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Photovoltaic Solar Energy

Prepared For:
The Los Angeles Community College District

DESCRIPTION OF TECHNOLOGY

History

Photovoltaics (PV) is a solid-state technology that converts solar radiation directly into electrical power, with no moving parts, requiring no fuel, and creating virtually no pollutants over its life cycle. As long as the sun is shining, energy can be developed directly by use of a PV module.

The PV effect is the physical phenomenon of converting light directly into electricity. Edmund Becquerel, a French physicist, first observed this phenomenon in 1839. He discovered that illuminating one of two electrodes in a weak solution produced a voltage. During the 1880s, the first PV cells were made from selenium. These preliminary cells operated with a conversion efficiency of 1-2%.

New photovoltaic technology was developed to power satellites, as part of the space program in the 1960's. In addition, advancement in the transistor industry provided for better materials. PVs and transistors are made from similar materials and many of their working principles are determined by the same physical mechanisms.

Most of today's PVs are made from silicon, similar to semiconductors. In the most common technology, the silicon is separated into two distinct layers, called negative (n-type) and positive (p-type.) through a process called doping. The n-type has an excess of electrons, and the p-type has vacancies or missing electrons. The two layers are separated by an n-p junction.

Light passes through the thin n-silicon layer and hits the p-silicon layer. The light is absorbed by the p-silicon layer. The photons in light displace the electrons in the p layer. Some of these displaced electrons have sufficient energy to pass through the n-p junction to the n layer. A potential (i.e. voltage) is developed between the n and p layers. For silicon, this potential is approximately one-half volt. By connecting the n and p layers through wires and a load, current (electrons) can flow from the negative layer back to the positive layer. The electrons which have returned to the positive layer are once again available for displacement, resulting in a completely renewable resource.

Crystalline Silicon Cells

Crystalline silicon cells are the most popular of the PV cells on the market today. Single-crystalline or monocrystalline silicon cell modules have a maximum efficiency of up to 14% and an output of 12-14 W/sq.ft.

Compared to monocrystalline cells, polycrystalline silicon cells are relatively easy to manufacture, but with some loss in efficiency. Typically, the polycrystalline cell modules on the market today reach a maximum of 12% efficiency. The general rule of thumb is to figure a net of 10 W/sq.ft. of solar array surface area, although higher outputs are possible.

BuildLACCD


Monocrystalline PV Array
Toyota Headquarters, Torrance, CA
LEED® Gold


Polycrystalline PV Array
used as an equipment screen


Monocrystalline PV Array
mounted at a fixed angle to optimize output


Monocrystalline PV sloped roof system

Although the manufacturing process for polycrystalline cells is much easier, the disadvantage of the polycrystalline cells is the wasted materials in the manufacturing process. The polycrystalline silicon is cast and sliced into thin silicon wafers. During the slicing process, almost half of the raw silicon is lost. Therefore, the final cost per Watt for the monocrystalline and polycrystalline cells is similar.

Thin-film Cells

A recent development in commercially-available photovoltaic technology is thin-film cells. Types of thin-film cells include amorphous silicon, copper indium diselenide (CIS), cadmium telluride (CdTe), and gallium arsenide (GaAs). The thin-film method uses less material and makes available a more automated manufacturing process. Therefore, they are generally less expensive than crystalline silicon cells.

A disadvantage to the thin-film cells is their relatively low efficiency. Recent developments with copper indium gallium selenide (CIGS) cells have made thin-films more efficient. CIGS cells efficiency can reach up to 20% compared to 4-8% efficiency of typical thin-film cells. CIGS energy outputs is up to 10-12 W/sq.ft compared to 3-5 W/sq.ft. outputs of other thin-film cells.

Thin-film can be incorporated into many building materials and applications. With the introduction of building integrated photovoltaic (BIPV) applications, more surface area can be utilized for PVs, offsetting the lower efficiency.

Building Integrated Photovoltaics

The term Building Integrated Photovoltaics (BIPV) refers to any technology that integrates PV cells into a building component.

Crystalline silicon cells have been used in BIPV applications such as roof tiles and glazing. The cells have the “solar cell look” and have a significant impact on the building’s aesthetic appearance. Nevertheless, crystalline panels can often be integrated into the building facade, and they also make excellent shading devices such as window overhangs or parking lot covers.

