RESOURCE GUIDE • TAS-RG-7

Residential Grid-Tied Photovoltaic Systems

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Contents

Fast Facts

- Currently, residential photovoltaic (PV) systems cost $8 to $10 per installed watt. This translates to about $0.38 per kilowatt-hour before rebates or other incentives.
- A residential grid-tied PV system typically ranges from 1 to 5 kilowatts of peak output capacity.
- Adjusted for inflation, PV module prices have dropped by half since 1993 and are expected to drop by another factor of two by the 2020s.
- In 2006, there were more than 30 megawatts of new grid-tied residential PV installed in the United States, a 300 percent jump since 2002.[1]
- The global solar industry grew at a rate of 30 to 40 percent annually from 1999 to 2005, but has since slowed to 19 percent due to an international silicon shortage.[2,3]
- Well-engineered PV modules have a 30-year lifetime, although the power output declines by up to 1 percent per year.[4]

Back to top

Overview

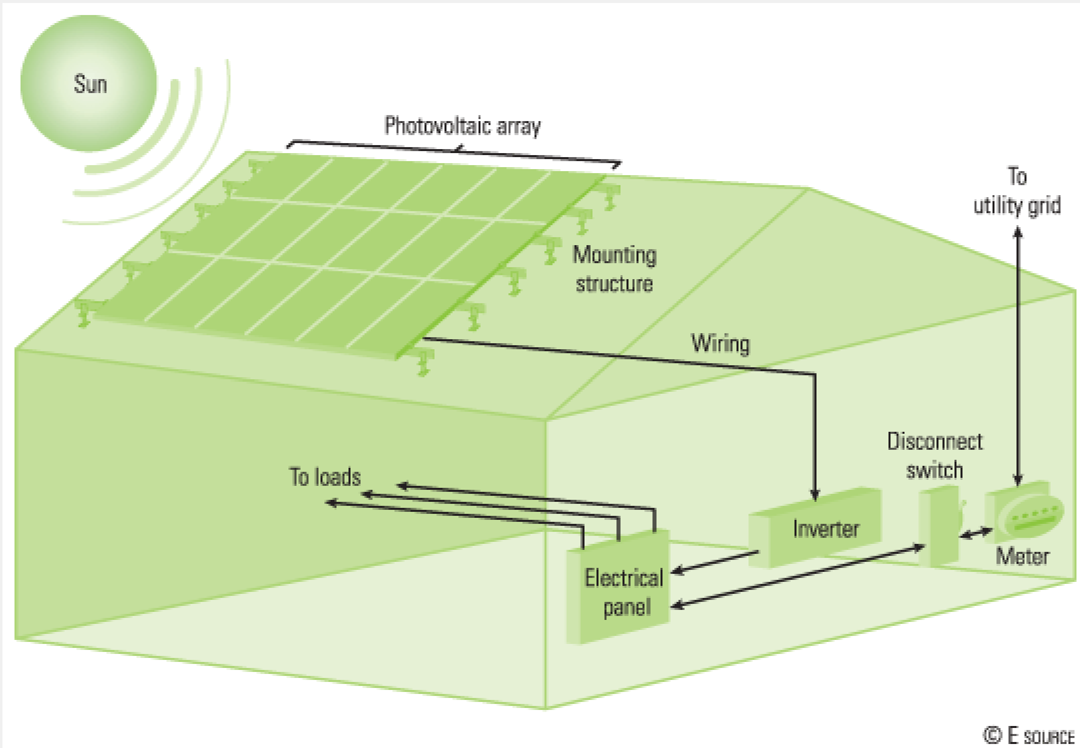
The residential grid-tied PV industry has grown rapidly since the late 1990s, due in large part to gradually declining system prices, improved equipment, increased consumer concerns regarding climate change, and a proliferation of government and utility incentive programs. Today, the single largest obstacle for residential PV remains system cost; it will likely be more than a decade before PV can directly compete with traditional grid electricity without subsidies or incentives.

A typical PV system contains two main subsystems: the array and the inverter. The array is composed of a series of PV modules, which themselves are composed of numerous PV cells. The cells are made mostly of silicon or another semiconducting material that converts incoming light energy into electricity (see Technical Details). Although there are many emerging PV array materials and designs, those that are widely commercialized include *single crystal*, *polycrystalline*, and *thin film*. An inverter is a power-conditioning device that converts the incoming direct current (DC) power from the PV array into alternating current (AC) power that most home electronic devices are designed to use.

The remaining components of a PV system are collectively referred to as the balance of system (BOS). The BOS includes the mounting structure, wiring, switches, and a metering apparatus that facilitates grid integration (**Figure 1**). Batteries or other energy storage devices are seldom used in grid-tied residential applications. Although a PV system in a commercial building will often be larger than one in a residential application, the technology employed and system setups are generally similar; a larger commercial system is often less expensive in terms of cost per watt.

Figure 1: Schematic of a residential grid-tied photovoltaic system

The key components of a residential photovoltaic system include the photovoltaic array, inverter, mounting structure, wiring, disconnect switch, and a meter that facilitates grid integration.



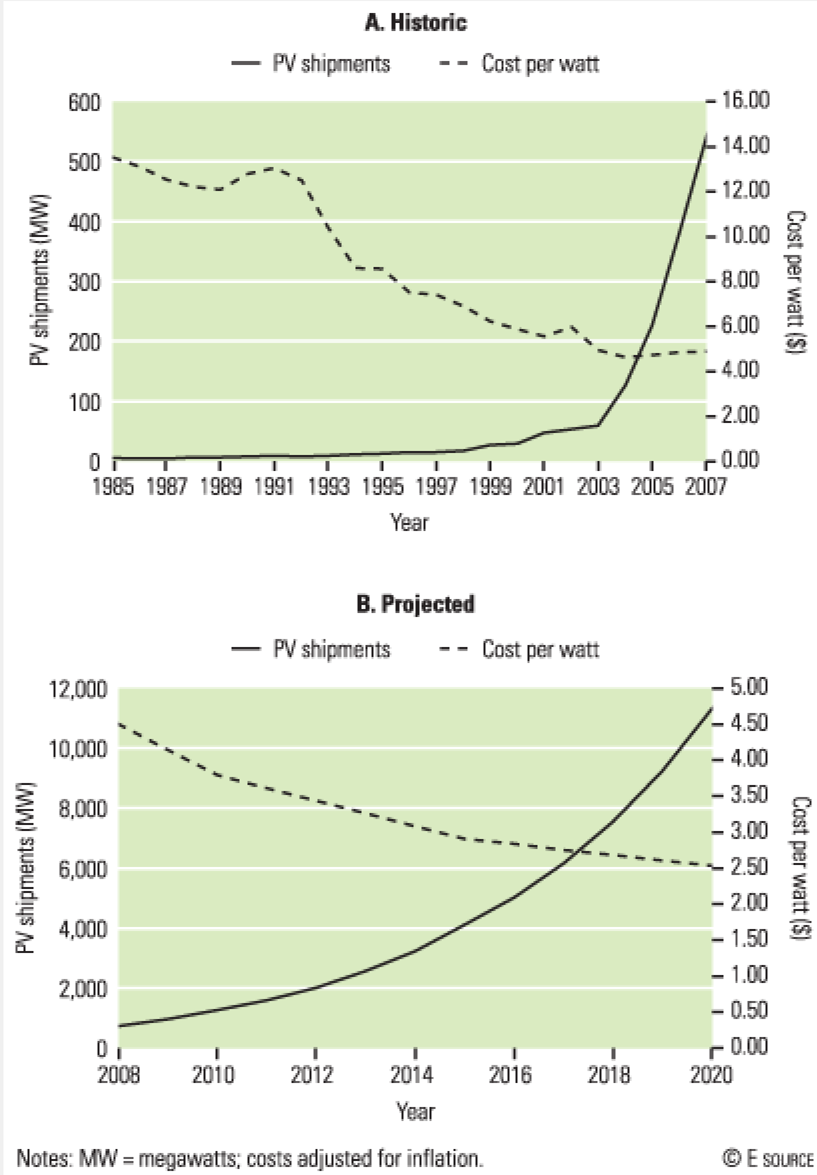
There are several different types of PV modules, each with its benefits and drawbacks. Single-crystal silicon technology is the oldest type and it accounted for 25 percent of domestic shipments in 2006. Single-crystal technology has the highest conversion efficiency of any widely commercialized residential PV type—as high as 20 percent—but it requires a larger input of energy and raw silicon. Polycrystalline technology accounted for 44 percent of sales in 2006 and has only slightly lower efficiencies than single-crystal technology—13 to 15 percent—meaning that more panels might be required to generate the same amount of energy, but this is mitigated by slightly lower costs. Finally, thin film, which accounted for 30 percent of the market in 2006, is the cheapest technology, but has substantially lower efficiency—about 5 to 8 percent. So for thin film, more modules, wiring, and installation labor are required to provide a given power output, making the installed cost of a thin-film system similar to that of single-crystal silicon systems on an output capacity basis.

