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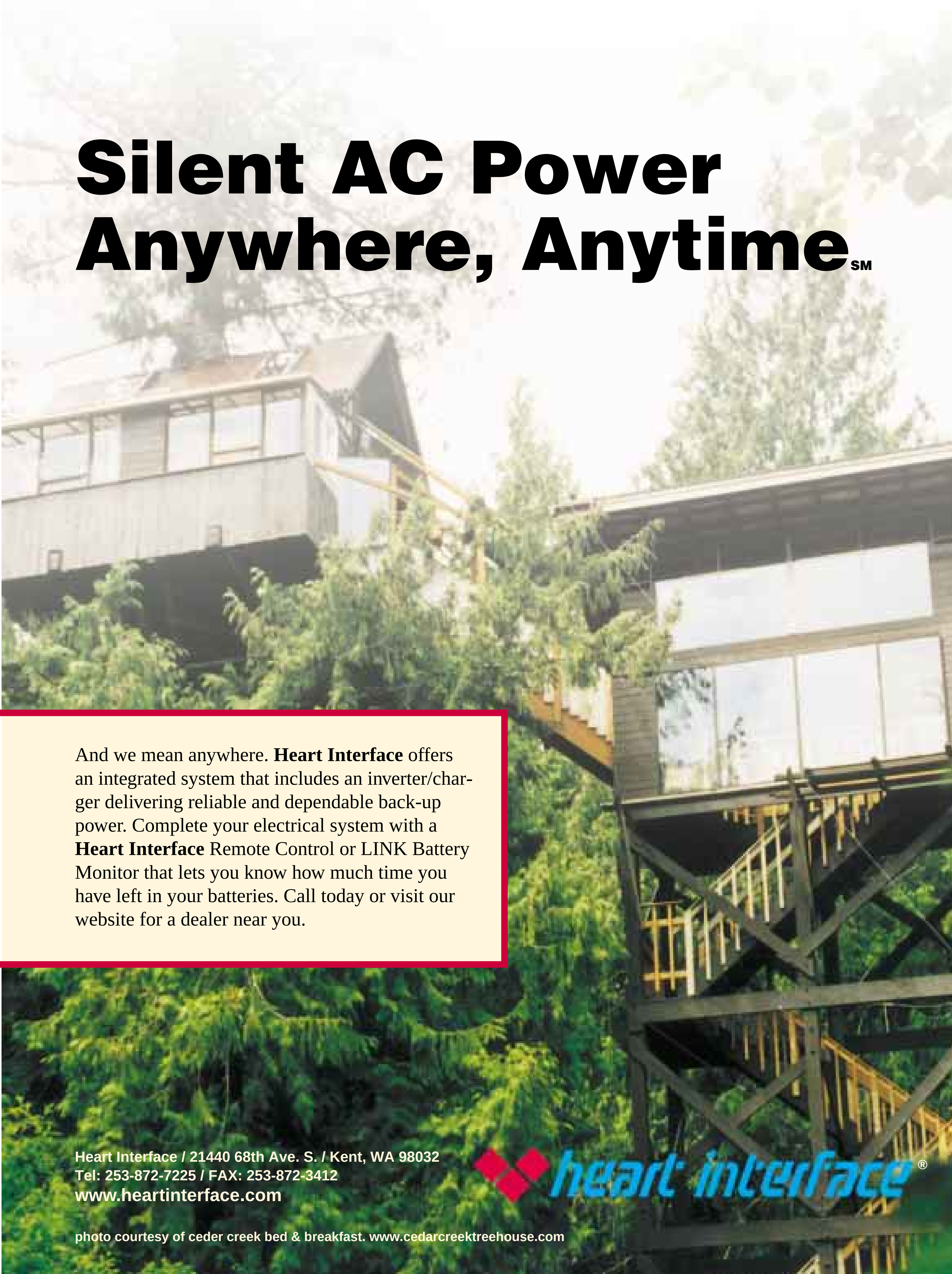

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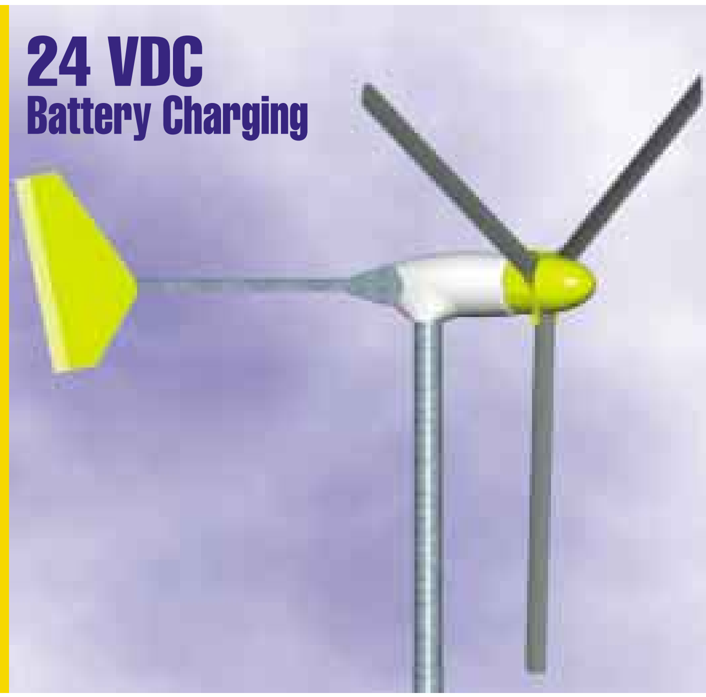

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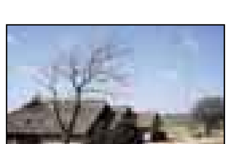

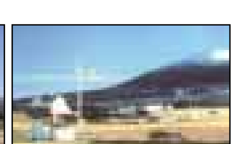

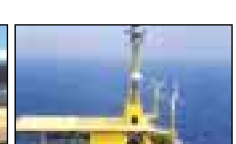

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HOME POWER

THE HANDS-ON JOURNAL OF HOME-MADE POWER

Issue #79 October / November 2000

Features

Features

GoPower

Cover: Peter Jones' electro-psychedelic "Funky Windmill" spins a pattern of colored LEDs at dusk. See page 54.

Homebrew

Things that Work!

Guerrilla Solar

Book Review

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Access Data

Home Power
PO Box 520
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What's It Worth?

The photograph above shows the new utility intertied solar-electric system we installed at the Grant County Fairgrounds in John Day, Oregon. This permanent PV array is rated at 1,120 watts, and all the electricity it makes goes directly into the local utility power grid.

This project was the brainchild of Jennifer Barker, the director of the SolWest Renewable Energy Fair. She was assisted by a crew of local contractors, and a group of students who spent three days of their lives learning about solar electricity. Joe Schwartz and I taught the pre-fair workshop that was focused on installing the system. All the RE equipment was donated by its manufacturers—many thanks to Solarex, Trace Engineering, and Two Seas Metalworks for their generosity. We will publish a technical article about this system in our next issue.

After the installation was complete, I began wondering… What's a solar electric system like this worth? I know that the hardware was worth about US$8,000. I know that nineteen students worked their butts off for three days under the scorching eastern Oregon sun, and that must be worth a grand or so. But what's it really worth? What did we, in the collective sense, really gain?

We, as inhabitants and custodians of this planet, took a miniscule step towards ensuring our planet's future. Each PV module on that sixteen module array will save putting one metric ton (2,200 pounds) of carbon dioxide into our atmosphere each year. Each module, each year. Over the next twenty years, this small system will displace 320 metric tons of CO_2 that would have been produced to make the same quantity of electricity. A small step to be sure, but a step in the right direction.

