Photovoltaics (PV)

Solar Electricity

Semiconductors that convert solar energy directly into electricity are called photovoltaic (PV) devices or solar cells. Although there are about 30 different types of PV devices under development, there are three main technologies in commercial production – monocrystalline cells, polycrystalline cells and thin-film cells.

The Technology

Monocrystalline – or single crystal – solar cells are manufactured from a wafer of high-quality silicon and are generally the most efficient of the three technologies at converting solar energy into electricity.

Polycrystalline solar cells are cut from a block of lower-quality multi-crystalline silicon and are less efficient but less expensive to produce.

Thin-film solar cells are manufactured in a very different process that is similar to tinting glass. These solar cells are made of semiconductor material deposited as a thin-film on a substrate such as glass or aluminum. Thin-film solar cells are generally less than half as efficient as the best cells, but much less expensive to produce. They are widely used for powering consumer devices.

Solar cells are encapsulated into *modules*, several of which are combined into an *array*. There is, however, a growing market of "building-integrated" PV devices that are manufactured as part of conventional building materials such as roof tiles or glass paneling.

A PV array is usually part of a *system* that may also include energy storage devices (usually batteries), support frames and electronic controllers; these are collectively referred to as the *balance-of-system* or BOS.

The amount of power from a PV array is directly proportional to the intensity of the light hitting the array. Photovoltaic arrays produce direct-current (DC) electricity but can be configured to produce any required combination of voltage and current – including conventional residential alternating current (AC) voltages.

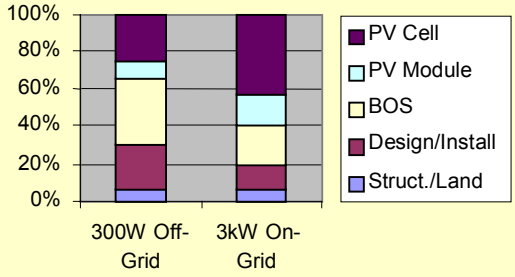
There are currently about 400,000-800,000 photovoltaic systems operating worldwide in applications ranging from individual consumer products and small-scale stand-alone units for rural use (for example, solar home systems) to grid-connected roof-top systems and large

Example of a PV grid-connected system. (Photo courtesy NREL.).

Costs

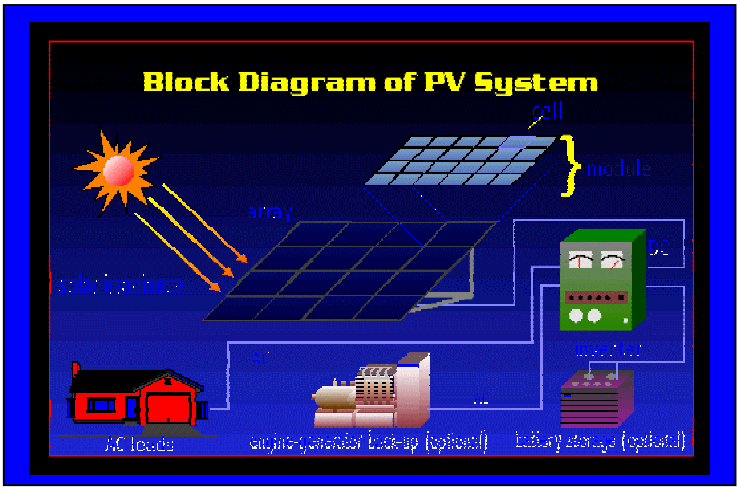
Capital cost PV module:	*$2600 - 5000/kW*
Capital cost PV system (3 kW)	*$4700 - 7000/kW*
Operating Life:	*30 years*

Typical Cost Breakdown



Key Points:

- *PV is most competitive in remote sites, far from the electric grid and when relatively small amounts of power are required, typically less than 10 kW.*
- *PV is a modular technology that can be used in most parts of the world and integrated with diesel, wind, and hydro systems;*
- *PV systems have high capital and low-operating costs.*
- *Few environmental risks are relevant to PV - planning approval and environmental assessment are usually not necessary.*
- *PV technology and systems continue to evolve rapidly.*



central-grid power stations. In the period 1995-2000, more than 20,000 solar pumps were installed globally.