One development in recent years is the integration of thin-film technology into roofing shingles (see A Village of PV Shingles). Other advanced technologies, such as organic semiconductor, copper indium diselenide, cadmium telluride, and copper indium gallium diselenide (CIGS), are either not yet commercialized or make up only a small part of the market. However, this could change as at least one large new CIGS facility began production in 2007.

The PV industry has grown rapidly since 2000 and is expected to continue to expand, according to industry and government projections. The global solar industry grew at a rate of at least 30 percent annually since 2003. In 2005, there were 1,700 megawatts (MW) of new PV installations globally, and by 2010 that figure is expected to more than triple.[5] While North America trails behind Japan and Germany in PV installations, it still accounts for a significant share of the global total, with 322 MW of customer-sited, grid-tied PV capacity in the U.S. and 1.4 MW in Canada at the end of 2006 (**Figure 2**).[6] In 2006 and 2007, there has been some slowdown in market growth due to a global silicon shortage, but most industry experts believe shortages are only short-term (see Market Outlook).

Figure 2: The long-term trends of rapidly expanding sales and declining prices are expected to continue in the residential PV market

From 1985 to 2007, photovoltaic (PV) module prices dropped by nearly a factor of three, while North American shipments increased from just over 4 MW to 540 MW (A). We expect the trend of declining prices and rapid sales to continue: By 2020, PV modules may drop below $3 per kW and shipments could rise as high as 10 gigawatts (B).



PV-generated electricity costs significantly more than electricity from other sources, but prices continue to decline. As of March 2008, the average retail PV module price was $4.82 per watt.[7] However, the module only represents around 40 to 60 percent of the total installed cost of a solar energy system. After adding the inverter, BOS, and installation, the total cost rises to around $8 to $10 per watt, before any rebates and incentives. This translates to almost $0.40 per kilowatt-hour (kWh) for an average installed PV system.[8] The long-term price of PV is expected to continue to decline as the industry matures and new types of PV cells are commercialized (see Economics and Market Outlook).

Back to top

Applications and Limitations

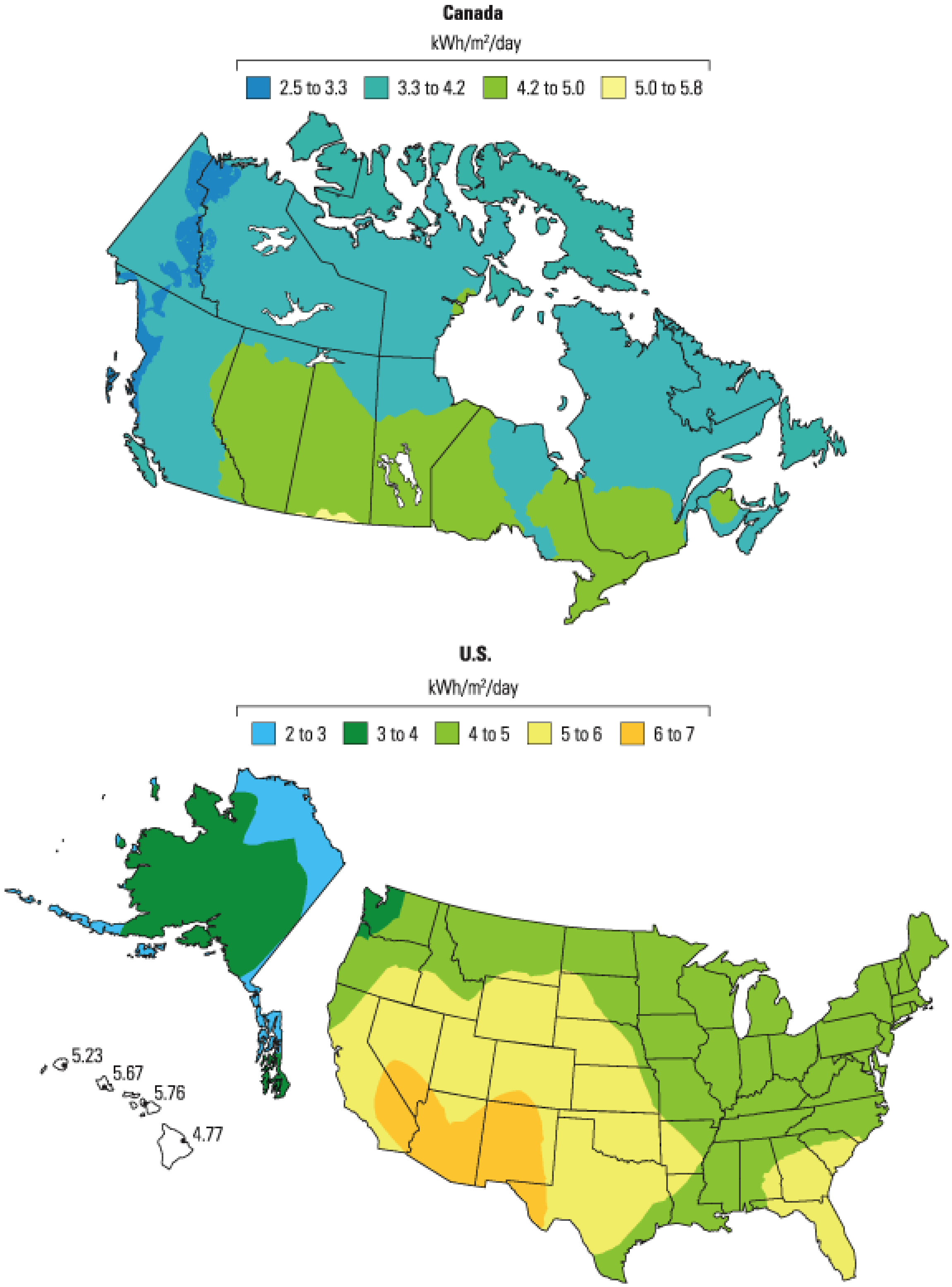
Although PV systems can be used in virtually any grid-tied home, there are a number of limitations that can deter consumers—most notably expense, lack of subsidies, local solar resource, and net metering legislation.

Initial cost. The single largest obstacle for widespread grid-tied PV adoption in the residential sector is the high capital cost. In jurisdictions that have minimal financial incentives, a homeowner might expect to pay $18,000 out-of-pocket for a system providing 2 kilowatts of peak power (kWp, or the peak AC output under optimal conditions). Utility rebates and government incentives are therefore critical in fostering PV adoption for most consumers (see Economics).

Solar resource. PV systems in regions with a high relative resource will produce more energy than those in areas that receive less sunlight, resulting in a faster payback period. The available solar resource depends on two variables: the latitude at which the array is located and the average cloud cover. The daily solar resource over North America varies significantly, from an average of less than 3 kWh per square meter (m^2) in parts of Canada and Alaska to more than 7 kWh/m^2 in the desert Southwest (**Figure 3**).[9] Residents living in sunny regions can also purchase fewer panels to achieve the same overall energy production. But with typical system efficiencies of 5 to 15 percent, any PV system is able to convert only a fraction of the sunlight that reaches the ground into useable electricity.

Figure 3: Average daily solar energy incident on a south-facing surface at latitude tilt

The amount of solar energy available to a photovoltaic array on an average day varies considerably across North America, from less than 3 kilowatt-hours (kWh) per square meter per day to more than 7 kWh.



Note: The solar resource is highly variable in Hawaii—the values shown represent locations where the resource was measured.

Source: National Renewable Energy Laboratory and Natural Resources Canada

Array orientation. To maximize the available solar resource at a given site, a PV system must be properly located and oriented. For best operation, PV systems should always be oriented due south (in the Northern Hemisphere) with a tilt angle corresponding to the latitude of the installation. Optimal array orientation is sometimes impossible due to existing roof orientation or shading obstructions, in which case a pole-mounted or ground-mounted system may be a better choice. Some PV systems also track the sun in one or two dimensions so that the array is always perpendicular to incoming solar radiation, thus maximizing efficiency. Although a system that tracks the sun produces more energy, it comes with added complexity, cost, and maintenance issues. For more information on proper site selection, see Estimating System Performance and Making the Right Choice.

