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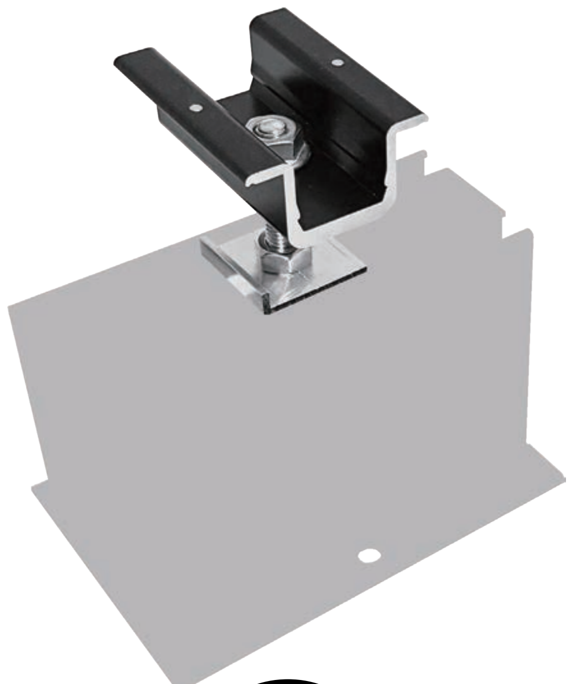


THE WORK IN FRONT OF YOU

An essay that is almost 60 years old still offers wisdom for today. "I, Pencil" was first published in 1958 by Austrian economics author Leonard Read. It traces the manufacture of a pencil, explaining the complexity of the design and manufacture of this seemingly simple writing implement. Read concludes that though it seems simple, "not a single person on the face of this earth knows how to make a pencil." It takes many different people to harvest the wood, make the needed equipment, and even grow and prepare the food eaten by the equipment builders, and so on. Tracing the pencil's lineage shows that no mastermind has all that it takes to make even something as small and "uncomplicated" as a pencil.

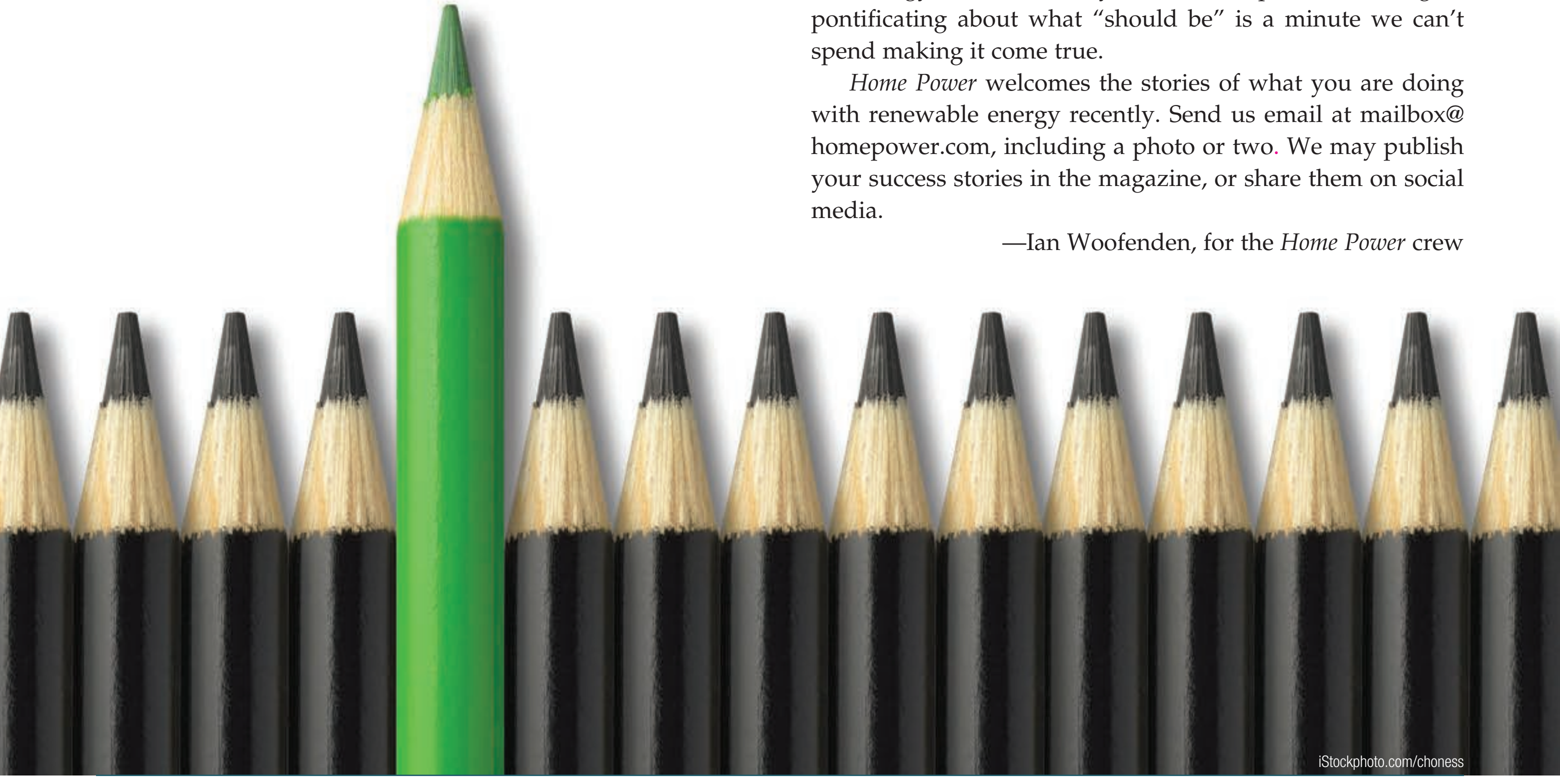
Similarly, not even experienced people in the renewable energy industry—including *Home Power*'s staff, writers, and readers—can see the whole picture. We don't know exactly what the next best steps are; what products and solutions will emerge; or how to design a "perfect" energy world. It takes many people with many abilities and viewpoints, working independently and together, to move clean energy forward.

Too often, we spend too much time just talking about renewable energy instead of doing it. While it may be entertaining to try to "solve the world's problems" from our armchairs, what makes pencil meet paper and bicycle tires meet the road is us getting up and working on what's right in front of us—changing our own energy picture, and assisting and encouraging our neighbors to do the same.

If we each do what we see and love, and spend more time acting and less time talking, we will surely improve our energy situation. Every minute we spend theorizing or pontificating about what "should be" is a minute we can't spend making it come true.

Home Power welcomes the stories of what you are doing with renewable energy recently. Send us email at mailbox@homepower.com, including a photo or two. We may publish your success stories in the magazine, or share them on social media.

—Ian Woofenden, for the *Home Power* crew



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Think About It...

"It's pretty amazing that our society has reached a point where the effort necessary to extract oil from the ground, ship it to a refinery, turn it into plastic, shape it appropriately, truck it to a store, buy it, and bring it home is considered to be less effort than what it takes to just wash the spoon when you're done with it."

—*"The Story of Stuff" (online movie, 2007)*

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On the Cover

The 2017 Volkswagen e-Golf is one of several new electric vehicles that offer longer range and more features.

Photo courtesy Volkswagen

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Photos courtesy: Chevrolet, Stiebel Eltron, OnSite Energy

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Up Front

Home Power (ISSN 1050-2416) is published bimonthly from offices in Ashland, OR 97520. Periodicals postage paid at Ashland, OR, and at additional mailing offices. POSTMASTER: Send address corrections to Home Power, PO Box 520, Ashland, OR 97520.

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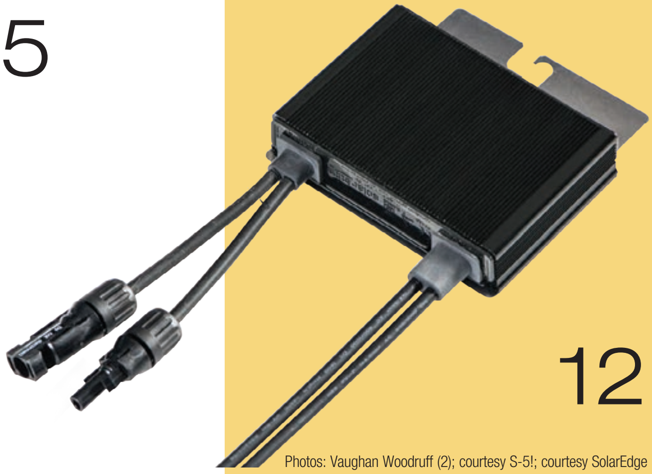

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Photos: Vaughan Woodruff (2); courtesy S-5!; courtesy SolarEdge

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contributors

this issue's experts

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

Ryan Mayfield is the principal at Renewable Energy Associates, a design, consulting, and educational firm in Corvallis, Oregon, with a focus on PV systems. He also teaches an online course in conjunction with *SolarPro* magazine and HeatSpring.

Jeremy Smithson started Puget Sound Solar in 2001 with 30 years of construction contracting experience and a desire to turn Seattle on to solar energy. In addition to leading the company, he also teaches about solar energy, and experiments relentlessly with various solar, energy-efficiency, and electric vehicle projects.

Brad Berman is the editor of PluginCars.com and HybridCars.com. Brad writes about alternative energy cars for *The New York Times,* Reuters, and other publications. He is frequently quoted in national media outlets, such as *USA Today*, National Public Radio, and CNBC. Brad is the transportation editor at *Home Power* magazine.

Kent Osterberg worked as an electrical engineer in the electric utility industry prior to moving to Oregon in 1989. In 1991, he installed one of the first grid-connected systems in Oregon at his residence. Kent is the principal system designer and installer for Blue Mountain Solar in Cove, Oregon.

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.

John Connell lives in Fremont, Ohio, where he's the vice president of the SLI Products Group for Crown Battery Manufacturing. He's advised clients on battery selection for off-grid and grid-tied renewable energy systems for more than 25 years.

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

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

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

Allan Sindelar installed his first off-grid PV system in 1988. He retired from Positive Energy Solar of Santa Fe, New Mexico, in 2014, and now designs, services, and consults on off-grid and water pumping systems. He is a licensed electrician with dual NABCEP certifications.

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

Contact Our Contributors

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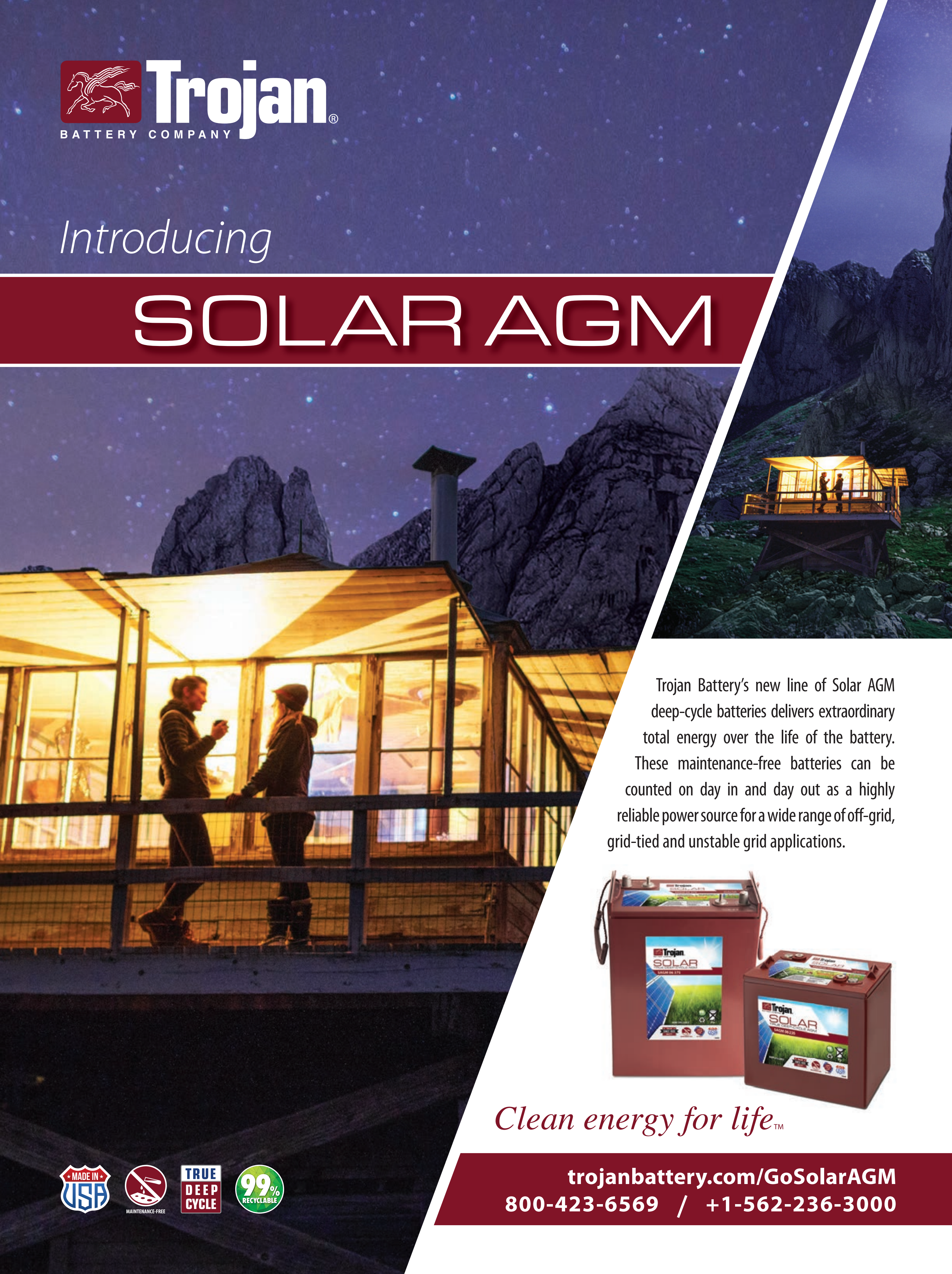
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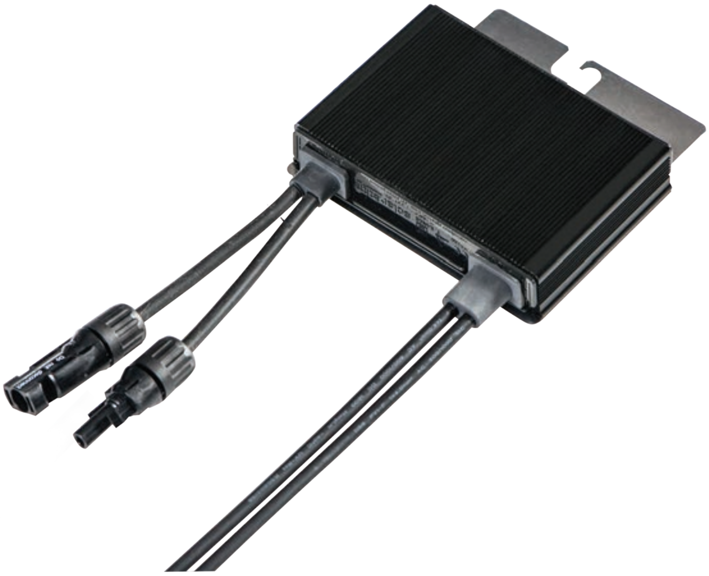
Courtesy SolarEdge

SolarEdge P370
Power Optimizer

SolarEdge (solaredge.com) added the P370 power optimizer to its line of DC-to-DC converters, which provide module-level maximum power point tracking and monitoring. Optimizers help mitigate series-string losses due to module mismatch and partial array shading, and provide a method of meeting *NEC* rapid shutdown requirements. This product accommodates 60- and 72-cell modules, with a maximum input voltage of 60 V, and maximum input current of 11 A.

—Justine Sanchez

Courtesy LG

LG RESU

Lithium-ion Energy Storage

LG Chem (lgchem.com) is offering lithium-ion (nickel-manganese-cobalt) residential energy storage systems (ESS) in North America. These batteries can be used in either DC- or AC-coupled PV systems. The 48 V options are offered in 3.3, 6.5, and 9.8 kWh capacities; the 400 V version is offered in 7.0 and 9.8 kWh, which is compatible with the SolarEdge StorEdge inverter. These batteries have a 10-year warranty, and their enclosure is suitable for indoor or outdoor installation.

—Justine Sanchez

Courtesy Trojan Battery

Trojan Solar

AGM Batteries

Trojan Battery (trojanbattery.com) released a line of maintenance-free absorbed glass mat (AGM) batteries geared toward renewable energy applications. These batteries feature Trojan's "smart carbon" additive that helps mitigate the effects of partial state-of-charge conditions common to RE battery banks. They're offered in 220, 315, and 375 Ah capacities at 6 V; 165 Ah at 8 V; and 135 and 205 Ah at 12 V; and come with a three-year warranty.

—Justine Sanchez


Courtesy S-5!

S-5! RibBracket I-IV

S-5!'s (s-5.com) RibBracket I-IV PV array mounting option is for exposed-fastened metal roofs with a trapezoidal profile. Four versions (I-IV) accommodate a variety of profiles, with four attachment points for each bracket and a weatherproofing EPDM gasket. The channel above the attachment points provides wire management and an air gap between the modules and the roof.

—Justine Sanchez

Top Considerations in FLA Battery Installation

Flooded lead-acid (FLA) batteries can deliver many years of cost-effective, reliable energy, but proper installation and maintenance are crucial to long life and maximum capacity. Once you've designed your renewable energy and battery system, there are these key considerations.

Start with safety. When working with batteries, always wear safety glasses, gloves, and an acid-resistant apron or old pants and long-sleeved shirt. Remove all jewelry, watches, electronic devices, and other metallic objects that could conduct electricity. Always treat metal battery maintenance tools with rubberized, insulating coating or wrap them in electrical tape, leaving only the necessary working end exposed. Alternatively, invest in insulated tools.