We, as the local utility, gained another power source—a power source that is radically different from any we previously had. This power source runs on sunshine. It produces no pollution—no CO_2, no acid rain, and no nuclear waste. This power source produces electricity during peak consumption hours, when we need it the most. It's a power source bought and installed without using a single cent of utility capital. A power source that brings energy close to where it is used, saving us the losses, expenses, and environmental damages of long distance power lines. The energy from this source is donated to us, and we can sell it to our customers. (Are the utilities grateful for this gift of clean energy? See *Ozonal Notes* on page 134 for the answer.)

We, as the installers of the system, gained experience in utility-intertied solar energy. We learned something that we will want to do again and again—it just felt right. Our biggest reward is watching the utility meter recording the 5 KWH of solar energy that the system pumps onto the grid each day.

Not a bad weekend's work…

–Richard Perez for the SolWest PV Workshop

People

Joy Anderson
Anil Baral
Chip Boggs
Clara Boggs
Mike Brown
Roy Butler
Sam Coleman
Eric Hansen
Rod Hyatt
Kathleen Jarschke-Schultze
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Everett Russell
Connie Said
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Anthony Skelton
Michael Welch
John Wiles
Dave Wilmeth
Myna Wilson
Ian Woofenden
Rue Wright
Solar Guerrilla 0011

"Think about it…"

Freedom is something you assume. Then you wait for someone to try to take it away from you. The degree to which you resist is the degree to which you are free.

-Ol' Campbell via Utah Phillips

My Grid-Connected Solar House

Anthony Skelton

Anthony Skelton's 1,020 Wp array of twelve BP-585 PV panels in Leek Wootton, U.K.

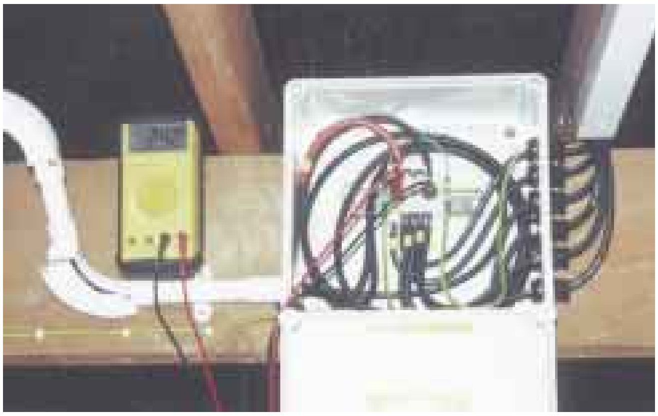
My interest in solar energy began when I was still in school. I was given an electronic kit that contained a small solar panel. Fascinated by the fact that this panel could generate electricity, I set to work building a solar-powered radio, one of the projects in the kit. It worked! Over the years, I have built various solar-powered items, including a stand-alone security system, garden lighting, and a solar-powered water garden and rock pool. My latest project was to connect twelve solar panels (1,020 Wp) to the mains electricity grid to generate power for my house.

Getting Permission First

The obvious place for me to install twelve BP-585 panels, each measuring 1,188 by 530 mm (46.8 x 20.9 inches), was on the roof. It's out of the way, and has almost no shading from trees or other objects. I contacted the local planning officer to see if planning permission was required, and in this case it was not.

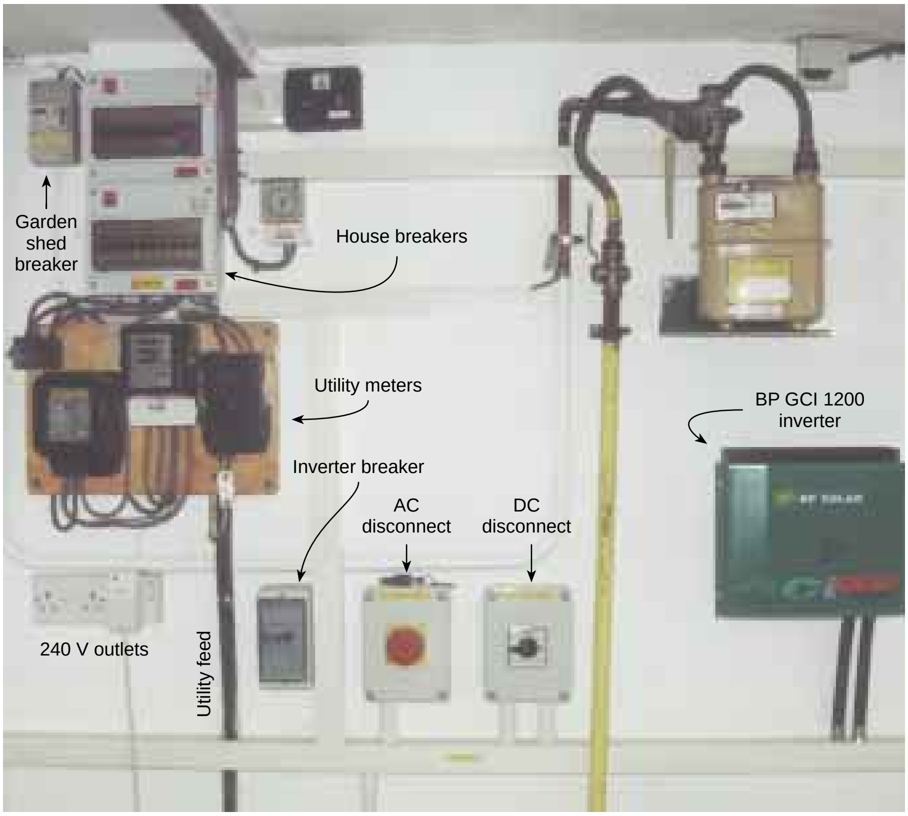
Because I wanted to connect to the grid, I had to get permission from my local electricity company, PowerGen. They were very cooperative in this matter, even though it was still quite an unusual request for them. After completing all the forms, permission to generate was given on the 5th of November, 1999.

Joint box in attic where solar subarrays are combined into one series string.