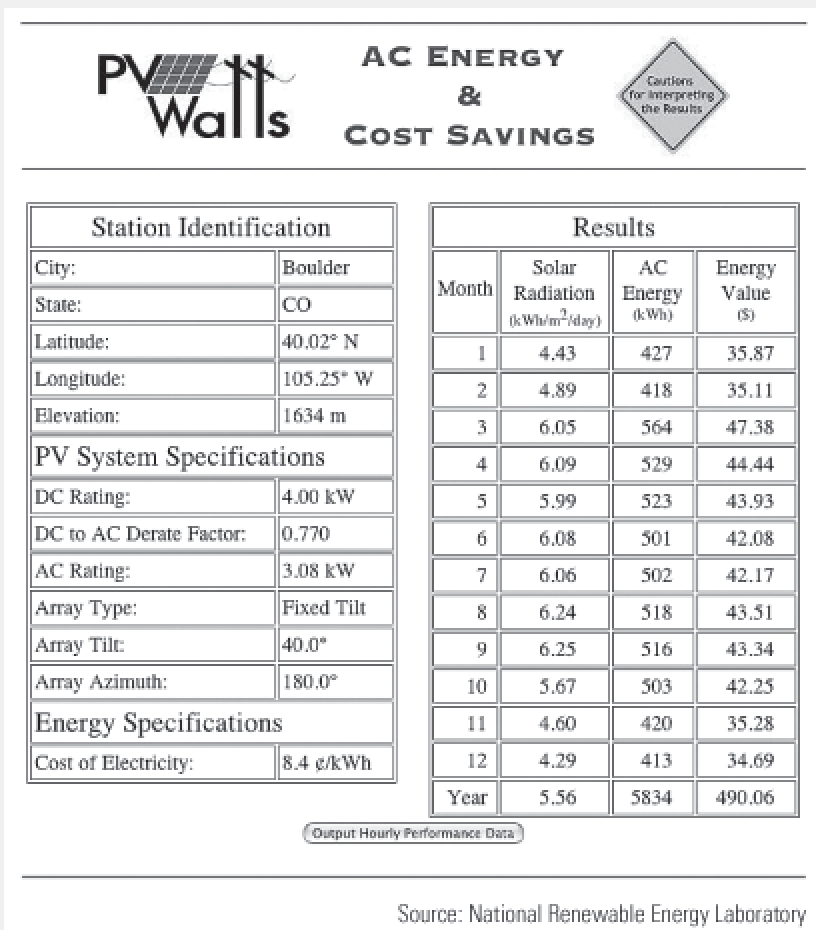
Net metering. The practice of PV customers "selling" unused PV electricity onto the grid is another important consideration because it contributes to the overall economic feasibility of grid-tied systems. Net metering benefits the resident because it avoids the need to purchase an expensive and unwieldy battery storage system. Net metering can also prove advantageous for utilities because it has the potential to help shave peak loads, which generally coincide with maximum PV power production. Currently, 42 U.S. states and the District of Columbia have provisions for net metering. See Market Outlook for more information on net metering.

Estimating System Performance

A number of tools are available that can provide reasonably accurate production estimates for a particular system design in a particular location, but perhaps the most trusted and most widely used is an Internet-based tool developed by the National Renewable Energy Laboratory called PVWatts. You start by selecting the system location from an interactive map or by entering a ZIP code and then entering the array's rating, its orientation (tilt and azimuth), and your electricity cost. You can also choose to accept the default system derate factor—which incorporates a number of factors that affect system performance—or modify the derate factor as desired (see Technical Details). PVWatts produces a table showing monthly and total annual electricity generation along with the dollar value of that generation for the specified system (**Figure 4**).

Figure 4: Results of a PVWatts simulation run

PVWatts is an easy-to-use online photovoltaic (PV) system production estimator that provides fairly accurate results based on the array's size, location, and orientation. The example shown here is the actual output of a simulation run.



Station Identification	
City:	Boulder
State:	CO
Latitude:	40.02° N
Longitude:	105.25° W
Elevation:	1634 m
PV System Specifications	
DC Rating:	4.00 kW
DC to AC Derate Factor:	0.770
AC Rating:	3.08 kW
Array Type:	Fixed Tilt
Array Tilt:	40.0°
Array Azimuth:	180.0°
Energy Specifications	
Cost of Electricity:	8.4 ¢/kWh

Results			
Month	Solar Radiation (kWh/m²/day)	AC Energy (kWh)	Energy Value ($)
1	4.43	427	35.87
2	4.89	418	35.11
3	6.05	564	47.38
4	6.09	529	44.44
5	5.99	523	43.93
6	6.08	501	42.08
7	6.06	502	42.17
8	6.24	518	43.51
9	6.25	516	43.34
10	5.67	503	42.25
11	4.60	420	35.28
12	4.29	413	34.69
Year	5.56	5834	490.06

Source: National Renewable Energy Laboratory

Some programs, such as Austin Energy's Solar Rebate Program, require contractors to run a PVWatts simulation for each proposed system and to provide the results to the customer and the utility.[10] This is an inexpensive, straightforward step utilities can take to ensure that their customers have realistic expectations for system generation.

Back to top

Economics

Compared to other energy sources, PV systems are an expensive way to generate electricity. Although government and utility incentives can cover a substantial amount of the expense in some areas, it may be many years before PV becomes cheap enough to compete directly with other energy sources.

On a per-kWh-basis, PV costs roughly 3 to 5 times as much as traditional retail electricity. As shown in **Table 1**, the current economics for a grid-tied PV system aren't very favorable for a homeowner. Even with incentives, residential PV systems are still more expensive than traditional electricity sources. However, with uncertainties in future energy costs and as new PV technologies become more widely available, this economic picture could change.

Table 1: Costs associated with a grid-tied residential PV system

A typical 2-kilowatt photovoltaic system will cost a homeowner $16,000 to $20,000 before rebates and incentives.

Module ($/watt)	4.83
Inverter ($/watt)	0.71
Balance of system ($/watt)	1.60
Installation, taxes, and other costs ($/watt)	1.55
Total system cost ($/watt)	**8.00 – 10.00**
Typical 2-kWp residential system ($)	18,000
Cost per kilowatt-hour ($)	0.38

Note: kWp = peak kilowatt power output under ideal conditions.

Beyond the costs of initial setup, a PV system will incur occasional maintenance costs. Today's modules usually come with 25-year warranties, but other system components—particularly the inverter—will have substantially shorter lifetimes. Most inverter manufacturers offer a 5 to 10 year warranty. Meanwhile, the BOS components can vary in their lifetimes and maintenance needs. Most mounting hardware, if properly engineered and installed, should last as long as the modules they support. The maintenance costs for wiring, switches, and other electronics can vary widely by setup, contractor practices, and manufacturer. To help choose contractors, the North American Board of Certified Energy Practitioners (NABCEP) maintains a database of qualified PV installers. The California Energy Commission and Underwriters Laboratories also maintain listings of equipment tested to meet certain performance criteria. And Solarbuzz, a PV industry information organization, provides up-to-date information on PV system costs.

Government and Utility Incentives

Until PV systems are cheap enough to compete directly with utility-generated electricity, rebates and incentives will be necessary for widespread adoption, particularly in the residential sector. Photovoltaic tax incentives are available at the federal, state/provincial, and local levels in many areas. Utilities also offer rebate, loan, and grant programs. However, the amount and nature of incentive programs vary considerably.

Federal. In 2005 the U.S. government took a step to boost both the viability and visibility of U.S. solar power. The Energy Policy Act of 2005 offers a tax credit for residents equal to 30 percent of the eligible solar project placed into service from January 1, 2006 through December 31, 2008.[11] The credit is capped at $2,000 for residential systems.[12] For more detailed information, see the Guide to Federal Tax Incentives from the Solar Energy Industry Association (SEIA).

Photovoltaic systems are less attractive in much of Canada because of the high latitudes, so most Canadian renewable incentives are geared toward other technologies. However, Canada does maintain a program called EcoENERGY, which provides a federal rebate of C$0.01 per kWh for any renewable generation project—including PV—constructed before March 31, 2011.[13]

State/provincial. In the U.S. there are widely varying state incentives. At least one state, Idaho, offers tax deductions that total 100 percent of the cost of a customer-sited PV system up to $20,000.[14] Dozens of other states offer tax breaks or other financial incentives for residential PV systems. The most comprehensive source for information about incentives, rebates, and related programs in the U.S. is North Carolina State University's Database of State Incentives for Renewables & Efficiency (DSIRE).

