POWER TOWER

Sometimes it takes a while for a dream to come true—like 30 years. As an aspiring architecture student in the late 1970s, I designed a fictional passive solar home on the west side of a remote island in the San Juan Islands, a diverse archipelago off the coast of Washington State. I had never visited the site, but maps showed it faced southwest, sloped gently to the south, and didn't have a lot of trees. It was a perfect site for solar energy, but it was just a project, and of course never got built. I played around with the active and passive renewable technologies of the time, eventually graduated with both a bachelor of arts and a master's degree in architecture, and moved forward with my career.

With Sun & Wind

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My college thesis advisor once told me that he felt young architects should be required to build their projects with their own money so they could make the tough decisions they expect clients to make. Interspersed between my clients' projects over the last two decades, I have developed several of my own projects and have had to make some hard decisions.

In 1994, with a family and an established architecture practice, my husband John and I decided it was time to purchase some getaway property. With John's background in construction and project management, the two of us comprise an entire design–build team, so we felt confident that purchasing undeveloped land was a good value for us.

Our search for property took us all over western Washington State. Waterfront was the primary criterion, with the next one being privacy. We live on a small lot in an older, established Seattle neighborhood, and we wanted a getaway that was just the opposite. We also wanted easy access, so we could use the property on weekends year-round.

We made our first trip to Guemes Island on a beautiful autumn day. Crossing Guemes Channel on the twenty-car, open-deck ferry, we wondered why we had never been there before. Guemes is one of the easternmost islands in the San Juans. We fell in love with and eventually purchased six acres of dramatic, steep, heavily forested, east-facing hillside. On our land, a series of flat benches are interspersed with breathtaking rock outcroppings.

The crew at the top of the tower's first section gets ready to receive and bolt the second section into place.

Moving Toward Renewable

The property had no utilities, so after building a road and digging a well, we turned our focus to getting electricity. Until we had some form of reliable electricity in place, we would not be ready to build our house.

The nearest electrical lines were a quarter of a mile away. I was bothered by the look of above-grade wires and poles, and also knew they had a reputation on the island of being hit and put out of commission by falling trees. So we investigated the cost of trenching through the rock to bury electrical line to the specification required by the local utility. This cost—more than US$30,000—prompted us to investigate renewable energy (RE) sources.

At first glance, solar energy did not seem viable because of our heavily forested, east-facing site, but we purchased one BP 80-watt photovoltaic (PV) panel to experiment with. We used it to charge our trailer's battery, and virtually eliminated the need to run our generator throughout an entire summer season. This success spurred us to further investigate RE technologies.

Then we discovered that Ian Woofenden, an RE consultant (and senior editor at *Home Power*), happened to live on Guemes. Ian visited the site, and walked the property with his Solar Pathfinder to assess our site's suitability for a solar-electric system.

Reinforcing steel and bolts were set into the foundation before pouring concrete.

A 50-ton crane lifted each assembled tower section into place. Amazingly enough, the first section lined up perfectly with the column bolts set into the concrete.

October 2004 seemed a long way off, but planning for the system started immediately. Besides working with the SEI team on the requirements and specifications of the hybrid system, we had to choose a tower, install infrastructure, apply for permits, and set aside the money to purchase all of the components. John estimated the loads for our planned home. We picked appliances out of catalogs and discussed what light fixtures to put into rooms that didn't yet exist. We made a spreadsheet of all the appliances we'd power, and we calculated that a system that could produce about 9 AC KWH would meet our daily energy needs.

We were fortunate to have a whole host of RE specialists participate in this project. SEI instructor Mick Sagrillo offered his wind energy expertise, and instructor E. H. Roy provided advice on the photovoltaic system. Kelly Keilwitz of Whidbey Sun and Wind designed our system and was our technical contractor for the two-week installation. Lance Moore, a licensed electrician, rounded out the professional team and handled the wiring work.

There was no moment of epiphany or assurance of how simple it would be to use renewables. Cutting down trees seemed to be inevitable to get any solar panels into the sunlight. Ian suggested wind power. At that time, I did not understand the perfect synergy of a PV–wind hybrid system, but in our rainy, northern, marine climate, sun and wind have an amazing reciprocal relationship. Our hillside site made us feel sheltered from the prevailing winds, but Ian thought wind was a good potential energy source for us. And, he said, once we built a tower to get the wind turbine above the trees, mounting a PV array on the south side of the tower could give us a viable hybrid system.