Typical system size varies from 50 watt (W) to 1 kilowatt (kW) for stand-alone systems with battery storage and small water pumping systems; from 500 W to 5 kW for roof-top grid connected systems and larger water pumping systems; and from 10 kW to megawatts for grid-connected ground-based systems and larger building-integrated systems.

Photovoltaic devices are solid state devices with no moving parts and a demonstrated record of reliability. PV modules may operate for 30 years and are usually sold with 10-20 year manufacturer warranties. Although PV modules themselves require little maintenance, other BOS components, particularly storage batteries, generally require maintenance.

To accurately assess the value of electricity from a PV system it is necessary to compare the cost of the PV system to the minimum cost of providing the *same energy service* by an equivalent alternative.

This is particularly relevant for stand-alone systems in remote areas where the temptation is to simply compare the capital costs between PV and other energy supply options. A more accurate approach is a life-cycle cost analysis that includes fuel, maintenance, depreciation, interest and other expenses. PV systems generally have a high capital cost, but a low running cost, as the "fuel" is sunlight.

For rural villages in developing countries, PV technology offers an immediate, direct and safe alternative to kerosene lamps and diesel generators. In such countries a solar home system to power lights and small appliances can be purchased for as little as $350 and may be much cheaper than a grid extension or diesel generator.

Project Risks

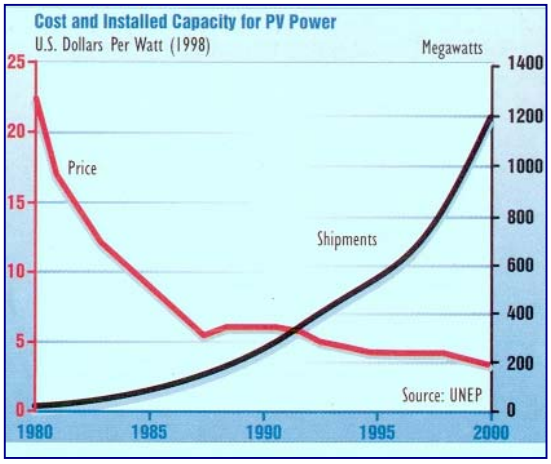
Technology: *Some BOS components, such as power electronics, are relatively new and may be prone to higher failure rates. System design, more than the individual components, is critical to technology risk management.*

Environmental: *Most commercial photovoltaic materials pose no threat to humans or the environment, but components such as batteries do contain hazardous materials. Small PV system projects do not generally require environmental impact assessments as the systems are usually fixed to existing structures. From a government policy perspective, however, recycling or disposal of system components, such as batteries, are important in the design of larger PV programmes.*

Planning: *Off-grid PV systems need minimal planning approvals. Grid-connected systems require grid access permits. These permits are usually standardized with fixed tariffs, and therefore project development risk is usually also low for these systems. PV systems can also be vulnerable to theft and vandalism.*

The Industry and Market Trends

The PV market grew by an average of 15 percent annually from 1990-2000. In 2000, approximately 200 MW of PV modules were sold for a total revenue exceeding US$1.1 billion. The total installed capacity worldwide is now about 1,200 MW, with an average cost of approximately US$4 per watt. Costs have fallen by 20 percent for each doubling of cumulative sales.



At least 30 firms worldwide fabricate PV cells and many more assemble these cells into modules. The top ten cell manufacturers control more than 79% of world shipments. Increasing mass production of PV technology continues to reduce costs in line with the classic "learning curve" for new technologies. Since 1975, PV costs have been reduced by 20 percent for each doubling of cumulative sales.

There is general consensus that thin-film technologies offer the best long-term prospects for very low production cost, but crystalline technology still has large potential for cost reduction through economies-of-scale and technological improvements. Research and development is aimed at improving both the cell and module efficiencies and reducing the cost for BOS components, which currently make up half the cost of the system.

