Creating A *Brighter* Future

by Justine Sanchez

Courtesy Khanti Munro

Justine Sanchez, shown with daughter Ruby and husband Mike, invested in home energy efficiency upgrades and a solar-electric system for a cleaner energy present—and future.

For the past eight years, I have been teaching solar electricity workshops for Solar Energy International (SEI). It's always been important to me to practice what I teach, so I can help students from firsthand experience. The funny thing is that my life keeps changing, and every time it does, I am again faced with a new home upgrade to meet my sustainability goals.

On the Move

When my husband Mike and I were first married, we rented a little two-bedroom, one-bath apartment. Since we didn't own the place, we weren't in a position to invest in a solar-electric (photovoltaic; PV) system, but we did what we could to make the apartment low impact in terms of our energy use. We installed compact fluorescent (CF) lightbulbs, purchased blocks of wind power from the local utility, and even succeeded in talking our landlords into upgrading the apartment's ancient refrigerator with a new, energy efficient model.

When our daughter Ruby came along, we decided it was time to purchase a home that would accommodate our growing family. We bought an existing house, instead of building from the ground up, for a couple of reasons. First, it would immediately provide more space for the three of us. But more importantly, we liked the idea of buying, rather than building, for environmental reasons—think of it as house "recycling."

Upgrading older homes for energy efficiency almost always results in a net decrease in resource consumption, because fewer construction materials need to be harvested, manufactured, and transported. With this in mind, we set out to reduce our energy use in this 3,000-square-foot home, and install a solar-electric system to meet all of our electricity needs.

Efficiency First

When we moved into our new home, the first thing we did was replace all incandescent lightbulbs with compact fluorescents, which only consume about a quarter of the electricity of incandescent bulbs, while providing the same amount of light.

Next, we used a watt-hour meter to determine which of our appliances use energy even when they are turned "off." We placed all of them—computer equipment, TV, VCR, and DVD player—on plug strips so we could conveniently and completely shut them down when not in use. Finally, we replaced the old pink 1970s-era refrigerator, dishwasher, and washer/dryer set with new Energy Star models (see Appliance Upgrades table for details).

The average U.S. home consumes about 940 kilowatt-hours (KWH) of electricity each month. The simple efficiency upgrades we made allowed us to bring our average monthly electricity consumption down to 210 KWH per month—or 7 KWH per day—less than a quarter of what a typical household consumes.

These basic energy efficiency strategies reduced our electric bill and also helped us meet our environmental goals. For every KWH we do not use, about 2.2 pounds of carbon dioxide (CO_2), a greenhouse gas, is kept out of the atmosphere, along with other pollutants emitted from the coal-based power plants that provide most of the utility electricity here in Colorado.

Appliance Upgrades for Energy Efficiency

Appliance	Cost (Approx.)	KWH Per Yr.	% KWH Reduction
Kenmore fridge, 18 c.f., Energy Star	$600	417	71%
Kenmore dishwasher, Energy Star	$250	319	40%
Kenmore clothes washer, horizontal axis, Energy Star	$900	161	76%
20 Compact fluorescent lightbulbs	$50	334	75%