Building a Good Foundation (& Tower)

The choice of wind turbine and PV panels took a backseat to the most important element—the tower. If we didn't get the components up into the sun and wind, energy generation was not going to happen. Major considerations

Our System Comes Together

With our interest in RE heightened, we signed up for classes offered by Solar Energy International (SEI). They teach workshops all over the world, but in yet another bit of synchronicity, classes would be offered that October (2003) on Guemes. During the "Introduction to Renewable Energy" workshop, we saw examples of wind, PV, microhydro, and other RE technologies. We were able to tour local installations of PV and PV–wind hybrid systems.

John took a weeklong PV class, and helped install a pole-mounted, 1,120-watt PV array and a homebuilt wind generator adjacent to Anderson's General Store on Guemes (see *HP102*). After these experiences, we were hooked on the concept of renewables for our property, and told Ian that we would like to be the site of the projects for the 2004 SEI classes.

The complete AWP wind turbine was bolted to the tower's top section prior to lift.

for the project were ease of installation and servicing the equipment on an island, overall cost, structural integrity, size, availability, and (of course) aesthetics.

After climbing, measuring, and siting from one of the tallest trees on the property, Ian felt that we needed the wind generator an absolute minimum of 120 feet (37 m) above the ground, with 160 feet (49 m) being an ideal height. This would ensure that the turbine would be above all turbulence—both now, and in the future as the trees grow. The higher the PV panels were out of the forest, the better they would perform too.

We researched both guyed and freestanding towers. Although we have a clear area at our site that serves as a required fire truck turnaround, this was nowhere near sufficient space to lower an assembled tilt-up tower. And the uneven, rocky topography and steep location did not lend itself to placing the multiple anchors required for a guyed tower. Our only choice seemed to be the more expensive freestanding tower.

We investigated the largest towers made for residential applications, and the smallest towers made for the telecommunications industry. We looked at monopoles and open truss. We weighed the benefits of new versus used. John and I had emotional discussions on whether to proceed with the project due to its escalating cost. But we had made a commitment to do an off-grid installation, and we both felt strongly about moving forward with the project. The cost of a scaled-back system would be a waste of money. It needed to be built as designed, or it was not worth doing.

Finally, we decided on a tower—a triangular-based, 160-foot-tall Eiffel Tower-style manufactured by Glen Martin Engineering. It was designed to handle a much larger wind generator and a larger PV array than we initially planned, so we could grow the system as we used our property more actively in the future. The marine environment required that it be resistant to corrosion. We investigated materials and settled on galvanized steel.