Introduction to Photovoltaic Systems

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HIGHLIGHTS

- **The energy needs of a typical home in Texas could be met by covering only half of its roof with solar electric panels.**
- **Photovoltaic (PV) cells convert sunlight directly into electricity without creating any air or water pollution.**

City of Austin Electric Utility

Retrofitted residential PV system *The solar panels on the roof produce electricity that travels through wires to the distribution panel on the side of the home.*

INTRODUCTION

Photovoltaics offer consumers the ability to generate electricity in a clean, quiet and reliable way. Photovoltaic systems are comprised of photovoltaic cells, devices that convert light energy directly into electricity. Because the source of light is usually the sun, they are often called solar cells. The word photovoltaic comes from "photo," meaning light, and "voltaic," which refers to producing electricity. Therefore, the photovoltaic process is "producing electricity directly from sunlight." Photovoltaics are often referred to as PV.

PV systems are being installed by Texans who already have grid-supplied electricity but want to begin to live more independently or who are concerned about the environment. For some applications where small amounts of electricity are required, like emergency call boxes, PV systems are often cost justified even when grid electricity is not very far away. When applications require larger amounts of electricity and are located away from existing power lines, photovoltaic systems can in many cases offer the least expensive, most viable option.

In use today on street lights, gate openers and other low power tasks, photovoltaics are gaining popularity in Texas and around the world as their price declines and efficiency increases.

HOW IT WORKS

PV cells convert sunlight directly into electricity without creating any air or water pollution. PV cells are

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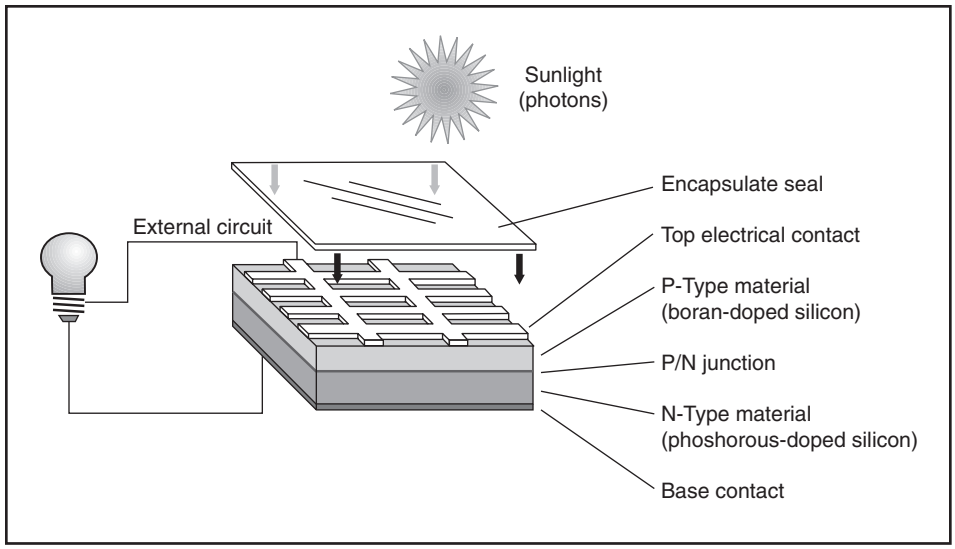
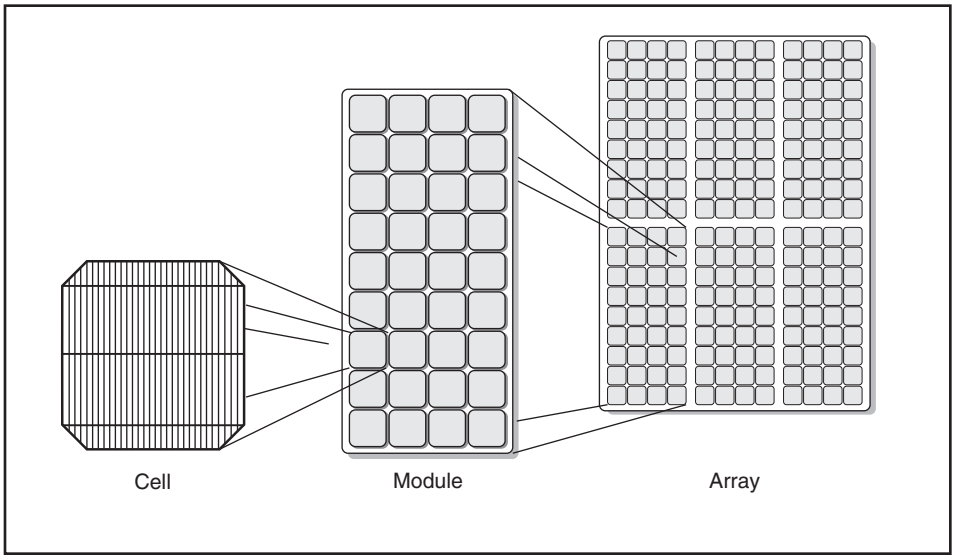
made of at least two layers of semiconductor material. One layer has a positive charge, the other negative. When light enters the cell, some of the photons from the light are absorbed by the semiconductor atoms, freeing electrons from the cell's negative layer to flow through an external circuit and back into the positive layer. This flow of electrons produces electric current.