In Canada, several provinces offer tax breaks or rebates, but only Ontario currently provides significant incentives. In Ontario, customer-sited PV systems are eligible for a rebate of C$0.42 per kWh produced for 20 years. Currently this incentive makes customer-sited PV highly competitive with utility-purchased electricity.[15,16]

Local. A number of cities and counties also offer financial incentives for installing residential PV systems. While these incentives tend to be smaller than those offered at the state or federal levels, residents are often able to take advantage of local tax breaks or rebates in addition to those offered at the state and federal level. DSIRE provides an up-to-date listing of local PV incentives.

Utility. Often a utility company is the single largest source of supplementary funding for residents who want to install a PV system. Unlike government incentives, which usually focus on tax breaks, utilities tend to offer rebates or other up-front sources of funding. By making funds immediately available for residents, utilities often provide the capital that enables consumers to pay for an otherwise unaffordable PV system. Utility companies vary widely in the size, scope, and strategy regarding incentive programs. For more information on structuring a PV rebate program and to review examples from around North America, see the E Source report, "Best Practices in PV Rebate Programs: Helping Customers Install Quality Photovoltaic Systems." Also, the *E Source DSMdat* database of demand-side management programs will include a comprehensive listing of utility PV programs by mid-2008. When you consider the wide range of incentive programs along with geographical variations in the available solar resource, the final cost of a residential PV system can vary considerably depending on location (**Table 2**).

Table 2: Cost comparison of sample 4-kilowatt residential PV systems in select cities

Photovoltaic (PV) system economics depend on many factors—particularly latitude, local climate, and incentive programs. With incentives, PV systems are just approaching a break-even point for the expected 30-year life span in some locations. Elsewhere, cheap grid electricity, small relative incentives, and low solar resource make PV systems less competitive. Note that this comparison does not take rising energy costs into account.

City	Estimated installed cost ($)	Estimated utility and government incentives ($)	Net consumer cost ($)	Local electricity cost ($/kWh)	Annual AC system output (kWh)	Annual offset electric costs ($)	Simple payback, after incentives (years)
Austin	35,000	20,000	15,000	0.094	5,359	504	30
Denver	35,000	20,000	15,000	0.086	5,813	500	30
Phoenix	35,000	18,000	17,000	0.087	6,184	538	32
Sacramento	35,000	12,000	23,000	0.113	5,638	637	36
Boston	35,000	13,500	21,500	0.110	4,468	491	44
Chicago	35,000	12,000	23,000	0.085	4,276	363	63

Note: Assumes fixed-tilt array, south-facing with angle equal to local latitude; DC to AC derate factor of 0.77; net-metering refunds not included; kWh = kilowatt-hour.

Economic Trends

Following a decades-long trend of gradually declining prices for PV systems, since 2004 there has been some stagnation. PV module costs dropped from more than $40 per watt in the 1970s to $10 by the mid 1990s and to less than $5 by 2004.[17] Since then, module prices have risen slightly due to strong demand and silicon shortages (see Figure 2).[18] But industry experts expect that as new polysilicon manufacturing capacity comes on line, PV module prices could drop as much as 40 percent by 2010 and 60 percent by 2017.[19,20]

To help spur additional price reductions, there have been significant public and private investments into PV research. In 2007 the U.S. Department of Energy (DOE) launched two solar research programs with a combined budget of $43.7 million as the centerpiece of the Solar America Initiative.[21,22] Program goals include reducing the average installed cost of grid-tied PV systems to $3.30 per watt by no later than 2015.[23] At that price, photovoltaic systems would be competitive with utility-generated electricity without rebates or incentives.[24] For more information on cost projections, see Market Outlook.

Back to top

Making the Right Choice

For consumers planning to install PV systems and utilities operating rebate programs for PV installations, there are essentially three types of choices: equipment, installation contractors, and array location.

Selecting Equipment

In many ways, the task of specifying quality equipment has already been completed by organizations that have been subsidizing PV systems for years, most notably the California Energy Commission (CEC). In fact, programs operating in several states simply require PV modules and inverters to be selected from the CEC's lists of eligible equipment in order to qualify for a rebate. In addition to complying with all safety and interconnection requirements, the CEC requires that inverters undergo performance testing by a qualified laboratory, and the CEC publishes the results of that testing for each inverter. For modules, the CEC's current "List of Eligible Photovoltaic Modules" is probably as good as any other, but neither the CEC nor any other North American entity we're aware of require module performance testing of any kind. This may have created a perverse incentive for module manufacturers to overstate the power ratings of their products; therefore utilities may want to be cautious in calculating the peak power output from a proposed array.

Inverters. The CEC has done PV program implementers everywhere a tremendous service by requiring not only that inverters pass Underwriters Laboratories tests for safe operation and interconnection with the utility systInverters.em (UL standard 1741, "Standard for Inverters, Converters, Controllers, and Interconnection System Equipment for Use with Distributed Energy Resources"), but also that they undergo a battery of performance tests to evaluate performance under a variety of conditions likely to exist in the field. These additional tests evaluate the inverter's maximum continuous output power, its conversion efficiency at various load points, and tare losses (the device's power consumption when turned off). The CEC maintains a List of Eligible Inverters.

Modules. For PV modules, specifying quality equipment can be as easy as simply requiring that the modules satisfy UL Standard 1703, "Standard for Safety for Flat-Plate Photovoltaic Modules and Panels." This is the only requirement we've identified for any program in the U.S., and it's the sole requirement for a PV module to make it onto the CEC's List of Eligible Photovoltaic Modules.

Although compliance with UL 1703 indicates that a given module will operate safely, the only thing it requires about a module's ability to convert solar energy is that its output is within 10 percent of the rating stamped on the back of the module. There is evidence[25] that actual module performance is biased toward the low end of the UL requirement—that is, closer to 90 percent of the module's rating. Because most utility rebate programs are based on rated power rather than actual measured performance, consumers and utilities may not be getting 100 percent of what they're paying for. This is a fact that few in the PV industry, and even fewer outside of that industry, are aware of. This situation appears to result in module ratings that are artificially high, so utilities may want to consider discounting module ratings by up to 10 percent when calculating system rebates.

The DOE has convened a process to consider establishing a voluntary PV module performance testing and certification program. In addition, Underwriters Laboratories is reportedly contemplating tightening the allowable tolerance for power rating. According to Tom Kimbis of the DOE's Solar Energy Technologies Program, one of these activities will close this loophole before the end of 2008.[26]

Selecting Qualified Installers

The demand for qualified installers has grown considerably in recent years as the demand for grid-connected PV systems has exploded. Many contractors have entered this field with little qualification or formal training in PV system design and installation, or in the provisions of the National Electrical Code regarding PV. This lack of PV-specific experience increases the possibility that inexperienced contractors will make design or installation errors that negatively affect system performance.

How can homeowners or utility program managers gain assurance that the contractors they're working with know what they're doing? Training, a track record of successful installations, and (for utility programs) pre- and post-installation assessments are certainly key elements in building confidence in contractor capabilities. Certification by a competent and credible organization can also be a good indicator of contractor proficiency. Many state and local solar industry associations offer certification and maintain lists of certified installation contractors. But such certifications are only as good as the training and testing they require of recipients. No doubt many certification programs are rigorous and credible, but it may take a fair amount of work just to determine whether the certification document that a given contractor presents is worth the paper it's printed on.

Since 2003, one ironclad indicator of contractor proficiency has been certification by the North American Board of Certified Energy Practitioners. This certification is conferred on PV installers who pass a rigorous exam developed with input from a broad swath of PV industry stakeholders. Before they are eligible to take the NABCEP exam—offered twice each year at many locations around North America—contractors must demonstrate that they possess the necessary experience and/or educational prerequisites (**Figure 5**).[27] NABCEP certification is widely recognized in the industry as the single most credible indicator (but not a guarantee) of contractor competency. As of late 2007, more than 470 contractors have received NABCEP certification (as listed in the NABCEP contractor database), and that number is growing quickly. Findsolar.com is another resource for finding local contractors and reviewing their certifications.

Figure 5: Prerequisites for the NABCEP exam

To qualify to take the certification exam offered by the North American Board of Certified Energy Practitioners, candidates must demonstrate that they possess one of the following combinations of experience and education.