With the development of thin-film technology, the opportunities for BIPV applications have grown due to the seamless integration with the architectural aesthetic. The film can be applied to roofing and siding materials as well as windows and skylights. When applied to a glass surface, the film can perforated with a laser to achieve the desired light transmission.

One advantage of using BIPVs is that the first cost of the solar cells is partially offset by the avoided cost of the replaced building component. For example, if a PV array is used as a mechanical equipment screen, the cost of a traditional screen is avoided.

With BIPV applications, it is especially important to remember that all PV technologies are sensitive to even partial shading of the cells. Both crystalline and thin-film cells should be applied in locations that will not be shaded by adjacent buildings, landscaping, or other obstructions. In applications where some shade cannot be avoided, technologies such as bypass diode are available to somewhat reduce the negative impacts.

Soliant Heliotube Concentrating Collector
With Integral Single-Axis Tracking

Soliant Concentrating Collector
With Integral Dual-Axis Tracking

SolFocus Concentrating Collector

Solaria Concentrating Collector
With Plastic Lenses

For custom-made BIPV units, a UL listing must be obtained as part of the project cost.

Concentrating Collectors

The latest development in commercially-available photovoltaic technology is concentrating collectors. In years past, concentrating collectors were only associated with large utility-scale solar installations in the desert. However, innovative commercial-scale concentrating collectors are expected to be introduced into the marketplace within the next year or two. The driver for this development is to reduce the amount of the most expensive component of the system, the photovoltaic material.

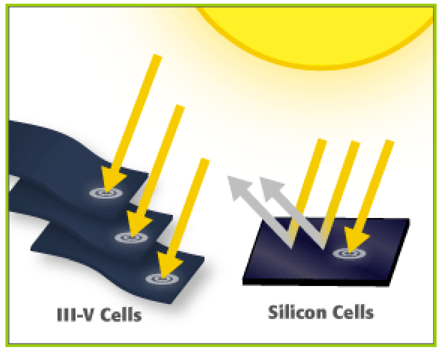
Concentrating collectors use mirrors or lenses to focus the sun's energy on a small area of photovoltaic material. These collectors are more sensitive to the angle of the sun than flat-plate collectors. Therefore, tracking devices are typically used to ensure that the solar radiation is always perpendicular to the collector.

Soliant Energy is a Pasadena-based start-up company with two innovative products. Their Heliotube panels consist of an array of small half-cylinder mirrors which track the sun along a single axis. Soliant also offers a solar concentrator panel which uses lenses and dual-axis tracking to further reduce the amount of photovoltaic material.

Similarly, SolFocus is a Palo Alto-based company which is developing a concentrating collector with dual-axis tracking.

Since concentrating collectors use less photovoltaic material, the manufacturers of these systems tend to use higher-cost, higher-efficiency photovoltaic materials to boost efficiency. Triple-junction cells, used by Soliant, are an example of this trend.

Triple-junction cells use specialized materials to capture a wider range of solar energy. While standard silicon cells only capture 15-20% of the sun's rays, today's triple junction cells can capture as much as 40% or more.



Solaria has taken a different approach to concentrating collectors, using inexpensive plastic lenses to produce low levels of concentration. The amount of photovoltaic material is only slightly reduced, but the cost of expensive mirrors, lenses, and tracking devices is avoided. This technology is expected to be on the market in 2008.

Given that the market for concentrating collectors is still emerging, the economics is likely to improve as the technology becomes more developed.


Monocrystalline BIPV glazing


Monocrystalline BIPV glazing


Thin-film BIPV skylight

Other System Components

Panel Connections. The various PV panels are interconnected through series and parallel connections to develop the desired voltages and currents.

Inverters. The inverter converts the direct current produced by the PV modules into a 120/208 volt three phase alternating current. This three-phase current can be directly injected into the building electrical system. When the building is in operation, the generated power is used within the building, reducing utility demand. When the building is not in use, the power is transformed and delivered back to the utility.

The technology for the inverter is very common with uses in uninterruptible power systems (UPS), variable speed drives (VSD), control systems, and other standard installations. Routine maintenance is required for the inverter and would take no more than eight hours per year.

Batteries. Batteries can be used to store the electricity generated in the daytime for use in the nighttime. However, for on-grid applications, it is typically more economical to sell any excess electricity back to the utility and avoid the cost and maintenance associated with batteries.