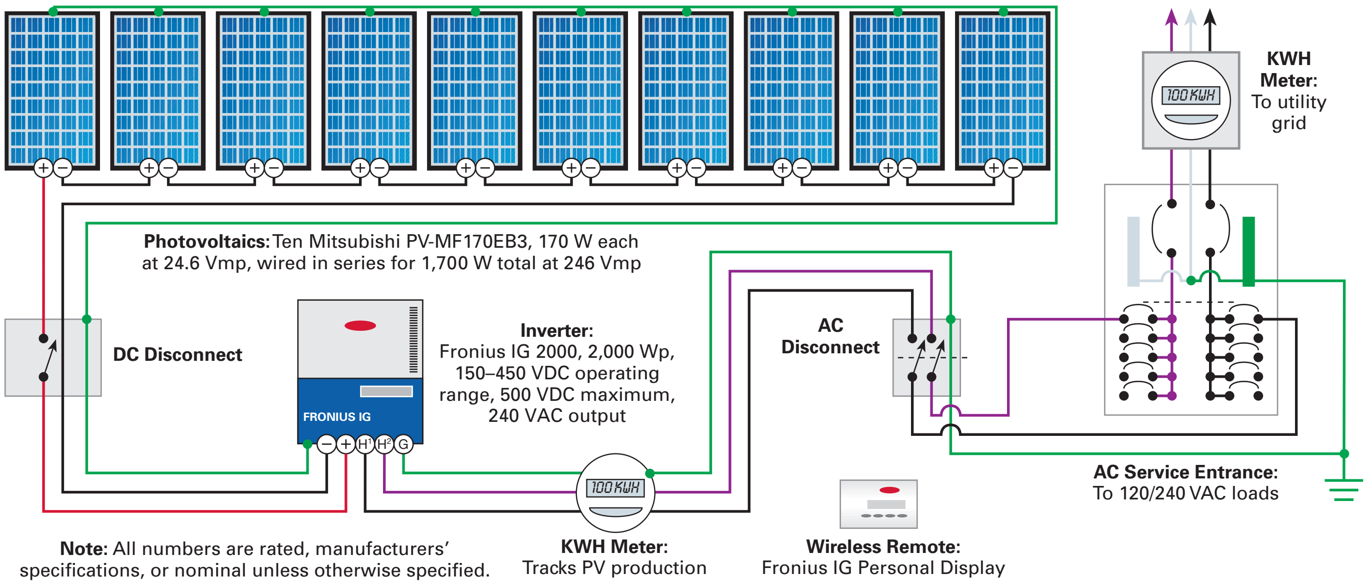
While our motivation for reducing electricity demand was primarily environmental (at about 8 cents per KWH, electricity rates in our town are relatively cheap), our goal of reducing our natural gas usage was primarily economic. During the first winter in our new home, we faced gas bills in excess of $360 per month! To reduce our natural gas consumption, we added another 12 inches of blown-in insulation on top of the fiberglass batts in the attic, and undertook the expensive project of replacing all the old, leaky aluminum-framed windows with new, top-quality double-pane, vinyl-framed windows. The new windows and increased insulation alone reduced our natural gas consumption by more than 25 percent.

Incentives & Net Metering

Finishing our energy efficiency upgrades just happened to coincide with some favorable legislation that got our PV system off the "wish list" and out into the sun, generating

The crew of volunteer installers checks out the solar-electric awning from below.

Sanchez On-Grid PV System



Running the DC wiring from the array to the disconnect.

clean, renewable energy. Last year, Colorado voters passed Amendment 37, which requires investor-owned utilities (IOUs) servicing Colorado to obtain 3 percent of their electricity from renewable energy resources by 2007 and 10 percent by 2015. As a result of this legislation, Xcel Energy is offering a solar-electric rebate program to customers in their territory.

Though we are not serviced by Xcel Energy, for a limited time, they also offered to buy renewable energy credits (RECs) from PV systems in Colorado that are outside of their service territory and purchase the RECs with a one-time payment of $2.50 per DC watt of installed PV. The Xcel Energy REC purchase offer, combined with the $2,000 federal tax credit now available for solar-electric and solar hot water systems, gave us the financial incentives we needed to design, purchase, and install our PV system immediately (see PV System Costs table).

Our local utility, Delta Montrose Electric Association (DMEA), offers net metering for systems up to 25 KW. Ironically, while DMEA is one of the progressive utility cooperatives in Colorado, their $20 monthly minimum utility bill policy can undermine the financial benefits of residential-scale grid-tied PV systems. The result is that even if you offset *all* of your electricity consumption with a solar-electric system, you will still be charged $240 each year for electricity! While this policy significantly reduces (or may even negate) the financial payback of a grid-tied PV system in their service territory, and is in direct conflict with energy efficiency and green power strategies otherwise promoted by DMEA, we refused to be deterred from accomplishing our green power goals.

An inside look at the Fronius inverter, which converts the DC generated by the PV array into AC for house loads and the grid.