To increase their utility, dozens of individual PV cells are interconnected together in a sealed, weatherproof package called a module. When two modules are wired together in series, their voltage is doubled while the current stays constant. When two modules are wired in parallel, their current is doubled while the voltage stays constant. To achieve the desired voltage and current, modules are wired in series and parallel into what is called a PV array. The flexibility of the modular PV system allows designers to create solar power systems that can meet a wide variety of electrical needs, no matter how large or small.



Basic solar cell construction *The sandwich of semiconductor materials produce electricity directly from the sunlight without any moving parts.*



Photovoltaic cells, modules and arrays *The building blocks of solar electricity are modular in nature, allowing great flexibility in applications.*

THE GRID: ON OR OFF?

Some homeowners in Texas are turning to PV as a clean and reliable energy source even though it is often more expensive than power available from their electric utility. These homeowners can supplement their energy needs with electricity from their local utility when their PV system is not supplying enough energy (at nighttime and on cloudy days)

and can export excess electricity back to their local utility when their PV system is generating more energy than is needed.

For locations that are "off the grid" — meaning they are far from, or do not use, existing power lines — PV systems can be used to power water pumps, electric fences or even an entire household.

While PV systems may require a substantial investment, they can be cheaper than paying the costs associated with extending the electric utility grid. A consumer in Texas may be asked to pay anywhere from $5,000 to $30,000 per mile to extend power lines.

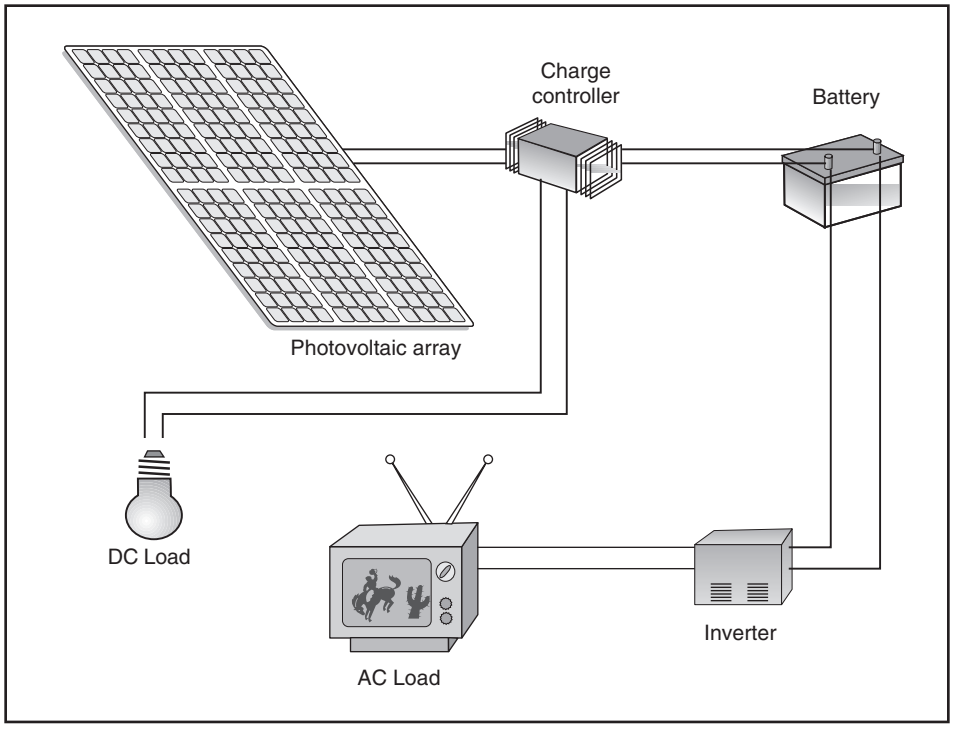
THE RIGHT EQUIPMENT FOR THE JOB

A grid-connected PV system will require a utility interactive DC to AC inverter. This device will convert the direct current (DC) electricity produced by the PV array into alternating current (AC) electricity typically required for loads such as radios, televisions and refrigerators. Utility interactive inverters also have built-in safety features required by electric utilities nationwide.

