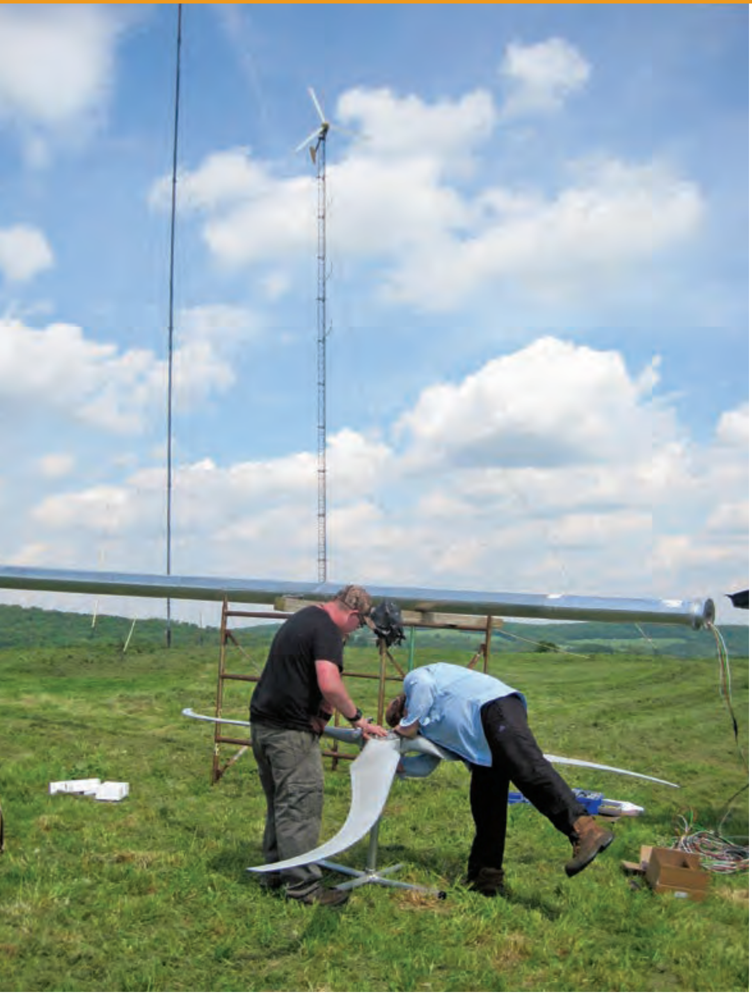


The lower portion of the curve (closer to the ground) has a shorter wind-speed vector. If the top of the curve is held at a constant wind speed, rougher surfaces will have a more drastic decline in wind speed at ground level. The more drastic the decline, the more the wind closer to the ground is "held back."

Above: Routine maintenance is more routine in this hands-on learning environment. Here, student Ben Wlock checks torque specs on the Bergey's 120-foot guyed lattice tower.

Cracked blades were changed on the Excel in 2015.

Students Jesse Symonds and Joe Haines balance the Skystream's blade assembly.



Phil Hofmeyer (3)

Turbulence Intensity

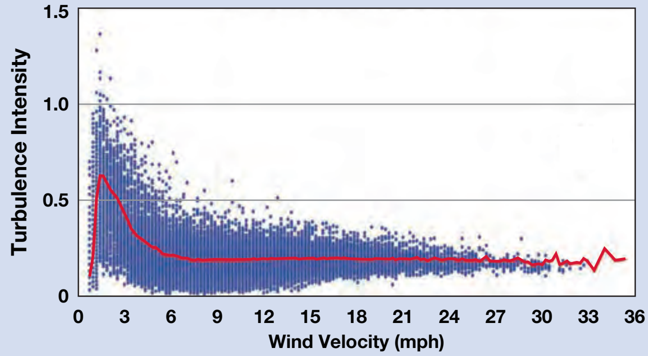
Turbulence is important because it reduces turbine performance and increases wear and tear. One commonly used approach to quantify turbulence is called turbulence intensity (TI):

$TI = \sigma_V \div \bar{V}$

It's the ratio of the standard deviation of the wind speed (σ_V, a measure of dispersion or inconsistency) over the average wind speed (**$\bar{V}$**) over a 1-minute period (measured at 1-second intervals).