Check electrolyte levels. FLA batteries must be inspected, and filled or topped off during installation and routine maintenance. While the system is not charging, remove the battery vent caps and inspect each cell. The batteries' electrolyte should be at least 1/4 inch above the plates. If the level is low, top off only with distilled or deionized water, then firmly secure the caps. Distilled water offers a mineral-free product because it is made by boiling water, then condensing the collected steam back into water. Best but costliest is deionized water, which removes positively and negatively charged ions from water and exchanges them with H^+ and OH^- ions.

Replacing the battery caps with Hydrocaps ($18 each) can cut electrolyte evaporation by 90%. The cap contains a catalytic converter which converts most of the vented oxygen and hydrogen back into water, which drips back into the cell. Save your original caps for use during battery equalization because the catalytic converter can overheat when batteries are gassing extensively. Finally, using a single-point battery watering system (SPWS) to top off batteries can shave significant time off maintenance and prevent overfilling. It's best to start the SPWS manually, observe the system until the filling is complete, and then turn off the SPWS.

Keep battery cables as short as possible, and use bolt connections rather than clamp-on post terminals. This bank offers no obstructions to easily checking and topping off electrolyte.

Courtesy Mark Snyder Electric

Install overcurrent protection. No matter what battery technology a system uses, overcurrent protection devices (OCPDs—fuses or circuit breakers) must be used. OCPDs protect system wiring from overheating and catching fire. They can also protect other devices from fire or damage following a short circuit. The *National Electrical Code* requires UL-listed OCPDs for battery systems (see "Code Corner" in *HP170*).

Use stainless steel for washers, nuts, and bolts because of its durability and corrosion resistance. Stainless steel is affordable and ideally suited for battery systems. Type 316 stainless-steel fasteners provide the best strength at elevated temperatures, and good general corrosion- and pitting-resistance.

Protect batteries from the elements. FLA battery specifications assume 77°F, and their optimal operating range is between 50°F and 85°F. Batteries exposed to lower temperatures—for instance, those stored in outdoor boxes or places exposed to extreme temperature—will not perform as well, and will lose capacity and longevity.

Battery capacity decreases by about 10% for every 15°F to 20°F drop below 80°F. Cold batteries lose capacity as power demand rises and PV production tapers. Heat increases capacity, but only within a narrow temperature range. Over

continued on page 18

continued from page 16

Courtesy Mark Snyder Electric (2)

Allowing for easy access to batteries makes it easier to provide the regular maintenance they need. But be sure to use a method of securing the enclosure from unauthorized people and critters.

Well-designed battery enclosures are well-insulated, have appropriate venting, are neat in appearance, and offer appropriate accessibility.

the long term, for every 15°F above 77°F, battery lifespan is halved. To maximize longevity and capacity:

- Install batteries off the floor in a well-insulated, vented box located in a climate-controlled space (see "Battery Box Design" in *HP141*, homepower.com/141.96).
- Leave 1/2 inch between batteries for heat dissipation and easier access.
- Never install spark-producing devices, breakers, or switches in the battery enclosure. Keep gas pilot lights, like those in water heaters, away from areas that are exposed to battery gassing.
- Ventilate batteries according to the *National Electrical Code* Article 480.9(A).
- Lock battery boxes to prevent unauthorized access and mount a dry chemical fire extinguisher in the room in which the batteries are located.

Size wires appropriately. Undersized cables mean voltage drops, make lights flicker, and can burn out motors early. They can even overheat (see "Inverter and Battery Cables" in *HP163*).

Safeguard against corrosion. Before assembling the bank, fully coat terminals, nuts, bolts, and wire lugs using a nonhardening sealant to prevent corrosion. Consider special-purpose battery protector and sealer, because petroleum jelly or oil-based anticorrosion gels attract dust and can be worn off the connections. After coating, seal any exposed cables at the terminal lug with rubber tape or heat-shrink tubing lined with adhesive.

Maximize life & performance after installation. For two weeks after installation, monitor the battery bank daily using a voltmeter and hydrometer:

Measure voltage and specific gravity (SG) after the batteries are "at rest," at least four hours after the charge controller signals that batteries are completely charged.

Measure voltage across each individual battery (or cell, if accessible) using a digital voltmeter; this should read at least 2.12 V per cell, or 6.36 V for a 6 V nominal battery. Measure SG in each cell using a hydrometer; specific gravity should be 1.265 or higher.

If both voltage and SG readings are below the minimums after the charge cycle, adjust charge controller settings to compensate using its manual equalization charging until voltage and SG are back to normal. After this, to avoid future incidents, adjust the LVD/DOD setting higher. Contact your charge controller OEM for specific instructions.

Set monthly reminders for battery care on your Web or smartphone calendar—make good maintenance a habit (see "Battery System Maintenance and Repair" in *HP161*, homepower.com/161.52).

— John Connell

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Continuing the Vision

It is with deep sadness that I read about *Home Power*'s cofounder Richard Perez's passing ("From the Crew: Our Founding Visionaries" in *HP178*). Richard is someone I had been in touch with ever since I became a subscriber to the magazine. (The original subscription was a gift to me by Dr. Ray Wjewardene, who has passed on, too.) Richard was such a helpful person whenever I asked for advice on solar-related matters, even going to the extent of sending me an article from the magazine if I could not find it!

I can only say how sorry I am to hear this news. Richard was indeed a visionary, and so was Karen. They both kept the "clean energy lamp" burning, although at the time they started *Home Power*, no one ever imagined that the cost of PV would have zoomed down to its present price! I learned so much about EVs and energy-efficient building design, too, from *Home Power.*

I have no doubt you and your team will take *Home Power* to new heights. That will be the best tribute you could pay to these wonderful human beings who made sure the air we breathe, wherever we live, is clean!

Ranjit Wijeratne • Sri Lanka

Solar Home Update

In *HP174*, a 3-D rendering of the small passive solar home I designed was published. I thought you might like to see how the actual home turned out.

I've only occupied the house for a couple of months, but I'm pleased and impressed with its performance so far. With R-42 walls and R-70+ in the ceiling, it usually stays in the low 60s on its own, and the 7 kW PV system installed by Solar Market has easily kept up with my electricity needs.

One nice feature of the house was how little waste was generated during the construction. My builder had only a small pile of OSB and framing lumber ends left when he was done. With conventional homes, he says he fills a Dumpster or two.

It was a lot of work, but the end result was worth it. I still have to finish the inside, but I'm having a lot of fun with it and enjoying the experience of being energy-independent.

Craig Merrow • Wells, Maine

Courtesy Craig Merrow

PV-Powered Boating

I finished my solar boat—Sun King—and went on a dream trip. I started on the Escambia River, north of Pensacola, Florida, and went down and over to Mobile, Alabama. Then I went upriver to Paducah, Kentucky, and down the Ohio and Mississippi rivers to New Orleans. From there, I went through waterways and across the Gulf back to home. This 1,920-mile-trip took 44 days. One thing I learned: Don't take a 20-foot boat down the Mississippi and across the Gulf!

The photo shows what Sun King looked like on the trip. The sliding center panel allowed egress at a high dock. The white plastic on the side is to keep out water. Before installing these shields, I wiped out a full set of expensive electronics on my first trip across Pensacola Bay. My system—1,620 watts of PV modules and a 350 Ah at 24 V battery bank—kept the boat going. My longest day of travel was from 5:30 a.m. (Deer Island, Mississippi) to midnight (Oyster Bay, Alabama). How many people can run their gas boats that long without refueling?

Wondering about the condition of the motor, I cracked it open when I got home. I had taken a complete set of spare parts and a spare MK 80 trolling motor, but it turns out there was virtually no wear—not even to the brushes—after almost 2,000 miles of travel. I did overheat a controller, but the boat was originally overpowered with two motors, so it was just a quick job to move over to the second controller, which was already in the electrics panel. I have since installed a fan on each controller.

Courtesy Neal Collier

This adventure whetted my appetite for a bigger adventure—the Great Loop, which goes around the tip of Florida then up the East Coast to New York City. From there, it goes up the Hudson, through the canals to the Great Lakes, out the canal at Chicago, and down the Mississippi. That's 6,000 miles in all, and I won't do it in the Sun King. I'll need a bigger boat. I have dragged home a 25-foot Catalina and a 27-foot Buccaneer. I will start with the Catalina as a test bed for the gear. The Buccaneer is a lot roomier for a minimum six-month cruise, but needs more "interior decorating."

The new boats will have 48 V PV systems, so none of my trusted 24 V gear will work. I have a static test bed tied in with my "solar shed," which provides power for my golf cart, power tools, and my home's central air. So far, I have purchased four different kinds of charge controllers for evaluation. I did something similar for the first boat; much of the solar shed uses leftovers from that project.

In 2014, I paid $0.68 a watt for 270-watt B-grade modules for the Sun King, and thought that was a deal. In 2016, I paid $0.35 cents a watt for 335-watt A-grade modules from Sun Electronics in Miami. Their prices are so low on some modules that it actually costs more to ship them than to buy them. My ever-growing solar shed is roofed with some of the roughly 450 roof-tile modules they gave me for the cost of shipping, so you can see why I'm a fan. On my last run to Miami, my pickup really complained about the weight of 13 kW of modules and two strings of batteries.

That's the simplified update of my life with solar-electric boats. Now that taxes are done, I can get back to the boat projects and maybe get something in the water by the end of the year. I am crossing my fingers on my motor selections. Any unsuitable selections in the powerhouse can charge my golf cart. Picking the wrong motor for the boat can get expensive. There is no American-made choice. One German motor is $5,000, and a Chinese motor is nearly $1,300. I think either will work, but what if it takes two? Or what if it won't last 6,000 miles? R&D can be an expensive process.

The first of my "solar yacht" projects is moving along slowly. I finally acquired a trailer for it, which will need to be serviced after I figure what to do with the "free" boat that came on it. I am already testing the yacht's power plant components, with output going to the home's battery banks. I know which MPPT controllers and other components I want to use. In the meantime, all that gear is running my central air while I build my savings to quadruple the size of the solar shed—and finish my next solar-powered boat.

Neal Collier • McDavid, Florida

Collective Tunnel Vision

Although the openly conservative mainstream news media might be expected to behave apologetically toward big environmental polluters, such as the corporate crude-oil sector, the relatively few, yet equally mainstream, outlets of an outwardly liberal slant might be expected to voice the alarm on all ecological threats.

However, from what I've observed over the last half-dozen years or so, the latter mentioned, here in Canada the *The Toronto Star* and *Metro*, fail to do so, even though basic common sense would dictate that genuine ecological threats and disasters would be given the highest priority…

Very disturbing is that voters in every provincial and federal election rate the environment as the very least (or next to it) of their listed election issues of importance. The economy is their primary concern. After all, seemingly goes the prevailing mentality, what back- and brain-busting labourer will readily retain the energy to worry about such things immediately unseen, regardless of their most immense importance?

Worsening the entire situation, widely published poll findings can perpetuate such skewed-logic priorities, as can a negligence of otherwise meriting eco-coverage erroneously imply there are no real, serious environmental concerns out there about which to worry.

I see it somewhat like a cafeteria lineup consisting of diversely socially represented people, all adamantly arguing over which identifiable traditionally marginalized person should be at the front and, conversely, at the back of the line. And furthermore, to whom amongst them should go the last piece of quality pie—all the while the interstellar spaceship on which they're all permanently confined is burning and suffering some serious storage-tank-breach spillage of lethally toxic chemicals at onboard locations that cannot be immediately seen.

As a species, we really can be so narrow-mindedly preoccupied with our own admittedly overwhelming little worlds that we'll miss the most critical and biggest of pictures.

Frank Sterle, Jr. • British Columbia, Canada

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

PV Array String Sizing

I was recently given the task of designing an 8 MW PV plant. I came across "Selecting Appropriate PV Array String Sizes" (*HP173*) and found this article to be very useful, but I have a couple of questions.

It's recommended to use the site's record minimum temperature (-28°C) to calculate the maximum Voc. This temperature probably occurred either late at night or early in the morning—when the sun wasn't shining. Wouldn't it be better to use the record low minimum daytime temperature? Or is it a matter of being safe rather than sorry?

Also, why wasn't the temperature adder due to the type of mounting used to calculate the maximum number of modules in series as it was done for calculating the minimum number of modules in series?

Jorge Garcia • Monterrey, Nuevo Leon, Mexico

Data of the minimum temperature occurring during daylight hours is not generally available. If they were available, it would probably be better to use that temperature. However, when considering data from over a year or more, it probably isn't much different than the minimum temperature for the full 24-hour day.

Typically, the highest Voc values will occur shortly after sunrise, when the modules are still cold. The temperature adders used for computing the minimum number of modules aren't applicable until the PV modules have had time to warm. They are the maximum temperature increase that will occur sometime later in the day. Don't use the temperature adders in the computation for the maximum number of modules. While PV modules will warm in the sunlight, their temperature—unlike irradiance—cannot change instantaneously. So we can't assume that just because the irradiance has reached 200 watts per square meter that the PV module temperature will have already increased by, say, 5°C.

In using the record minimum temperature to compute the maximum number of series modules, I'm taking a conservative and safe approach. As you say, it is better to be safe than sorry. Many installers will compute the maximum number of modules using the ASHRAE minimum expected temperature instead of the record minimum temperature. This calculation will often result in one more PV module in a string. I'm not saying that approach is wrong, just that there is some risk to the method.

Example Local Temperature Data

Data	Amount	Source
Record minimum	-28°C	weather.com
Extreme minimum	-17°C	solarabcs.org
High temp., 2%	32°C	solarabcs.org
High temp., 0.4%	37°C	solarabcs.org
Record maximum	42°C	weather.com

Editors' Note: Commonly, PV system designers use the ASHRAE "extreme minimum" temperature in calculating the maximum number of modules in series. The reasoning is that a module's voltage shouldn't reach its maximum until irradiance levels exceed 200 W/m^2, which will be after the record minimum temperature has occurred.

As I point out in the article, the extreme minimum temperatures in the ASHRAE table are an average annual minimum temperature; about 50% of all years will have some days when the temperature is lower than the ASHRAE extreme minimum. Also, PV modules can be a bit colder than the coldest air temperature of the night. This happens because of night-sky radiation (the same phenomenon that can cause ice on the car windshield though the temperature never dropped below freezing).

Kent Osterberg • Blue Mountain Solar

EV Charger Wiring

We're installing an off-grid solar-electric system this spring, and need some advice on off-grid charging for an electric vehicle (EV)—a 90 kWh pre-owned Tesla, which we hope to buy in the next couple of years.

Our daily commute is 5 miles round-trip, so there typically won't be large daily recharging demands. Our other electrical loads are minimal, and we'd only recharge the EV when it's sunny. We previously had a 1.5 kW home PV system, which was destroyed in a wildfire. With the additional EV charging load, we're estimating a 6 or 7 kW PV system. How big of a battery bank would we need?

Would it be better to have a dedicated charging station, or just plug into 240 VAC? Is using a DC charger for the car possible, and would it be more efficient?

Sheryl & Larry Nims • via email

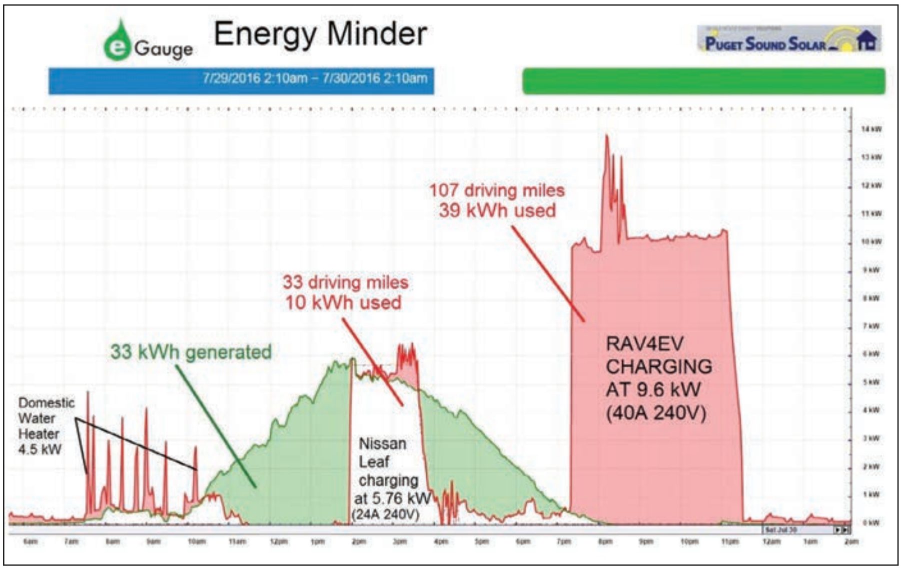
To size a PV array for charging your car, we need to know how much electricity the car's battery will require to recharge, and how much sun the PV array will get.

The size of the battery bank depends on whether it is used for charging the car and, since you are installing an off-grid system, on household loads.

It may be better to have a dedicated charging station rather than using the plug-in Mobile Connector that comes with a Tesla because you can limit how much power the car draws from your PV system when it's charging. Charging the Tesla battery with DC electricity would require a charging system that could "talk" to the Tesla battery management system.

Your Tesla should travel about 3 miles per AC-charging kWh; if you work five days a week, the car will need 8.3 kWh per week for the 5-mile round-trip. Adding a few more miles for weekend errand-running could bump that up to a weekly average of 12 kWh for charging (that's 624 kWh per year).

For example, say that you were using 1,680 kWh of electricity per year (1.5 kW STC × 1.4 × 80%). Adding the car's load, that total will be 2,304 kWh. If the car is charging only when it is sunny, we will assume that there will be little additional cycling of the household battery system, so a 6 or 7 kW PV system would be more than enough for your driving and the load previously served by the 1.5 kW system. If the battery for your PV system is not used for car charging, then the size would be determined by the usual calculations for "days of autonomy" based on daily household loads (see "Battery Bank Design & Sizing" in this issue).