Four (4) years of experience installing PV.
Two (2) years of experience installing PV systems in addition to completion of a board-recognized training program.
Be an existing licensed contractor in good standing in solar or electrical-construction-related areas with one (1) year of experience installing PV systems.
Four (4) years of electrical-construction-related experience working for a licensed contractor, including one (1) year of experience installing PV systems.
Three (3) years experience in a U.S. Dept. of Labor approved electrical-construction trade apprentice program, including one (1) year of experience installing PV systems.
Two-year electrical-construction-related, or electrical engineering technology, or renewable energy technology/technician degree from an educational institution plus one (1) year of experience installing PV systems.
Four-year construction-related or engineering degree from an educational institution, including one (1) year experience installing PV systems. For definitions of experience and acceptable training, please refer to the Candidate Information Handbook.

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Array Location

Three important criteria to consider when selecting the location for residential PV installations are the orientation of the rooftop, the condition of the existing roof and its support structure, and the presence of any objects that will shade the array.

Rooftop orientation. For most residential applications, the array orientation will be largely dictated by the orientation of the available rooftop space. Moderate variation of array tilt angle from its optimal value—a tilt equal to the site's latitude—changes the time of year when the system output peaks but has relatively little impact on annual energy production. For example, for a system in Tucson, Arizona, increasing or decreasing array tilt by 15 degrees from its optimal 35 degrees reduces annual generation by less than 4 percent.

A PV system's annual energy output is similarly forgiving with regard to the array's orientation relative to due south, known as the azimuth angle. A change in azimuth angle will alter the time of day that system output peaks, but as long as the array faces in a southerly direction, its annual energy output will be close to one that faces due south. In Tucson, a change of plus or minus 45 degrees from due south reduces annual output by about 8 percent.

Condition of the existing roof. It's vital for homeowners to be apprised of the condition of their roof prior to installing a PV array because the cost of reroofing will be substantially greater once the array is in place. So if the existing roof is in poor condition, the time to address this problem is before the array is installed. For this reason, some utility PV rebate programs require homeowners or contractors to submit documentation of roof condition along with their initial application to participate in the program.

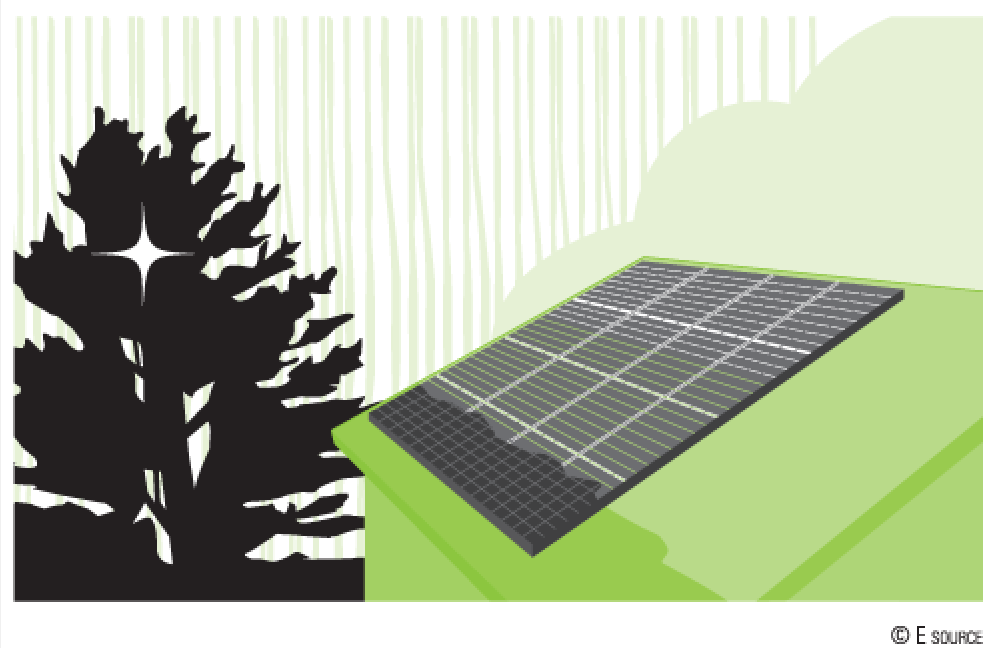
In most cases, the rafters that hold up a roof are more than adequate to securely mount an array. But in cases where the roof has been compromised, perhaps by leakage or a fallen tree limb, it's vital to ensure that the roof's supporting members are in good physical condition prior to array installation.

Shading. When an individual cell within a module or an individual module within an array is shaded, its output will be reduced—and this will typically reduce module or array power to a degree much greater than simply the proportion of the module or array area that's shaded. This is because PV modules are composed of numerous individual solar cells connected in series to provide the desired module voltage. Often, a module will contain several series "strings" of cells that are wired together in parallel to the module terminals. The current output of any given cell string is limited to the current output of the least productive cell in the string. Similarly, an array is typically composed of at least one string of modules that are wired in series to provide a DC voltage compatible with the system's inverter. The current output of a series string of modules, and thus the power that it can deliver, is limited to the current output of the least productive module in the string. So if part or all of one module in the string is shaded, the power output of the remaining modules in the string will also be reduced.

It's difficult to predict the actual amount of reduction because it depends not only on the pattern of shading, which in itself can be quite complex, but it also depends on the array layout. For example, if an array is composed of four series strings of modules connected in parallel, and each string has at least one module that is partially or completely shaded for part of the day, the impact will be greater than if all of the shaded modules are from one string and the other three strings remain completely unshaded all day. In the former case, the output of all four strings will be reduced, and the array voltage may drop below the inverter's operating window, shutting the system down entirely. In the latter case, the three unshaded strings will perform normally, keeping the array voltage up and allowing the system to deliver at least 75 percent of what an equivalent unshaded array would produce (**Figure 6**).

Figure 6: The effects of shading

The impact of shading on the power output of a photovoltaic array depends both on the portion of the array that is shaded and the electrical layout of the modules. In this array, if the four modules in each column were wired together in series and those four columns were wired in parallel, then the output of all four series strings would be reduced because each string contains one shaded module. If, however, the array were designed so that modules in each row are connected in series and the rows are connected in parallel to the inverter, the output of the top three rows would be unaffected by shading—and more power is delivered to the inverter.



The ideal situation is of course to select a location where the array will remain completely unshaded all day throughout the year. But this is often not possible because trees, neighboring buildings, or other objects will block sunlight at least part of the year. Measurement tools and software from companies such as Solar Pathfinder and Solmetric are available to assess the degree of shading a proposed array will experience throughout the year. Some utility rebate programs mandate the use of such tools, and some require that the proposed array have a minimum number of unshaded hours per day (often six) throughout the year.

Back to top

Retrofit Options

PV technology can be easily integrated into most existing buildings. Many houses have some amount of south-facing roofing of an angle that receives a suitable amount of sunlight. Many utility rebate programs require that a PV system have a minimum of six hours of unobstructed sunlight per day. However, retrofitting an existing home rather than specifically designing a new PV-ready home might mean the roof angle is optimized for collection at a different time of day or year than a homeowner may prefer. If customers want their PV modules to have an angle different from the slope of their roof, this is easily achieved with added mounting hardware. If a house is highly shaded or has a roof that's completely inadequate for a solar array, a free-standing (but somewhat more expensive) system might be the best option.

If a roof is in poor condition, it may be best to reroof the building before installing an array because that work will be much more expensive once an array is in place. Some utilities require contractors to verify that the roof is in good condition before rebate applications can move forward.

Wind is also an important consideration in PV module placement, as strong gusts can exert powerful forces on an array. Installers must properly site and anchor a PV array to eliminate the risk of damage to the system or to the roof under all but the most extreme weather conditions.

Roof-mounted PV systems are considered by some to be an eyesore. There have been instances of neighborhood covenants that explicitly ban solar arrays. However, a number of states, counties, and municipalities have solar easement laws that forbid solar array bans. You can find out about local easement allowances in the "Solar Access Law/Guideline" areas of the DSIRE database.

Back to top

Maintaining Performance

Other than occasional cleaning and perhaps snow removal, there is little system maintenance that the residential owner needs to perform, or even can perform. Inverters require maintenance far more frequently than modules, but in most cases, the system owner's role is limited to notifying the installer that the inverter needs service.

Module maintenance. Once installed, PV arrays are relatively maintenance-free. Modules have no moving parts and usually carry a warranty of at least 20 years. Soil accumulation on the module surface has been observed to reduce energy generation by up to 25 percent in some dry and highly polluted areas of California,[28] but in most locations the effect will be much smaller—typically no more than a few percent. Regular rainfall is often sufficient to keep soiling losses negligible, but where rain is infrequent, occasionally rinsing modules off with water will restore full power operation.