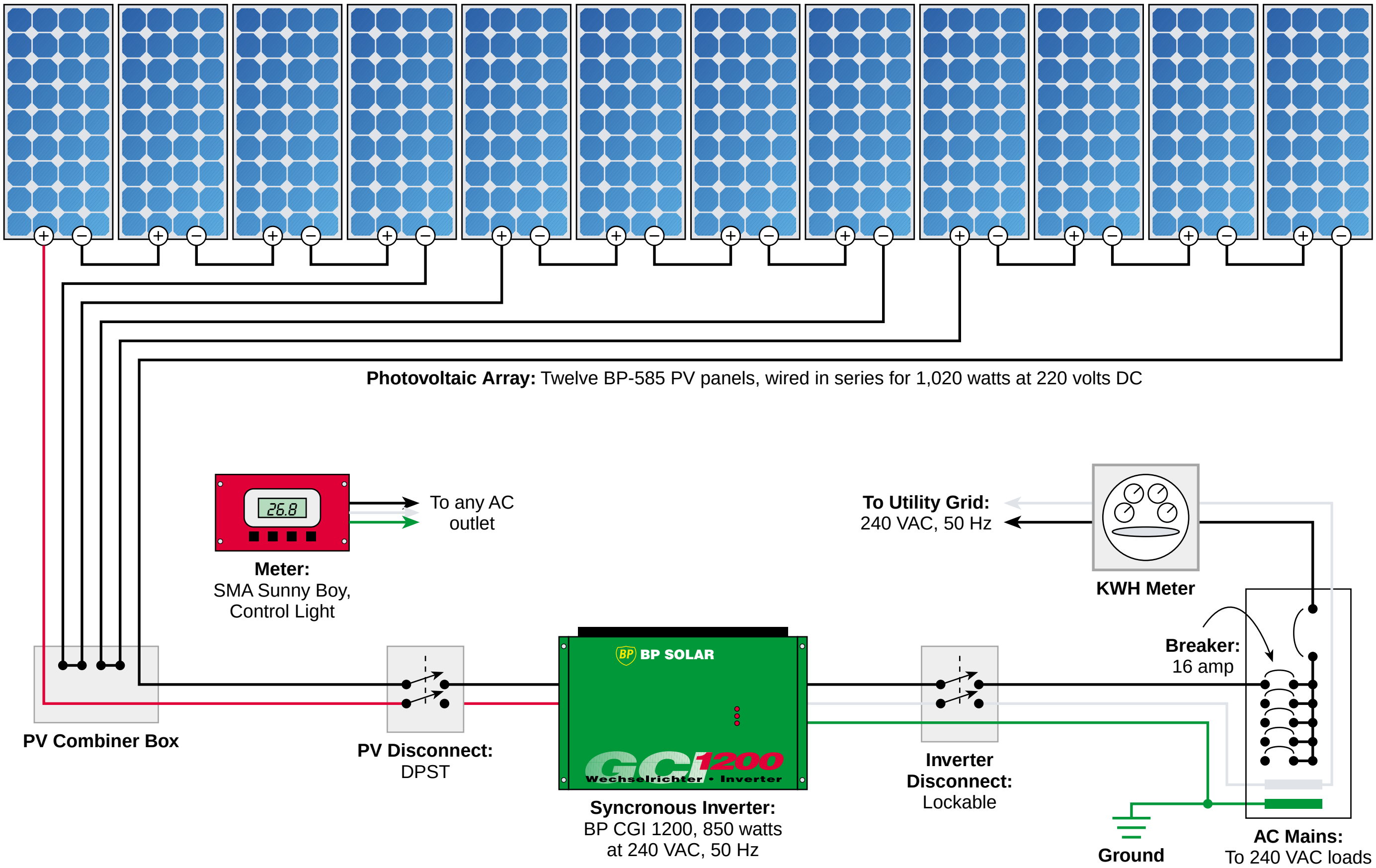


Phantom Loads!
Phantom loads are electrical loads connected to the power supply 24 hours a day. They do little more than run up your electricity bill. Examples are VCRs, televisions, radios, and many computers with external speakers. When you switch off these items, in most cases it does not switch off the mains supply. These items consume very little, but they are on for 24 hours a day. All these small loads soon add up. (See *HP37*, page 46, for an article on phantom loads.)

Whether you have a solar-electric system or not, it is a good idea to make a few checks for yourself. I set up a digital multimeter and a cord and socket set so that I could check each appliance for phantom loads. I solved the problems by either doing without the offending appliance or buying more efficient appliances.



Anthony Skelton's System



The Groundwork
Since it was winter, it was not a good time to be clambering about on the roof. I had twelve stainless steel brackets made to hold the PVs. These were pre-assembled and ready to go onto the roof when the weather was better. The two-pole DC disconnect and lockable AC isolation switch and the BP inverter were installed in the garage. A separate fuse board was installed for the system, and connected to the house distribution board that was just above it.

A DC disconnect switch was fitted to isolate the high voltage from the solar panels, and an AC disconnect switch was fitted to isolate the mains grid. As an extra, a modem was fitted to the inverter to transmit system data to a display in the house, via the existing mains cable. To make cabling easy and neat, trunking and plastic tubing ("conduit" to North Americans) was used. Once the cables were in the roof, I installed a large junction box to terminate all incoming cables from the panels on the roof. All the cables from the panels were wired in series in this box.

I was grateful for the help from Steve Wade of Wind and Sun (the company that supplied all the equipment). His technical assistance and advice during the planning stages and the final commissioning and setup were critical to the success of the project. When taking on this type of project, it is well worth having expert advice at an early stage.

Panels Up & Pull the Switch
A local builder helped me fit the brackets to hold the solar panels, and lift the three solar arrays onto the roof. The two days it took to fit could not have been better, with fine sunny weather. Working on the roof was not that bad after all, except for bruised knees! The connection to the inverter was straightforward, since I had done most of the work in the previous weeks.

Sunny Boy display panel. Information is transmitted at high frequency via the existing mains wiring.

Skelton System Costs

Items	*Cost (UK£)**	*%*
12 BP-585F solar modules	£4,500	69%
BP GCI 1200 grid connect inverter	1,095	17%
Sunny Boy inverter display and control	375	6%
12 stainless steel brackets for modules	120	2%
DC disconnect in enclosure	100	2%
Modem for inverter display	100	2%
Other sundry items	100	2%
6 mm^2 double insulated cable, 50 m	58	1%
4 mm^2 double insulated cable, 25 m	33	1%
AC disconnect in enclosure	25	0%
Consumer fuse board	25	0%
Total	£6,531	

* Includes 17.5% tax

Before we turned the first switch on, Steve came to the house to check over the system to make sure all was in order. I am pleased to say that it was, and I threw the switch. The green light on the inverter came on and within a minute, power started to flow from my solar panels into the electricity system. It was the first solar-electric system to be connected to the utility grid in the area!

What's Going On?
A Sunny Boy control unit was installed in the house so I can see what is going on with the system at any time. It shows live information about wattage, total energy day by day, system status, voltage of the PV array, grid voltage, grid frequency, and resistance between power lines and earth. It's also the user interface for the inverter.

Almost everything you might need to know regarding the performance of the system can be measured, displayed, or recorded with this unit. The most useful of these is probably "daily energy." This shows each day's KWH production for the last year. From this, spreadsheets or graphs can be generated, which clearly show any unusual days or possible problems. The information on the display is transmitted across the mains cabling at high frequency. By simply plugging the display into any mains outlet, you can see what is going on.

There is a data port on the display panel that allows connection to a PC, so it is possible to print out data and graphs for any day or month. When I have time, this will be next on my list of things to do. The annual average energy production for a system like this is about 850 KWH. After three months, the display in the house indicates that the system is on target.

Why?
Why buy a system like this when the grid is connected to the house? What is the payback time for a system like this? These are the two most commonly asked questions. The answer to the first question is simple. I bought the system because I wanted to. My personal interest in solar technology inspired me, and I believe it is the power source of the future that I am able to use today.

The payback is a long time out, if you look at this purely in monetary terms, but I don't. When was the last time you heard a person walk into a car showroom and ask about the payback time on a new car? I rest my case.

The future of PV technology looks very bright, and from a personal point of view, I enjoy using it. To me, the environmental benefits far outweigh the monetary payback.