Jeremy Smithson

Teslas come with a Mobile Connector that plugs into a NEMA 14-50 receptacle (like those used for an electric range). When connected to 240 VAC, it draws 40 A (9.6 kW). This Mobile Connector can also be plugged into a dedicated 20 A, 120 VAC receptacle, for a "slow charge" that draws only 1.92 kW. The slow charge would be sufficient to provide overnight charging for the 5-mile commute, but that wouldn't fit with your plan to charge in the sun.

If you are charging the car on the weekend when it is home during the day, you will want to do it quickly, so this is where your 6 or 7 kW PV system comes in handy. If the house is using 1.5 kW, let's say you have 5 kW left for car-charging. A 20 A, 240 V charging station, such as the Clippercreek LCS-20, will limit the car to 4,800 watts, leaving enough PV electricity for the house, and allowing the car to charge sufficiently during a sunny day or two.

Charging stations contain a relay that energizes the connector only after it is plugged into the car and does a little "handshake" recognition. The station sends a pilot signal to the charging system onboard the car; the pilot signal tells the car how many amps the station can deliver. By choosing the right charging station, you can tailor car-charging loads to your renewable energy system's capacity.

See the graph comparison of car-charging loads, PV production for the day, and typical load spikes of domestic water heating from my house one day last July. It shows our Nissan Leaf charging at 5.76 kW during peak PV production hours and our Toyota RAV4 EV (which has a Tesla battery) charging at 9.6 kW off-peak.

Jeremy Smithson • Puget Sound Solar

Ground-Source Heat Pumps?

I am interested in putting in a geothermal heating and cooling system, but can't seem to find anything in the *Home Power* archives for those systems. I want my house to be 100% self-sufficient. We are about to tackle a substantial remodel, and this is the first step of the project.

Michaele Thunen • via email

If you're contemplating a major remodel, it's an excellent time to consider the big picture, and assess your priorities. While heating/cooling systems are usually the largest energy users, it may be best to take a harder look at your home design and building envelope first. Doing it right at this level can dramatically shrink the need for active heating and cooling systems. Depending on your climate and site, passive solar heating strategies may be able to provide most or even all of your heating needs. Likewise, proper home design can minimize or eliminate the need for active cooling systems.

Superinsulation, careful air sealing, and attention to detail with windows, doors, and other openings can make a dramatic difference in the need for heating and cooling energy. Shrinking these needs also shrinks the size and cost of any systems needed, allowing those on limited budgets to invest in the most efficient and long-lasting solutions. As with other aspects of energy design, focusing on the load first and paring it down to the minimum is usually the best move in the long run.

Before you invest time and money in a geothermal system, which is expensive and complex, consider air-source heat pumps, particularly ductless minisplit systems, which are now approaching the efficiency of ground-source (aka geothermal) systems. They are much less expensive, since they simply capture heat from the ambient air instead of from a well or buried pipes. They also have a more streamlined delivery system—independent indoor units with only a few small pipes and wires connecting them to the outside unit—which means they are cheaper and easier as well.

The best minisplits still are efficient below 0°F, so you have to be in pretty cold country to really need a ground-source heating system. In my climate (coastal Washington State), there's no justification for ever using ground-source heat pumps—though it doesn't stop the salespeople from pushing them. *Home Power* building technology editor Alex Wilson says, "In Vermont, our Mitsubishi minisplit has performed reasonably well down to about –15°F, though to maintain comfortable conditions in our house when it's that cold, I sometimes fire up our small wood heater. (This past winter we only used it twice.) I believe that our minisplit would totally cease operation at –17°F, though its output drops somewhat with temperatures below about 0°F."

Unless you live in a very cold climate, look into the ductless minisplit option. These units are an unsung renewable energy technology. They use 1 kilowatt-hour of electricity to pump 3-5 kilowatt-hours of "free" heat from the outside ambient air into your house. Since heating and/or cooling are typically the largest loads in a North American home, it's important from a financial and environmental standpoint to focus on efficiency there.

If you are considering running either of these systems during a utility outage, you will need a substantial generating system, battery bank, and likely a backup generator, too. Heating is a significant load however it's accomplished (unless it's purely passive!). See "Minisplit: Efficient Heating with Minisplit Heat Pumps" in this issue for more information on ductless minisplits.

Ian Woofenden • *Home Power* senior editor

Adding to a PV System

I would like to add more capacity to my existing PV system and am toying with either adding new modules to my system or replacing my existing system with new modules.

The 48 V system consists of eight Shell 165 W modules on a pole-mount with an OutBack MX60 charge controller. I need more energy; in the winter, I have to run the generator a little too often.

I've been considering adding four 300 W modules to the system, along with an additional pole and mount. I calculated I would need:

- **Four 300 W modules: $1,200**
- **Pole mount: $900**
- **Six-inch pole, concrete, excavation, wiring: $500**

This would give me a total system size of 2,520 W. To replace the existing modules, I would need to buy eight new modules, and I may be able to recoup some cost by selling my old ones.

- **Eight 300 W modules: $2,400**
- **I would use the existing pole-mount.**

This would result in a total system size of 2,400 W.

The cost of adding modules to the existing system or replacing the old modules is about the same, so I'm leaning toward replacing the existing panels—keeping my footprint the same size and saving the time to install a new pole, etc. What are your thoughts?

Cliff Grimes • Carbondale, Colorado

Courtesy Allan Sindelar

Your situation brings up several issues common to array upgrades: string voltage; input conductors; pole and concrete base capacity; and desired total array size, as well as cost. In most situations, adding to an existing array is preferable to replacing it with modern modules. The main exceptions are if the existing array has had weak or failed modules, which suggests that more may also fail in the future; or if it is quite small and old, as when a new homeowner is upgrading an early generation system. Sometimes an early system is 12 V, and rewiring many small modules to 24 V or 48 V may not be worth the added labor.

String voltage is of primary importance, as the number of cells in each series string must closely match for maximum output. Two decades ago, most standard PV modules had 36 5-inch (125 mm) cells. Later modules, including your Shell 165 W modules, used 72 5-inch (125 mm) cells for 24 V nominal. You have four strings of two modules each to charge your 48 V battery bank; each string has 144 cells in series.

Due to grid-tied applications, modules with 60 6-inch (156 mm) cells have become a more common standard. However, with their lower Vmp, a two-module string won't fully charge your 48 V battery in high summer temperatures. Modern 48 V battery-based systems typically use sets of three 60-cell modules in each series string. This results in strings of 180 cells each, which won't play well with your existing 144-cell strings.

A new array can have a completely different input voltage if it uses separate input conductors and its own charge controller. This is a common solution, as each controller will match the input voltage of its array, and compatibility is assured.

A new, larger array is usually best installed on its own rack and pole. An old rack will seldom fit larger modern modules, as the attachment points will be different and the rails will often be too short. Also, the engineering of both pole and footings were likely based on a smaller array surface area—the mount may lack the structural strength to resist high winds.

Off-grid systems often used pole-mounted arrays, as they are easiest to adjust seasonally, but a fixed (nonadjustable) roof- or ground-mounted array will save the cost of the pole and may reduce excavation and concrete. In this case, the array is set near its winter angle to provide the boost when it's most needed, while keeping the adjustable pole-mounted system. This combined approach can often nearly eliminate generator runtime, as it supplies the bulk of its energy in winter, when it is most needed.

A common 60 A charge controller will handle more than 3,000 watts of PV at 48 V. Modules with 72 5-inch (125 mm) cells, typically rated at 180 W to 200 W, are uncommon, but available through some suppliers specializing in off-grid applications. Modules with 72 6-inch (156 mm) cells are now offered by some module manufacturers, typically in the 315 W to 350 W range. Using either of these would allow one charge controller to handle both old and new arrays.

Allan Sindelar • Sindelar Solar

write to:

asktheexperts@homepower.com

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

Comment & Discuss this article @ homepower.com/180.26

Courtesy OnSite Energy

Battery Bank Design & Sizing

by Justine Sanchez

Batteries are used in renewable energy (RE) systems for many reasons. For example, if your home is off-grid and powered by a PV array, you'll need to store the solar energy in batteries for use at night or during cloudy weather. If your home is on the grid, a battery bank can provide electricity during a utility outage. In areas with utilities unfriendly to net billing, some systems are designed for self-consumption—with batteries to store RE energy as it's created and all of the RE-generated electricity used on-site.

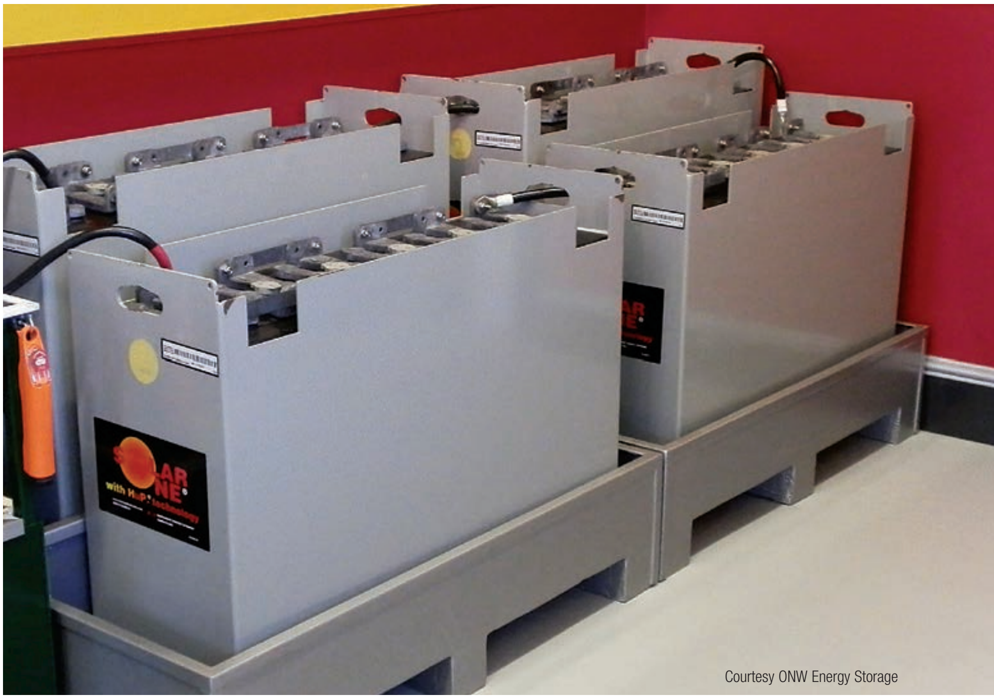
Which Batteries?

In these situations, you'll need to figure out which batteries are best for your situation and how many of them you will need. There are many battery types to choose from and battery bank designs depend upon factors such as application, budget, and maintenance preferences. For background information on the common battery types used in RE systems, see "Battery Chemistry" in *HP179*. The battery types discussed here are being mass-produced—there is a formalized testing process in place with material safety handling data sheets, etc.—and are currently available for the U.S. residential storage market.

While each battery chemistry could hypothetically be used for any system, certain battery types are more commonly deployed in specific types of systems. And while this may change as prices for different battery chemistries fluctuate, the following is currently how we are seeing batteries being deployed in homes.

Flooded Lead-Acid

Flooded lead-acid (FLA) batteries are most common in off-grid systems. These battery banks tend to be larger than for on-grid. Since there is no electric utility to depend on, they have to support all of the household loads. The lower purchase price of FLA batteries compared to other options is attractive when you need a lot of storage. FLAs require regular watering and maintenance. However, folks living off-grid generally are more self-reliant due to living farther way from in-town services. They are usually very hands-on, often dealing with pumping their own water, maintaining road access, etc. Thus, maintaining a battery bank becomes another part of the overall property upkeep (see "Methods" in this issue for information on maintenance and watering systems).



Courtesy ONW Energy Storage

FLAs can offer large-capacity battery banks at lower upfront cost; the flip side is that regular watering is required. These batteries from HuP Solar-One are available in large amp-hour capacities and can minimize the number of parallel strings.

Valve Regulated Lead-Acid

Valve regulated lead-acid (VRLA, also known as "sealed" lead-acid) batteries are often used for battery backup in grid-tied systems. These systems spend most of their time in "float" service (fully charged), waiting for a utility outage—they are cycled less than in off-grid and self-consumption systems, which cycle batteries daily. Compared to other chemistries, sealed batteries have a low to moderate cycle life. They also have a lower self-discharge rate (how fast they lose energy while sitting unused), which is helpful since they spend so much time in standby mode.

Sealed batteries are more expensive than their flooded counterparts. However, since battery backup systems usually need to provide energy only for the home's "critical" loads (such as refrigeration, medical equipment, and communications) during an outage, the battery bank can be smaller, which can make up for their higher cost. Since they do not need to be watered, they can make sense for those on-grid folks who may not be willing to perform the upkeep required of FLA batteries. Additionally, some off-grid systems will also employ sealed batteries to avoid the required maintenance of FLAs (and thus reduce the risk of ruining those batteries if they are not watered).

Courtesy Innovative Energy

VRLA batteries require far less maintenance than FLA batteries. Since they do not gas when charging within specifications, they require less venting. They do require a more controlled charging regimen, however. These 2 V absorbed glass mat (AGM) cells from OutBack Power are combined in a single string for 1,716 Ah at 48 V (82.4 kWh).

Lithium-Ion

While lithium-ion (Li-ion) batteries have a high cycle life and no maintenance, their purchase price can be high. As such, these batteries are commonly found in systems with small battery banks that require frequent cycling. This can be the case for self-consumption grid-tied systems that are designed to utilize as much PV energy during the day as possible and need a battery only large enough to store excess PV-generated energy for use during non-solar hours. These systems are sometimes designed to take advantage of time-of-use (TOU) utility rate structures, which charge higher rates during peak energy usage periods, like late afternoon and early evening—during those times, the home uses PV energy stored in the battery bank, instead of high-rate utility electricity (see "Maximizing Solar Self-Consumption" in *HP178*).

Self-consumption systems can offer battery backup when the utility is down. However, these may require larger battery banks than those designed for self-consumption alone, as they need to support all the loads on the critical load subpanel during an outage. On the flipside, Li-ion banks can be cycled more deeply (and still maintain high cycle life), compensating somewhat for their higher cost. The common depth of discharge is 80% or 90%. In comparison, LA batteries usually are designed to have a lower DOD—30% to 50%—to help maintain their cycle life. As such, you can accomplish the same goal with a smaller Li-ion bank, since the loads can use more of its capacity.

LFP batteries are a very stable lithium-ion battery option. Like all Li-ion batteries, they can offer long cycle life and are maintenance-free. High energy density combined with deeper DOD means a smaller battery bank footprint and less space required for Li-ion energy storage.

NiFe batteries are designed to be deeply cycled and can last decades. Due to their substantial gassing, these banks will need adequate venting and regular watering. Single-point watering systems can simplify and speed up the watering process.

Courtesy Iron Edison

Nickel Iron

Nickel-iron (NiFe) battery banks are used mostly in off-grid systems. These battery banks are very robust (tolerant of over- and undercharging, and freezing), and offer extremely long cycle life. They also provide some protection from the occasional deep discharges and daily cycling an off-grid battery bank experiences. Like Li-ion, NiFe banks are often designed for an 80% DOD, which allows a smaller battery bank. Their disadvantage is their frequent watering requirement, which is about two to three times that of FLAs. Again, this maintenance is generally a better match for off-grid systems, rather than for on-grid ones. These batteries are good candidates for single-point battery watering systems, which allow you to add water to multiple cells simultaneously. Their higher self-discharge rate makes them an unlikely choice for backup systems, which spend most of their time in standby mode. Due to their high purchase price, NiFE battery banks aren't as common as FLA banks in off-grid systems.

Sizing Methods

No matter what type of system you have, there are some basic pieces of information you will need for sizing. This includes the daily energy the battery bank will need to supply and the DOD recommended for that battery type.

Off-grid

Off-grid systems need enough battery capacity to power loads in the home at night and during cloudy stretches of weather. Calculate your daily energy consumption by tallying up each electrical appliance's energy use over 24 hours. Although this sounds simple, it often involves researching each electrical load and determining its consumption. This may be presented as "average yearly kWh" (as on an Energy Star label). More often, this information is given on electrical labels or needs to be measured with a watt meter. Handheld energy meters, such as P3's Kill A Watt, plug between the wall socket and appliances to show amps, volts, watts, and watt-hours. If you leave them plugged in over 24 hours, they can show watt-hours per day. Alternatively, you can estimate how often the appliance is consuming power and multiply the load watts by number of hours per day.

DC battery bank voltage needs to be determined for off-grid system design. Smaller systems might use 24 volts, and very small systems (for example, a cabin system) might use 12 V. Modern residential systems are most commonly 48 V.

Energy meters take the guesswork out of determining the daily watt-hour consumption of 120 VAC appliances.

Justine Sanchez

Operating at this voltage means smaller, cheaper DC wiring can be used; and it matches the input voltage of the larger off-grid inverters.

A primary factor in off-grid battery bank design is "days of autonomy"—the number of days that the bank should meet loads without being recharged due to clouds hampering PV output. A common approach is to design for two to three days of autonomy and include a backup generator to charge the battery bank and power loads after cloudy days.

Inverter inefficiency needs to be accounted for as the conversion from low-voltage DC to household-voltage AC takes energy to process. Off-grid inverter manufacturers list "peak efficiency" in their specifications, but this isn't necessarily representative of an inverter's average efficiency. Designers have to make an educated guess about the actual output level at which the inverter will spend the majority of its time, and use the inverter's efficiency curve to determine the system's average efficiency.