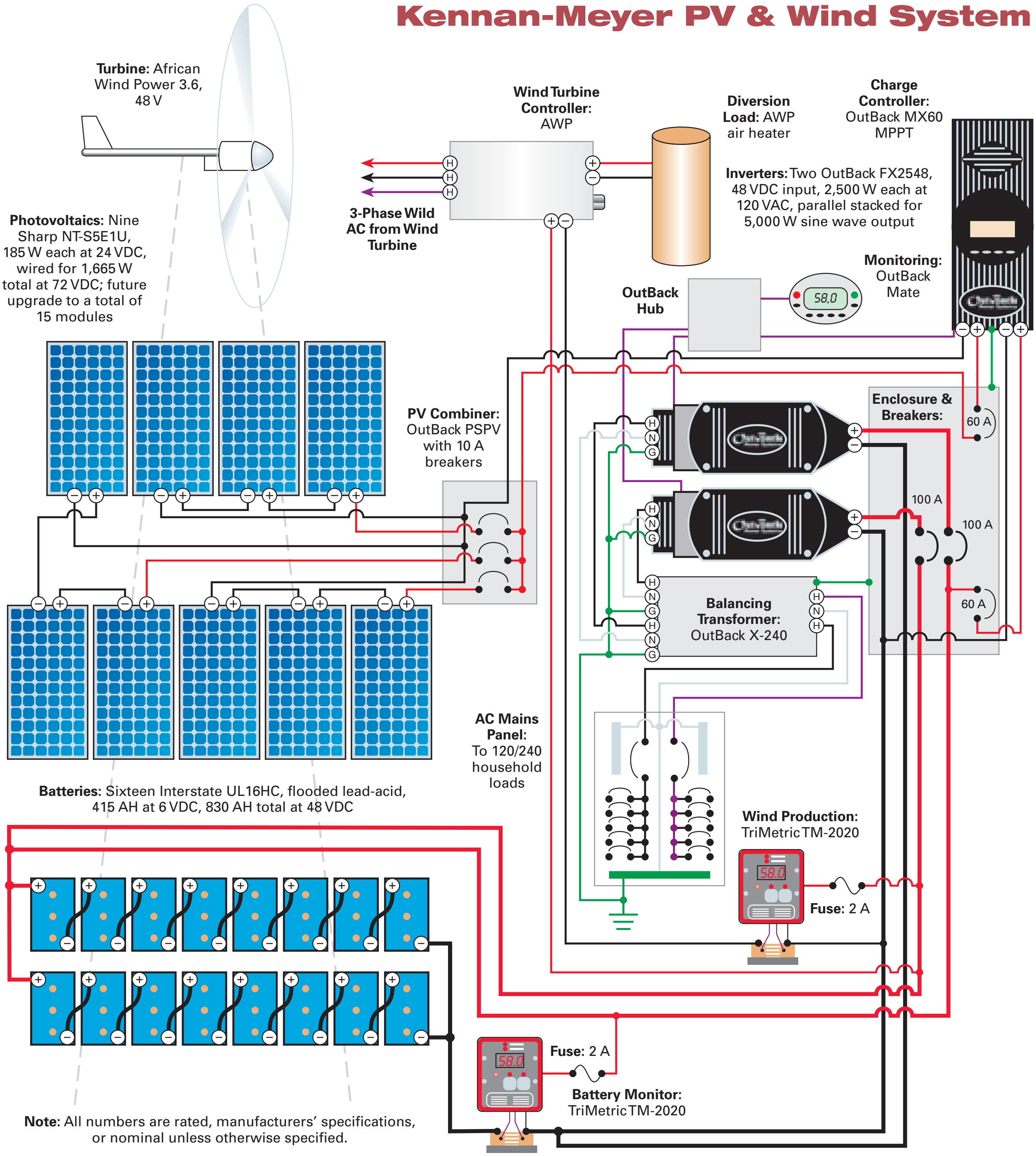
With the wind generator installation complete, it's time to begin installing the PVs.

Before the class, the tower foundation had to be complete. We started in January 2004 for an October installation. Local county codes required that we complete a Washington State Environmental Policy Act review and obtain a building permit for the structure. Glen Martin furnished us with drawings and stamped structural calculations for the tower. I completed the site plan and environmental checklist. Possible concerns included noise from the wind generator, the turbine's potential impact on birds, and the impact of the tower on views. With performance data, calculations, and scientific journal information, we were able to respond to these issues to both the county's and our satisfaction.

Tower foundation construction started in May. John removed several trees and we determined the tower's exact location. The initial excavation required a hole approximately 20 by 20 by 10 feet (6 x 6 x 3 m) deep be cut out of the rock. The excavator was not big enough, and the hydraulic rock hammer broke down daily.

Kelly Keilwitz and E. H. Roy give SEI students instructions on the procedure for lifting the first array for placement on the tower.

Kennan-Meyer PV & Wind System



The foundation design provided by Glen Martin's engineer included #6 (3/4 in.; 19 mm) reinforcing bar on both top and bottom. Because the overturning load on the tower is so large, we rely on both the weight of the concrete and the weight of 6 feet (1.8 m) of rock ballast placed on top of the foundation to resist the force. Three round columns of concrete rise out of the foundation to support the tower legs. The tower sections would be lifted onto these legs, and the 6-foot-long anchor bolts in each column had to be positioned perfectly for a tower that was not even on site, let alone complete. Templates for the anchor bolts provided by Glen Martin helped guarantee a perfect match.

The foundation used more than 60 cubic yards (46 m^3) of concrete—more than what is used in most single-family homes in this region—and each load of concrete had to come over on the ferry. With the rock ballast in place, the

Kennan-Meyer PV & Wind Tech Specs

System Overview

Type: Off-grid, battery-based PV–wind hybrid system

Location: Guemes Island, Washington

Solar resource: 5.2 average daily sun hours (summer); 3.2 hrs./day (fall/spring); 1.9 hrs./day (winter)

PV production (AC KWH per day): Existing system—summer, 5.0; fall, 3.4; winter, 1.9. Future full array—summer, 8.3; fall, 5.6; winter, 3.2

Wind resource: 7 mph (3.1 m/s) annual average

Wind production (AC KWH per day): Summer, 0.5; fall/spring, 2.0; winter, 3.0

Photovoltaics

Modules: Nine Sharp NT-S5E1U, 185 W STC, 36.2 Vmp, 24 VDC nominal; future upgrade to a total of 15 modules

Array: Three, three-module strings for 1,665 W STC total, 108.6 Vmp, 72 VDC nominal; future upgrade to five strings for 2,775 W STC total

Array combiner box: OutBack PSPV with three, 10 A OutBack OBPV-10 breakers

Array disconnect: OutBack 60 A breaker

Array installation: Direct Power & Water custom design mount at 60 ft. tower elevation; south-facing, 63-degree tilt

Wind Turbine, Tower & Controls

Turbine: African Wind Power (AWP) 3.6, 48 V

Rotor diameter: 3.6 m (11.8 ft.)