Wiring. NEC 690 contains the special wiring requirements for PV systems. DC wiring from the modules must be in metal raceway from the point that it enters the building until the first readily accessible disconnecting means, typically near the inverter. In addition, the DC wiring must have DC-rated disconnect switches and fuses, and ground fault protection is required for the DC circuits.

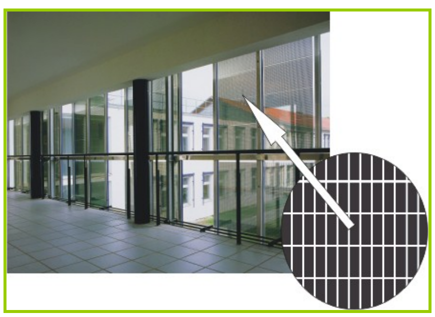
Tracking Devices. Solar tracking devices are available that rotate the solar panels to follow the movement of the sun. These devices increase the total energy output, but their higher first cost and maintenance generally do not justify this small increase in output for flat-panel collectors. Fixed panels are appropriate for most commercial building applications with conventional flat panels.

LOS ANGELES FIRE DEPARTMENT REQUIREMENTS

For roof-mounted PV arrays, the Los Angeles Fire Department has established requirements to allow adequate firefighter emergency access. The requirements include maximum array sizes, adjacent clearances, and quick-release hardware. For additional information, contact the Los Angeles Fire Department or refer to lafd.org/prevention/pdfforms/solar_pwr_req.pdf

Thin-film BIPV skylight

Thin-film BIPV glazing



Thin-film BIPV glazing

Thin-film BIPV facade

ECONOMIC ANALYSIS

Photovoltaics are recently becoming more economically feasible due to the following factors.

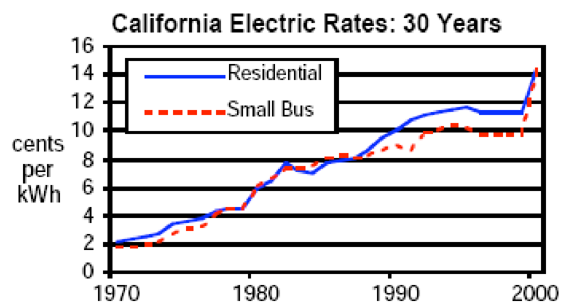
- Continuing advances in cell manufacturing technology
- Government and utility rebates and incentives
- Rising electricity costs

Los Angeles DWP Rebates and Incentives

The Los Angeles DWP's Solar Power Incentive will rebate $0.14/kWh for non-profits or government agencies. An additional $0.02/kWh is available for BIPV systems or systems qualifying for the Los Angeles Manufacturing Credit. The incentive is based on the total calculated energy (kWh) produced over the expected 20-year system life. The energy is calculated using the LADWP's on-line calculator found at http://mapserve2.nrel.gov/website/LA_PVWatts/viewer.htm.

Electricity Rates in California

For California commercial customers, average electricity rates have fluctuated between 0.12 - 0.15 /kWh over the last five years (Source: www.cpuc.ca.gov). The longer historical trend shows that rates have increased an average of 6.7% over the 30-year period from 1970-2000 as shown in the graph below (Source: CPUC "Electric Rate Compendium" 2001). These figures include energy, peak usage, and other charges combined.



Current commercial rates are currently around $0.15 /kWh. Future electricity rates are quite uncertain given the upcoming carbon cap-and-trade system that will be implemented in 2012. The carbon cap-and-trade program is part of California's Climate Change Program as described in the California AB32 Scope Plan prepared by the California Air Resources Board. For more information visit http://www.arb.ca.gov/cc/cc.htm.

Thin-film BIPV roof system

Thin-film BIPV roof system

BIPV roof shingles

Monocrystalline BIPV roof tiles

Estimated Costs and Paybacks of PV Systems in California

The cost and payback period of a photovoltaic system will vary depending on several factors.

- Type of PV cells
- Size of system
- Whether the PV cells avoid the cost of another building component (BIPV)
- Rebates or incentives
- Electricity rates
- Local market conditions for materials and labor

The cost examples below are based on Glumac's research and experience across a broad range of projects.