Battery temperature also needs to be considered. FLA batteries will put out hydrogen (H_2) gas and require ventilation, so need to be housed in a battery box usually located in an unconditioned space. Knowing the average low temperature for the battery box location lets you adjust the battery capacity used in your bank sizing. The temperature correction factor can be found in the battery specifications.

Example Load Analysis

Load	Qty.	x	Watts	x	Hrs. / Day	x	Days / Wk.	÷ 7 =	Avg. Daily Wh
Refrigerator	1		507		3		7		1,521
Fans	2		100		8		5		1,143
Computers	2		80		8		5		914
Wireless router	1		15		24		7		360
Printer	1		200		0.5		5		71
Lights	8		25		6		7		1,200
Clothes washer	1		320		1		2		91
Total Power			1,602				**Total Energy**		5,300

A common approach in off-grid systems is to design for only a few days of autonomy and include a backup generator.

Courtesy Kohler

web extras

"Analyzing your Electrical Loads" by Ian Woofenden in *HP156* • **homepower.com/156.104**

"Considerations for Off-Grid Systems" by Carol Weis in *HP152* • **homepower.com/152.62**

"Before You Go Off-Grid" by Alan Sindelar in *HP137* • **homepower.com/137.100**

Example Off-Grid System Battery Bank Sizing

Flooded Lead-Acid Option

Daily consumption: 10 kWh
Battery choice: FLA
Battery bank voltage: 48 VDC
DOD: 50%
Days of autonomy: 2
Inverter average efficiency estimate: 90%
Average battery temperature: 55°F (10% loss per every 15°F below 77°F = 85% of battery capacity)

Sizing Calculations:
10,000 Wh ÷ 48 V = 208.3 Ah
208.3 Ah ÷ 0.5 DOD = 416.7 Ah
416.7 Ah × 2 days of autonomy = 833.4 Ah
833.4 Ah ÷ 0.90 inverter efficiency = 926 Ah
926 Ah ÷ 0.85 temperature factor = 1,089 Ah

The "ideal" battery bank has only one series string of batteries to ensure equal charging and discharging across the cells, but two parallel strings are acceptable. Three parallel strings should be the maximum. Seek a capacity that matches or slightly exceeds the Ah requirement. For this example, a 2-volt battery with a capacity of 1,110 Ah (at the 20-hr discharge rate, which most closely reflects our daily cycling regime) was selected.

48 V ÷ 2 V = 24 batteries, yields a 53.3 kWh battery bank (24 batteries × 2 V × 1,110 Ah = 53,280 Wh)

Cost: $8,400

At 50% DOD, 1,700 cycles can be expected from these batteries. If we assume daily cycling, batteries may last four to five years. However, because we factored in two days of autonomy, it is more likely that we will only be discharging these batteries normally to 25% DOD or so. At that level, we can expect about 3,500 cycles, or nine to 10 years. This assumes the batteries are well-maintained—fully recharged (usually daily), watered regularly, and electrical connections cleaned periodically.

Simple lifetime cost estimate ($ per kWh): $0.18 / kWh
53.3 kWh × 0.25 DOD = 13.3 kWh per day
13.3 kWh × 3,500 cycles = 46,550 kWh total
$8,400 ÷ 46,550 kWh = $0.18/kWh

Lithium-Ion Option

48 V, 700 Ah (lithium iron phosphate, LFP) bank, designed to be cycled to 80% DOD. Includes battery box, battery management system, and DC disconnect.

Cost: $24,600

Longevity: 6,000 cycles expected at 40% DOD, and no maintenance required.

Simple lifetime cost estimate ($ per kWh): $0.31/kWh
33.6 kWh × 0.40 DOD = 13.4 kWh per day
13.4 kWh × 6,000 cycles = 80,400 kWh total
$24,600 ÷ 80,400 kWh = $0.31/kWh

Nickel-Iron Option

NiFe: 48 V, 675 Ah (@ 20-hour rate) bank, designed to be cycled to 80% DOD

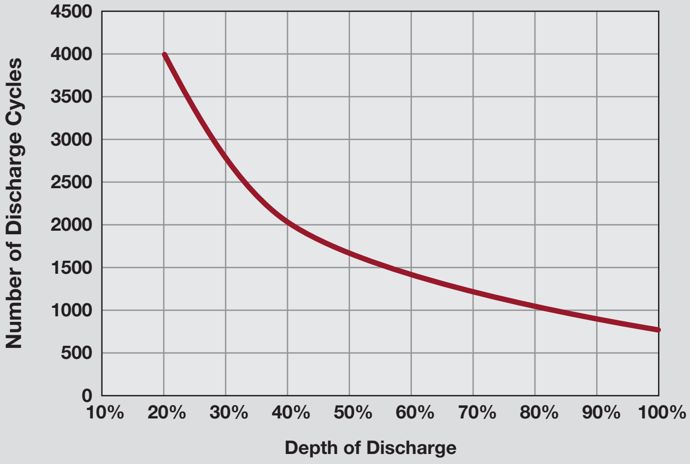
Cost: $22,320

Longevity: 11,000 cycles (replacement ~30 years); maintenance required

Simple lifetime cost estimate ($ per kWh): $0.16/kWh
32.4 kWh × 0.40 DOD = 13.0 kWh per day
13.0 kWh × 11,000 cycles = 143,000 kWh total
$22,320 ÷ 143,000 kWh = $0.16/kWh

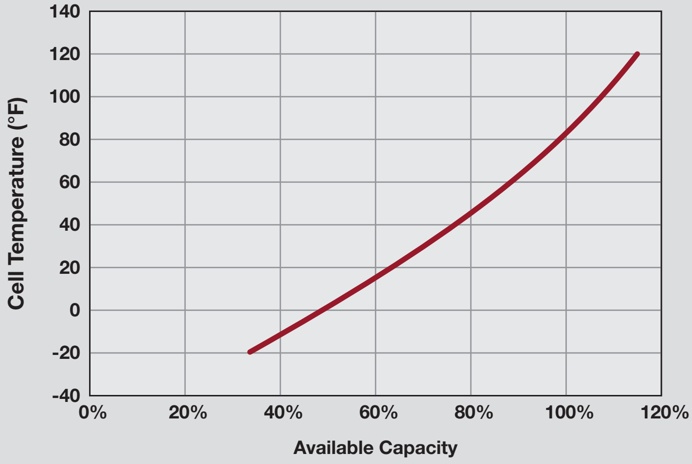
Reducing energy consumption also reduces the needed battery bank size. Energy conservation will also reduce the rest of the system requirements—modules, racks, balance of system (BOS) components, labor, shipping expense, and tax. For more information on energy-conservation strategies, see "Toast, Pancakes & Waffles" in *HP133*.

Example FLA Cycle Life vs. DOD



The number of cycles you can expect from your batteries, which impacts their lifetime cost ($ per kWh), depends on how deeply you cycle them.

Example FLA Capacity vs. Temperature



The available energy capacity of a battery diminishes with cell temperature, necessitating larger systems and higher upfront costs in colder environments.

Grid-tied with backup

With these systems, it's important to determine the "critical" loads that you want to run during a utility outage and how long you need to run them. These may include refrigeration, lighting, and communications (phone charging, Internet router, computer, radio, and TV). Perhaps your area has severe storms that can interrupt utility power for several days, or maybe outages are a rarity and short in duration. You need to know the case for your location, so you can make an educated choice for number of days of energy storage required.

Once you know the critical loads in kWh/day and the amount of time you want to keep those loads powered, sizing the backup battery bank for grid-tied systems is very similar to off-grid battery bank sizing. You still need to account for inverter efficiency and battery bank voltage, as well as proposed DOD and the batteries' temperature.

In a backup system, a design DOD of 80% can be justified since these batteries spend most of their time in standby mode, are not cycled daily, and are usually quickly recharged by the grid. If you're looking for fewer maintenance requirements, sealed batteries can be a good choice since they do not require watering. Although they generally aren't installed in living spaces (they have pressure valves to allow small amounts of gassing if overcharged), they are commonly installed in a garage or equipment room, which can mean less capacity loss due to temperature, since this can be a semiconditioned space.

The battery bank size for backup, GT systems depends on the critical load profile and the number of outage days anticipated. This AGM backup bank requires no watering and only minimal venting.

Courtesy OnSite Energy

Some battery banks are designed to provide energy only for critical loads, such as a chest freezer.

Courtesy Kenmore

Example Grid-Tied with Battery Backup Sizing

Valve-Regulated Lead-Acid Option

Daily critical loads consumption: 3 kWh
Battery choice: VRLA
Battery bank voltage: 48 VDC
DOD: 80%
Days of backup: 2
Inverter average efficiency estimate: 90%
Average battery temperature: 65°F, yields 92% battery capacity

Sizing Calculations:
3,000 Wh ÷ 48 V = 62.5 Ah
62.5 Ah ÷ 0.8 DOD = 78.1 Ah
78.1 Ah × 2 days of autonomy = 156.2 Ah
156.2 Ah ÷ 0.9 inverter efficiency = 173.6 Ah
173.6 Ah ÷ 0.92 temperature factor = 188.7 Ah

For this example, a 12 V battery with a capacity of 212 Ah (at the 20-hour discharge rate) is selected.

48 V ÷ 12 V = 4 batteries (10.2 kWh battery bank)

Cost: $2,150

Lithium-Ion Option

48 V, 200 Ah (LFP) bank

Cost: $7,200

In a purely backup situation, Li-ion might not make sense because you would be paying for cycle life that is unlikely to be fully used.

web extras

"Backup Power for Grid-Tied PV Systems" by Zeke Yewdall in *HP170* • **homepower.com/170.44**

"Grid-Tied with Battery Backup!" by Flint Richter in *HP139* • **homepower.com/139.60**

"Sizing a Grid-Tied PV System…with Battery Backup" by Flint Richter in *HP139* • **homepower.com/139.66**

Self-Consumption Grid-Tied Systems

These systems represent a newer breed of battery-based PV systems and the sizing process hasn't been standardized. One method involves obtaining a detailed load-versus-time profile with energy-monitoring equipment. Current transformers (CTs) are installed around the conductors in the home's service panel, and data is collected and sent to a monitoring system. This information can be used to size a PV array to offset all of or the desired portion of the home's energy consumption. The battery bank is sized to store the portion of the PV array's daily energy that would normally be exported to the grid in a net-metered system, so that it can be consumed by the home instead.

This data also can be used for load-shifting strategies, such as using timers for appliances, that can maximize the energy being consumed as it is produced by the PV system and minimize the energy draw in the evening, which reduces the size of the battery bank needed.

Once you know the kWh per day the PV system will produce, and the percentage of that energy that is consumed outside of the daytime window, the sizing is pretty straightforward. Since the batteries will be cycling daily, lithium-ion batteries, which do not require watering and are often discharged down to 80%, are usually chosen. Li-ion capacity isn't as affected by low temperatures and, since these batteries don't produce gas, they can be kept in an enclosure inside living spaces if the authority having jurisdiction approves. Actually they should be kept in a somewhat conditioned space, since it is generally recommended that they not undergo charging while they are below 32°F.

To save installation time and avoid equipment compatibility issues stemming from using a newer-generation battery technology, a full energy-storage system (ESS) may be a good choice. This self-contained enclosure includes the batteries, possibly an inverter integrated with the BMS, and the required BOS components. ESS units are specified by their kWh capacity, so there is no need convert to amp-hours for these calculations.

The sonnenBatterie eco series energy-storage systems combine Sony LFP batteries with OutBack Radian inverters in a freestanding enclosure. They are available in capacities ranging from 4 to 16 kWh (in 2 kWh increments).

Example Self-Consumption GT System Sizing

Li-Ion ESS Option

PV system production estimate: 14k Wh per day
Energy consumed during nonsolar window: 60%
Battery choice: Li-ion
Inverter efficiency: 93%
DOD: 90% (not designed for standby backup power)

Sizing Calculations:
14 kWh × 0.6 = 8.4 kWh
8.4 kWh ÷ 0.93 inverter efficiency = 9.0 kWh
9.0 kWh ÷ 0.9 DOD = 10 kWh

For this example, a 10 kWh LFP ESS is selected.

Cost: $16,750 (this is MSRP and not necessarily representative of available pricing), includes inverter.

Longevity: The spec sheet reports 10,000 cycles at 100% DOD.

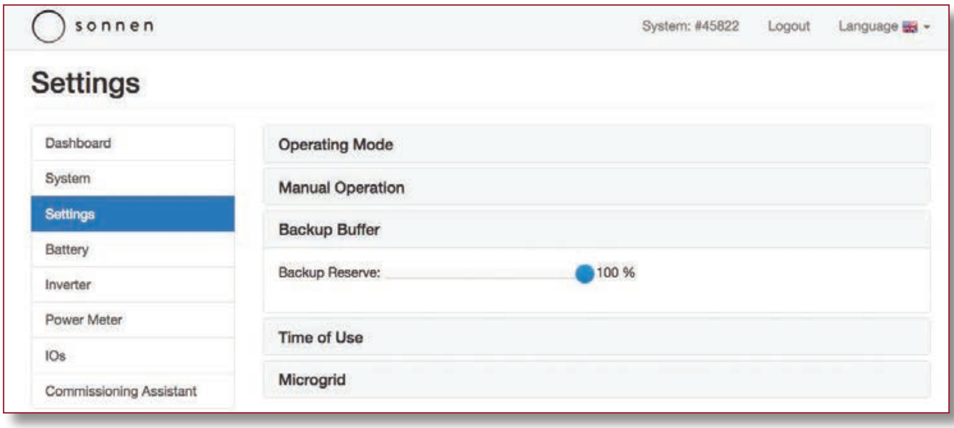
Another Li-Ion ESS for Comparison

Li-ion: 14 kWh (lithium nickel manganese cobalt; NMC)

Cost: $5,500, includes inverter.

Longevity: Cycle life is not stated (but the battery carries a 10-year warranty), actual availability is unknown. NMC is not as stable as LFP.

Courtesy sonnenBatterie (2)



Courtesy sonnenBatterie

sonnenBatterie eco programming options include the ability for users to change their settings from primarily a self-consumption system to a fully backup system, or somewhere in between.

Courtesy Enphase Energy

Current transformers (CTs) are placed around a home's main service conductors to track household energy consumption.

Battery Comparison Variables & Considerations

This article provides an overview of various battery technologies and applications, battery bank sizing methodology, and simplified cost comparison examples. It's important to note that there are many variables that make apples-to-apples comparisons of the cost and longevity or cycle life of various batteries difficult.

Variables that can have a significant impact on battery performance and longevity are the environment in which they're installed and thorough battery maintenance, if required. In terms of battery design and manufacturing, even within a specific technology group there can be important differences in materials, construction, and intended cycle or design life. Battery testing and specification reporting is generally not as standardized or as easily compared as components such as PV modules. As such, even manufacturers sometimes disagree on the accuracy of published specifications, which can have big implications when comparing cost per kWh or life-cycle cost.

Finally, there is a wide range of pricing variation within each battery type or system. For example, some flooded lead–acid batteries may cost twice as much as other flooded lead-acid models but offer significantly longer cycle life guarantees. Users also need to be aware that some energy-storage system products include power electronics such as inverters, which can impact cost comparisons.

The bottom line is that general or high-level cost comparisons can get you in the ballpark, but manufacturer-specific specifications and costs, as well as site and application details, need to be analyzed and compared on a case-by-case basis.

Self-consumption grid-tied systems with backup. These designs will need to accommodate the nonsolar load and the critical load profiles. One sizing method is based on cycling the battery bank less each day so there is reserve capacity left for unexpected outages. This requires increasing the size of the battery bank—that extra capacity may or may not get used, depending on the length and frequency of outages. Using the previous sizing example for self-consumption, but using a 75% DOD means that a 12 kWh ESS ($18,750) could be used. This would provide a minimum of 3 kWh of backup storage after normal daily discharge.

An option offered by some ESS units that doesn't require more battery capacity is to reprogram them to shift from a self-consumption system to a purely backup system (useful if the system owner knows a storm is coming). This makes the entire battery bank available to critical loads during an outage.