Access
Author: Anthony Skelton, Hillcrest, Hill Wootton Rd., Leek Wootton, Warwick CV35 7QL, U.K.
Phone/Fax: 44 1926 854289

Steve Wade, Wind and Sun Ltd., Humber Marsh, Stoke Prior, Leominster, Herefordshire HR6 0NE, U.K.
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steve@windandsun.co.uk • www.windandsun.co.uk
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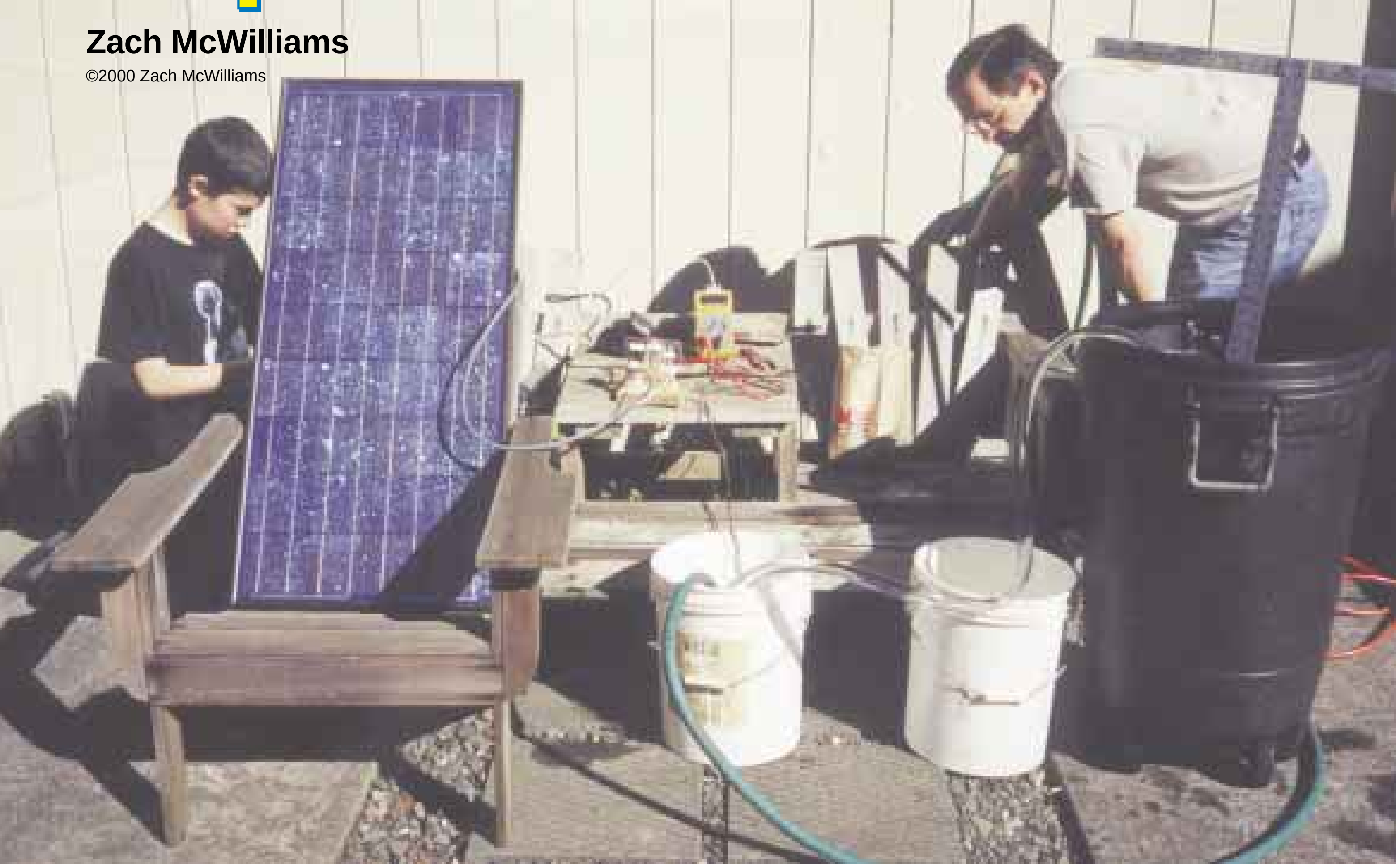
Stupendous Solar Science!

Zach McWilliams



Zach monitors the readings on the laptop computer while his dad adjusts the water flow into the pump bucket.

What do you think of when you hear "winter," or "California's North Coast"? Sun and warm temperatures? I don't think so! North Coast winters are very bleak, and only once in a while do we enjoy a sun-filled day. Lucky for me, the sun came out long enough to do my solar science experiment.

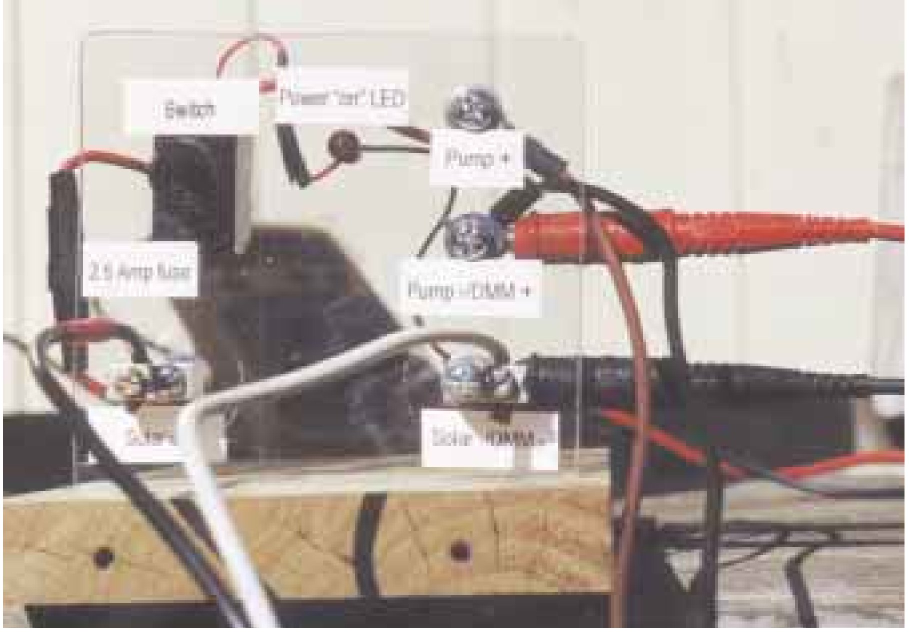
I'm Zach McWilliams, and I'm in the eighth grade at Pacific Union school in Arcata, California. My science project last year was designed to answer these questions: *Does the angle of the sun during the day affect a solar panel's output?* and *What is the energy generated by one solar panel capable of doing?*

In the course of the experiment, I learned how to set up an electrical circuit, use a digital multimeter (DMM) and monitoring software, and test the directional and shade sensitivity of a solar panel. These are skills useful to anyone interested in solar energy.

Parts & Setup

For my experiment, I needed a solar panel, so I called on Michael Welch of Redwood Alliance and *Home Power* magazine, who loaned me a 63 watt Solarex polycrystalline silicon solar panel (Thank you, Michael!). Then I needed something to measure amps and volts. A Radio Shack 22-805 digital multimeter (US$40), with PC interface, covered that. I also needed a load. A pump would work just fine. Online, I found Eric Jensen of Sunmotor International, who sent me a Rule 12 VDC pump at no charge (Thank you, Eric!).

After these main components, little things were needed. To do my project, I used a piece of wood that was about 6 by 5 inches (13 x 15 cm), and cut a slit at the end that went the width of the wood. Next, I put a piece of plastic that was about 1/4 inch (6 mm) thick in the slit. In the plastic, I drilled holes for an SPST switch, an LED, a 2.5 amp fuse, two screws for conductors, and two more screws that were attached to a power bus. I then put all the components in place in the plastic.



The home-built circuit board ready for action.