In northern latitudes or at higher elevations, snow cover can significantly reduce system output for long periods. According to PVWatts documentation, the output of a system installed in Minnesota at a tilt angle of 23 degrees (well below the optimal latitude tilt) was reduced by 70 percent during winter, while snow cover reduced generation of a nearby system installed at a tilt angle of 40 degrees (which is still lower than optimal) by 40 percent.[29] In such locations, higher tilt angles allow snow to slide off of modules more readily, thereby minimizing its effect on generation. Where manual snow removal is feasible, this will also obviously improve system performance—although the value of the additional kWh generated may in some cases be insufficient to justify the trip up to the snow-covered roof.

Inverter maintenance. Although inverter reliability has improved dramatically since the 1990s, inverters remain the weak link in overall system reliability and the most frequent source of maintenance calls. The industry standard warranty for inverters is five years, with inverter mean time between failures in the range of 5 to 10 years.[30] Although some fault modes can be cleared by simply cycling the AC power to the inverter, maintenance usually requires the services of a trained electrician and involves replacement or repair at an authorized service facility. This limits the maintenance role of the system owner to regularly monitoring the status indicators on the inverter or identifying a sharp decline in system output that cannot be explained by factors like snow cover.

Back to top

Technical Details

Many factors combine to determine the amount of energy a given PV system can produce. The available solar resource is of course a primary determinant, as is array orientation, but the material that the modules are made of, the system's design, and other factors such as module mismatch and soiling or snow cover will also affect system performance.

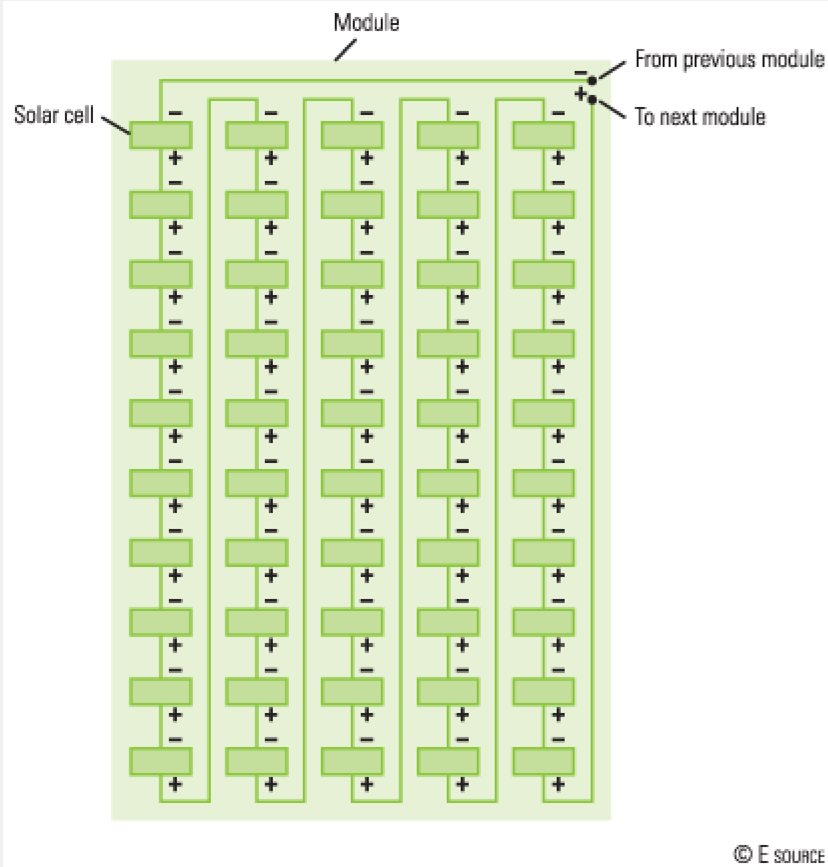
How PV Systems Work

Solar cells work by capturing the energy in solar photons and transferring it to electrons within the semiconductor material of the cell. If the photons have sufficient energy, these electrons, which were previously bound to the atoms that make up the cell, become free to move around the cell. An internal electric field that exists within the cell provides the voltage needed to drive these freed electrons through an external circuit. Numerous online sources, such as BP Solar's "How Solar Works," provide much more detailed and rigorous descriptions of the inner workings of the solar cell.

Because the voltage available from a single cell is quite small, on the order of 0.6 volts DC, a typical PV module is composed of many cells wired together in series. For modules intended for grid-connected systems, voltages range from about 30 to over 70 volts. Even this voltage is too low to produce grid-quality electricity, so many modules are wired together in a series string in a typical PV rooftop array (**Figure 7**). The open-circuit voltage of an array on a residential rooftop can range from as low as 200 to as high as 600 volts, which is the limit allowed by the U.S. National Electrical Code. Often PV arrays include several strings of modules all operating at the same voltage to provide the desired power level.

Figure 7: Cell, module, and array voltages

To establish the direct-current voltages necessary for the system's inverter (and to reduce the very large cables that would be required for lower voltages), many solar cells must be wired in series within a module, and many modules must be wired in series within an array. Some modules have several series strings of cells operating in parallel. Likewise, arrays often have several series strings of modules that also operate in parallel. In this module, each solar cell has an open circuit voltage of 0.6 volts so that the series string of 50 cells produces an open-circuit voltage of 30.0 volts.



The DC power from the array flows through cables to the input of an inverter—a sophisticated electronic device that, for grid-tied residential systems, converts DC power to 120-volt, AC power. Besides performing power conversion, most inverters are also equipped to operate the PV array at the specific DC voltage that optimizes power output. This optimal voltage changes over the course of a day depending on the amount of insolation and the temperature of the modules.

Depending on the requirements of the local electric utility, the AC output of the inverter may be connected directly through a home's electrical distribution panel, going first through an electrical meter that monitors PV energy production. Alternatively, the system may be connected on the utility side of the meter. Most utilities require that a lockable disconnect switch be installed at the home's service entrance so that power from the PV system cannot be fed back into the utility grid in the event of a power failure.

Types of PV Cells

There are many material systems and production techniques used to create PV cells. Historically, silicon (Si) has been the workhorse material of the PV industry and its dominance continues today. According to the National Renewable Energy Laboratory (NREL), Si accounted for 96 percent of PV products in 2007.[31] There are several emerging PV technologies in various stages of development and commercialization, most of which don't use Si. Some of these technologies promise significantly lower-cost production, so the days of Si's dominance of the field may be numbered.

Silicon. After oxygen, Si is the second most abundant element on Earth. It's so ubiquitous that you might expect it to be dirt cheap. But one can't merely collect sand from the beach, melt it down, and create solar cells. Like computer chips, solar cells require extremely pure Si to function well, and creating that purity is an energy-intensive, time-consuming, and expensive process—the primary reason Si-based solar cells are so expensive.

The three common types of Si solar cells include single-crystal, polycrystalline, and thin-film. As their name implies, *single-crystal* cells are wafers of pure Si cut from an ingot that is pulled slowly out of a vat of molten Si. As the molten Si cools and solidifies, the atoms arrange themselves in a regular crystalline structure. Single-crystal cells have the highest conversion efficiencies of any commercial PV modules for terrestrial application—up to about 20 percent—but because they use the greatest amount of pure Si, they're also the most expensive. In 2006, single-crystal modules made up 25 percent of U.S. PV module shipments (**Table 3**).[32]

Table 3: Photovoltaic cell and module shipments by type, 2004–2006

The market share of the various module types has shifted radically in recent years. Single-crystal modules, which made up more than half of the market in 2004, dropped to just 25 percent of the market in 2006 due to dramatic growth in the popularity of polycrystalline (cast and ribbon types) and thin-film modules.

Type	Shipments (peak kilowatts) 2004	2005	2006	Percent of all shipments 2004	2005	2006
Single-crystal silicon	94,899	71,901	85,627	52	32	25
Cast and ribbon silicon	64,239	101,065	147,892	35	45	44
Total crystalline silicon	**159,138**	**172,965**	**233,518**	**88**	**76**	**69**
Thin-film	21,978	53,826	101,766	12	24	30
Concentrator	0	125	1,984	0	< 0.5	1
Other[a]	0	0	0	0	0	0
Total	**181,116**	**226,916**	**337,268**	**100**	**100**	**100**

Notes: Data do not include shipments of cells and modules for space/satellite applications; totals may not equal sum of components due to rounding.
a. Includes categories not identified by reporting companies.