Turbulence increases as wind speed increases but, once the average wind speed is accounted for, TI usually decreases at higher average wind speeds and at higher heights above the ground. (The accompanying graph shows a 5-minute interval rather than 1-minute interval.)

5-Minute Turbulence Intensity at 122 Ft.



Wind Lab Systems

Attribute	Bergey Excel 10	Xzeres Skystream 3.7
Blade diameter (ft.)	23	12
Hub height (ft.)	120	71
Tower type	Guyed lattice	Tilt-up monopole
Rated power (kW)	10.0	3.7
Year installed	2006	2013
Avg. wind speed (mph)	9.8	8.1
Turbulence Intensity	22.7%	26.7%
Avg. energy output (kWh/yr.)	8,993	1,694

inverter in the nacelle. It can be configured to sync with either split-phase 120/240 VAC grids or three-phase 120/208 VAC grids. When connecting to three-phase grids, only two phases are produced. In high wind conditions, the rotor is stall-regulated by a fixed rpm. It has a set of redundant braking relays that short the alternator phases to bring the rotor to a stop as a fail-safe backup to stall regulation. This turbine is certified by the Small Wind Certification Council to produce 3,420 kWh per year in a 11.2 mph average wind speed and has a peak power of 2.4 kW at 31.3 mph.

Wind System Incentives

Incentives, including tax credits, can reduce out-of-pocket costs for wind-electric systems. The Database of State Incentives for Renewables and Efficiency lists local, state, and federal incentives.

At the federal level, there is a 30% personal tax credit that can be applied to small wind systems up to 100 kW in rated capacity. This credit can carry over for additional years and does not expire until December 31, 2021, but it drops to 26% after December 31, 2019. If the small wind system is purchased for an agricultural or commercial facility, a 30% investment tax credit (ITC) can be applied, along with a production tax credit (PTC).

For rural projects, the USDA Renewable Energy for America Program (REAP) often provides grants and low-interest loans for small wind systems. Most locations have local agents who administer the grants and can help with proposal development. These are challenging and lengthy to write, but may be a viable option for some.

Since SUNY-Morrisville is a nontaxable entity, it received no tax credits for its wind system installations. And, since the Skystream was installed as part of the college curriculum, it was ineligible to receive the state's RE rebate.

Long-Term Maintenance

Wind turbines work under grueling conditions. As Paul Gipe describes in his book, *Wind Energy for the Rest of Us*, a small wind turbine in its first six months of operation may experience the same wear and tear on its "engine" as an automobile driven 100,000 miles. Routine maintenance is needed to protect the initial investment.

Phil Hofmeyer (2)

Top: The dusty environment necessitates regular replacement of the leading-edge tape on the blades.

Above: Student Ryan Storke works on the Bergey's slip-ring brush assembly, a typical maintenance item on turbines that yaw automatically.

At our wind lab, we perform maintenance on our machines more often because our systems are used in technical training programs. At least once each year, the Bergey system is tested for guy-wire tension and all guy anchors are inspected. We periodically check the torque on the tower flange bolts, inspect all fasteners, and check the torque on blade bolts. We inspect the yaw brush block assembly in the nacelle as part of our routine yearly maintenance check.

Because the wind systems are located at an active farming site, summer dust can be an issue. We have replaced the blades' leading edge tape several times on the Bergey because of the abrasive dust. Our blades developed stress cracks along the leading edge in 2015. We replaced the damaged blades early in 2016.

Phil Hofmeyer (3)

Above left: Author/instructor Phil Hofmeyer leads the hands-on, off-the-ground, wind-power curriculum.

Top right: With the Skystream tilted down, students adjust torque on the vibration-dampening system.

Above: Students torque the bolts on the base flange of the Skystream's 71-foot monopole tilt-up tower.

Maintenance is required on the furling cable, which is used to winch the tail boom to hold the rotor out of the wind during maintenance. Because we use this tower for our students and for training in tower-climbing safety and rescue techniques, we furl the machine frequently. Where the furling cable leaves the nacelle, it rubs, frays, and eventually can break. We put a lot more stress on that component than it was likely designed to handle.