Rated energy output: 220 DC KWH per month at 12 mph (5.4 m/s)

Rated peak power output: 1,000 W at 24 mph (10.7 m/s)

Tower: Glen Martin Engineering 157 ft. (47.8 m) freestanding lattice; with stub tower, turbine hub height at 163 ft. (49.7 m)

Wind turbine controller & diversion load: AWP 48 V

Energy Storage

Batteries: Sixteen Interstate UL16HC, 6 VDC nominal, 415 AH at 20-hour rate, flooded lead-acid

Battery bank: 48 VDC nominal, 830 AH total

Battery/inverter disconnect: Two OutBack OBDC-100, 100 A breakers

Balance of System

Charge controller: OutBack MX60, 60 A MPPT, 72 VDC nominal input voltage, 48 VDC nominal output voltage

Inverter: Two OutBack FX2548, 2,500 W each, 5,000 W total, 48 VDC nominal input, 120/240 VAC output; OutBack X-240 balancing auto transformer for 240 V loads

System performance metering: TriMetric TM-2020 battery monitor; TriMetric TM-2020 wind output monitor; PV datalogging via OutBack MX60

weight of the foundation is calculated at more than 325,000 pounds (147 metric tons)!

Installation Begins

The tower began as a pile of 20-foot-long steel tubes and a heap of steel angle-braces. Each piece had to be bolted together into what would eventually become leg sections. The legs were combined into two 60-foot-long (18 m) and one 40-foot-long (12 m), triangular tower sections. The height of the tower required us to use one of the largest cranes available locally.

The 3.6-meter-diameter (11.8 ft.) African Wind Power (AWP) turbine was removed from the box that shipped it from the factory in Zimbabwe. Class members attached the blades, constructed the tail, and mounted the stub tower. The top tower section would be lifted with the turbine bolted in place.

In four days of assembly, the tower was ready to be raised. Getting the crane up our narrow, steep, gravel road was challenging, but it rolled into the clearing. After a year of intensive preparation, the tower would finally be lifted into place. The first section was raised as the collective breaths of students and guests were held. It fit onto the eighteen anchor bolts perfectly, and students scrambled to tighten bolts.

Ian and the students climbed up the tower to receive the next section as it was lifted into place. Watching a 60-foot-tall, steel truss tower section fly through the air to line up with 1-inch-diameter (2.5 cm) bolt holes sounds impossible, but that's how it is done. Once the second section was secured, the remaining section was placed with the turbine at the top. The job was by no means finished, but the structure was up.

An OutBack charge controller and inverters are housed in the power shed, which is also home to a dump load, weather monitoring equipment, and the battery bank.

A 12- by 10-foot (3.6 x 3 m) power shed houses the inverters, charge controllers, dump load, battery bank and watering system, weather monitoring equipment, and other electronics. Conduit from the tower was routed into the shed before the concrete slab was poured.

The power shed was our Fourth of July weekend family project. The tower looms over the forest, and I wanted the shed to complement the tower and not look like a playhouse. The power shed design combines a simple plan and roof form with pleasing proportions and simple materials. The shed is insulated wood-frame construction with plywood panel siding and a galvanized aluminum channel roof.

The remainder of the workshop's second week was spent wiring the power shed. A large dry-erase board with the wiring schematic made the trip back and forth from the classroom to the power shed daily. On the last day of the workshop, the breakers were flipped and the displays in the power shed lit up. Everything was operational! We were generating electricity!

The Ease of PVs

After the complexity of the turbine and the precision of the tower, mounting the PV panels looked like easy work. The rack mounting system from Direct Power & Water was modified to accommodate placing the PV panels on the tower. Nine 185-watt Sharp PV panels were wired into three-panel, 72-volt nominal arrays. The panels step up the tower in a triangle, and the bottom two rows—with five and four panels each—are in place. The rows above—with three panels, two panels, and one panel, respectively—will be installed once the house is built. Due to cost concerns, we decided not to purchase and install all fifteen panels at once.