Conductors for the AC and DC disconnects, and KWH meter base with lightning arrestor, are routed through a wiring gutter.

Designing the System

Our initial goal was to design a grid-tied PV system that would offset 100 percent of our annual electricity use. The next consideration was whether to include batteries to provide a backup energy source for some of our household appliances when the utility grid goes down. We rarely experience utility outages at our location, and when we do, they are typically short in duration and don't inconvenience us much, so we opted for a batteryless system. In fact, we look at utility outages as a nice little break from all the technology that surrounds us day in and day out.

We used our average annual electrical consumption of 2,520 KWH to size our PV array (see System Sizing Calculations sidebar) and, after making a few calculations, determined that a 1.7 KW array would meet our electrical needs. Our home's roof faces east and west, and has trees blocking the sun on both sides. Thankfully, we didn't have to do much tree trimming to allow the south wall of our house full solar access from 9 AM to 3 PM—the optimal solar window. The two-story construction of the house allowed us to design an awning structure to support a PV array that would both generate electricity and, during the summertime, shade our first-floor windows, while admitting full sun through the windows during the winter months.

PV System Costs

Item	Cost
10 Mitsubishi PV modules, 170 W	$10,950
Fronius IG 2000 inverter	2,295
2 DP&W PV mounts	1,062
Misc. wire, electrical, hardware, etc.	600
Fronius wireless display	410
DC disconnect	165
AC disconnect	60
Total, Before Incentives	$15,542
Federal tax credit	-$2,000
Green tags ($2.50 per W)	-4,250
Grand Total	$9,292

Tech Specs

Overview

System type: Batteryless, grid-tie solar-electric

Location: Paonia, Colorado

Solar resource: 5.8 average daily peak sun-hours

Production: Designed for 210 AC KWH per month, average

Utility electricity offset: 100 percent

Photovoltaics

Modules: Ten Mitsubishi PV-MF170EB3, 170 W STC, 24.6 Vmp

Array: One, 10-module series string, 1,700 W STC total, 246 Vmp

Array installation: Two Direct Power & Water Roof/Ground Mounts (low profile with telescoping legs), each holding five modules; installed on south-facing wall, 40-degree tilt

Balance of System

Inverter: Fronius IG 2000, 2,000 Wp, 150–450 VDC operating range, 500 VDC maximum, 240 VAC output

System performance metering: Wireless Fronius IG Personal Display and AC KWH meter


Courtesy Mike Pendy

The dual-purpose solar-electric awning generates year-round electricity and, in the summertime, shades the first-floor windows.

Have Modules, Add Sunshine

We decided to use Mitsubishi modules (sourced from Bob-O Schultze of Electron Connection) and a Fronius inverter. We also ordered a prefabricated Direct Power and Water (DP&W) mount that we could simply attach to the house. Jeff Randall from DP&W helped us adapt their standard mounting structure for our particular situation. The roof–ground mount is normally installed so that the adjustable legs sit underneath the top of the array. For wall-mounting, we flipped the mount so that the legs would be adjustable from the bottom of the array.

Our PV project coincided with one of SEI's PV Design and Installation workshops, and we were fortunate to have several of the students volunteer to help with the installation. Their skills and attention to detail were top notch. We spent two and a half days mounting and wiring all the system components—PV array, AC and DC disconnects, inverter, and an AC PV system production meter (required by our local utility)—along with mounting the junction box and wiring gutter, running and securing the conduit, pulling the wire, and, finally, completing all wiring connections.

On the last day of the installation, after double-checking our wiring and connections, it was finally time to bring the system online. Once the inverter was energized and producing electricity, we all rushed over to see the electrical meter merrily spinning in reverse! And as all of us were cheering, I was reminded that this was the first grid-tied PV installation these students had been involved with, and what a thrill it is to see solar energy hit the grid for the first time.

Another Day in the Sun

The system has worked flawlessly since its installation. When the sun is shining, the PV array produces more electricity than we typically use around the house. In this case, our electrical meter spins backwards and the utility gives us a "credit" for the surplus kilowatt-hours generated. When the PV array produces less electricity than we consume, we simply pull whatever amount of additional electricity is needed from the grid, dipping into our surplus credits.