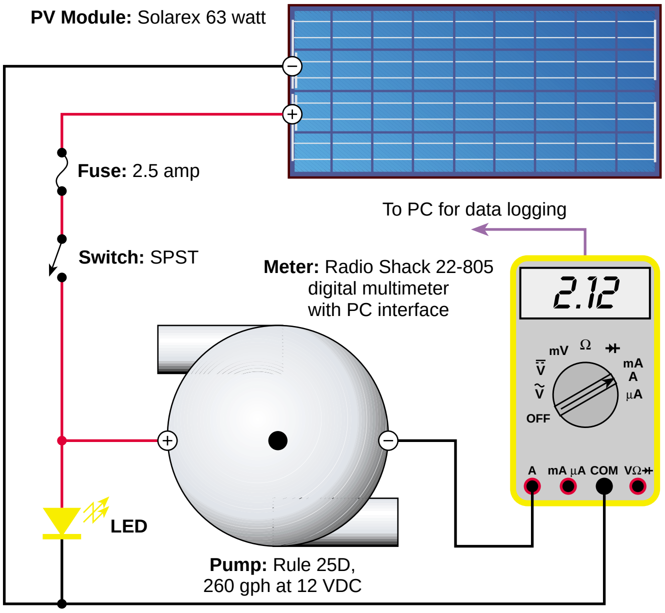
The idea was to let the solar panel power the pump, and hope the pump would move water from one five gallon bucket to another. To start, I put the solar panel on a chair outside, and hooked it up to my makeshift circuit board. Next, I connected the digital multimeter to the circuit board. Then I connected the digital multimeter to a 486 laptop with a serial cable to monitor the amps, so that I would have information to convert to graphs.

The digital multimeter came with a program to log the data onto a computer. We programmed it to log data every 15 seconds. So every 15 seconds, a reading would appear for the output of the panel. We just added up all these readings, and divided them by the total number of readings to find the average output.

The Radio Shack 22-805 DMM.

Then I attached the pump. Because the pump was rated at 500 gallons (1,900 l) per hour, I used a 2 meter piece of 3/4 inch vinyl hose to move the water. This reduced the rated output to 260 gallons (1,000 l) per hour (gph). From this I hypothesized that it would take several minutes to move five gallons (19 1) of water between buckets. I put the pump and tubing into the five gallon bucket for starters, and flipped the switch.

PV Test Schematic



Filling the trash can.

It Pumps!

In less than a minute, I figured out that I needed a 30 gallon (114 l) trash can instead of a bucket. My first conclusion was that solar power works really well!

That's when the "revised hypothesis" struck me: How long would it take for the panel to fill the trash can at different times of the day? And what would be the average amperage? I decided to take one test in the morning, one in the afternoon, and one in the evening. My hypothesis was that the panel would do best—and the pump would pump fastest—in the afternoon, because there would be direct sunlight on the panel.

I set up the equipment the same as before, except that the pump tubing went into a trash can instead of the bucket. This would be the "morning test." It was slightly overcast, but I figured the panel would do fine. I flipped the switch, and the panel produced an average of 1.155 amps while the pump was running. It took nine minutes to pump 20 gallons (76 l) of water into the trash can.

Later, I did the "afternoon test." There was a change in the amount of sun and the output of the panel. It was very bright, and the sun was directly on the solar panel. The panel produced about 2.041 amps, and the trash can was filled in four and half minutes.

For my last test, I set everything up at about 5 PM. The sun was still out,

McWilliams Solar Project Parts List

Description	*US$*
Radio Shack 22-805 DMM, w/ PC interface	$40.00
Vinyl tubing, 3/4 inch inside diameter, 7 feet	3.50
Switch, SPST	2.00
Fuse, 2.5 amp	1.50
LED (light emitting diode)	0.95
Laptop computer, 486 PC, on hand	0.00
Plastic, 1/4 by 6 by 6 inches, recycled	0.00
Power bus, recycled	0.00
Rule 25D 12 VDC pump, donated	0.00
Solarex MAE000 63 watt module, borrowed	0.00
Steel screws, on hand	0.00
Trash can, 30 gallon, on hand	0.00
Bucket, 5 gallon, on hand	0.00
Wood base, 6 by 5 inches, recycled	0.00
Total	$47.95

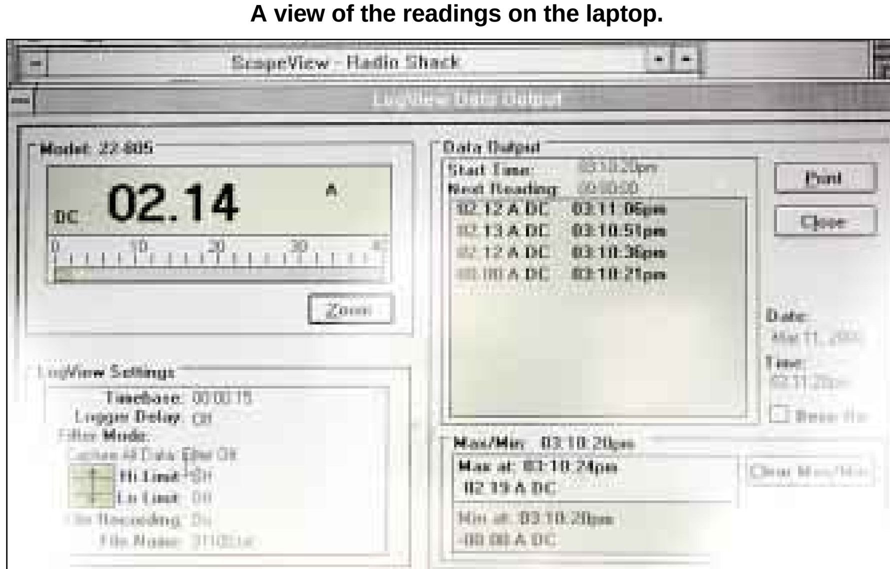
and mostly on the panel. This time the trash can was filled in five minutes at an average of 1.763 amps. I was amazed at how little difference there was from the afternoon to the evening.

Experiment & Learn

By experimenting, I found out that the pump would only work if the panel was producing at least 0.80 A. The slightest shadow (like when my mom walked in front of the panel) would cause a pause in the circulation of water, and the amperage would drop.

During this project, I learned many things. I think that the most important one for North Coast solar users is that you should put your panels in a place that usually

A view of the readings on the laptop.



Output from Radio Shack Software into Microsoft Excel

**			
'LogView File; ScopeView Version:1.08			
'Copyright 1994-1999.			
'File Created: 11:13:20am Feb 19, 2000			
**			
'Timebase: 00:00:30			
'Hi Limit: Off			
'Lo Limit: Off			
'Filter Mode: Capture All Data; Filter Off			
**			
11:13:21am	0	A	DC
11:13:51am	1.12	A	DC
11:14:21am	1.11	A	DC
11:14:51am	1.14	A	DC
11:15:21am	1.13	A	DC
11:15:51am	1.14	A	DC
11:16:21am	1.14	A	DC
11:16:51am	1.15	A	DC
11:17:21am	1.15	A	DC
11:17:51am	1.15	A	DC
11:18:21am	1.16	A	DC
11:18:51am	1.16	A	DC
11:19:21am	1.17	A	DC
11:19:51am	1.17	A	DC
11:20:21am	1.16	A	DC
11:20:51am	1.17	A	DC
11:21:21am	1.19	A	DC
11:21:51am	1.19	A	DC
11:22:21am	1.19	A	DC
11:22:51am	0	A	DC
11:23:21am	0	A	DC
11:23:51am	0	A	DC
11:24:21am	0	A	DC

gets lots of sun. Also, for consistent output over time, you need to hook the panels up to batteries. This makes it so you can have the pump working nonstop, and you don't need a "direct sun connection" for the panel. For our test purposes, we didn't need batteries. But for real-world scenarios, you should use them for consistent output. Then you can power things inside such as lamps and other electrical devices too.