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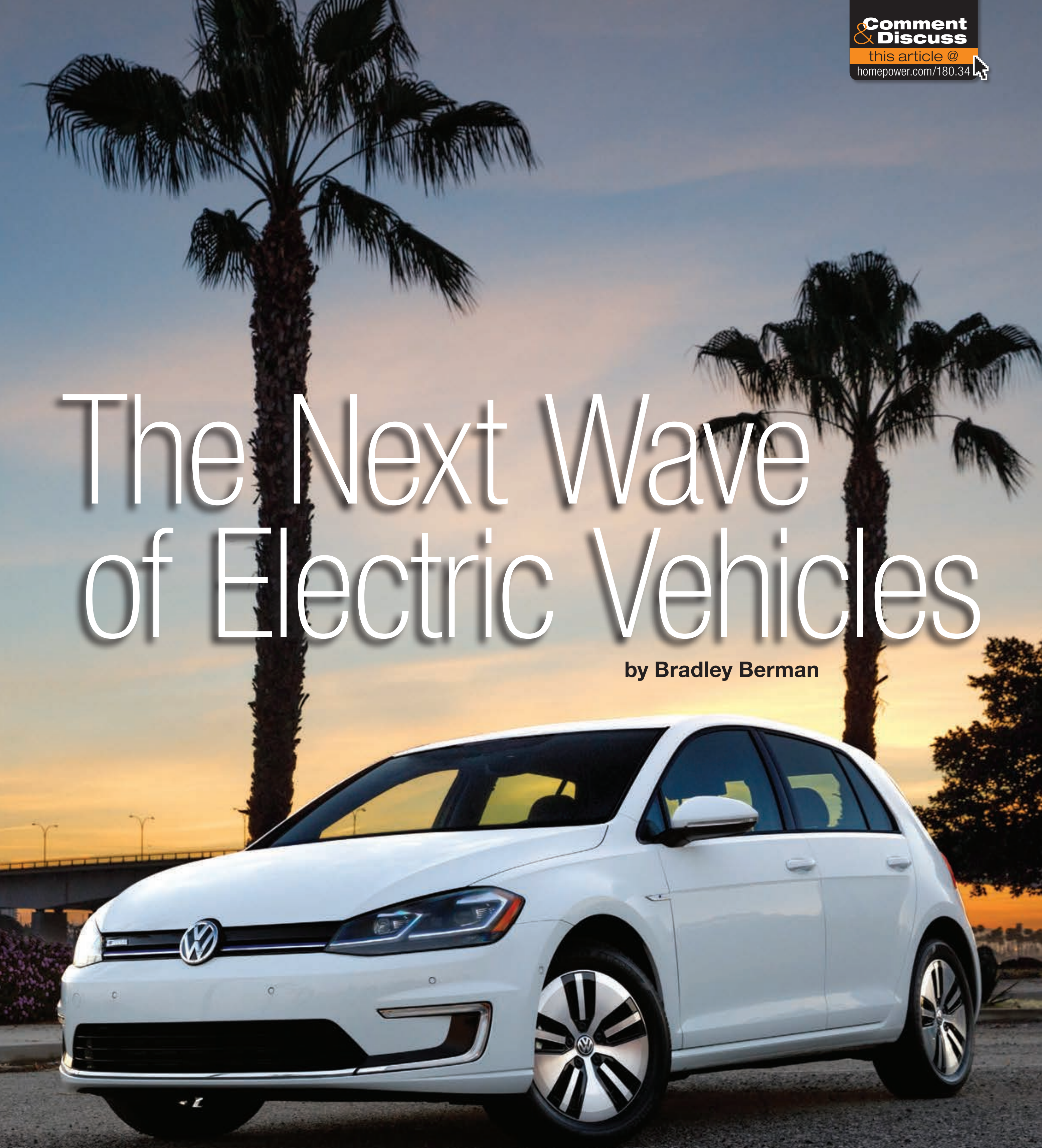


The Next Wave of Electric Vehicles

by Bradley Berman

Electric cars are no longer exotic. In the six-plus years since the first modern electric cars showed up at U.S. dealerships—primarily in California—more than 600,000 eco-oriented, high-tech, and relatively affluent early adopters jumped at the chance to drive a vehicle powered by the plug rather than the pump. The EV take-rate has grown in those years, although the percentage of car buyers opting for an EV is still modest—about 1%.

All photos courtesy respective manufacturers

Meanwhile, most car shoppers have remained on the sidelines—even those who believe electric cars are ready for prime time. But that may be about to change. The shift is not just a matter of a potential battery technology breakthrough or a future spike in oil prices, but more mundane developments that should convince new ranks of consumers that it's time to dump the pump. The trends that may make the difference include:

Greater choice & affordability. There are now more than 30 plug-in vehicles available to U.S. car buyers, ranging from subcompacts to big SUVs and minivans. Prices begin below $30,000 and climb beyond $100,000. The style and performance choices are as diverse as the manufacturers offering the cars.

Multiple power trains in single model. In the 1990s and 2000s, most of the EVs on the road were electric conversions (VW Rabbits were popular due to their small size and light weight) and a few "test-market" models that were usually only sold as fleet vehicles. Today, electric cars blend into the showroom, since they are offered mostly as a power train choice for the same vehicles offered as gasoline-powered. For example, the Hyundai Ioniq hatchback is available as a hybrid, plug-in hybrid, or battery-electric car—but not as a gasoline-only vehicle.

Longer range per charge. A long-standing objection to EVs has been their limited range. Even though the vast majority of Americans drive fewer than 40 miles a day on average, consumers don't want limitations like needing to recharge their cars after 80 to 90 miles. General Motors shattered the ceiling on an affordable long-range EV with Chevy Bolt, which offers an EPA-estimated 238 miles of range on a single charge. Before the end of 2017, Tesla is expected to make the first deliveries of its much-anticipated Model 3 with a 215-mile range.

New 200-mile EVs garner headlines, but the more important trend is the increase in battery capacity between first and second generations of EVs. Early adopters buying between 2011 and 2015 bought first-generation models with batteries that provided about 80 miles per charge. For many would-be buyers, that limitation yielded "range anxiety." Today's second-generation models commonly offer a 50% range improvement over their predecessors. For example, the first-generation Ford Focus offered about 76 miles on a fully charged battery, while the 2017 Focus Electric provides 115 miles of range.

Many EVs are a power-train option on a car with other available configurations. The BMW i3 comes with two battery-pack capacity choices and an onboard gasoline-engine charging option.

EV Incentives

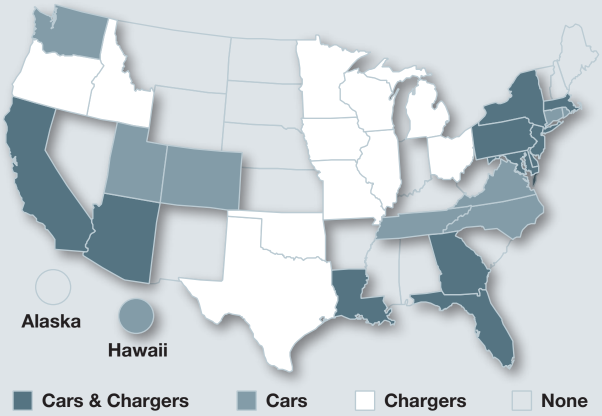
Buyers of EVs and plug-in hybrids benefit from the IRS's Plug-In Electric Drive Vehicle Credit of $2,500 to $7,500, depending on the size of the car's battery. Cars with 4 kWh battery packs qualify for a $2,500 tax credit and the credit maxes out at $7,500 for cars like the Chevy Volt, which has a 16 kWh battery pack. The incentive begins phasing out after an automaker sells 200,000 eligible vehicles.

Beyond federal tax credits, several states also offer tax credits, incentives, and rebates to EV owners. Many electric utilities around the country offer special rates, including time-of-use (TOU) rates, to reduce the cost of charging an electric car or plug-in hybrid. Check with your local utility company for rates and other details.

Several major insurance companies, such as Farmers Insurance, offer discounts of 5 percent or more for owners of electric and hybrid cars. Inquire with your insurance agent for details.

Some states offer EV buyers and businesses a credit for the purchase and costs of charging equipment. Residential recharging equipment may be eligible for a federal tax credit up to $1,000.

For more information, see **bit.ly/IncentivesEVs.**



web extras

Search for all-electric, plug-in, and hybrid vehicles at **fueleconomy.gov**—just click on "Advanced Cars & Fuels."

Quicker charging. The advantage of a larger-capacity battery is longer range, but the catch is that charging time can be longer. Tesla set the fast-charging standard with its 120 kW Superchargers that can add as much as 170 miles of range in about 30 to 40 minutes. Owners of non-Tesla EVs are excluded from using the extensive Supercharger network, so other car companies are teaming up to populate major highway corridors with 150 kW chargers. That means nearly all properly equipped EVs will soon be able to refuel just as quickly as Tesla EVs. In the next decade, a planned network of ultrafast 350 kW chargers could provide ubiquitous 10-minute pit stops for all-electric road trips. EVs can tap into the PlugShare app to easily locate charging stations.

New high-power chargers are able to put more energy, and miles, into cars faster than ever.

EV Contenders

These are the three longest-range affordable models of 2017. Tesla offers even longer range, but their EVs cost a lot more.

Chevrolet Bolt

The Bolt is a tall all-electric hatchback. It isn't the biggest, most spacious or most stylish EV available, but its 238 miles of range beats its similarly priced competition for long-distance travel. That range, combined with a surprising amount of interior space for a compact car, should eliminate concerns about an electric car not being an everyday vehicle. Two minutes behind the wheel will destroy any misconception about electric cars being slow.

The Bolt's 150 kW electric motor produces 200 horsepower and 266 foot-pounds of torque. That means zero-to-60 mph acceleration in less than seven seconds. If anything, the Bolt's electric propulsion is too powerful for its platform. Its low rolling resistance tires chirp when you stomp on the accelerator. The Bolt is not quite as exhilarating on the highway compared to driving at lower speeds or when launching from a standstill, but it doesn't lack passing power.

As with most EVs, owners should install a 240-volt charging station at home. A home charging station allows the Bolt's 7.2-kilowatt onboard charger to add about 25 miles of range in one hour, or fully charges the battery bank overnight.

Chevy Bolt

Range: 238 miles
Size: Compact
Starting price: $37,495

Hyundai Ioniq

Range: 124 miles
Size: Compact
Starting price: $29,500

Hyundai Ioniq

The Hyundai Ioniq offers 124 miles of range on a full battery, which is about half as much as the Chevy Bolt. But 124 miles is more than enough for most regional driving.

The Ioniq is significantly bigger than the Bolt. Its dashboard layout is more intuitive and better placed for driver access; the plastic materials, which Hyundai says incorporate sugar cane fiber, powdered wood, and volcanic stone, feel nicer to the touch. Automakers seeking to push beyond the enviro-niche need to appeal to car buyers based on core features beyond the electric power train.

The Ioniq costs $8,000 less than the Bolt. Its entry-level price tag of $29,500 drops to $22,000 after taking the federal tax incentive. For $29,000 (after incentives) consumers get the premium trim package, with a sunroof, premium audio, LED lighting, a bigger touch-screen, emergency braking, and lane departure warning.

Volkswagen e-Golf

The new 2017 Volkswagen e-Golf increased its range by 50% compared to the 2016 model. The 2017 e-Golf has a 35.8 kWh battery pack to provide an EPA-estimate average range of 124 miles—right in line with the Hyundai Ioniq.

The 2017 e-Golf employs the classic good looks of German car design, such as a sleek front fascia and LED headlights. The improvement in the e-Golf's range is matched by an increase in horsepower from 115 to 134 ponies. The e-Golf particularly shines in zero-to-30-mph sprints, in city maneuvers, and at higher speeds around tight corners. At the time of this writing, VW has not announced pricing for the 2017 e-Golf. The outgoing model started at $29,800 including destination, before any federal, state, or local incentives.

VW e-Golf

Range: 124 miles
Size: Compact
Starting price: $29,800 (earlier model)

More of the Electric Pack

BMW i3

Like competing models, BMW also boosted the range of its EV in 2017 from 81 to 114 miles. The i3 is still pricey at $42,400 before incentives. The aerodynamic, lightweight electric Beemer has a cool factor, although detractors say its exterior is too quirky for a BMW. The interior is undeniably gorgeous.

BMW i3

Range: 114 miles
Size: Subcompact
Starting price: $42,400

Nissan Leaf

The Nissan Leaf is one of the most popular EVs—and for good reasons. It's well-equipped, has room for five adults, and can travel up to 107 miles on a charge. Some may not appreciate the Leaf's gizmo aesthetic, but the electric power train combines zippy acceleration and zero-emissions driving. The base-level Nissan LEAF S starts at $30,680 before the $7,500 tax incentive. Many Nissan dealerships entice new buyers with rock-bottom monthly lease deals.

Nissan Leaf

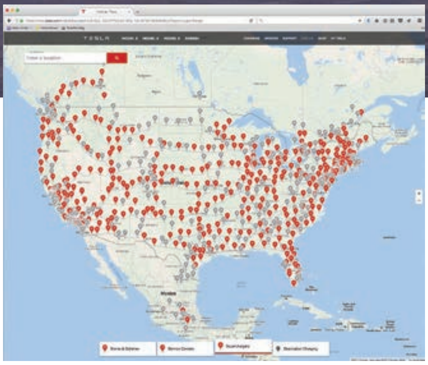
Range: 107 miles
Size: Compact
Starting price: $30,680

Tesla Model S

Range: 259–351 miles
Size: Large sedan
Starting price: $69,500

Tesla Model S

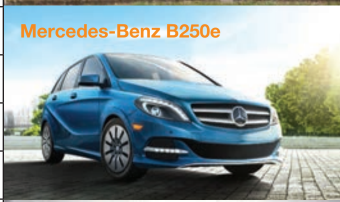
While Tesla lowered the price on the 75 kWh model that yields 249 miles on a charge, it's still spendy at $69,500. But what you get is remarkable: a big, fast, luxury sedan with more powerful batteries in a unique high-power configuration, self-driving features, and over-the-air software updates. The Model S comes with free access to a network of the company's quick-charging Superchargers.

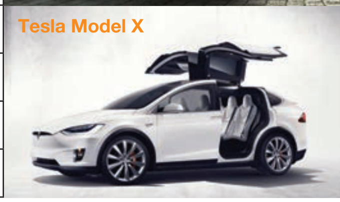


Existing and planned Tesla Supercharger locations.

EV Market Overview

Vehicle	Size / Type	Starting Price	Range (Miles)	Energy Used Per 100 mi. (kWh)	Annual Fuel Cost*
BMW i3 BEV	Subcompact	$42,400	114	27-29	$550
Chevrolet Bolt EV	Compact	$37,495	238	28	$550
Fiat 500e	Compact	$32,600	84	30	$600
Ford Focus Electric	Compact	$29,200	115	31	$600
Hyundai Ioniq Electric	Compact	$29,500	124	25	$500
Kia Soul Electric	Crossover	$33,135	93	32	$600
Mercedes-Benz B250e	Small hatchback	$42,400	85	40	$800
Mitsubishi i-MiEV	Subcompact	$22,995	62	30	$600
Nissan Leaf	Compact	$30,680	107	30	$600
Tesla Model S	Lux Sedan	$69,500	259–351	32–35	$600–$700
Tesla Model X	Crossover	$82,500	237–289	36–39	$700–$750
Volkswagen e-Golf	Compact	$29,800	124	28	$550





Considering a Plug-In Hybrid

Plug-in hybrids provide most of the benefits of a pure electric car, but eliminate range anxiety. After the battery pack is depleted, a gas engine takes over.

Chevrolet Volt

The Volt operates entirely on battery for the first 53 miles. After that, a 1.4-liter gasoline engine provides about 367 more miles when the 8.9-gallon tank is full. The current model provides seating for five—an improvement over the first-generation Volt, which had rear seating for only two adults. Price: $34,095.

Toyota Prius Prime

The quintessential hybrid car has a plug-in version that offers 25 miles of driving from the electric motor. It can stay in electric mode at speeds up to 84 miles per hour. Like the popular hybrid, the Prime is a small hatchback (room for only four people) that reflects Toyota's reputation for reliability. The Prime doesn't provide an exciting ride, but its hallmark is fuel efficiency. After those first 25 or so miles, the Prime reverts back to a conventional hybrid design, achieving an estimated fuel economy of 54 miles per gallon. Price: $27,100.

Chrysler Pacifica Plug-in

In 2017, Chrysler introduced the auto industry's first hybrid and plug-in hybrid minivan. The new Pacifica has earned praise as the most elegant midsize van on the market. It also is decently powered with 3.6-liter V6 engine, a continuously variable transmission (CVT), and two electric motors that generate 260 hp total. But what's more remarkable is how the 16 kilowatt-hour battery pack allows this family-hauler to travel more than 30 miles only on electricity—an EPA efficiency of 84 miles-per-gallon equivalent. Price: $41,995

The federal incentive for plug-ins is based on battery size. Unfortunately, there are no longer any incentives for conventional hybrids.

On the Horizon

Tesla Model 3

Tesla said it would begin production of the Model 3 in July 2017 and ramp up to producing 5,000 cars by the end the year. The company's goal is to reach production of 500,000 Model 3s a year by the end of 2018. The price tag is not yet final, but will likely be about $35,000 before incentives. That's remarkable for a vehicle with all the styles and high-tech features of a Tesla and a range greater than 200 miles per charge. The base-level Tesla Model 3 will come standard with a rear-mounted single motor, capable of launching the car from a standstill to 60 miles per hour in about six seconds. A $1,000 deposit will add you to the list of buyers waiting for their Model 3s to roll off the assembly line.

Audi E-Tron Quattro

VW promises the Audi Q6 E-Tron Quattro, a 300-mile-range pure electric SUV, by 2019. The E-Tron Quattro concept, unveiled at the 2015 Frankfurt motor show, uses three electric motors—one driving the front axle and two more on the rear axle. It will be exceptionally powerful at about 500 hp, but the bigger advantage is the use of torque control to actively distribute power between the wheels for maximum stability. All this in a luxurious crossover sport utility vehicle. The anticipated price will likely be in the six digits.

Next-Generation Nissan Leaf

Nissan is working to extend the Leaf's range for 2018, but CEO Hiroto Saikawa didn't say how much battery capacity would be added. The company promised that by 2020, an unspecified Nissan electric vehicle will push the limits of EV range to 300 miles in an affordable car.

Pairing Water Heaters with a PV System

by Claire Anderson

©iStockphoto.com/nikkytok

Modern water-heating technologies and efficiency strategies can offer energy savings in any household. With water heating consuming up to 20% of a household's total energy usage, it's a significant load. Here are more sustainable choices that can be offset by a PV or other renewably fueled system.

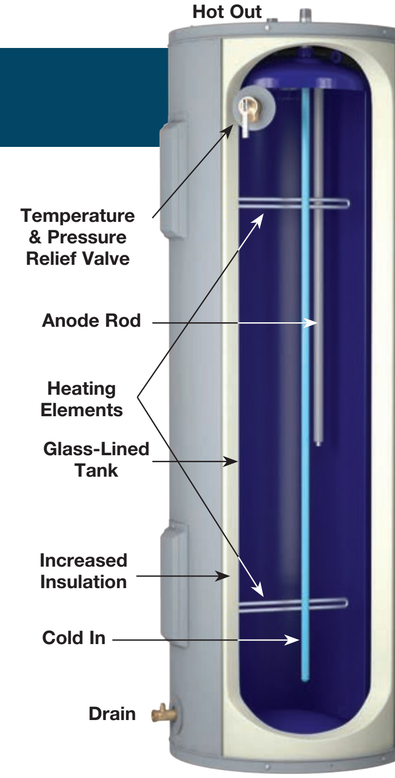
Electric Resistance, Plus

WHAT: Superinsulated electric tank-style water heater.