Our annual maintenance of the Skystream involves tilting the monopole tower down, rather than climbing. We check turbine flange torque through the vibration isolators, check rotor balance, and verify blade bolt torque. Once tilted back up, we verify the level of the top flange plate rather than plumbing the tower. Because the Skystream is a downwind turbine, it seems to be more sensitive to leveling the top plate for orientation with changing wind directions. If it is not level, it slumps slightly to a side and does not yaw properly.

web extras

Database of State Incentives for Renewables and Efficiency • **dsireusa.org**

NREL wind maps • **nrel.gov/gis/wind.html**

Wind Exchange wind maps • **windexchange.energy.gov**

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Circuit Calculations

by Ryan Mayfield

A recurring and confounding topic is circuit calculations and conductor sizing. Except for PV systems greater than 100 kW, the methods for calculating voltages and currents haven't changed in recent *Code* cycles, yet the topic remains confusing. In *HP182*, I reviewed the major changes in Part II of Article 690. In this article, I'll clarify the calculations in Section 690.8 to illustrate how to apply the *Code* requirements.

The calculations required for the circuit current and overcurrent protective devices (OCPDs) are outlined in *NEC* 690.8 and 690.9. The first step in this process is to calculate the maximum circuit current per 690.8(A). This calculation is dependent upon which portion of the circuit is being evaluated. Understanding the six subsections is important.

Section 690.8(A)(1)(1) or (2) calculates the PV source-circuit currents. The second subsection is new to 2017 and only applies to PV systems greater than 100 kW, which is beyond the scope of this article.

Section 690.8(A)(1)(1) dictates that we multiply the PV source-circuit short-circuit current (Isc) values by 125%. This will typically be a single module, or a series string of modules, that creates a PV source circuit. The 125% multiplier accounts for scenarios in which the irradiance is greater than the STC conditions, such as edge-of-cloud effects, increased irradiance at higher elevations, and reflectance from snow.

Section 690.8(A)(2) applies to the PV output circuits. The value calculated in the first subsection is multiplied by the number of circuits in parallel. This applies to cases in which a DC combiner box was used to place multiple source circuits in parallel and provides a single output into an inverter or charge controller.

Section 690.8(A)(3) pertains to the inverter output circuit. There is no multiplier to use. The inverter's continuous output current rating is the value used for the maximum inverter output-circuit current. Regardless of the PV input, inverters cannot output more current than they are designed for. Section 690.8(A)(4) covers stand-alone inverter input circuit current requirements, which are not discussed in this "Code Corner."

Sections 690.8(A)(5) and (6) are for systems that use DC-to-DC converters, such as optimizers. Similar to inverters, these power electronics control the circuit's current output, so the maximum source circuit current is the rated value of the converter's continuous output. If multiple circuits are placed in parallel, the output circuit is the number of circuits in parallel multiplied by the continuous output rating.

Section 690.8(B) deals with the calculation of conductor ampacities and requirements for conductor sizing. This section dictates that PV circuits shall be considered continuous and calls for conductors to be sized based on the largest conductor calculated in the first two subsections, or where protected by an adjustable OCPD, as dictated in the third subsection. The third subsection is new to 2017 and a method unlikely to be used in residential and small commercial applications. Large-scale PV arrays may benefit from the adjustable OCPDs, but are special cases.

The first subsection, 690.8(B)(1), requires that the conductors cannot be sized smaller than 125% of the maximum circuit currents calculated in 690.8(A). Many solar designers will refer to the combination of the requirements from 690.8(A)(1)(1) and 690.8(B) as the "156% rule" for circuit sizing (125% × 125% = 156%). This has become a common, but overused, correction factor. Many designers apply this correction factor universally to all circuits and in all cases, instead of just on the PV circuits connected to the input side of power electronics.

In addition, 690.8(B)(1) states that this calculated value is used without applying any additional "conditions of use"—correction factors applied to conductors when they are exposed to temperatures above 30°C and in installations in which there are more than three current-carrying conductors in a conduit, thereby creating more heat as current flows in a constricted area.

While the second subsection, 690.8(B)(2), factors in the conditions of use, the ampacity for the conductor (after the conditions of use have been accounted for) only needs to be greater than that calculated in 690.8(A) when a single 125% factor was applied to circuits ahead of any power electronics. I've seen the 156% multiplier applied on top of conditions of use, with the result of oversizing the conductor. In the eyes of *Code* and your inspectors, that's not a problem. But it is an unnecessary cost.

