TOOLBASE.
TECHSPECS

Photovoltaic Systems

TECH @ A GLANCE

BENEFITS (+)/DRAWBACKS (–)

+ Produces high-value electrical energy that can be used directly in a home
+ If net metering is available, credit can be received from the utility for excess electricity generation
– EXPENSE—Photovoltaic systems start at about $10,000 for a small residential (1-kW) system.
– ECONOMICS—Given current utility rates and PV system costs, without financial incentives, the electrical energy produced by a PV system will cost more than utility-supplied electricity.
– SPACE REQUIREMENT—There may be difficulty finding ample roof area for PV systems on some homes, especially those with complex roof lines.

MAKING THE SWITCH

Roof-mounted PV systems require a specialty solar firm to design and install the system. However, the industry infrastructure is mature and system designers and installers are relatively easy to find. Installing a PV system on a new home requires some coordination between the PV installer, the electrician, and the roofer.

INITIAL COST

PV systems cost about $10,000 for a 1-kW grid-tied system. State and regional incentives, existing local industry infrastructure, and other factors can greatly affect cost. A system anticipated to supply an entire home's electricity would need to be on the order of 5- to 10-kW, depending on climate, the home's design, and the homeowner's lifestyle. A 2006 California[1] study showed that per-kW costs decline slightly with a larger capacity system, to about $45,000 ($9,000 per kW) for a 5-kW system.

OPERATIONAL COST

There is very little maintenance cost for a PV system, especially a grid-connected system that does not have a battery backup. System reliability is very good and many systems have been operating for more than 20 years, although energy output diminishes slightly over time (by about 20% in 20 years). Systems that use a battery bank for back-up power must be maintained and periodically replaced. Most grid-connected systems have an inverter that may require replacement in 5 to 10 years.

Electricity can be produced by a grid-connected PV system at approximately $0.25 per kWh over the expected life of the system. Compared with utility-supplied power, PV-supplied electricity is not cost competitive. However, economics are more favorable in areas of high utility cost and when incentives drive down the initial cost. The economics of PV systems are often comparable in off-grid situations when the cost of extending a utility line is considered.

CODE ACCEPTANCE

The National Electrical Code (NEC) applies to all electrical systems, including photovoltaic systems. Numerous articles from the NEC are of particular significance to photovoltaic systems. Article 690 of the NEC outlines requirements for designing and installing PV systems.

For grid-connected systems, it is necessary to use equipment that meets the strict standards for managing and conditioning power. Including:

- UL 1741: Standard for Static Inverters and Charge Controllers for Use in Photovoltaic Power Systems
- Institute of Electrical and Electronic Engineers (IEEE), P929: Recommended Practice for Utility Interface of Photovoltaic Systems

RESULTS FROM THE FIELD

PV systems provided from 20% to 82% of the studied homes' electrical demand. Though limited by cost, this shows PV systems can be very effective in reducing a home's electricity demand from municipal sources. It is important to note that location and orientation are important to maximizing efficiency.

WARRANTY

- Manufacturer warranties on system components vary between 10 and 25 years for workmanship and defects.
- Installer parts and labor warranties of two years are typical and often required by rebate programs.
- Check with the PV installer to determine if system installation will affect the roof warranty.

[1] Wiser, R., M. Bolinger, P. Cappers, and R. Margolis, 2006. "Letting the Sun Shine on Solar Costs: An Empirical Investigation of Photovoltaic Cost Trends in California," LBNL report 59282.

THE BASICS

Photovoltaic systems convert sunlight to electricity. In a PV system, sunlight strikes a PV cell—made from semiconducting material—which frees an electron to produce an electric current. PV cells are connected together in a module and several modules are tied together in a PV array (which comprises the entire PV collector area for the house). Direct current (DC) electricity produced by the PV array is inverted to alternating current (AC) electricity for residential use. An inverter that converts the PV-produced DC power to AC power ensures compatibility with the utility. A PV system consists of the PV array, wiring, an inverter, and any optional energy storage system. Systems may be connected to the utility grid (grid-connected) or be stand-alone (off-grid).

In a grid-connected system, which is becoming increasingly popular in new homes due to its low cost and maintenance, batteries are not typically used, although a small battery back-up system, similar to a UPS system for a computer, may be added for critical loads such as sump pumps. Rather, excess PV production (electricity that is not needed in the home at the time it is produced) is sent back to the utility grid, essentially turning the electrical meter backwards. Special equipment is typically supplied by the utility to ensure that, in the event of a power outage, the PV system does not supply electricity to the house or the grid, which could harm line workers.

Off-grid systems supply an entire home's electrical needs. Off-grid systems typically include a large bank of batteries to store the DC power before it is inverted. Off-grid systems tend to be the system of choice for remote areas where extending the utility line to the home is very expensive.