For a second test, my dad kind of took charge, and attached an additional 20 watt Solarex MSX panel to the circuit board. He then compared the results to the original ones. With the 20 watt panel added, the trash can was filled in an astonishing three and a half minutes, and the average amperage was 2.375! We then tried it with only the 20 watt panel, and the results came out more like the morning test for the 60 watt panel, though that test was done in the middle of the afternoon.

Stupendous Solar Science Test Results

Test	*Ounces Pumped*	*Pumping Minutes*	*Ounces per Minute*	*Avg. Amps*
Morning	2,608	9.0	290	1.155
Afternoon	2,608	4.5	580	2.041
Evening	2,608	5.0	522	1.763
Two panel	2,608	3.5	745	2.375
20 watt panel	2,608	11.0	237	0.973

Special Thanks

Thanks to Michael Welch and Redwood Alliance, for loaning me the solar panel and handing out advice, and to Kelly Larson for giving me great ideas. Also to Eric Jensen, of Sunmotor International, who sent me the pump. And last but not least, my dad, for all the editing, and for helping and supporting me throughout this whole thing!

I did this project for a school science fair. My classmates didn't get to actually see the panel hooked up, but I showed them my backboard, as well as pictures of the whole setup. They seemed very interested, and apparently enjoyed learning about my experiments.

I had a great time doing this project, and learned tons about solar energy. My "revised hypothesis" was correct. The panel did do best in the afternoon, and the pump transported the water at an astonishing rate. For all those people out there who like conserving energy and being self-reliant, I have one thing to say—Solar Rocks!

Access

Author: Zach McWilliams, 402 Tanglewood, Arcata, CA 95521 • 707-822-8212 • zachmcwilliams@hotmail.com

Eric Jensen, M.Sc., P. Eng., Sunmotor International, 104, 5037 - 50 Street, Olds, AB T4H 1R8 Canada
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RE Novices Tackle PV/Gen Design and Installation

Chip and Clara Boggs

Clara Boggs (center), with friends Rick Rogers and Jim Beaver, in front of the power shed.

Three years ago, we knew almost nothing about renewable energy (RE) systems. Since then, we've gone through the process of choosing to build a renewable energy system, and designing and installing it. Our RE system has allowed us to go online with our computer, step up homestead progress, and enjoy some amenities. We'd like to share with you what we learned on this journey, focusing on the decision-making process, the power shed, and how these can relate to each other.

Where, When, & Why
RE systems differ from centralized power generation in their site dependency and sensitivity. Our homestead is located on 360 acres of rainforest in Oregon's Coast Range. The land is a long, hilly east-west valley in the Coquille River watershed. About half the land faces south, including the main homestead.

The climate is typical of western Oregon. The dry season lasts for about four months. Most of the 68 inch (173 cm) average annual precipitation falls from October to May. Being only fifteen miles (24 km) from the coast, temperatures are mild overall, and snow is an unusual event.

All projects on our property have been low capital, high labor input. The buildings are made of salvaged or native materials, with wood heat, gravity flow water, organic gardens, composting latrine, and other back-to-the-land amenities.

We bought the land in 1989. We had no intention of bringing grid power in, but as a tactic in negotiating for the land, we priced it anyway. US$15,000 would bring power 1/2 mile (0.8 km) from the corner of the land to the homestead. No thanks!

For two years, we lived with no phone or electricity. Generally, we enjoyed non-electric living (with a few exceptions). In 1992, we planned to leave the land for a year to make money. The future caretakers needed a phone for their business. We dug the trench, and the phone company gave us the cable.

Have you noticed that life is what happens while you make other plans? Well, our "one year" absence dragged out to five years, during which time we became involved in defending wrongly convicted people, which was mostly online work. We returned to Oregon in 1997, but two obstacles prevented us from moving back onto our land. First, the homestead was in acute disrepair. Second, even though there was a phone, there was no electricity for our computer, and our online justice work was becoming critical to more and more people.

The RE Decision Process
The first thing we needed to do was research. We had botched a few projects in our brief career as homesteaders. The lessons learned usually cost us more time than money. However, an RE system costs a lot, so we wanted to do it right. It justified a proportionately greater amount of research. We ordered all the back issues of *Home Power.*

PV, wind, or hydro? Wind was not a realistic option. Hydro held the greatest potential, but seemed more complex than solar. Admittedly, we didn't know enough about either resource to make a truly informed decision. However, we did know that hydropower would involve laying lots of pipe through thick vegetation on steep, unstable slopes. Then, too, there are clogged intakes, moving parts, and regular maintenance. Finally, the creek is 600 feet (180 m) from the house, while there's sun on the front porch.

The vented battery box is built onto two small pallets to keep the batteries off the floor. Twelve Interstate 6 volt, 350 AH batteries provide 1,050 amp-hours at 24 volts.

Our immediate need was for a few KWH per day—not for the ultimate potential of the site. We do hope to have microhydro power in the future. But PV, with no moving parts and some siting flexibility, seemed like the way to go.

Who & How
Since we are inveterate do-it-yourselfers, we had always assumed that we would install the system ourselves. However, after reading *What to Expect from Your RE Dealer (HP61,* page 40), we had second thoughts. The article did help us clarify our options:

DC power comes in from the modules, through the safety disconnect (left) and charge controller (right), and then goes to the batteries. Power for DC loads comes directly off the batteries through the DC load center (below).

- Have a dealer/installer do the whole works.
- Contact a full service dealer to design the system, supply the components, and advise us on installation.
- Design our own system, shop competitively from discount RE suppliers, and order everything and install it ourselves (possibly with no advice from the supplier).

With our experience level, we never seriously considered the third option. If we hired a dealer, we wanted to do the low-tech labor ourselves, as suggested in the article. Typically, the low-tech labor comes *after* load analysis and system siting, but *before* system installation. We did not know of a local RE dealer, so this presented another set of options:

- Perform the load analysis, system siting, and low-tech labor ourselves. Have the dealer install the system, paying for only one travel trip.
- Pay the dealer for two trips; first for the load analysis and siting and later for the installation.