You must perform the calculations in both of these subsections to determine the required conductor size in each scenario. The calculation that results in the larger-diameter conductor becomes the minimum conductor size per 690.8(B).

NEC Section 310.15 covers the rules and allowances for conductor ampacity calculations. Reading the entire section—not just the tables—should help clarify the requirements. For example, the 310.15(A)(2) Exception allows for the use of a higher conductor ampacity when specific circuit length requirements are met. Once the section is understood, the tables become the most referred-to portion of this section.

There are two conditions of use correction factors applied in PV systems. One is when there are more than three current-carrying conductors in a raceway. Table 310.15(B)(3)(a) covers the correction factors required based on the number of current-carrying conductors in a raceway or cable. Do not include the grounding conductors, as they do not normally carry current and do not impact the conductor count. Each DC PV circuit will have two current-carrying conductors.

The other correction factor used commonly in PV design is based on the ambient temperature the conductors are exposed to. Table 310.15(B)(2)(a) lists the various correction factors for conductors based on the ambient temperature and the insulation rating of the conductors' protective coating. This temperature should be used for conductors in locations exposed to temperatures greater than 30°C to account for the additional heat. ASHRAE temperature values are a good source for exterior ambient temperature and are available from the Solar ABCs website (see "Resources").

In the 2008 *NEC*, a subsection was added to increase the ambient temperature calculation for conductors in raceways exposed to sunlight on roofs. The basic premise was that if raceways were located on a roof and in the sun, the temperature inside that raceway would be higher than the ambient temperature. The table associated with that subsection called out temperature adders for the ambient temperature based on the height of the raceway off the roof surface. That table was eliminated in 2017; now, a rooftop raceway temperature adder is necessary only if the raceway is less than 7/8 inches off the roof surface.

The rules described for 310.15 directly apply to the conductor selection process as outlined in 690.8 and allow you to determine the minimum conductor size based on circuit ampacities. The next step is to apply the rules for OCPDs in 690.9 to make sure the conductors are properly protected. In subsequent "Code Corners," I will give examples for calculating the ampacities and conductor sizing and OCPDs for different circuits.

resources

Solar ABCs map • **bit.ly/SolarabcMap**

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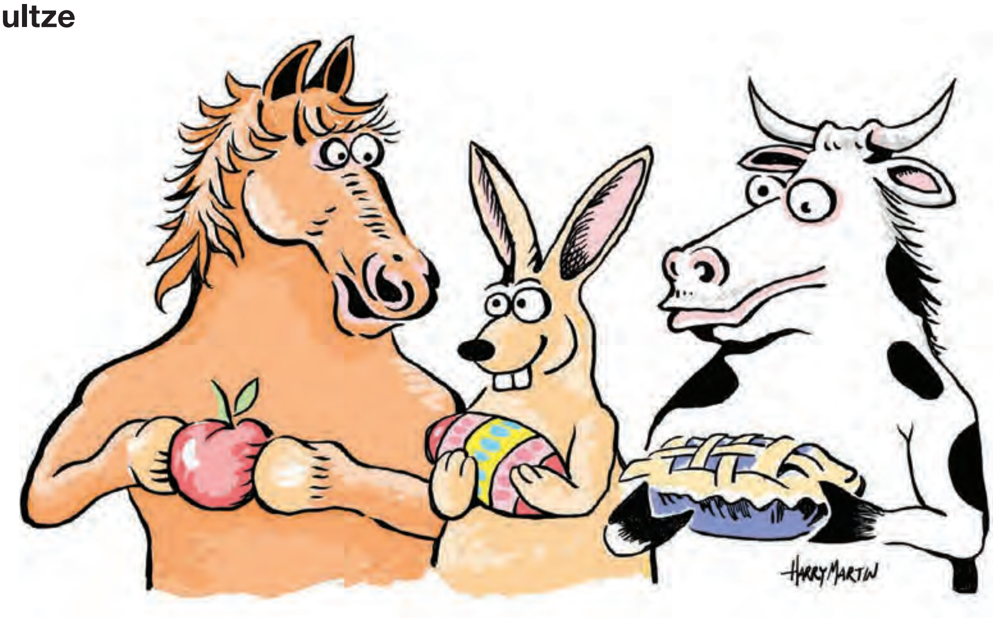
Horse Pucky

by Kathleen Jarschke-Schultze



I was raised in the country, and I can tell a cow pie from a horse apple. And with our ever-expanding gardens, harvesting horse apples every spring is an earnest endeavor. Over the years, my husband Bob-O and I have perfected our garden-amendment techniques and our vegetables are all the better for it.