The Fronius inverter and its wireless display have proven to be very user-friendly, and overall system production has been impressive. On bright, sunny days during the fall, our 1,700-watt array produced about 10 AC KWH each day. Around the winter solstice, the system produced about 8 AC KWH on sunny days. This past year we experienced an unusually cloudy late fall and early winter, so our total KWH production has been lower than expected. But considering that our PV modules will generate electricity for 30 years or more, there's a lot of sunshine—and solar electricity—coming our way!

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An Eye on Electricity

Although electricity is an indispensable part of our everyday lives, most people know very little about how much electricity they use, where it comes from, or what the environmental consequences are. Part of the problem is that electricity is invisible—it just does its job in the background. But some grid-tie inverter manufacturers now offer convenient, wireless system performance displays that allow system owners to "see" the results of their investment in solar energy.

Once our system was installed, we were excited to try out the new wireless display available for Fronius inverters, especially since it was a piece of PV gear that I had not installed before. The Fronius IG Personal Display shows instantaneous data such as power, voltage, and current, and daily and cumulative energy (KWH) production values. You can also view CO_2 offset and the amount of money your PV system is saving.

The wireless display works great anywhere in our house or out in the yard (the manual says the range is 150 feet indoors or up to 450 feet outdoors). We tend to leave it on our kitchen counter so we can check our system's performance over a cup of coffee in the morning or before we sit down for dinner.

*Fronius Wireless Display Values**

Max. Watts Today: 1,461 W

KWH Today: 8 KWH

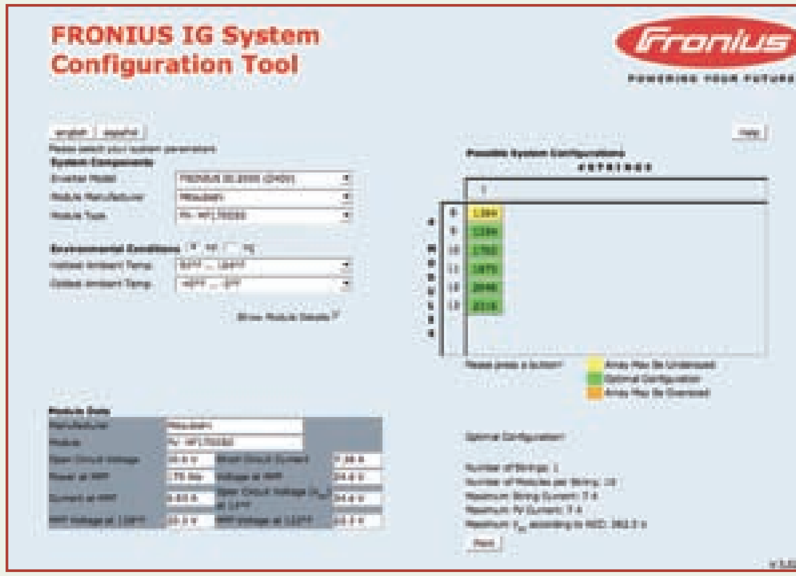
KWH Total: 642 KWH

CO_2 Offset: 1,251 lbs

$ Saved: $89

*Reading from 12/23/2006; system installation completed 8/31/2006

System Sizing Calculations



If you're thinking about designing a grid-tied PV system for your home, here's a simplified overview of the steps required. System sizing relies on electricity consumption, site-specific solar insolation data, and array shading, tilt, and orientation specifics.

Step 1: Determine average daily AC electricity use. Grid-tied PV systems can provide some or all of your home's electricity. Reviewing your past year's electric bills will get you started. In our case, we wanted to offset 100 percent of our grid electricity with solar electricity.

2,520 AC KWH/year ÷ 365 days/year =
6.9 AC KWH/day

On average, we'd need our PV system to generate 6.9 AC KWH per day.