Other Infrastructure

We spent the rest of the two workshop weeks installing the electronics and the battery system. The 48 VDC nominal, 41.5 KWH battery bank will provide backup energy for about three days of foggy, calm conditions. After that, we usually have wind, or clearing and sun. If that doesn't happen, we can run an engine generator to charge the batteries.

System Costs

Item	Cost (US$)
Tower (delivered); includes structural design fees	$17,500
Foundation & backfill for tower	14,500
Sharp PV panels & custom mounting rack on tower	10,275
Wire, conduit, misc.	8,000
Power shed	5,500
OutBack equipment	4,575
Clearing & excavation for tower	4,500
AWP turbine, controller, diversion load & stub tower	3,500
Battery bank	2,875
Soils engineering & testing; permits	2,200
Crane (for tower erection)	1,800
Electrician	1,200
Battery watering system	775
Total Cost	$77,200

System Performance

Overall, the system functions well. Our solar and wind energy production is exceeding the preliminary estimates and easily keeping our battery bank full. Since we do not have a house load on the system yet, the dump load is activating and consistently keeping the shed 10 to 20°F (6–11°C) above the outside air temperature. Eventually, the dump load will be used to preheat household water.

We chose a watering system from Battery Filling Systems (BFS) to help us take better care of the batteries. Without this system, we'd have to remove the caps of each battery by hand, check the water level, and add distilled water as necessary. The watering system we chose makes this tedious task much easier. The factory caps on the batteries were removed, and replaced with BFS threaded plugs equipped with floats. Clear PVC tubing runs from a small holding tank, which contains distilled water, to each plug. About once a month, we use a small hand pump to pressurize the tank, which then distributes water to top off the cells.

Off-Grid Living

When you live on the grid, you often take electricity for granted. With an RE system, you think about where every watt-hour comes from, and where you are using it. As my wise college advisor predicted, having—and paying for—my own RE system makes me able and willing to discuss renewables with clients, and encourages them to listen. I hope to incorporate the things we have done into future designs for clients.

Renewable energy is a choice, like any other component in a home. When people ask what the payback time for the system will be, I truthfully reply that I don't know. Most homeowners don't consider the payback time for a high-end, commercial-grade range or refrigerator, or custom cabinets—they put them in because that is what they want, and that is how they choose to spend their money. That's how I feel about our RE system, and I'm helping the planet as well.

Access

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Abundant Renewable Energy, 22700 NE Mountain Top Rd., Newberg, OR 97132 • 503-538-8298 • Fax: 503-538-8782 • robert@abundantre.com • www.abundantre.com • U.S. distributor for African Wind Power (AWP) wind generator

Battery Filling Systems of the Americas, 5723 Country Club Rd., Ste. B, Winston-Salem, NC 27104 • 877-522-5431 or 336-946-0895 • Fax: 336-946-0897 • freeinfo@batteryfillingsystems.com • www.batteryfillingsystems.com • Single-point battery watering system

Bogart Engineering, 19020 Two Bar Rd., Boulder Creek, CA 95006 • 831-339-0616 • Fax: 831-338-2337 • bogart@bogartengineering.com • www.bogartengineering.com • TriMetric battery monitor

BP Solar, 630 Solarex Ct., Frederick, MD 21703 • 800-521-7652 or 410-981-0240 • Fax: 410-981-0278 • info@bpsolar.com • www.bpsolar.com • PV panel

Direct Power & Water, 4000 Vassar Dr. NE, Albuquerque, NM 87107 • 800-260-3792 or 505-889-3585 • Fax: 505-889-3548 • info@directpower.com • www.directpower.com • PV mounting rack

Glen Martin Engineering, 13620 Old Hwy. 40, Boonville, MO 65233 • 800-486-1223 or 660-882-2734 • Fax: 775-490-1300 • info@glenmartin.com • www.glenmartin.com • Tower

Interstate Batteries, 1700 Dixon St., Des Moines, IA 50316 • 866-842-5368 • customerservice@interstatebatteries.com • www.interstatebatteries.com • Batteries

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OutBack Power Systems, 19009 62nd Ave. NE, Arlington, WA 98223 • 360-435-6030 • Fax: 360-435-6019 • sales@outbackpower.com • www.outbackpower.com • Inverters, charge controller, DC disconnect, breakers

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