Shovel

When we lived near the Salmon River, our closest neighbor Sarah had a big black horse. She welcomed our manure fetish, as she had more than she could use in her small garden. We would drive our pickup to her Indian Creek homestead with our shovels and gloves. It would take an hour or so to fill the bed with manure from the always-available big pile. After driving a mile and a half home, we would park the truck on our wide turnout. From there, we shoveled our treasure into our wheelbarrow, and ferried the load down a little dirt path to a four-foot-wide suspension bridge that Bob-O had built across the river, to our cabin on the other side. Bob-O would wheel the heavy loads to our very old Willys jeep, where we would shovel the manure into the back. We would drive it up the trail, through a small tributary, past the cabin, and on to the one open space in the forest where we gardened. Finally, we would shovel the manure into a pile to be added later to our garden plots. It took many trips to empty the truck. Eventually, Bob-O bought a garden cart (which I still use); we hitched it to the jeep like a trailer and cut the number of trips by half.

Now, on Camp Creek, we still use manure to enrich our clay soil. For 28 years, we have added the brown gold to our garden areas and tilled it in. When we started gardening at this house, we made an annual pilgrimage to the local 4-H rabbit husbandry teacher's house. His name, oddly enough, was Bob Schultz. He would call us in the spring and say, "Bob Schultze, this is Bob Schultz—and I have a load of crap for you."

The poop that piled up under his rabbit cages was only shoveled out by us—once a year, and it was a big mounded pickup load. With our wheelbarrow and shovels, we would descend on his backyard hutches and fill our 'barrow and his. We got pretty good at heaving the 'barrows up onto the lip of the bed and tipping them to empty them. At home, we could just rake the poop out into a pile using a McLeod (a firefighting tool that is a hoe and rake on steroids). I liked to rescue the red worms we found in the poop and put them into the worm bed I made from our old bathtub, out under the apple tree.

Bob Schultz got old and quit teaching rabbit husbandry, so we switched back to horse manure. Lucky for us, our county is chock-full of horse-loving cowhands. And for us, the best part is that not all of them garden, but all of them are glad to get rid of the nugget piles that build up by their stables. We really like it when the pile is steaming—that means it's already starting to compost. The scooping and shoveling and dumping we do just aerates the manure, speeding the composting process along.

Scoop

We prefer horse apples to cow pies—the apples come in nuggets, not splats, and are much easier to shovel, spread, and till in. We are not young anymore. Now, we only get manure from ranchers who have tractors to load it for us. Bob-O's 5-by-8-foot dump trailer has been built up with wooden rails to provide about a 4-foot-tall bed. While the manure is free, Bob-O always slips the rancher some money for the loading. It is so worth it to us.

Spread

At home, we just dump the load at the end of the largest garden area. As our gardens are prepped for planting, Bob-O uses the tractor to scoop and spread it where we need it. The tractor's rototiller attachment incorporates the manure smoothly. Like Bob-O says, "We let the horses do the work." He means horsepower, but it is twofold with the fertilizing matter we put into our soil.

