Solar Master Plan

OAKLAND UNIFIED SCHOOL DISTRICT (OUSD)

Chapter 5

Solar Photovoltaic Technology Overview

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This chapter provides a basic overview of how a solar photovoltaic (PV) system works, as well as providing information on net metering rules, monitoring systems, incentives, and security equipment. The chapter also includes links to valuable resources that can provide quick estimates of how much electricity a PV system can produce and how much money can be saved by avoiding the purchase of electricity from the local utility.

The process of converting the energy in light to electricity has not changed much since Charles Fritts built the first conversion device in 1883. The first commercial solar cells were produced in 1956 at a cost of about $300/watt. Today's solar panels sell for less than $3/watt with production costs of about $1 per watt. So, although there have been many improvements in solar energy technologies over time (e.g., more efficient panels and inverters, better mounting systems, fewer wires, better and faster monitoring, security improvements, longer lasting components), the biggest change has been in the cost of PV. Delaying the purchase of PV in the hope that a newer, more efficient solar panel will come along will only delay the savings and benefits that could be accruing now.

See SolarBuzz for more on current pricing:
www.solarbuzz.com/facts-and-figures/retail-price-environment/module-prices

SEQUOIA FOUNDATION - SOLAR SCHOOLS ASSESSMENT AND IMPLEMENTATION PROJECT (SSAIP)

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Solar PV Technology Overview

Photovoltaic (PV) arrays convert sunlight to electricity without moving parts and without producing fuel waste, air pollution, or greenhouse gases (GHG). They require very little maintenance and make no noise. Arrays can be mounted on all types of buildings and structures. PV direct current (dc) output can be conditioned into grid-quality alternating current (ac) electricity or used to charge batteries.

Traditional "single crystal" solar cells are made from silicon, are usually flat-plate, and generally are the most efficient. "Multi-crystal" are a similar technology but slightly less efficient. A third type of cells is called "thin-film" solar cells because they are made from amorphous silicon or nonsilicon materials such as cadmium telluride. Thin film solar cells use layers of semiconductor materials only a few micrometers thick. Table 1 presents typical module efficiencies for each type of module.

Table 1. Typical Efficiency of Different Types of PV Modules

Single Crystal	14–19%
Multi-crystal	13–17%
Thin Film	6–11%

Building-integrated PV (BIPV) products can double as rooftop shingles and tiles, building facades, or the glazing for skylights.[1] They can be particularly well-suited for applications on historic buildings or where the PV panel needs to architecturally blend in with a building. Figure 1 shows an example of this technology integrated into shingles. Other examples of building-integrated PV (BIPV) include singly-ply membrane, standing seam metal roofs, among others. In some cases BIPV can add cost and complexity to a project and may not be universally available, but may help enhance acceptance of a project on a visible surface.

Figure 1. Thin film solar PV shingles (Credit: United Solar Ovonic/PIX 13572)

Most systems installed today are in flat-plate configurations which are typically made from solar cells combined into modules that hold about 40 cells. A typical home will use about 10 to 20 solar panels to power the home. Many solar panels combined together to create one system is called a solar array. For large electric utility or industrial applications, hundreds of solar arrays are interconnected to form a large utility-scale PV system.[2] These systems are generally fixed in a single position, but can be mounted

[1] http://www.nrel.gov/learning/re_photovoltaics.html
[2] http://www.nrel.gov/learning/re_photovoltaics.html

on structures that tilt toward the sun on a seasonal basis or on structures that roll east to west over the course of a day.[3] The figure below shows the components of a typical PV system.

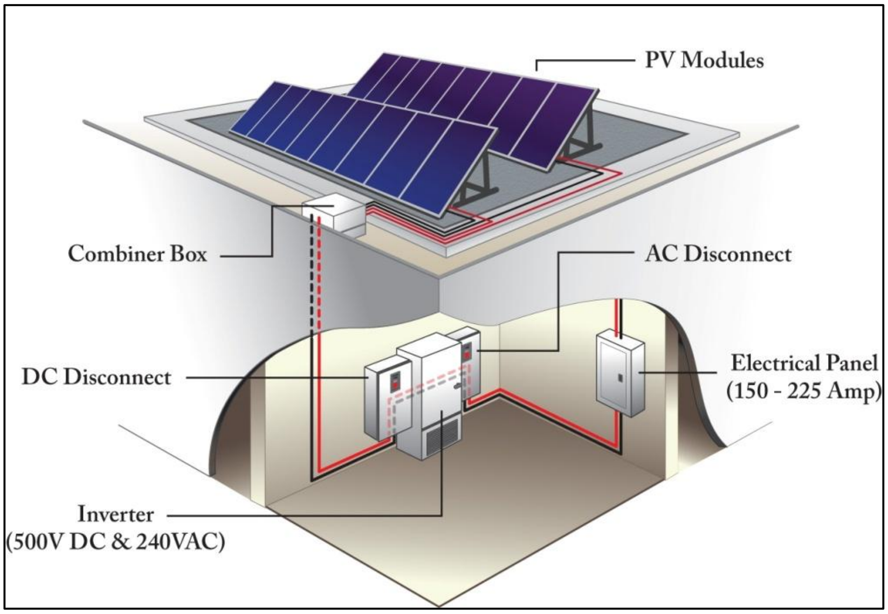

Figure 2: PV system schematic (Credit: Jim Leyshon, NREL)