PV systems have been around for decades. Newer products include building-integrated PV systems, in which a building material (such as a roofing material) has integral PV cells. Technological advances have improved system reliability, especially of inverters which have historically been troublesome.

PV systems are relatively simple to operate and require little maintenance. They operate quietly and produce no pollution while generating electricity from the sun. They are an excellent component of a green home building package.

FOOD FOR THOUGHT

This section provides some things to think about before switching to this building technology – make sure it's the right choice for you.

- When considering a PV system, determine if there is a suitable location (typically on the roof) that is free from potential shading and has sufficient area for the PV modules. A general rule is that one s.f. of PV area produces between 5 and 10 watts of power in bright sunlight. Therefore, a 1-kW system requires about 100 to 200 s.f. of roof area.
- Look for ways to reduce electricity consumption before adding solar PV capacity—it is often more cost effective to improve efficiency than add equivalent generating capacity.
- PV systems can work in almost any U.S. climate and generate electricity without generating pollution. However, a sunny climate will harness more electricity from a PV system than an identical system in a less sunny climate.
- Look into incentives for installing PV systems.
- PV systems can be installed in new or retrofit. Installations are typically easier and, hence, less expensive in new home construction. For an existing home, a great time to install a PV system is when re-roofing.
- A simple roofline facilitates the use of PV systems.
- Systems do not need to face due south. Although a southerly orientation is ideal, systems can be up to 45° east or west of south without greatly compromising performance.
- Building-integrated products serve a dual function—roofing (or other) material plus electricity generation—and, hence, may defray costs.
- When building in locations where extending a utility line is the alternative, going off-grid and using PV for electricity may be more economical than extending the utility line.

TECH CHECK

Below is a checklist of steps to follow in order to implement this technology in each of your projects.

☐ Do as much as possible to reduce electricity consumption through efficiency measures

☐ Investigate local or state incentives for PV systems

☐ Find a contractor who is certified by the North American Board of Certified Energy Practitioners to help you:

- Determine if there is a suitable location for a PV system at the site
- Determine cost and system design options
- Design a system
- Install a system
- Warranty the installation
- Work with the local utility to obtain an interconnection agreement, if applicable

MAKING THE SWITCH

What is required to transition from your current building practices to using this technology?

Installing a PV system requires coordination between a new subcontractor, the PV installer, and the electrical contractor and roofer. In a grid-connected system, an interconnection agreement is needed, which will require coordination with the local utility.

DOLLARS AND SENSE

The amortized cost of electricity produced by a PV system (without incentives) is about $0.25 per kWh[2], or about 2.4 times the 2006 average rate for the United States. When compared to the highest U.S. utility rates in 2006 (NY at 16.89 ¢/kWh), the amortized PV rate is almost 50% higher.

[2] U.S. DOE, 2003, *Get Your Power from the Sun, A Consumer's Guide.*

PV arrays at John Wesley Miller Armory Park del Sol Field Evaluation site

RESULTS FROM THE FIELD

This technology has been evaluated by other builders in real-world building projects – learn from their experiences.

Bel Air, Md., Bob Ward Homes (2007 PATH Field Evaluation)

- 2,566-s.f. production home with high efficiency features, solar water heating, and a 3.85 kW (dc) PV system
- Efficiency measures reduced the home's consumption by about 14,000 kWh over the year compared to typical regional construction
- PV system produced about 4,000 kWh over a year, or about 25% of the home's total usage over the year

Tucson, Ariz., John Wesley Miller Zero Energy Home (2005 PATH Field Evaluation)

- 4.2-kW PV array on ultra-efficient home designed to meet 100% of the home's annual energy load; part of 99-home solar subdivision in which each home had at least 1-kW of PV capacity on rooftop; two people occupied the Zero Energy Home during monitoring
- In 2005, the PV system supplied 82% (7207 kWh) of the home's energy needs; the total utility bill for the all-electric home averaged $15 per month
- Performance from 2004 and earlier was not as good as that in 2005 due to certain technical issues which were later corrected (the tankless water heater caused the PV inverter to shut off temporarily; there was thermosiphoning and high thermal energy losses from the hot water storage tank)
- The PV system installation was relatively simple with a knowledgeable designer/installer and the parallel connection to the electric grid was straightforward and economical
- The aesthetics of the PV system were neutral due to the flat rooftop
- The utility company, which functioned as a strong proponent for PV systems, added immense value (financially and logistically) to the PV system installation

San Diego, Calif., Shea Homes (2003 Field Evaluation)