Source: Energy Information Administration

In efforts to reduce the cost of Si-based solar cells, researchers in industry, federal laboratories, and academia developed alternative production methods. Several of these methods result in what is known as *polycrystalline* Si—an aggregation of small grains of single-crystal Si. In one of the more common production techniques, very pure molten Si is poured into a cast where it cools and solidifies in bulk. Wafers are subsequently sliced from the resulting ingot, which is typically rectangular in cross section. More advanced techniques pull a thin linear meniscus of molten Si from a crucible, creating a long narrow sheet of polycrystalline material that is subsequently cut to the desired cell length. These techniques use only about a third as much Si as single-crystal cells, but this savings is offset to a degree by the fact that commercial efficiencies of polycrystalline cells reach only about 10 to 14 percent. Polycrystalline solar cells accounted for about 44 percent of module shipments in 2006.[33]

To make *thin-film* Si solar cells, gaseous Si in the form of silane (SiH_4) is deposited onto a glass, steel, or plastic substrate. The resulting material doesn't have a regular crystalline structure, so this material is often called "amorphous." Amorphous Si absorbs light much more strongly than does single-crystal Si, so only a very thin layer is needed—about 1 micrometer thick instead of 200 or more micrometers thick for crystalline Si cells. This of course reduces the material cost of the cell substantially, but because conversion efficiency is reduced to only about 6 to 8 percent, a much larger array is required for the same power output. About 30 percent of module shipments in 2006 were thin-film cells, and the bulk of these used thin-film Si.[34]

Researchers are developing many other materials and production techniques for use in terrestrial PV systems. Some of these are quite promising but face technical challenges that may prevent them from ever becoming commercialized. Others are already in commercial production and have the potential to revolutionize the PV industry.

Cadmium telluride (CdTe). CdTe is in many respects an excellent material for PV because it can absorb a wide swath of the solar spectrum and it can be deposited as a very thin film on a substrate. CdTe test cells have been measured up to 16.5 percent conversion efficiency, although commercially available modules offer conversion efficiencies closer to 10.5 to 11.5 percent. The primary drawback of this technology is the fact that cadmium is a toxic heavy metal. In the form of CdTe PV modules, the cadmium is quite stable and is neither water soluble nor combustible. Nonetheless, end-of-life disposal of these modules is a potential environmental problem. To address this, at least one manufacturer of CdTe modules—First Solar of Phoenix, Arizona—has established a collection and recycling program for its modules. AVA Solar of Fort Collins, Colorado, has announced that its new facility supplying 200 MW of module capacity per year will go into commercial operation in 2008; it anticipates eventually producing modules at less than $1 per watt.[35]

Copper indium diselenide (CIS) and copper indium gallium diselenide (CIGS). These two PV material systems are now being commercialized after two decades of research. They offer tremendous potential for low-cost production of thin-film PV modules because they lend themselves to continuous, roll-to-roll processing on inexpensive flexible substrates. CIS modules, currently manufactured by Avancis GmbH and Wurth Solar in Germany, have achieved conversion efficiencies of nearly 13 percent.

Adding gallium to the alloy improves the material's optical and electronic properties. CIGS test cells have achieved efficiencies of up to 19.5 percent, but commercial module efficiencies are typically much lower, at around 5 to 11 percent. Several companies, including Global Solar, DayStar, Miasole, Ascent Solar, ISET, and SoloPower are gearing up for commercial production,[36] and Nanosolar began commercial production in late 2007.

Organic PV. Certain types of organic molecules such as semiconducting polymers and exotic, golf-ball-shaped molecules known as fullerenes have been investigated for application to PV, with some success. These materials have the advantage of being inexpensive to prepare and they can literally be sprayed onto a substrate in a process similar to screen printing. But they also pose some difficult technological challenges that will have to be overcome if they are to advance to commercialization. As of late 2007, the world record conversion efficiency for an organic PV cell was 5.4 percent. For more on this technology, see "Whatever Happened to Organic Photovoltaics" in *ET Currents 52*.

Factors Affecting System Performance

In addition to site-related factors (see Making the Right Choice), a number of often-ignored factors that individually reduce performance by small amounts can jointly result in a noticeable disparity between expected and actual system performance. These include module mismatch, light-induced degradation, and wiring losses.

Module mismatch. Module manufacturers sort individual solar cells so that all cells in a module have similar current and voltage characteristics. When similar cells are grouped together in a PV module, each individual cell can operate near its peak efficiency. Likewise, for an array to operate efficiently, all modules in a string (a set of modules wired together in series) must have similar current and voltage characteristics. When there is a mismatch between module characteristics, overall array performance will be diminished. In the field, a mismatch will typically reduce power output by less than 1 percent of the array's rating.[37]

Light-induced degradation. All types of modules degrade in performance to some extent upon initial exposure to sunlight, but different semiconductor materials degrade to different degrees. Amorphous Si modules have a well-known degradation of about 15 percent that occurs over the course of the first several months of operation. For the more common crystalline and polycrystalline modules, light-induced degradation is typically about 2 percent.[38]

Losses in AC and DC wiring and protective diodes. Current flowing through system wiring dissipates power as heat. In addition, blocking diodes that prevent reverse current flow through the array also dissipate a small amount of power. Together, these loss mechanisms amount to about 3 percent of the array's rating.[39]

The PVWatts system performance simulation program accounts for each of these effects in its user-modifiable derating factor.

Back to top

Market Outlook

We expect the PV industry to continue its rapid growth, particularly as new production capacity comes on line to alleviate Si shortages. As PV becomes cheaper and more cost-competitive, the industry growth rate should remain strong. According to the Energy Information Administration, the U.S.-installed solar electric base in 2006 was 670 MW.[40] The DOE's Solar America Initiative (SAI) projects 5,000 to 10,000 MW of total PV capacity could be installed by 2015 and 70,000 to 100,000 MW could be installed by 2030, a significant portion of which would be in the residential sector.[41] Any continued growth in the residential PV market largely depends on policy, technology, and economics.

Policy drivers. In the U.S. and Canada, it's likely that in the next several years there will be national legislation that sets limits or reduction goals for greenhouse gas emissions. However, such legislation isn't likely to immediately extend to the residential sector, so it shouldn't have a direct impact on the residential PV market. But as utilities aim to green their portfolios under the pressure of emission restrictions, there could be increased size and breadth of the renewable incentives they offer to customers.

Similarly, an increasing number of U.S. states are adopting renewable energy portfolio standards (RPSs). RPS programs seek to incorporate a certain amount of renewable generation into a state's energy portfolio by a particular date. Thus far New York has the most ambitious program: It seeks to generate 24 percent of its energy from renewable sources by 2013. Much in the same way that carbon caps can spur additional utility incentives, state renewable mandates have the potential to increase the number, widen the scope, and raise the financial incentive of programs that promote residential PV. As of December 2007, 24 states and the District of Columbia had established renewable portfolio standards.[42] In Canada, seven of its 13 provinces and territories have implemented or proposed RPSs.[43] The DOE maintains a database of States with Renewable Portfolio Standards and Environment Canada has published a Survey of Renewable Energy Fiscal Instruments.

Net metering is another mechanism that can foster industry growth. Research at NREL shows a correlation between net metering and consumer acceptance of residential renewable technology. However, if a net metering policy is cumbersome or unduly bureaucratic, it tends to discourage involvement. When net metering is combined with other incentive programs or is established in areas with high electricity prices, consumer participation is higher.[44] DSIRE's collection of national summary maps includes one for net metering, and for Canadian consumers, the environmental group Pollution Probe maintains a page on Net Metering—Getting Credit for the Electricity You Generate.

Finally, tax incentives provide one of the most direct and responsive ways to facilitate PV market growth in the residential sector. While the number of tax incentive programs is growing as the North American residential PV market continues to mature, the monetary amount of incentives should decline in the long term as the cost of PV systems continues to drop. By the time PV becomes directly cost-competitive with conventional electricity, there will be little need to use tax breaks to promote PV purchases. The federal, state, and local incentives range from sales tax waivers on new PV equipment to income tax write-offs. DSIRE provides incentive information for any jurisdiction in the U.S., and the Lawrence Berkeley National Laboratory (LBNL) has information about the links between market growth and public policy in its library of renewable energy publications.

Technical drivers. Since 2005 there has been a global shortage of solar-grade Si. The shortage has roots in the dot-com crash, which caused a rapid decline in prices, to a low of $9 per kilogram.[45] Costs had recovered somewhat by 2004: Si traded near $30 per kilogram, but that was still below production cost.[46] Because of these low prices, Si producers could not justify capital expenditures to expand operations. But as the PV market continued to grow and the computer industry rebounded, demand returned and prices reached record highs.