For an off-grid PV system, consumers should consider whether they want to use the direct current (DC) from the PV's or convert the power into alternating current (AC). Appliances and lights for AC are much more common and are generally cheaper, but the conversion of DC power into AC can consume up to 20 percent of all the power produced by the PV system.

To store electricity from PV's, batteries will be needed. The batteries used for PV systems are different from car batteries. The batteries best suited for use with PV systems are called secondary or deep cycle batteries. There are two types of deep cycle batteries: lead acid, which require the periodic addition of water, and captive electrolyte (or gelcell) batteries, which are maintenance free.

In addition, PV systems require proper wiring, switches and fuses for safety, controllers to prevent the batteries from being overcharged or overly discharged, diodes to allow current to flow in the right direction, and grounding mechanisms to protect against lightning strikes.



Components of a typical off-grid PV system *Solar electricity can be used for many purposes, either directly, or by storing in batteries for use when the sun is not shining.*

InfinitePower.org

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ORGANIZATIONS

American Solar Energy Society
2400 Central Ave., G-1
Boulder, CO 80301
(303) 443-3130
www.ases.org
Great list of publications

Texas Solar Energy Society
P.O. Box 1447
Austin, TX 78767-1447
(512) 326-3391 or (800) 465-5049
e-mail: info@txses.org
www.txses.org
Solar goings on in Texas

Solar Energy International
P.O. Box 715
Carbondale, CO 81623-0715
(970) 963-8855
www.solarenergy.org
Info on PV design, installation workshops

Solar Energy Industries Association
1616 H Street, NW 8th Floor
Washington, DC 20006 (202) 628-7979
(301) 951-3231
www.seia.org
Comprehensive list of PV manufacturers

Texas Renewable Energy Industries Association
Box 16469
Austin, TX 78761
(512) 345-5446
www2.treia.org/treia/
Comprehensive list of PV suppliers and installers

RESOURCES

FREE TEXAS RENEWABLE ENERGY INFORMATION

For more information on how you can put Texas' abundant renewable energy resources to use in your home or business, visit our website at **www.InifinitePower.org** or call us at 1-800-531-5441 ext 31796. Ask about our free lesson plans and videos available to teachers and home schoolers.

ON THE WORLD WIDE WEB:

Center for Renewable Energy and Sustainable Technology (CREST)
This site has a comprehensive list of related web sites. **solstice.crest.org**

Florida Solar Energy Center. Information on photovoltaics, batteries, alternative buildings systems, solar heaters. FSEC offers training courses such as, "Installation of Grid-Connected Photovoltaic Systems." **www.fsec.ucf.edu**

Real Goods. Site offers introductory explanations of solar technologies. You can buy a wide variety of solar goods, PV modules, compact fluorescent bulbs and other gear. A worthy stop for anyone shopping for solar-powered or energy efficient items. **www.realgoods.com**

Department of Energy. Web pages run by the Department of Energy. This site has a much more detailed fact sheet on PV basics. **www.eren.doe.gov/erec/factsheets/pvbasics.html**

Sandia National Laboratory Photovoltaic Program. This site offers descriptions of a variety of PV systems. This rich site also includes system sizing worksheets, PV codes and standards, and PV economics. **www.sandia.gov/pv/**

Department of Energy' Photovoltaic Program
This web site contains a comprehensive directory of U.S. organizations involved in PV.
www.eren.doe.gov/pv/pvdirectory.html

BOOK:

Just Add Sunshine, Solar Electricity Will Set You Free. J. Michael Mooney, ARC Press of Cane Hill, 1997. A self study guidebook on the exciting world of solar electricity. Detailed examples of PV systems to power both large and small dwellings are included. (Available at 1-800-340-8242)

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