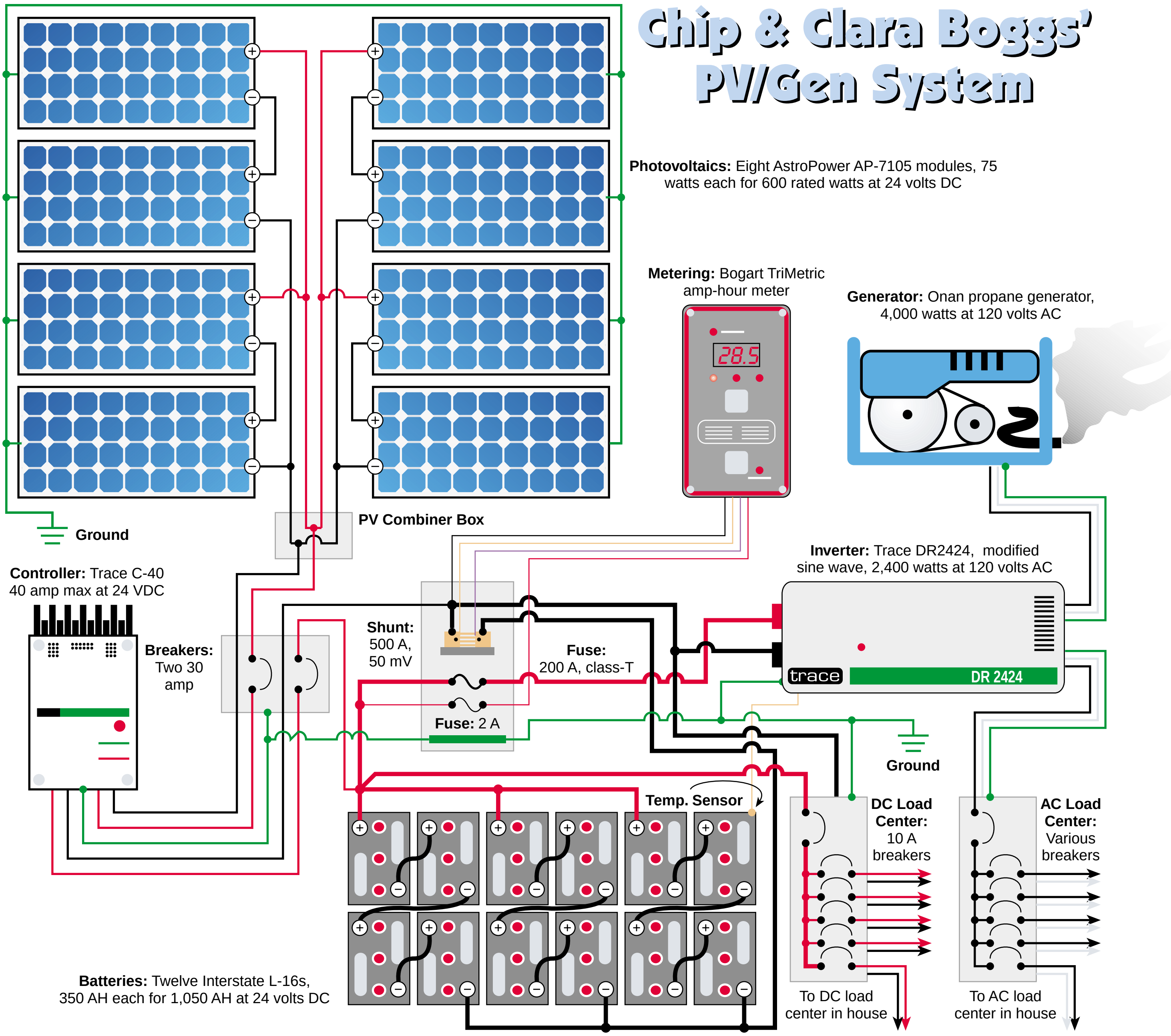
Load analysis and siting seemed easy compared to installation, so we chose the first option.

We ordered a Solar Pathfinder *(HP57,* page 32), and made a homebrew ammeter *(HP33,* page 82). Only the eventual users of the system can carefully analyze their loads, and determine what their lifestyle and electrical consumption will be. Doing this analysis was fun and easy *(HP58,* page 38).

The homebrew ammeter worked just as the article said it would. We measured the amperage of each appliance and multiplied by 110 volts to find the watts. We estimated the time each appliance was used. Adding standard losses for the inverter and overall system, we arrived at 1,769 watt-hours per day. With this data, we could generically size the system and estimate the cost. It appeared that we could afford a system sized to meet our needs.

I started wandering around the homestead with the Solar Pathfinder. At first, my self confidence wavered as I contemplated the numerous variables. Gradually, I realized that I had my own site knowledge that no

The AC output from the inverter feeds the AC load center. One circuit breaker goes to Chip & Clara's cabin, with lots of room for more breakers.



expert could duplicate. The Pathfinder quantifies the most important variable (solar access), but other variables can be integrated by more intuitive means.

I knew that PV modules, batteries, and inverter should be as close to each other as possible. So by siting the modules, I was spatially arranging the whole system. The best alternative was to build a power shed above and behind the homestead. Mentally summarizing the "low-tech labor" part of the project, I decided to:

1. Design and build the power shed.
2. Build and install the module racks.
3. Build the battery enclosure and place the batteries in it.
4. Dig the trench between the power shed and the house.
5. Run conduit and pull cable from the power shed to the house.

During this time, we met someone who had ordered a PV system from Real Goods and had installed it himself. The psychic pendulum started to swing back towards installing the system ourselves. At about this point, I realized that if I trusted myself to do the load

Clara Boggs at her PV-powered computer workstation.

Boggs System Loads

Item	*WH/day*	*%*
Computer	1,106	56.3%
3 CF lights	343	17.4%
Coffee maker	187	9.5%
Inverter, standby	160	8.1%
Laser printer/copier	31	1.6%
Word processor	32	1.6%
Visitor's computer	29	1.5%
Radio	24	1.2%
Washing machine	24	1.2%
Power saw	17	0.9%
Power drill	5	0.3%
Juicer	5	0.3%
Blender	3	0.2%
Total WH/day	1,966	

and site analysis and low-tech labor, that with some outside advice, I might as well attempt the entire installation.

Our next decision was which RE dealer to purchase our equipment from. We did not research this much, but called Real Goods, with whom we were most familiar. We knew that they could design the system, select the components, and advise us on installation. On the phone, we met Roger Breslin, who became our personal consultant.

Once we decided to cast our lot with Real Goods, we were not bashful about asking advice. Roger even helped us compare sites for the power shed and PVs (over the phone!). He recommended the site 50 feet (15 m) behind the house, even though a site 100 feet (30 m) away had slightly better sun. (Pruning can improve the nearer site over time.)

The Power Shed

In our county, a 10 by 12 foot (3 x 3.7 m) building is allowed without a permit. The system would not require this large of a building, but we knew the extra space would be handy. The nice thing about building a power shed is that you don't have to compromise on the design. Every element of shed design supports or enhances a feature of the RE system.

Equipment layout, doors, and floor plans were adjusted to the nearest inch to maximize use of the space. The building is oriented due solar south, and has a concrete slab floor for thermal mass and to support the battery bank. It has a large double-glazed window for passive solar heat, and a roof overhang that gives it sun in the winter but shade in the summer. Batteries don't like to get cold, and we didn't want to provide a heating system.

With the rack design in *HP57,* page 32, you can't adjust the summer angle *below* the roof angle. Our latitude is 43 degrees, so the ideal summer angle is 28 degrees. Also, airflow behind the modules is necessary, particularly in summer, so you don't want them lying flat on the roof. A roof angle of 11 degrees (2.5 in 12 pitch) provides summer airflow, but is also steep enough to shed our abundant rainfall.

We wanted to provide room for future modules. The roof overhangs 4 feet (1.2 m) on the north side and about 1-1/2 feet (0.45 m) on the other sides, giving a total surface area of about 16 by 15 feet (4.9 x 4.6 m). This will accommodate six racks, each holding four modules, or 24 modules total. Our initial system has two racks (eight modules), so we could triple the size of our array in the future if need be.

Generator

We focused on safety in our power shed design. A lengthwise interior wall separates the generator from the batteries and controls. This also doubles the wall surface inside the shed. The interior door is placed at the end of the wall to maximize unbroken wall space. Propane tanks are placed outside, under the 4 foot (1.2 m) roof overhang, separating them from the generator.