Step 2: Determine the initial array size (unadjusted for system efficiency) necessary to meet your average daily AC KWH solar-electric generation goal. You'll need to know the average daily peak sun-hours at your location (visit http://rredc.nrel.gov/solar) and what percentage of the total solar resource is available, depending on shading at your site and array orientation. A solar resource evaluation tool, like the Solar Pathfinder, is needed to determine array shading. Our array faces true south, so no adjustment for orientation was necessary.

Average daily peak sun-hours at our location: 5.8 (Grand Junction, CO data)

6.9 AC KWH/day ÷ 5.8 average daily peak sun-hours =
1.19 KW (initial array size needed, unadjusted for system efficiency)

1.19 KW ÷ 0.90 (fraction of total solar resource available) =
1.32 KW (initial array size, adjusted for solar resource at site, unadjusted for system efficiency)

Step 3: Determine array size based on system efficiency factors. Precisely calculating overall system conversion efficiency depends on a number of variables, including module performance at elevated temperatures, the production tolerance specified for a given PV module, mismatch between individual modules wired in series, and inverter efficiency. Installation-specific details, such as array mounting as it relates to air circulation and cooling, transmission losses in system wiring, and PV output losses due to soiling/dust buildup, all come into play.

Overall efficiencies for grid-tied PV systems typically fall between 75 and 85 percent of the rated array output at standard test conditions (STC; 25°C, 1,000 W/m^2).

Our estimation, considering the variables above, is based on a predicted system conversion efficiency of 77.5 percent.

1.32 KW (unadjusted PV array rating) ÷ 0.775 =
1.7 KW (specified array size)

Step 4: Determine the number of modules required to meet energy generation criteria. We were planning on installing Mitsubishi 170 W modules. Dividing our specified array size by 170 watts gives us the total number of modules required.

1.7 KW x 1,000 W/KW = 1,700 W

1,700 W ÷ 170 W/module = 10 modules

Step 5: Determine array voltage based on compatibility with selected inverter model. Almost all modern grid-tied inverters are high voltage, with maximum DC voltages of 600 volts for some models. Pay attention to several variables when matching your PV array requirements to a specific inverter.

We decided to install a Fronius inverter, based on the product's reputation for solid performance and reliability in the field. We chose a 2,000-watt IG 2000 model based on our calculated array size of 1,700 watts.

The next step was to check what module string voltages are compatible with the inverter. Most grid-tie inverter manufacturers, including Fronius, have convenient string sizing calculators available online. Factors that affect array string sizing include maximum power, peak and open-circuit module voltage specifications, and the inverter's maximum voltage limit and operating voltage range. Because array voltage increases as temperature decreases (and vice versa), string sizing calculators require the input of the record low and high temperatures at your site (visit www.weather.com/common/home/climatology.html).

The record low temperature in our town of Paonia, Colorado, is 31°F below zero. The Fronius configuration tool confirmed that, at our location, ten 170 W Mitsubishi modules in series were a good match for the IG 2000 inverter, and that the maximum DC input voltage would not exceed the inverter's 500 VDC limit, even during record cold temperatures.

A Cleaner Future

It has been a fun and exciting project to blend our growing family needs with our "green power" goals. If your primary goal is environmental, it's best to pursue energy efficiency strategies first. Once a home's energy efficiency has been addressed, installing a PV system to meet the remaining electrical demand makes good sense, both financially and environmentally.

By investing in a PV system when we did, we were able to take advantage of solar incentive programs that reduced the up-front cost, while hedging ourselves against future electricity rate increases. But the primary factor that motivated us to invest in energy efficiency and PV technology wasn't money or cutting-edge PV gear; we did it to create a cleaner environment for our daughter Ruby and the generations that follow.

Access

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Electron Connection • 530-475-3401 • www.electronconnection.com • Equipment supplier

System Components:

Direct Power and Water Corp. • 800-260-3792 • www.directpower.com • PV rack

Fronius USA LLC • 805-683-2200 • www.fronius-usa.com • Inverter & display

Mitsubishi Electric Corp. • 714-229-3814 • www.mitsubishielectric.com/products/solar.html • PVs