Scavenge

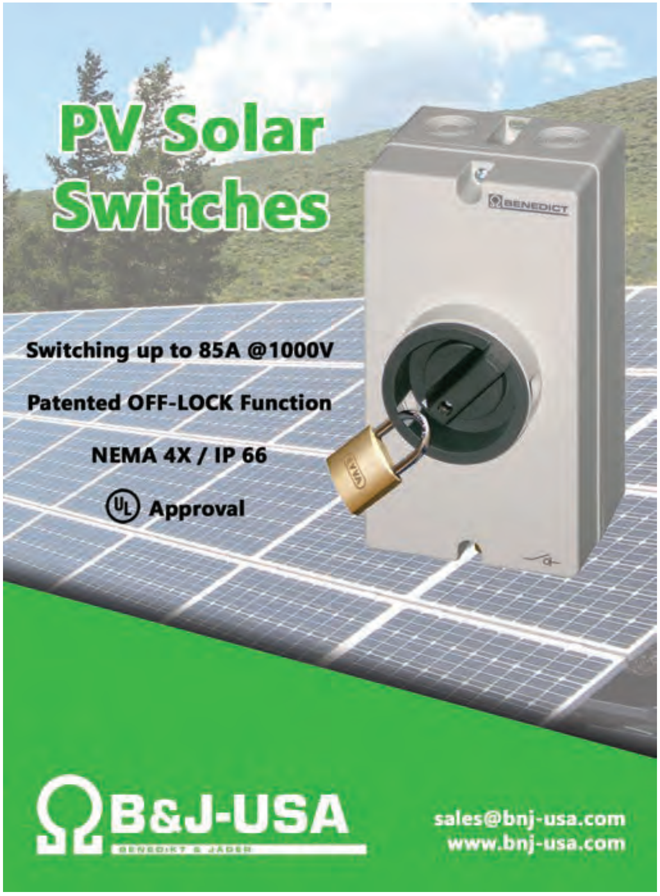
Living in the middle of open range, we found another way to get organic horse manure. Our little electric golf cart, Evie, has a small steel bed for hauling all kinds of things around our homestead. While we have fenced 5 acres of our 124 acres, the rest is open range and frequented by various wild and semiwild horse herds. Before I lived here, I really did not know that wild horses will poop in the same place. It's like they are roaming around, see a pile of poop, and think, "Oh, this is where I should poop."

For us, this is a boon. When the weather is fair and our chores are done, we will drive Evie into our large pasture, which is frequented by several horse herds, and collect horse apples. With the manure waiting for us in piles already, it doesn't take long to fill the small steel bed.

The wild horses are curious and will sometimes come over to see what we are doing. There is a herd of three that we call the Three Amigos. Respectively, we have named them Black, White, and Red for their coat colors. White is the stallion and the pushiest of the bunch. We have been giving them some of our wizened winter-stored apples for treats when we are in the pasture collecting manure or walking up the creek to clean the microhydro intake screen. Now that the apples are gone, we bring them each a carrot. They think Bob-O is great and come to him whenever they see him.

Our Airedale, Lucea, wants to play with the horses and their spring colts, but the stallion will place himself between her and the mother and foal. Meanwhile, without seeming to, all of the other horses in the herd point their heads toward Lucea, although they continue eating.

Although it seems odd, collecting manure with Bob-O and Lucea out in the pasture during a warm spring evening is one of the facets of my off-grid life that I deeply appreciate. And I hugely enjoy the fact that our yearly applications of manure—12 to 14 yards of it— have transformed our impoverished clay (I actually once shaped it into a bowl) into a friable, nutrient-rich soil for our vegetable gardens.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Women in Solar Energy

Courtesy WISE (2)

WISE

Who: Women in Solar Energy (WISE)

Headquarters: Boston, Massachusetts

Founded by: Kristen M. Nicole, solar industry veteran. Kristen has contributed to a variety of cutting-edge solar industry efforts, including national endeavors in grid-integration research, development, and energy policy. In addition to solar projects across a variety of market segments, Kristen is an account director at Dividend Finance, selling an integrated financial technology solution, and serves on the North American Board of Certified Energy Practitioners' board of directors.

Mission: "To advance women in all aspects of the solar energy industry.

Women in Solar Energy (WISE) is the networking center point of the solar energy industry, united toward a common goal of advancing women in all aspects of the solar energy industry and promoting diversity, inclusion, and forward-thinking business practices in our community. This is done through education, capacity building, advocacy, strategic partnerships, networking, and events.

WISE was founded on the idea that the collective power of the female community is massive, and if we can all work together, the end result can be revolutionary."

Recent Projects & Programs:

- WISE Tribe and WISE Web are the organization's membership and portal hubs, respectively, for individuals looking for online resources, networking, and information to advance and support a robust career in the solar energy industry.
- WISE Global is a partnership effort with like-minded international NGOs working to promote the mission and vision of WISE internationally.
- WISE Solar is the project development arm that is actively seeking to develop solar projects on women's and domestic violence shelters around the country.
- WISE Honey is a partnership initiative with sexual assault and violence prevention programs, and provides economic support, trauma-recovery information, and networked resources.

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