We put the generator in the room away from the house to minimize noise. The interior was plastered with a gypsum/perlite mix for acoustical absorption. The exhaust pipe runs out the north side of the shed. It then

The 4 KW Onan generator in the north room of the power shed. The air intake is under the wooden stand.

runs underground through a protective shroud of old stove pipe, ending at the top of a drainage ditch. The north door is 36 inches (91 cm) wide to facilitate generator removal for servicing. A 1/2 inch (13 mm) eyebolt is screwed into a rafter for hanging a chain hoist.

The generator only occupies 6 square feet (0.5 m^2) in the 50 square foot (4.6 m^2) room (the north half). This leaves enough space for the Staber washer and a clothes sorting table. There was even room left over for a few shelves for food storage. The exterior doors open out instead of in, to conserve space. In the south half, this leaves room for tool shelves.

System Design and Installation

I recommend generically sizing the system yourself, even if someone else is designing your system. *(The Solar Electric House* and *Real Goods Sourcebook* have good formulas.) Then let your dealer select the specific components. They will know product compatibility, application, and the best value for your budget.

Our inverter, charge controller, and battery bank were oversized so that only more PV modules would be needed to expand the system. Roger recommended eight 350 AH batteries, but we decided to go with twelve. We wanted to build easy expandability into the system, but knew it is best not to add more batteries later.

All the equipment arrived in excellent condition. Pulling everything out of the boxes, I was still unsure of how it was all going to fit together. After all the low-tech jobs were done, I finally had to start wiring. Roger sent me a

Boggs System Costs

Item	*US$*
8 AstroPower AP7105 75 W modules	$3,032.40
12 Interstate batteries, 6 V, 350 AH	2,239.92
Onan generator, 4 KW, used	1,738.00
Trace DR2424 inverter	1,220.75
Wire, conduit, & misc. supplies	244.00
PV rack materials	215.00
Power shed construction	200.00
Trace C-40 charge controller	175.00
13 battery interconnect cables, #2/0	146.25
150 ft. twisted pair wire (for TriMetric)	138.00
TriMetric 2020 monitor	132.05
AC service panel, 200 A with breakers	120.00
DC service panel with breakers	120.00
2 inverter cables, 10 ft.	85.45
Cable, #2 & #4,140 ft. each	60.00
Safety equipment & hydrometer	50.30
Lightning protector	47.45
Junction box, 10 x 8 x 4 inches	37.95
Safety disconnect, 2 pole, 30 A	33.25
Power distribution block, 2 pole	28.45
Shunt, 500 amp / 50 mV (for TriMetric)	27.55
Trace battery temperature sensor	18.95
2 RK5-30 fuses, 30 A	7.50
Total	$10,118.22

wiring diagram, and it took me about a week to hook everything up. I was also helped by Chapter 12 of the *Solar Electric Independent Home Book,* which gives a step-by-step generic procedure for PV/Gen system installation.

Even during installation, I was still a little skeptical about whether everything would actually work. Finally, I removed the coverings from the modules and started charging the batteries—I got a real charge out of that. An electrician friend came over to install the final fuses, energize the breakers, and connect power to the house. We found a few shorts in the house wiring, but no errors in the RE system. In a few hours, we emerged from the “smelly darkness” forever!

System Operation

We record generator run times, battery waterings, and propane tank changeouts. We ran the generator 240 hours the first year, exceeding the break-even point of genny vs. PV module cost *(HP51,* page 66). In December 1999, we added eight more modules, doubling the array size. Generator use has been

Chip Boggs flips the AC load center's main breaker in the house.

reduced by two-thirds, and we have excess power for over half the year.

The larger than expected usage comes from Clara running her computer twice as much as I thought she would. But I can't complain, since the main reason we installed the system was to support the justice work she does on the Internet. Although the computer processor stays on most of the day, Clara turns off the monitor whenever possible.

We are not running any pumps, motors, compressors, or resistive loads (except for the coffee maker). The washing machine is usually run when the generator is on. There is no television. Most lights are compact fluorescents. The buildings are also wired for 24 VDC—we'd like to have a few LED lights which could be used without the inverter. A TriMetric system monitor is mounted on the front porch, where everyone can see it.

Lessons Learned

I would not make any changes in the system design, siting, or power shed. Most of the lessons came during installation.

The 1-1/2 inch conduit was tight for the main cables running from the power shed to the house (two #2 (33 mm^2) cables for AC and two #4 (21 mm^2) cables for DC). Both AC and DC cables were sized for 5 percent or less voltage drop. AC cable was rated for about 100 amps, and DC cable was rated for about 10 amps. Direct burial cable was used—the conduit was for physical protection only. The straight lengths were OK, but the wire seems to expand when it makes a turn. We also overlooked running the system monitoring (TriMetric) wires. So I had to dig up the conduit, already stuffed with wires, and force the cable through it.

I designed the power shed before the equipment arrived. I did not take into account which side of the inverter the battery cables must attach to. This made a difference of 3 feet (0.9 m), so my 10 foot (3 m) inverter cables wouldn't reach. This necessitated redesigning the entire layout of the battery and control room.

I built the PV racks as shown in *HP57,* page 32, but didn't take into account the large corrugations of the metal roofing. So I had to add 4 inch (10 cm) legs between the skids and the bottom of the rack, lifting the bottom of the rack over the corrugations. I also built the battery box before I understood the battery wiring. The positive main terminal is twice as far (10 feet; 3 m) from the inverter as the negative terminal (5 feet; 1.5 m). Oh well, that's how it's gonna stay.

Thanks

We are grateful to Roger Breslin at Real Goods for his patience with us. We called him about once a week for six months. He always returned our calls, and got other help when necessary. In a word, the service was exemplary.

In the same room as the generator, there's plenty of room for a Staber washer, laundry table, and food storage.

We are also grateful for *Home Power* magazine. We would not have attempted this without their decades of wisdom, experience, and inspiration. Specifically, our "top ten" most helpful *HP* articles were (not in order):

- *Grounding Separate Structures, HP65,* page 70.
- *Two In Maine* (power sheds), *HP40,* page 6.
- *What to Expect from Your RE Dealer, HP61,* page 40 (commentaries in *HP62,* page 99).
- *Generators as a Backup Power Source, HP51,* page 66.
- *Where and How to Mount PV Modules, HP57,* page 32.
- *Battery Rooms—a Cellular Home, HP33,* page 42.
- *Doing a Load Analysis, HP58,* page 38.
- *A Beginner's AC Ammeter Project, HP33,* page 82.
- *Buying and Using a Digital Multimeter, HP60,* page 42.
- *Are Photovoltaics Right for Me?, HP1,* page 11.

Pioneering with RE

The decision to install the system ourselves was protracted. Someone else's decision tree will be different, though it might resemble ours in some respects. Our installation goofs only cost us extra labor, and did not compromise the safety or efficiency of the system.

Looking back, we're glad we did it ourselves. The project certainly built our technical self-confidence. Adding the extra PV modules was a snap, and we're looking forward to microhydro. Even with such user-friendly equipment available these days, there is still a pioneering aspect to RE, an aspect which is enriched by doing it yourself.

Access

Authors: Chip & Clara Boggs, 95245 Rink Creek Ln., Coquille, OR 97423 • 541-396-4764
chipnclara@aol.com • www.justicedenied.org

Real Goods Trading Corporation, 200 Clara Ave., Ukiah, CA 95482 • 800-762-7325 or 707-468-9292
realgoods@realgoods.com • www.realgoods.com

The Solar Electric Independent Home Book ©1998, US$19.95 postpaid from New England Solar Electric, Inc., 3 South Worthington Rd., Worthington, MA 01098
800-914-4131 or 413-238-5974 • Fax: 413-238-0203
nesolar@newenglandsolar.com
www.newenglandsolar.com