Example 1: 200-kW Polycrystalline Array. This hypothetical example is for a 200-kW, 20,000 sq.ft. polycrystalline silicon PV array mounted with a fixed horizontal orientation. The installation is owned by LACCD and receives LA DWP rebates. The estimated cost break down is as follows.

	Cost ($/Watt)	Cost ($)
Installed Cost LA DWP rebate ($0.14 /kWh, 20 yrs, 0.9 degradation factor)	$8.40	$1680 k -$662 k
Net Cost	$5.09	$1018 k

The estimated electricity production and payback period for this array would be as follows.

Output (kWh/yr)	Savings ($/yr)	Simple Payback (yrs)
262,850	$36,800	27.7

The above values assume a DC-to-AC derate factor of 0.77 and a conservative average electricity rate of $0.14 /kWh.

Example 2: 200-kW Polycrystalline BIPV. This hypothetical example is the same as the previous example, with the exception that the PV panels replace a building component. The avoided cost of the component is assumed to be $20 /sq.ft. The estimated cost break down is as follows.

	Cost ($/Watt)	Cost ($)
Installed Cost LA DWP rebate ($0.14 /kWh, 20 yrs, 0.9 degradation factor)	$8.40	$1680 k -$662 k
 Avoided Building Cost	$5.09	$1018 k -$400 k
Net Cost	$3.09	$618 k


BIPV roof tiles


Thin-film BIPV roof shingles


BIPV window overhangs


BIPV window overhangs

The estimated electricity production and payback period for this array would be as follows.

Output (kWh/yr)	Savings ($/yr)	Simple Payback (yrs)
262,850	$36,800	16.8

As shown above, the avoided cost of replaced building components has a significant impact on the economic feasibility of PV systems. If the avoided cost were higher, the payback period of the PV system would be shorter.

Financing Options

Many commercial building projects are not able to install PV systems due to the high initial cost of these systems. However, a new business model has emerged that allows buildings to install renewable energy PV systems without upfront capital.

Several firms are offering third-party, turn-key financing and installation of PV systems to customers who enter long-term power purchase agreements for the electrical output of the on-site PV system. Typically these third-party PV installers are seeking customers with at least 25,000 sq.ft. of unshaded roof or site area suitable for a 200-kW or larger PV system. These companies tend to work in states such as California that offer rebates and incentives for PV systems, along with utility net-metering laws. The PV installer designs, installs, and maintains the systems which are located at the customer's facility. Generally customers must sign a 10 to 20-year power purchase contract with the PV installer, but often the power purchase agreement guarantees that the electrical rates charged by the PV installer for the on-site renewable energy will be at or below prevailing utility rates. At the end of the power purchase agreement, ownership of the PV system typically transfers to the customer. The customer hosts a significant PV installation, contributing zero-emission renewable energy to their facility, with no up-front cost and with annual electrical costs that are at or below prevailing utility rates. The PV installers have learned how to leverage rebates, tax incentives, economies-of-scale and commercial financing to make a reasonable return for their investors over the long term power purchase contracts.

This type of third-party PV financing arrangement is a win-win for buildings with significant electrical loads and large unshaded roof area who can sign a long term agreement for their facility. A variety of customers meeting this basic criteria, including grocery stores, big-box retail stores, distribution warehouses, self-storage facilities, and government office buildings have all signed up for deals with third-party PV installations to provide renewable energy to their facility while maintaining or reducing their long term utility costs.
Leading firms that offer commercial financing of PV systems include the following.

- BP Solar – www.bpsolar.com
- Chevron – www.chevron.com/deliveringenergy/solar
- Conergy – www.conenergy.com
- EI Solutions – www.eispv.com
- Powerlight – www.powerlight.com
- Solar Integrated Technologies – www.solarintegrated.com
- Stellar Energy – www.stellarenergy.com
- SunEdison – www.sunedison.com


BIPV facade


PV sun shades in parking lot


BIPV architectural sculpture

ADDITIONAL RESOURCES

The following websites contain additional information on photovoltaics.

Government websites
- www.consumerenergycenter.org
- www.cpuc.ca.gov
- www.eere.energy.gov
- www.gosolarcalifornia.ca.gov
- www.nrel.gov

Utility websites
- www.ladwp.com

Industry websites
- www.ases.org
- www.californiasolarcenter.org
- www.seia.org
- www.sf.solarmap.org

Manufacturer websites
- www.inovussolar.com
- www.us.schott.com