- Three homes equipped with PV systems and advanced energy-efficiency measures (TXV valves on air conditioners and radiant barrier roof decking) were monitored for energy use and PV system performance over one year of occupancy and compared to two baseline homes which did not have PV systems or advanced efficiency features; homeowners adjusted thermostats and used electricity normally
- Because PV systems were installed on production homes, they had less-than-ideal orientation and tilt: two PV systems faced 78 degrees west of south, while one faced 13 degrees west of south; all PV systems were tilted at 22.6 degrees instead of 32 degrees which is optimal for the location
- Despite similarities in size and construction of the five homes, annual energy usage spanned a broad range, about twofold between the highest and lowest consuming homes
- Homeowner behavior was a greater factor in electricity consumption than was efficiency or energy generation; the home that used the least electricity (after crediting for PV generation) did not have a PV system
- Electric loads were dominated by lighting, appliances, and plug loads due to mild climate
- The 1.32-kW PV systems supplied between 20 and 32% of the homes' electrical power over a year
- The PV systems reduced peak utility power demand, on average, by 686 watts between 11 a.m. and 2 p.m.
- The less-than-ideal PV system orientation resulted in a small energy penalty; the two more westerly facing systems provided about 10% less energy than the more southerly system

Chicago, Ill., Claretian Associates (2005 PATH Field Evaluation)

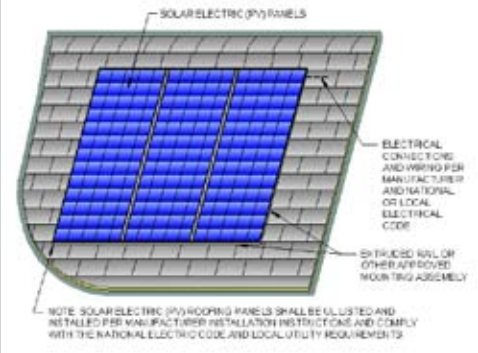
- 12 of 25 affordable homes feature 1.2 kW PV systems
- Each system is valued at $14,000 (half was paid for by the state; other half was covered by Chicago's Department of the Environment)
- The systems generate about 3 kWh per day, potentially saving a few hundred dollars a year in electric bills and contributing to the home's affordability

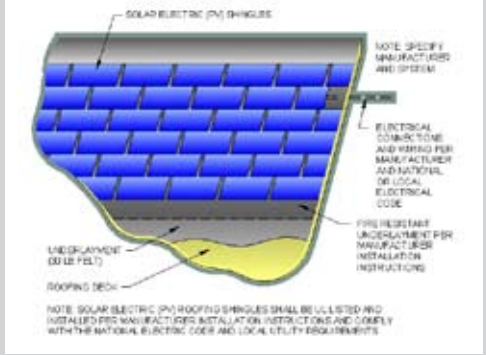
Roof integrated PV panels, Source: 2005 EVHA Gold Award Winner Pardee Homes

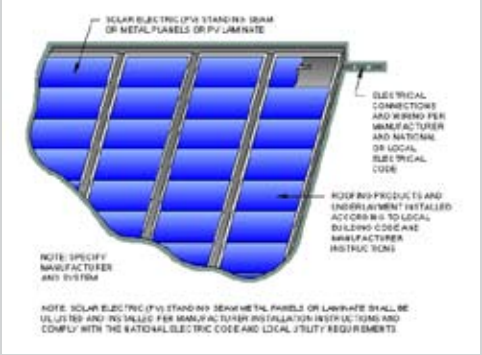
Roof mounted PV system along with solar hot water heating coil (lower right panels), Source: 2008 EVHA Silver Award Winner Sustainable Development, Inc.

PV Inverter and electric panel interface, Source: 2007 EVHA Silver Award Winner Bob Ward Companies

PV Power storage batteries







CAD drawings created for the ToolBase Technology Inventory – see www.toolbase.org/BIPV-CAD

DEFINITIONS

Photovoltaic
A device that produces electricity when energized by light.

Capacity
The amount of electricity that can be produced by a PV array when it is operated under its rated conditions (typically noon on a sunny day while facing perpendicular to the sun).

PATH
Partnership for Advancing Technology in Housing

The Partnership for Advancing Technology in Housing (PATH) is dedicated to accelerating the development and use of technologies that radically improve the quality, durability, energy efficiency, and affordability of America's housing. Managed by HUD, the PATH partnership includes the homebuilding, manufacturing, insurance and financial industries, and Federal agencies concerned with housing.

PATH addresses barriers to innovation, provides information on advanced building technologies, and advances housing technology research; making affordable, quality American homes a reality.

For more information on the PATH program, visit www.pathnet.org.

TechSpecs are prepared for PATH by the NAHB Research Center.

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RESOURCES

General information about photovoltaic systems and their installation:

ToolBase Services

Information on this building technology and many others brought to you by PATH and the building scientists at the NAHB Research Center.

ToolBase Technology Inventory

www.toolbase.org

Database of State Incentives for Renewable Energy

www.dsireusa.org

North American Board of Certified Energy Practitioners - NABCEP Certified Solar PV Installer Directory

www.nabcep.org/list.cfm?normalFlag=yes

Solar Electric Power Association

www.solarelectricpower.org

A Consumer's Guide: Get Your Power from the Sun

www.nrel.gov/docs/fy04osti/35297.pdf