HOW: Electric resistance elements inside the tank are energized and transfer heat to the stored water. "Extra" insulation in the walls of the tank reduces the water's heat loss through the tank walls. Although the conversion of electricity to heat is 100% efficient, heating a large volume of water is energy-intensive.

ENERGY: Electricity.

SUITABILITY: Grid-tied RE systems, may also be PV-direct (see "Web Extras").



Courtesy A.O. Smith

Extra insulation is the key to this tank's improved efficiency. This A.O. Smith ProLine electric tank heater has an EF of 0.95.

BENEFITS:

- DIY installation.
- Easy to retrofit/replace, though superinsulated tanks have a larger footprint than typical or older models.
- Stainless-steel and polybutene tanks last longer than glass-lined steel.
- Relatively inexpensive.

DRAWBACKS:

- Recovery time—the tank may run out of hot water during periods of high use, depending on capacity.
- More expensive than "typical" tank-style heaters.

BOOST CONSERVATION BY: Adding a timer to turn off electricity to tank when not needed. For example, if the house is unoccupied during the day, set the timer to turn on just before inhabitation.

WHAT TO LOOK FOR: Look for a high "energy factor (EF)." Rheem's Marathon tank and A.O. Smith's ProLine, for example, have an EF of 0.95.

Courtesy Rheem

This Rheem Marathon 40-gallon electric water heater's tank is made with cross-fiber polybutene that is impervious to rust and corrosion. Because of this, it requires no sacrificial anode rod and carries a limited lifetime warranty against leakage. It has an EF of 0.95, meaning that it has standby losses (heat transfer through the tank walls) of 5% or less per 24-hour period.

Stretch Your Savings

Consider these other inexpensive conservation measures to further enhance water-heating energy savings:

- Put a timer on your electric tank-style water heater to reduce standby heat loss.
- Insulate hot water pipes.
- Add insulation to your water heater with a water heater blanket.

Don't Make Heat, Move It

Courtesy A.O. Smith

A.O. Smith's Voltex hybrid electric heat-pump water heaters, like this HPTU-50N 50-gallon model, offer up to four different modes—efficiency, hybrid, electric, and vacation. With up to a 3.24 EF rating, they can offer significant savings compared to tank-style heaters. This model boasts an EF greater than 2.0 and carries a six-year limited warranty.

WHAT: Heat-pump water heater (HPWH).

HOW: HPWHs use electricity to move heat from one place to another, instead of generating heat with electric resistance elements. They can be two to three times more energy-efficient compared to electric-element water heaters.

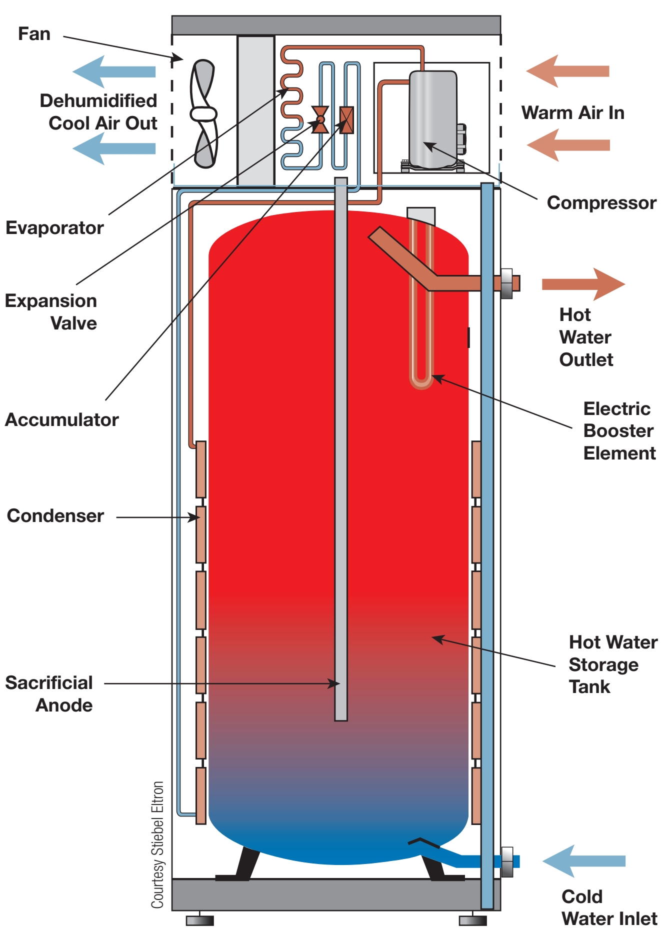
ENERGY: Electricity drives a phase-change loop (for more information, see "Back Page Basics" and "Minisplit" in this issue).

SUITABILITY: Grid-tied RE systems.

MAIN BENEFIT:

- High energy efficiency—a 2014 report from the ACEEE states that HPWHs have "a theoretical energy savings of up to 63%" compared to electric tank-style heaters.

Heat Pump Water Heater Function



DRAWBACKS:

- Space requirements: For optimal operation, HPWHs need significant space for air to circulate around them—at least 800 ft.^{3}, about equal to a 10-by-10-foot room with an 8-foot ceiling. If these space requirements cannot be met, a ducted HPWH that has supply and exhaust ducting is an option.
- Climate requirements: HPWHs need to be installed in a space that remains between 40°F and 90°F—they won't operate efficiently at colder temperatures.
- Most cool the space around the unit, thus cooling conditioned space.
- More expensive than superinsulated tank-style heaters.
- More complicated than tank-style heaters to repair or service.

PRICE: $1,827 (for 80-gallon GE Hybrid)

WARRANTY RANGE: 6 to 12 yrs.

On-Demand

WHAT: Tankless on-demand (aka instantaneous) electric water heater.

HOW: When a hot water tap is turned on, the flow of water through the heater signals an electric element to turn on, heating the water.

ENERGY: Electricity.

HOW: Via a high-wattage, resistance-based heating element (typical range is 15,000 to 28,000 W).

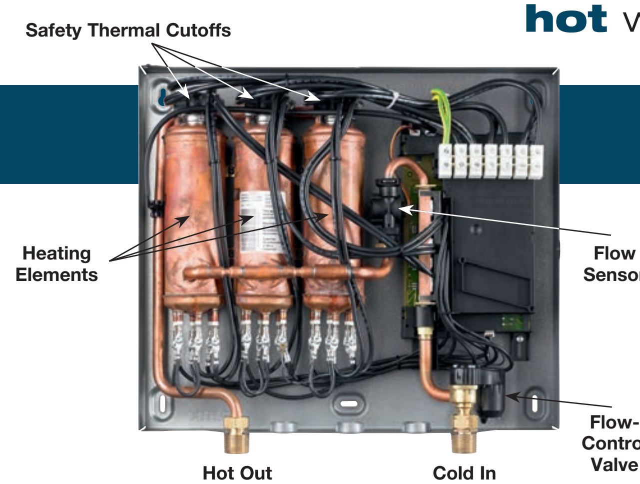
SUITABILITY: Grid-tied RE systems.

BENEFITS:

- Can work as a backup for a solar water heating system when space for another storage tank isn't available.
- More energy efficient—no standby heat losses. The U.S. Department of Energy estimates that for homes that use "41 gallons or less of hot water daily, demand water heaters can be 24% to 34% more energy efficient than conventional storage tank water heaters." For homes that use more than this, demand heaters can be 8% to 14% more energy efficient. Depending on pipe lengths, greater energy savings (between 27% and 50%) can be achieved by installing a point-of-use, on-demand water heater at each hot water outlet.

Stiebel Eltron's Tempra tankless water heaters have special flow control/microprocessor technology to ensure a constant temperature output that matches the setpoint—no matter the demand for hot water. It carries a three-year parts and seven-year leakage warranty.

Courtesy Stiebel Eltron (2)



This cutaway illustration of a Stiebel Eltron Tempra 36 Plus shows its three heating elements. This unit requires three 50 A, 240 VAC breakers in the AC distribution panel.

DRAWBACKS:

- Output temperature of the water depends on incoming water temperature and if simultaneous demands for hot water are being made. While there are different sizes of demand water heaters to meet different loads, they may not be able to supply adequate hot water to multiple simultaneous demands (i.e., showering while the dishwasher runs).
- High electrical energy use—may be more expensive depending on utility rate structure (i.e., time-of-use programs, demand charges, etc.). If on a tiered rate plan, peak demand charges could ensue if your heater consumes electricity over a certain threshold during certain periods.
- Large amperage draw versus voltage draw; may need to upgrade amperage on the home's electrical service.
- In locales with hard (mineral-rich) water, scaling may result, plugging the heat exchanger. Some units may have removable filters that can be cleaned regularly and descaling the unit every few months will help prolong its life. In areas with extra-hard water, a water softener may be necessary. Check the warranty for the maximum pH the water can be.
- Increased complexity (compared to a tank-style heater) means less ability for DIY repairs or parts replacement.

PRICE: $500-$600

TIPS: Unless the unit has a microprocessor to maintain output, you may need to compensate for use with low-flow fixtures, etc., by installing a higher-wattage heater or by installing two heaters in series—the first warms the water halfway, and the second warms it to the final temperature.

Go Solar, Thermal

WHAT: Solar hot water collectors.

HOW: Specially coated metal absorber tubes inside a box with a glazed face absorb sunlight and transfer heat to water or propylene glycol that circulates through a series of tubes and a heat exchanger; heated water is stored in an insulated tank.

ENERGY: Solar, plus electricity for circulator pump(s).

SUITABILITY: Grid-tied RE systems, off-grid systems.

BENEFITS:

- Use free energy from the sun.
- PV-direct circulator pumps can be used.
- Can be used for preheating before a conventionally fueled water heater.
- Can heat water even if the grid goes down.

DRAWBACKS:

- Climate- and weather-dependent.
- Takes up valuable roof space (which could be used for PV modules), although SWH collectors can generate more energy per square foot (i.e., are more efficient).
- Precautions needed to prevent system overheating during summer months.
- May produce highest output during times when usage is nil or minimal.
- Effectiveness depends upon total hot water usage; most effective for high-volume users.

PRICE (SYSTEM): Varies depending on number of collectors and system complexity. Smaller systems can start at about $6,000.

Solar thermal flat-plate collectors (above) and balance-of-system components (below) make up this SunMaxx solar water heating system.

Courtesy SunMaxx (2)

Courtesy Stiebel Eltron

With 25.82 square feet of absorber area, Stiebel Eltron's SOLkit 2 collector and system is designed to offset conventional water heating for a two- to three-person household. The kit includes an 80-gallon storage tank with in-tank backup electric element. The system comes with a 10-year warranty on the collectors, racks, and tank and is priced at about $7,800 (not including tankless backup shown).

Here & Now

WHAT: Point-of-use water heaters—tank or tankless.

HOW: With a tank-style unit, an electric element in the small tank is energized by a tank thermostat. A tankless style's element heats water flowing through a pipe only when the water flows, eliminating standby energy losses.

ENERGY: Electricity.

SUITABILITY: Grid-tied & off-grid RE systems.

BENEFITS:

- Reduces heat loss inefficiencies by eliminating long pipe runs and wasted water, since you're not waiting for hot water to arrive at the fixture.
- Easy to install.
- Fairly inexpensive.
- Some plug in directly to 120 VAC outlet; others may require 240 VAC.
- No recovery time for a POU tankless unit.

DRAWBACK:

- Recovery time for a small tank-style unit.

PRICE: $150+

WARRANTY: 1 yr. to 7 yrs. (depending on mfr.)

Courtesy Stiebel Eltron (2)

At 5.5 inches tall, 7.5 inches wide, and 2.75 inches deep, Stiebel Eltron's Mini 2 on-demand heater can fit unobtrusively in most bathroom, kitchen, or laundry sink cabinets. It operates at standard 120 VAC and requires a flow of only 0.21 gpm to activate.

Courtesy A.O. Smith

This A.O. Smith EJC-2 point-of-use heater with a 2.5-gallon tank uses a 1,500 W heating element at 120 VAC.

web extras

"Solar Water Heating Basics" • **homepower.com/SWHbasics**

"PV-Direct Water Heating" by Pete Gruendeman in "Off-Grid Water Heating" *HP177* • **homepower.com/177.52**

"Saving Water" by Claire Anderson in *HP145* • **homepower.com/145.66**

"Domestic Hot Water Efficiency" by Alex Wilson in *HP152* • **homepower.com/152.72**

How Much Wood...

WHAT: Wood boiler and heat exchangers for wood heaters.

HOW: Heat from a wood boiler is captured by a heat exchanger, then transferred to a storage tank.

ENERGY: Wood.

SUITABILITY: On- and off-grid, with access to woodlot or renewable wood supply.

MAIN BENEFIT:

- Relies on a renewable resource.

DRAWBACKS:

- Chop, split, carry—repeat.
- Water is heated only when wood heater is fired.

PRICE: Therma-Coil stainless steel heat exchanger—$130 for the heat exchanger only. You'll also need a storage tank and, possibly, a pump, controller, relief valves, etc.

Therma-Coil's stainless-steel heat exchanger for wood-burning applications has almost 3 feet of tubing inside the wood heater.

Courtesy Therma-Coil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MINI SPLIT

Efficient Heating with Minisplit Heat Pumps

Story & photos by Vaughan Woodruff

Low-maintenance, high-efficiency minisplit heat pumps provide significant energy savings for both heating and cooling.

Unlike resistance heat, which uses electric elements to generate heat, a minisplit heat pump (MSHP) moves heat from one location to another using refrigerant, a compressor, heat exchangers, and an expansion valve. During the summer, an MSHP moves heat from inside the building to the outside. During the heating season, the unit operates in reverse, capturing heat from the outside air and moving it into the home. Since the heat source for these units is air, they are commonly referred to as air-source (or air-to-air) heat pumps.

These systems are referred to as "split" systems because they use two units—an outdoor unit (the condenser) and an indoor unit (the evaporator)—to transfer heat. They are referred to as "minisplits" to differentiate them from larger heat-pump systems, such as commercial HVAC systems that utilize large roof-mounted units and often ductwork.

The idea that heat can be extracted from outdoor winter air can be a bit perplexing, but it is this same refrigeration principle that allows a fridge or freezer to use room-temperature air to cool its inside. As long as the temperature of the refrigerant is below the outdoor air temperature, it will be able to absorb heat. This is accomplished by blowing the warmer outdoor air past a heat exchanger containing the refrigerant. The refrigerant changes to a gas as it is heated, and its pressure and temperature are increased by a compressor. This superheated gas is then transported to a heat exchanger in the indoor unit. A fan in the unit circulates indoor air past the heat exchanger to heat the inside of the home. As the heat is released, the refrigerant condenses and is returned to the outdoor unit. An expansion valve reduces the pressure of the liquid at the outdoor unit, and the refrigerant becomes a gas again as it absorbs heat from the outdoor air.

With electric resistance, each kilowatt-hour consumed generates 1 kWh of heat (3,412 Btu). An MSHP can collect, move, and release 1.5 to 4 kWh of heat for each kWh of electricity consumed, depending upon the unit's efficiency and the outdoor and indoor temperatures. Compared to other conventional heating appliances, an MSHP system can reduce heating costs significantly.

Since an MSHP can pump heat out of a building, it can also provide air conditioning. With a better distribution system and more efficient components, MSHPs provide better comfort than a traditional window unit at less than half of the operating cost. For example, an Energy Star window-type air conditioner may provide 12 kWh of cooling capacity per kWh of electricity consumed by the unit. An equivalently sized heat pump might provide 25 kWh of cooling per kWh consumed.

This wall-mounted indoor air handler is equipped with a pump that is used when the condensate cannot drain by gravity.

A ceiling-mounted indoor air handler can be slightly less efficient, but is less obtrusive than a wall-mounted unit.

Applications

Most MSHP systems are ductless, making them a versatile option for retrofits. Heated or cooled air is distributed via a fan in the indoor unit, which may be mounted on a wall, on a floor, or in the ceiling. Since airflow is resistant to constrictions, such as doorways, these units have the greatest impact in open spaces that permit broad distribution. In homes that are heavily partitioned, multiple indoor units may be needed to provide comfort throughout the home. For some applications, small ducted indoor units may be used.

Because ductless MSHPs are point sources of heating and cooling, this often makes them best suited to reducing the energy demands of a central heating system rather than replacing the system entirely. In a new, well-insulated and sealed home, many designers combine heat pumps with strategically located electric resistance heat in bathrooms and other critical areas to avoid the need for a central heating system.