By 2005 the global shortage was obvious and manufacturers began scrambling to expand operations—but it takes three years for a new polysilicon manufacturing facility to come on line. Because of this lag, the shortage is expected to continue at least through 2008 and possibly through 2013.[47] In 2006, there were isolated reports of Si trading as high as $200 per kilogram, leading to higher module prices and a slowdown in the PV market.[48,49]

Although the length and severity of the current shortage may not be fully realized for some time, there could be a significant impact on PV industry growth. Prolonged Si scarcity could mean significant shortfalls in the goals for industry expansion set forth by governments and solar advocates. It could also mean that utilities and governments have to continue to dole out large rebates to consumers for longer than originally projected. In 2006 Merrill Lynch reported governments around the world would have to provide an estimated $24 billion in rebates over the next three years in order meet PV deployment goals. One analyst quoted in the *Financial Times* indicated the situation could cause a "substantial delay" in the industry projection of 2018 as the date when PV would become directly competitive with traditional electricity without subsidies.[50]

The shortage has also helped spur interest in alternative PV materials and production methods that require less Si. NREL and others have funneled millions of dollars into research of organic PV, CIS, CdTe, and CIGS, helping the latter two become commercially available. Thin-film Si PV, which can be engineered with a layer of Si only micrometers in thickness, has begun to see more use during the global shortage, particularly in PV roofing shingles (see A Village of PV Shingles). Because the duration and full impacts of the current Si shortage are unclear, the extent to which these new and emerging technologies will impact the PV market remains uncertain.

Economic drivers. Cost has traditionally been the single largest barrier to widespread residential PV adoption. The Solar Energy Industry Association has found a direct link between costs and sales: For every doubling of solar power sales volume, costs have historically declined by at least 10 percent.[51] Assuming the global Si shortage eventually ends, or an alternative technology overtakes traditional Si-based modules, PV costs should resume their downward march. The SEIA has set goals of $4.65 per installed watt as the goal for installed PV system costs by 2015 and $2.33 per watt by 2030; the SAI has set 2015 as the target date for solar to directly compete with traditional electricity, which translates to a system cost of roughly $3.50 per watt.[52]

Regardless of when PV becomes directly competitive with traditional electricity sources, it's important to remember that solar power still requires a very substantial initial investment. Even though it could become competitive on a cost-per-kWh basis as soon as 2015, the initial installation cost of thousands of dollars will remain a barrier for many. Without innovative financing programs from utilities, government, and solar providers, residential PV adoption will be limited to particular swaths of the population. This phenomenon has already been observed in a few isolated pockets of the U.S. that have exceedingly high electricity costs. In these locations, PV is already directly cost competitive with grid-generated electricity, but due to factors such as slow utility program adoption, the number of installations remains relatively low.[53]

LBNL offers more information on the link between system costs and consumer acceptance as well as discussions on what utilities are doing to remove cost barriers in its library of renewable energy publications.

Back to top

Manufacturers

Scores of companies—including these leading manufacturers—produce PV panels, inverters, and system components. For a more complete listing see the Underwriters Laboratories Information for Regulators and Utilities and the California Energy Commission Lists of Eligible Renewable Equipment.

Module Manufacturers

- GE Energy—Solar Power
- BP Solar
- Canadian Solar
- Evergreen Solar
- Mitsubishi Electric—Solar Power
- Nanosolar
- Sanyo Electric
- SCHOTT Solar
- Sharp Electronics
- SunPower
- United Solar Ovonic

Inverter Manufacturers

- Fronius USA
- Power-One

- PV Powered
- SMA America
- SunPower
- Xantrex Technology

Back to top

Success Story

In January 2007, homebuilder Lennar celebrated the grand opening its new solar village in Roseville, California (**see sidebar**). The development was the largest solar neighborhood in the U.S.—spanning three subdivisions and including more than 300 homes—with a total peak generating capacity of 700 kWp. When the sales office opened, consumer interest was extremely strong; Lennar reported three times as many inquiries as their local competitors in the weeks leading up to the grand opening.[54]

After the opening, Jeff Panasiti, Lennar's Sacramento Division President, commented: "We knew that this area was ready for us to build solar and energy-efficient homes, but we didn't foresee the amazing response we've had."[55]

The stock 2.3 kWp rooftop systems cost home buyers an additional $10,000 to $12,000 after utility rebates from Roseville Electric. The cost was rolled into the sale price, which averaged $455,000.[56] According to Panasiti, this breaks down to about $48 per month for the life of the mortgage.[57] The PVWatts calculator estimates the system should displace a monthly average of $30 in utility electricity (assuming optimal orientation), meaning that the PV system would cost residents about $0.06 per kWh more than electricity at current Sacramento rates.

In the weeks after the grand opening, the solar homes sold at twice the rate Lennar expected, making it the company's fastest-selling project in the region.[58] The program was so successful that Lennar soon teamed up with local utilities and announced plans to incorporate PV into all of their Sacramento and Bay Area housing developments. This plan includes more than 2,000 homes to be built with grid-tied PV by 2010.[59]

A Village of PV Shingles

Homebuilder Lennar's solar village in Roseville, California, uses photovoltaic (PV) roofing shingles on all of its homes.[60] The shingles use a thin-film substrate and are part of a class of products known as building-integrated photovoltaics (BIPV). As silicon shortages have driven up prices in recent years, thin-film-based BIPV products have become increasingly cost-competitive because they require substantially less silicon than most competing technologies. Currently, an installed BIPV shingle system still costs slightly more than a traditional PV system—about $10 to $12 per watt.[61] The main drawback of thin-film technologies is their low efficiency—they take up roughly twice the roof space to generate the same amount of energy as a crystalline system. However, BIPV shingles have important advantages that make them more appealing: In new construction, they can eliminate the need for traditional roofing materials and associated construction costs, making them more cost-competitive; and the shingles' low-profile, modular design has led Lennar and many other contractors to choose them over bulky crystalline modules for aesthetic reasons.

Back to top

Utility Program Example

Salt River Project (SRP), a Phoenix-based utility that serves almost 1 million customers, has a residential PV program called EarthWise. At the end of 2007, EarthWise had about 300 residential solar installations totaling around 1 MW of capacity. The program offers rebates of $3 per watt for customer-sited, grid-tied PV systems. SRP has developed a highly streamlined program that facilitates rapid installation with minimal costs or processing on the part of the utility, all while safeguarding against poorly performing systems or shoddy contractor work. The utility created a five-step process for securing rebates:[62]

1. Customer submits an application detailing the incentive they are seeking along with other interconnection paperwork. SRP approval takes about a week, and funds are reserved for six months.
2. SRP undertakes a two-week design review of the proposed system.
3. Upon design review approval, SRP prepares an interconnection agreement for the customer. Simultaneously, the billing department is notified that the customer will begin net metering when the utility has received the executed interconnection agreement. This step takes about two weeks.
4. Within a few days, a utility technician performs a site inspection and meter installation.
5. SRP issues the incentive to the customer about two weeks after the inspection.

The total cycle time for SRP—from initial customer application to issuing a rebate check—is only about three months. This relatively fast turnaround is due partly to the fact that SRP requires more initial work from the customer and contractor compared with many other utilities. Customers must meet with a contractor, submit completed technical drawings, and have a construction quote before the application will be considered. And once the system is installed, SRP doesn't complete a comprehensive inspection—instead, it requires the contractor to call the city out to inspect the system for code requirements. After passing that inspection, SRP technicians come to the site to make sure the system satisfies the interconnection requirement.[63]

By requiring more up-front work, SRP says it's able to focus resources only on those customers who are serious about installing systems and are already moving forward. To further facilitate smooth program operations, SRP has a single person as the point of contact within the organization for residential customers. This person then distributes work to others in the organization as needed. As the program continues to grow, SRP says this may become more work than one person can handle, but the utility also expects to continue with the model of a single contact person for any particular customer.[64]

When SRP conducted a satisfaction survey of all its residential program participants, it found that most customers were pleased with how the program runs and they felt the process was smooth. The survey also found program participants were happy with the contractors, the installation process, and the application and interconnection processes.[65]

To learn more about other residential PV programs in North America, see the E Source report, "Best Practices in PV Rebate Programs: Helping Customers Install Quality Photovoltaic Systems."

Back to top

For More Information

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My Solar Estimator, Findsolar.com

Directory of NABCEP-Certified PV Installers, North American Board of Certified Energy Practitioners

Solar Energy Industries Association

Back to top

Got a Question About This Technology?

View recently answered member inquiries about PV on our technology questions page or ask a new question using the *E Source Member Inquiry Service*. As a member, you get direct access to our experts for quick answers to your questions or for timely referrals to other resources.

Back to top

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Back to top