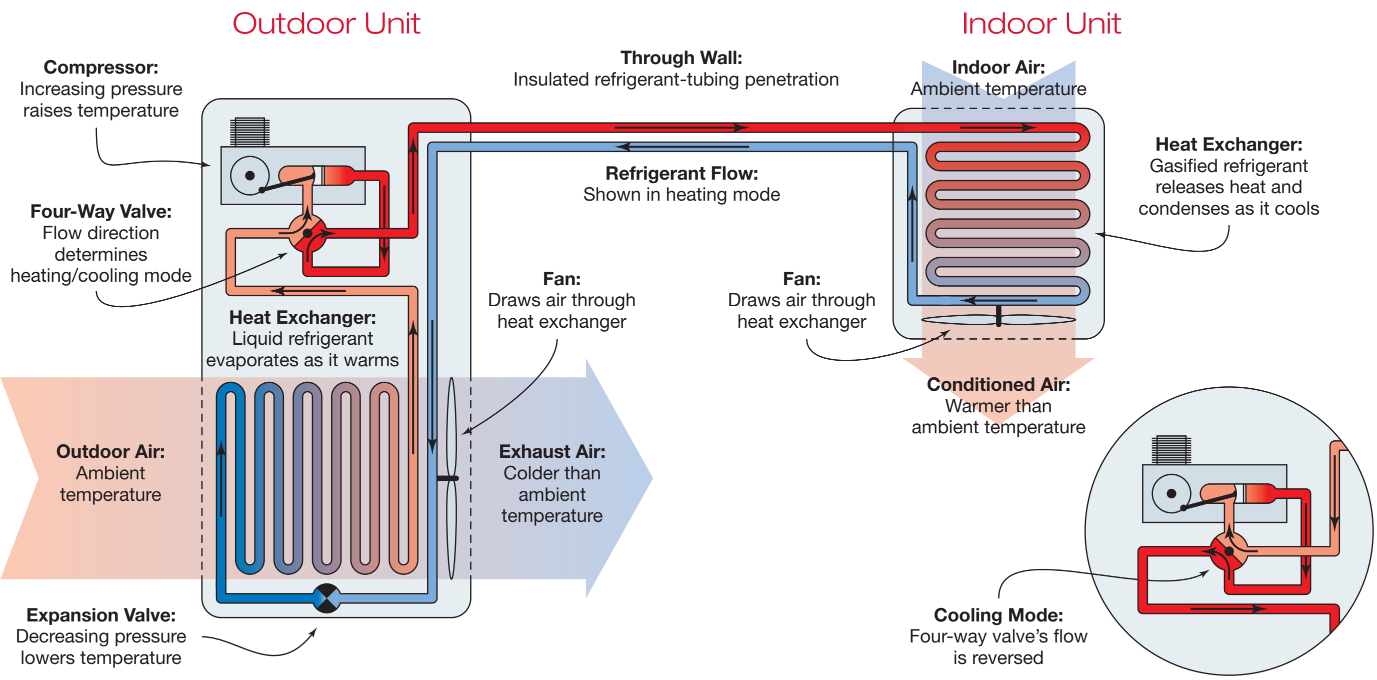
Installation Considerations

The indoor unit's style typically depends upon the wall space available, whether the installation is for a retrofit application or a new home, and your aesthetic. For example, a floor- or ceiling-mounted indoor unit might be preferred due to aesthetics, or the available width on a wall may dictate the model that will fit in that space.

Indoor units are connected to their outdoor units via electrical wiring and two insulated copper lines. The wiring provides electricity to the indoor unit from the outdoor unit and provides communication between the two units. An additional line drains condensate that is captured by the indoor unit when running in cooling or dehumidification mode and transports it to the building's exterior.

The practical details for routing these lines may affect the style and placement of indoor unit that is used. Wall-mounted units tend to have the highest rated capacity and

MINISPLIT HEAT-PUMP OPERATION



can be simpler to install when mounted on an exterior wall or on a wall with a closet or chase on the opposite side. These configurations allow easy access to the refrigeration fittings and often permit the lines to be surface-mounted within a chase. When refrigeration lines are concealed in building partitions, the installation process is more complex.

Floor-mounted units share a physical size similar to that of modern radiators. When installing these units, the refrigeration piping, wiring, and condensate can be routed through the wall or through the floor. In rooms with limited upper wall space or depending on your aesthetic, these models may be preferable to wall-mounted units.

If you'd prefer less-visible indoor units, ceiling cassettes and units with limited ducting may be used. One particular model of indoor unit serves as a picture frame to disguise the presence of a heat pump. Some of these units may have reduced performance, installation limitations, or may be significantly more expensive.

Most outdoor units look similar to one another, with a key difference being that outdoor units with larger capacities tend to be physically larger. When used in areas with little to no snowfall, outdoor units can be installed on a slab. In cold climates, outdoor units are typically installed on a wall bracket or a ground stand to elevate them above the snow line and to provide adequate clearance for draining during defrost mode.

When determining the location of the outdoor unit, there are a few considerations. If the unit is located under a drip edge at a roof eave, a rain cap should be installed to direct any rain or snow melt to the front of the unit. If this moisture splashes onto the back of the unit, it will likely be pulled into the heat exchanger, where it could freeze. Additionally, there needs to be sufficient airflow for the fan. If the unit is mounted with a shrub in front of it, this will decrease the output by restricting the amount of air that can be used for extracting or expelling heat. The electrical system in the outdoor unit is considered a source of combustion and must have adequate clearances from propane tanks and gas regulators.

A floor-mounted indoor air handler looks like a space heater, but with heat-pump efficiency.

A stand-mounted outdoor unit, raised above typical snow levels. The cap prevents snowmelt from accumulating on the coil.

A wall-mounted outdoor heat pump allows placement flexibility and simplifies installation. Care should be taken to avoid installing outdoor units near bedroom windows.

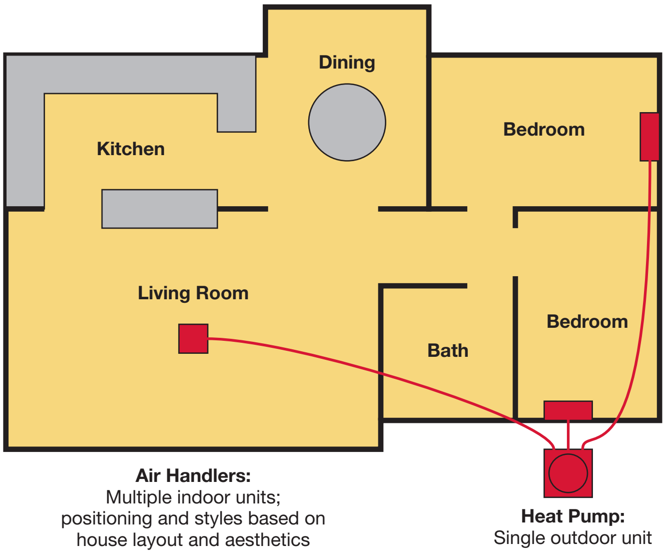
Multizone Systems

There are several approaches to integrating a heat pump into a home. The most budget-minded solution is to install a single-zone unit in the most heavily used living space. If more conditioned zones are needed, multiple single-zone units may be used, but another option is a multizone heat pump.

Multizone MSHP systems connect a single outdoor unit to several separate indoor units. Each indoor unit has its own controls. Indoor unit styles can be mixed and matched. For example, one zone of the MSHP might utilize a wall-mounted indoor unit, while another zone could utilize a floor-mounted or ducted unit.

Using a multizone system reduces the electrical installation work compared to multiple single-zone units. The trade-off is that the cold-weather output of one multizone MSHP is typically less than that of multiple single-zone MSHPs. For example, the heat output of two Fujitsu 12,000 Btu/hour single-zone heat pumps at 5°F is 75% higher than the output a single Fujitsu 24,000 Btu/hour multi-zone heat pump with two indoor units attached.

Multizone System



DEFROST CYCLE

As heat is transferred from outdoor air to the refrigerant passing through the heat exchanger in the outdoor unit, some moisture in the air condenses on the heat exchanger. This moisture freezes and accumulates on the coil. Temperature sensors in the outdoor unit determine when the frost accumulation is significantly impacting the system's performance and will initiate defrost mode.

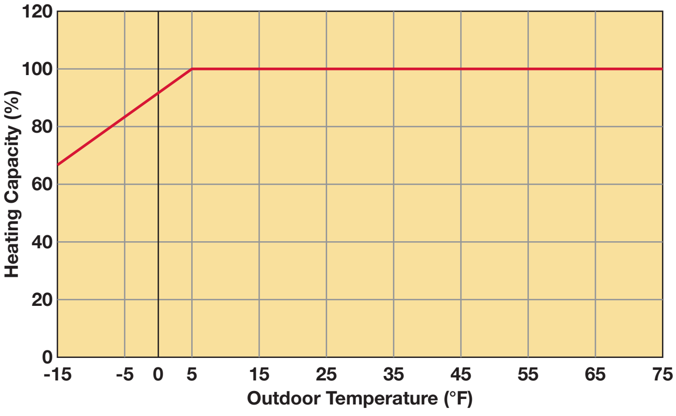
During defrost mode, the outdoor unit's large fan turns off and the MSHP reverses the refrigerant flow, moving heat from inside the house to melt the frost on the coil. The drain pan in the outdoor unit allows the melted frost to drain. In cold weather, icicles can form on the bottom of the unit. For proper defrosting, the outdoor unit needs to be elevated off the ground which also puts the unit above the snow line to maximize winter performance in freezing climates.

A key consideration is the noise the outdoor unit fan makes when the defrost cycle is completed. In many units, the outdoor fan turns off during the defrost cycle and then ramps up to its maximum speed to recover heat that was expelled to defrost the heat exchanger. If the outdoor unit is located near a bedroom window, this abrupt change in fan speed can be annoying.

A key characteristic of MSHPs is that as the outdoor ambient temperature drops, so does the amount of heat that the MSHP can extract from the outdoor air. The drop in efficiency varies by manufacturer and model. Multizone MSHPs often see a larger drop in efficiency when compared to comparable single-zone units.

While multizone units suffer some efficiency challenges relative to single-zone units in climates with long stretches of freezing weather, they can also have significant benefits. In homes with lots of smaller rooms that are heated and cooled with electricity, having numerous outdoor units scattered along the exterior of the home can be unsightly. In addition, some single-zone units may be oversized for the heating demands of a small room. With careful planning, these small rooms can be served by a single outdoor unit to provide the same level of comfort with less equipment, less visual impact, and less cost.

Heating Capacity Increases with Outdoor Temperature



HEAT CAPACITY TABLES & HSPF

One method for comparing the heating efficiency of MSHPs is the "heating seasonal performance factor" (HSPF). This value is the ratio of the system's heat output (in Btu) to the amount of electricity consumed (in Wh) to move this capacity of heat. The HSPF is essentially a seasonal coefficient of performance (COP) for a unit. To convert to COP, simply divide the HSPF by 3.412, which is the number of Btu/hour in a watt.

While HSPF can be an effective measure for a particular MSHP model's efficiency, it is also important to evaluate the unit's heat capacity tables to best understand how the unit will perform for your site's conditions. Some units may have a higher HSPF than a competing model, but may have a far different capacity at lower temperatures. If the MSHP is being used as the sole source of heat in a particular portion of the house, the total heating capacity of the unit is as important as how efficiently it can provide this heat.

For example, the heat capacity table illustrates the performance of a particular single-zone MSHP model. As the outdoor temperature decreases, so does the heat capacity of the unit. If the design temperature is 5°F and the anticipated room temperature is 70°F, the unit can provide 15,400 Btu/hour of heat. Comparing this value to the heating demand for the room aids in the selection process.

Example Minisplit Heat-Pump Operating Capacity

Heating capacity at various indoor/outdoor temperatures

Outdoor Temperature (°F)		Indoor Temperature (°F) 60°		65°		70°		75°	
DB	WB	TC	IP	TC	IP	TC	IP	TC	IP
-15°	-17°	11.6	2.15	11.4	2.19	11.1	2.23	10.5	2.31
-5°	-7°	14.7	2.16	14.3	2.20	14.0	2.24	13.3	2.32
5°	3°	16.1	2.17	15.7	2.21	15.4	2.25	14.6	2.34
14°	12°	16.8	2.13	16.4	2.17	16.0	2.22	15.2	2.30
23°	19°	18.3	2.10	17.9	2.14	17.5	2.18	16.6	2.26
32°	28°	18.8	2.06	18.4	2.10	17.9	2.14	17.0	2.22
41°	37°	21.3	1.88	20.8	1.92	20.3	1.95	19.3	2.03
47°	43°	23.1	1.85	22.6	1.89	22.0	1.93	20.9	2.01
50°	47°	25.5	1.84	24.9	1.88	24.3	1.91	23.1	1.99
59°	50°	26.5	1.63	25.8	1.67	25.2	1.70	23.9	1.77

Air flow rate: 487 cfm; DB = Dry-bulb temperature; WB = Wet-bulb temperature; TC = Total capacity (kBtu/h); IP = Input power (kW)

Data courtesy Fujitsu

MSHP production during cold temperatures can be improved by selecting a model that utilizes a pan heater to reduce the unit's defrost cycling. During a defrost cycle, the unit extracts heat from inside the home to melt any frost that has accumulated on the outdoor unit's heat exchanger. The pan heater is an electric resistance heater that reduces the accumulation of frost on the outdoor unit and minimizes these cycles (see "Defrost Cycle" sidebar). These models can be rated for outdoor temperatures as low as -15°F. As might be expected, this feature requires more electricity than for a unit without the pan heater.

Common Features

In addition to heating and cooling modes, MSHPs commonly have a dehumidification mode and a fan mode. Dehumidification mode is similar to cooling mode—the unit removes moisture from the air, which condenses on the indoor heat exchanger and is drained to the outside. Dehumidification mode is less precise than cooling mode, in that it runs at a low fan speed to constantly cycle the air through the unit and a cooling capacity that is a fraction of the unit's maximum output.

The fan mode can be used to cycle the air in the room through the unit to provide a more even distribution of temperature in the room, without turning on the heat pump. This may help distribute heat from a wood heater in the winter, for example, or simply provide more comfortable air movement in the summer.

The indoor unit also contains filters that limit the amount of dust and other airborne contaminants that accumulate on the heat exchanger, and help purify the air. These filters need to be cleaned regularly and are easily vacuumed with a soft-brush attachment or rinsed with tap water. The filters may need to be cleaned only every few months in homes with good air quality. In homes with smokers, where candles are used regularly, or that have airborne contaminants like pet hair, the removable filters need to be cleaned more frequently. If they are not cleaned, the airflow will be reduced, reducing the heat output.

coming up

Coming up in *HP181*: MSHP installation methods and best practices.

Air filters help improve indoor air quality. They are easy to remove and clean with soap and water or a soft vacuum brush.

Controls

The indoor unit functions are controlled by a wireless remote, a wired control, or through a wireless network to provide local or distance control with a smartphone app. Unlike standard heating systems that use a room thermostat to tell the unit when to turn on and off, MSHPs measure the room's air temperature with a sensor at the indoor unit's air intake. Another sensor in the indoor unit measures the temperature of the conditioned output. These temperatures determine how the indoor unit is run and are compared to temperatures measured by the outdoor unit to determine the speeds of the compressor and fans. Even when there is no heating or cooling demand, the indoor fan runs at its lowest speed to monitor the room temperature, unless turned off entirely.

Courtesy Mitsubishi

Heat pump controls can be on-the-unit or wall-mounted thermostats, handheld remote controls, or smartphone apps.

PAIRING MSHPs with PV SYSTEMS

In states with attractive net-metering policies, homeowners may size a PV system to produce surplus electricity during peak generation periods and draw on these credits in the winter to offset the electrical demand of heating. Because MSHPs are significantly more energy-efficient than electric resistance heaters, using an MSHP increases the value of each kilowatt-hour—by 1.5 to three times.

In the third part of this series, we'll discuss PV system sizing and accommodating the energy load of an MSHP system.

Additional Features

Some indoor units have occupancy sensors (i.e., motion sensors) that can reduce temperature when there is no movement in the room, modifying its target temperature by up to 8°F to save energy. For example, if the control is set at 70°F and there is no movement in the room for 20 minutes, the unit will gradually adjust its target heating temperature to 62°F until someone enters the room. At that point, the unit ramps up to 100% of its output to increase the room temperature.

Some units provide timer programming similar to a programmable thermostat. Other features may include:

- A sweep function that directs the airflow out of the unit up and down and left to right, similar to the behavior of an oscillating fan, to more evenly distribute heat.
- For homeowners bothered by the outdoor fan, a mode that reduces the capacity of the MSHP, thereby decreasing the amount of noise made by the outdoor unit.
- An infrared sensor that can sense areas of a room that are hotter or colder than others and can redirect the airflow to provide consistent comfort.

These features may drive the selection of a unit for a particular installation. For example, if an indoor unit is placed

web extras

Efficiency Maine heat pump tips • bit.ly/MSHPUserTips

Northeast Energy Efficiency Partnerships' Air-Source Heat Pump • bit.ly/MSHPNEEP

YouTube Heat Pump User Tips channel • bit.ly/MSHPYouTube

Comparing Home Heating Cost calculator • bit.ly/CompareHeating

on the longer wall in a narrow room, the automated sweep function or infrared sensor may significantly improve the room's heat distribution.

Determining the best MSHP for your application depends upon several factors. Heating and cooling loads will determine capacity and whether you need a cold climate unit with a pan heater. The layout of the home and your heating zones will dictate how many indoor units are needed. The layout and available space for the indoor units in each room; the installation details needed to connect the indoor unit to the outdoor unit; and aesthetic preferences may influence the type of indoor unit you choose.

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Simpler *NEC* Disconnection Rules

by Ryan Mayfield

One of the biggest changes in the *National Electrical Code (NEC)*'s Article 690 from 2014 to 2017 came in Part III, Disconnecting Means. Several sections have been deleted, the entire part is now only two sections, 690.13 and 690.15. The two sections deal with system disconnecting means and the disconnection of the equipment. The changes have simplified the rules and should be a big help for installers.

To fully understand *NEC* PV system disconnecting means requirements, look at definitions (found in Article 100) and refer to new diagrams included in 690.1. Article 100 defines a PV system as "the total components and subsystem that, in combination, convert solar energy into electric energy for connection to a utilization load. (CMP-4)." This definition is one that will come up for proper application of several *NEC* rules, so it is always worth rereading when in doubt.

In conjunction with the definition, the new figures located in 690.1(b) are a huge step forward in helping determine where PV systems "end" relative to other electrical systems that may be present. The diagrams in 690.1(b), show the location of the PV system disconnect, which can be on the DC or AC side of the system.

For proper application of Part III's PV system disconnecting means, make sure you are applying the rules to the correct disconnect. This is how the combination of the definition and figures comes into play. When trying to determine if you are at the PV system disconnect, it can be easiest to look downstream (electrically speaking) from the disconnect. Does any of the equipment downstream require the PV array to operate? If the answer is yes, then you are not yet at the PV system disconnect. If none of the pieces of electrical equipment after that disconnect require the PV array to operate, then you are at the disconnect.

All of the *NEC* definitions are now reviewed and changed by a *Code*-making panel (CMP) that is charged with wording the definition. This was done to ensure that definitions are maintained by those most directly knowledgeable with the impacts of the definition.

Let's look at relatively simple example, a PV array connected to a DC disconnect, which is connected to an inverter with the inverter connected to a circuit breaker in the main distribution panel, such as the diagram labeled "Interactive system" in 690.1(b). There are two options for the PV system disconnect—the DC disconnect and the circuit breaker connected to the inverter. Since the inverter is downstream of the DC disconnect and requires the PV array to operate, that would not be the PV system disconnect. The circuit breaker would be considered the PV system disconnect, since none of the equipment downstream (the loads connected to the main distribution panel) requires the PV array to operate.

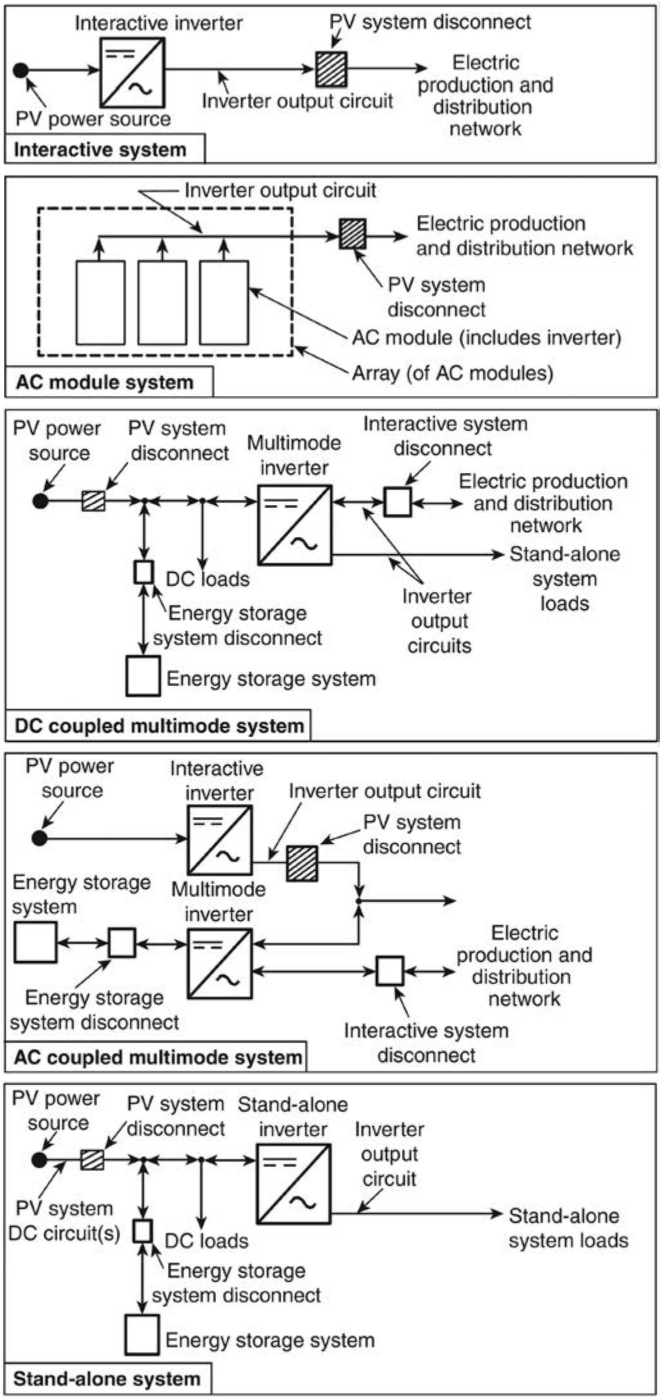
A more complex system including additional equipment (especially energy storage) is the "DC-coupled multimode system." In this case, the PV system disconnect is on the DC side of the inverter, directly after the PV array. Again, looking downstream of the PV system disconnect, none of the equipment requires the PV array to operate. The energy storage system and multimode inverter require each other, but the PV array is not an absolute requirement for operation. Note that in this diagram, a DC charge controller is not shown; it would typically be located between the array and PV system disconnect.

Having an effective means to define the PV system disconnect location makes it easier apply the Part III rules. Back to 690.13, Photovoltaic System Disconnecting Means, which says, "means shall be provided to disconnect the PV system from all wiring systems, including power systems, energy storage systems, and utilization equipment and its associated premises wiring." This impacts rapid shutdown requirements and the controlled conductors (Section 690.12).

Section 690.13 is divided into six subsections, which help define the location, markings, suitability, number of disconnects, ratings, and types of allowable disconnects. These subsections are similar to the requirements in the 2014 *Code*. The disconnect still needs to be at a readily accessible location. The words "PV System Disconnect" or equivalent need to be added to the disconnect, which is in line with the wording for labels in 705.10.

If the disconnect is on the supply side of the main service disconnect, then it needs to be suitable for use as service

Figure 690.1(b): Identification of PV System Components in Common Configurations



(1) These diagrams are intended to be a means of identification for PV system components, circuits, and connections.

(2) The PV system disconnect in these diagrams separates the PV system from all other systems.

(3) Not all disconnecting means required by Article 690, Part III, are shown.

(4) System grounding and equipment grounding are not shown (see Article 690, Part V).

(5) Custom designs occur in each configuration, and some components are optional.

equipment. As per previous *NEC* requirements, the PV system disconnects can't exceed six disconnecting means, and the disconnects must be properly rated for the voltage and current present. The final subsection, (F) Type of Disconnect, is new and outlines some of requirements for operation and ratings for DC-rated switches. It eliminates a long list of approved types of switches, and instead calls out general-use switches, circuit breakers, or other approved means as acceptable disconnects.

The last section in Part III for 2017 is 690.15, "Disconnection of Photovoltaic Equipment," which outlines the acceptable methods for disconnecting PV equipment from the other system circuits, while 690.13 focused on disconnecting the system as a whole. This section states that "isolating devices shall be provided to isolate PV modules, AC PV modules, fuses, DC-to-DC converters, inverters, and charge controllers from all conductors that are not solidly grounded." Section 690.15(C) provides more information on isolating devices. For systems that are currently being installed, the first two items—connectors and touch-safe fuse holders—will likely meet the requirements for isolating devices.

The next two sentences state that "an equipment-disconnecting means or a PV system disconnecting means shall be permitted in place of an isolating device. Where the maximum circuit current is greater than 30 amperes for the output circuit of a DC combiner or the input circuit of a charge controller or inverter, an equipment-disconnecting means shall be provided for isolation." In these cases, a disconnect can be used in place of an isolation means, but a disconnect must be used when the circuit current exceeds 30 A. The section provides an allowance to use a single disconnecting means to isolate multiple input circuits—for example, a single disconnect switching multiple strings that feed an MPPT in an inverter.

Per 690.15(A), the isolating device or equipment-disconnecting means must be integral to or within sight of and no more than 10 feet from the equipment. A remote disconnect is allowed, provided the operation of that disconnect can occur within 10 feet of the equipment.

Section 690.15(B) further clarifies isolating device requirements. Disconnecting means must have an interrupt rating to disconnect the power source from the equipment, but isolating devices don't require any interrupt rating. If you are using isolating devices that can't interrupt the current flow, a disconnect needs to be provided so that the isolating devices can be used safely. Finally, 690.15(D) gives requirements for the operation of and allowable forms for the equipment-disconnecting means.

All Washed Up

by Kathleen Jarschke-Schultze

"I'd like to do a song of great social and poetical import;
it goes like this…

Oh, Lord, won't you buy me a dishwashing machine,
My dog licks each plate twice, they still don't come clean,
My friends think I'm the biggest slob they've ever seen,
So, oh Lord, won't you buy me a dishwashing machine."

—Sung to the tune of Janis Joplin's "Mercedes Benz"

The time finally came when our old Asko dishwasher would not turn on. No cycle would start, no water would flow; only the hum of a motor would echo somewhere in the bowels of the machine. We could hear the pump trying to pump the water that wasn't there.

We knew it was old, we just could not remember how old. I have gotten into the habit of writing the purchase date on the cover of the appliance owner's manuals before I file them. Evidently, we bought the dishwasher before I started this practice. Then I hit on the idea of looking in back issues of *Home Power* to find out when I had written about my first dishwasher.

Turns out we bought the Asko 1355 more than two decades ago—in March 1996. I wrote about the purchase in "Home & Heart" (*HP52* and *HP53*). My dishwasher was 21 years old! We were flabbergasted. We had never had a problem or repair on the unit until it quit.

After some online research, we realized we would not be able to find some parts for it. The one circuit board we found may have (or may not have) been the fix. We didn't want to chance it and decided to buy a new dishwasher.

We went to local appliance dealers and to big-box stores. We met a woman who was also shopping for a dishwasher and a salesman told her she could only expect three years out of a new unit. That was unacceptable to us. We were coming off a 21-year run.

At the local appliance dealer, we found an Asko on sale—it was a floor model. Regularly $1,100, the price was marked down to $950. They offered a fix-or-replace warranty for $100. They have their own repair shop, so that was tempting.

We wrote down the model number and the next day Bob-O called Asko to ask about that model. Were parts readily available? Had there been any recalls or issues with that particular model? Turns out, that model hadn't been manufactured in the last two years. But we figured if it had another 20-year run, being two years old out of the gate wouldn't make a big difference.

Bob-O called the salesman we had talked to and relayed the news that the machine was not being made anymore. He talked the guy down to $750, including the service warranty. He had told us he was formerly a used car salesman, but he had nothing on Bob-O's bargaining skill.

We brought it home and installed it with some cursing and shoving to get it back under the counter. Although the new unit was the same size as the old, there is more room inside the tub, which is taller. The tub is stainless steel, just like the 1355.

The old 1355 was the last Asko model to have manual controls; the new one has all-electronic controls. Like the old model, it has its own water heater and a heated dry cycle. While we can't shut down the water heater, we can opt out

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of the heated drying cycle. Instead, once the wash and rinse cycles are complete, we just open the door and pull out the racks for air-drying—just as we've always done.

The unit is quiet. We anticipated that, but what we did not expect is its superior cleaning ability. Maybe our old dishwasher was losing its abilities so gradually that we didn't notice. Now, our glasses shine clearly and our plates gleam like diamonds in the light. We like it.

Washed Out

Not two weeks later my clothes washer quit. Just sat there and hummed—no cycle, no water—nada. I've had to put the big tub's drive belt back on its track before, which involves pulling the machine out and removing the back. I was hoping that was all it was, but when we pulled it out and took the back off, we found multiple injuries. The tub belt was starting to shred, and a shock arm on one side of the tub had broken off in such a way that its base was broken, too. It was going to cost hundreds of dollars to fix. We went shopping again.

This time, I scored at a big-box store, finding an LG #WM4270HWA 4.5-cubic-foot high-efficiency front-load washer with steam cycle on sale for $623.21. It has an inverter direct-drive motor—no more belt—and is more energy-efficient at lower speeds. It is Energy Star-rated and has a tier-two rating from the Consortium for Energy Efficiency (CEE). CEE is an EPA Climate Protection award-winning consortium. For example, the Super Efficient Home Appliance Initiative specifies three tiers of efficiency for clothes washers, taking into account power and water usage.

Bob-O modified the pedestal from the old machine to work with this slightly larger washer. This machine looks futuristic. I appreciate that the soap dispenser lifts easily out of the drawer for filling. The large, clear plastic "squircle" window in the front door is ringed with wide band of bright chrome. (A squircle is a mathematical shape that's part square and part circle.) When I press a button, an LED inside the washer issues an eerie, bright light that gleams coldly on the stainless steel tub. When I stand in front of it, I find myself murmuring, "Open the pod bay doors, HAL."

There are a variety of washing configurations I can choose from; using type of load, bright/whites, heavy soil, bulky/large, quick sport, etc.—and I can add the "Allergiene" steam cycle to reduce bacteria. The water temperature can be very hot, hot, warm, cold, and tap cold. Spin cycles include extra high, high, medium, low, and no spin.

Sensors in the machine can tell just how much or how little water should be used. After the sensors do their job, the readout displays the cycle length. When the cycle is finished, the washer plays a cheerful little tune, much unlike the game-show wrong-answer buzz my last washer broadcast. This machine is so quiet that when I'm upstairs I cannot hear it running.

If I had a compatible smartphone, I could communicate with my new washer via near-field communication, setting specific cycles, recording the machine's energy usage, and even run a diagnostics program. Since I don't have that capability, we used a Kill-A-Watt meter to record its electricity consumption.

The new Asko dishwasher.

The new LG clothes washer.

Kathleen Jarschke-Schultze (2)

In *HP25*, I wrote a "Things That Work!" article about installing a Guzzle-Busters Kit (GBK) on an older, used Maytag washing machine to lower its electricity usage. At the time, the average washer used 350 to 750 watt-hours per load. After I installed the kit, my test loads were coming in at 129.98 to 155.42 watt-hours per load. Back in the days of small RE systems, this was a huge energy savings and worth the time, effort, and expense of installing the GBK.

My new washer tests out at 130 watt-hours for a "Cotton/Normal, Tap Cold, Extra High Spin, Normal Soil" load to 1,490 watt-hours for a "Heavy Duty, Steam, High Spin, Heavy Soil" load. The first cycle combination is the norm for me; my inner energy nerd made me test the latter.

I am well pleased with our respective washer purchases. Although our renewable energy system is larger than it was 20 years ago and can handle more consumption, it is satisfying to know there are so many energy-efficient appliances now available and often on sale, so anyone who wants to conserve energy can easily find them.

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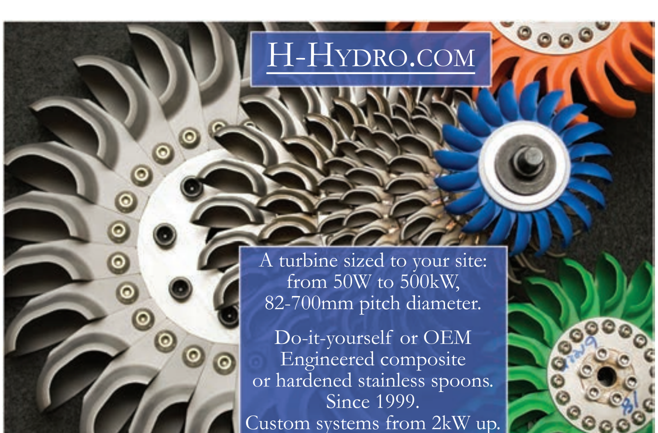

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Refrigerants in Heat Pumps

Heat naturally flows from a hot area to a cold one. But with the expenditure of some energy, heat can be extracted from a colder body and moved to a warmer location. This is a heat pump's function.

Your refrigerator and air conditioner are two types of heat pumps—they pick up heat from one place and transfer (pump) it to another. A fridge pumps the heat inside its cold box into the kitchen. It's the same with your household air conditioner, pumping the inside heat outdoors.

A heat-pump heater grabs ambient heat from the outside and pumps it inside to warm the home. With a heat pump, more than three units of heat energy can be transferred with the expenditure of one unit of electrical energy, saving energy and reducing your carbon footprint.

The mechanism for a heat pump uses refrigerant—a fluid that can change its phase to a gas and back again. Different substances are used as refrigerants, and each has different traits that become trade-offs in their utility. The ideal refrigerant would have the best thermodynamic and density properties; be noncorrosive to the system; be nonflammable and nontoxic; and not cause environmental harm if released.

Most early refrigerants were ammonia-based, and propane was used as well. But the trade-off was toxicity and flammability, respectively, if accidentally released. Most propane refrigerators in off-grid homes use ammonia as the refrigerant. Propane is not the refrigerant, but fuels a small, pilot-sized flame since there is no compressor in the fridge.

Other inert substance mixtures were developed as replacements:

Chlorofluorocarbons (CFCs) contain carbon, fluorine, and chlorine chemicals. CFCs were excellent performing refrigerants. However, released into the atmosphere, CFCs deplete the Earth's protective ozone layer and are also a greenhouse gas (GHG). CFCs have been banned in most countries for these reasons.

HCFCs contain hydrogen along with the other CFC substances. They are still ozone depleters, but with considerably lower capability compared to CFCs. They are considered transitional substitutes for CFCs, at least until ozone-safe alternatives could take over.

HFCs leave out the chlorine component, and are the most common refrigerant currently in use. They have no ozone depletion potential, but they are a powerful GHG. Depending upon the formula, they are up to 20,000 times more detrimental than our most common GHG, carbon dioxide (CO_2).

Vaughan Woodruff

Refrigerant charging and recovery equipment.

Because of their environmental dangers, the above refrigerants must be captured rather than merely released when heat pumps (including refrigerators) are serviced or decommissioned. Inadvertent leaks in these systems still cause pollution, so more environmentally friendly refrigerants have been developed and tested in recent years:

HFO, a relative newcomer, contains hydrogen, fluorine, and olefin, and is commercially available. It's slightly flammable, is not an ozone-depleter, and has GHG capability only four times greater than CO_2.

CO_2 was used in the early days of refrigeration, and it may be making a comeback. It's commercially available as a refrigerant, and its venting into the environment is not a serious issue during refrigerant replacement or system dismantling. Its downside is that it requires compression five to 10 times greater than many conventional refrigerants, so equipment and plumbing must be more robust, and more electrical energy is used.

For now, most environmentally safe refrigerants are being used and tested in modern vehicles' air conditioners. Cars and trucks are a large use of air conditioning, and also have the most problems with refrigerant leakage and accidental release. But Japanese companies are starting to use CO_2-based heat pumps in larger air-to-water heating systems, and some companies are developing home-scale CO_2 heat pumps. It remains to be seen if it will become more commonly used in household heat pumps.

—Michael Welch