The cost of PV-generated electricity has dropped 15- to 20-fold in the last 40 years; grid-connected PV systems sell for about \$5/Wp to \$8/Wp (20¢/kWh to 32¢/kWh) in 2011, including support structures and power conditioning equipment. Here "Wp" stands for "watt peak," which is the power rating that a PV system measures under standard test conditions, and under which a panel could be expected to deliver its peak output. A National Renewable Energy Laboratory (NREL) study of 7,074 PV systems installed in 2007 reported a range of total capital cost averaging \$8.32/Wp for small systems less than 10 kW and \$6.87/Wp for large systems greater than 100 kW. Costs reported for PV projects are falling rapidly so a local solar installer may be your best source of cost information. Operation and maintenance costs are reported at \$0.008/kWh produced, or at 0.17% of capital cost without tracking and 0.35% with tracking.[4] Solar panels are very reliable and last 20 years or longer.

The amount of electricity that a system produces depends on the system type, orientation, and the available solar resource. The solar resource is the amount of the sun's energy reaching the earth's surface, which varies across the United States. A higher solar resource means that more of the sun's energy is reaching the surface, which is optimal for PV system performance. The solar resource map in Figure 3 details the available solar resource throughout the country in kWh/m^2/day. Resources are highest in the Southwest, and fairly high throughout the western states, Texas, and Florida.

[3] DOD RE Replication Pilot ESPC
[4] Mortensen, J. *Factors Associated with Photovoltaic System Costs*. NREL/TP 620.29649. June 2001; p. 3.

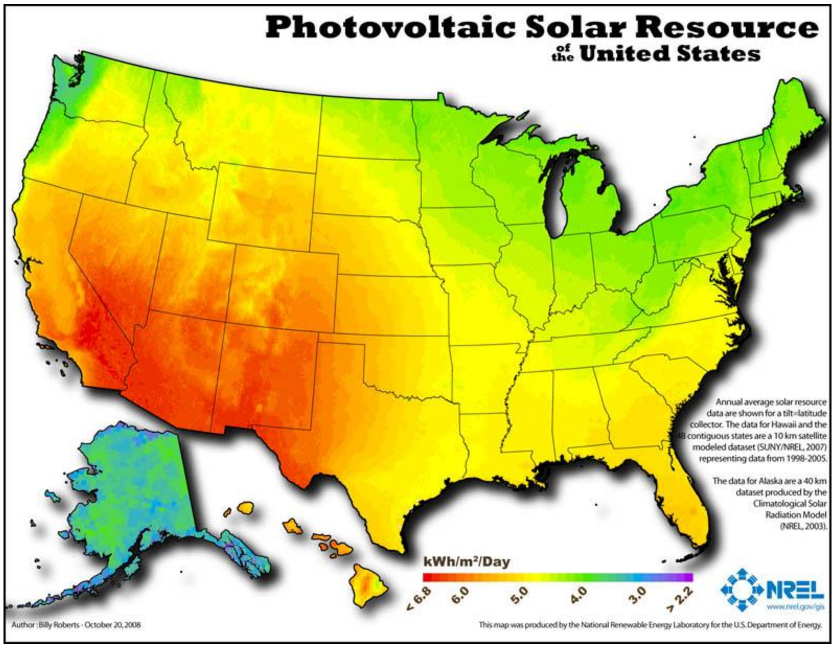

Figure 3. GIS map of U.S. solar resources[5]

Referring to Figure 3, a properly oriented and unshaded PV panel in Washington state, west of the Cascade mountains, may be expected to deliver its rated capacity for about 3.4 hours per day, while one in the desert in Daggett, CA may deliver its capacity for 6.6 hours per day. A typical house uses about 25 kWh/day. Considering losses in the PV system, this could be supplied by a system of about 6.5 kW which would occupy about 500 sf of roof area.

Siting of Solar PV

There are typically three size-based categories of solar installations: utility-scale, commercial, and residential. Note that while there are no industry-standard definitions, these general distinctions are useful to understand.

- Utility-scale installations are very large arrays located on open lands, providing power for hundreds or even thousands of homes and businesses.
- Commercial systems are smaller and may provide power for multiple or single commercial or municipal buildings on campuses, in complexes, in neighborhoods, or in other special districts.
  - Commercial-scale systems offer potential advantages for locating solar PV in historic districts and campuses. Rather than attempting to find appropriate locations for solar panels on individual historic structures, a commercial-scale system might be located in a less visible or impactful location, such as above a parking structure or on an open lot. Power can be lost in transmission from these arrays to the end use location, however, so distances need to be minimized.
- Residential-scale photovoltaic systems produce power for use on a single property.

[5] http://www.nrel.gov/gis/images/map_pv_national_lo-res.jpg

This publication focuses on commercial-scale solar installations.

The major challenge for siting solar PV technologies is identifying an appropriate location for maximum electricity production. An ideal solar installation would be situated in an unshaded, south-facing location with an optimum tilt angle, and would supply electricity to a site where there is a demand for the electricity being produced. Not all sites are suitable for solar technologies. There are a few general rules that may be helpful in siting a solar PV system.

- It is important to identify an unshaded area for solar PV installation, particularly between the peak hours of 9 a.m.–3 p.m. Shade will reduce the output of a solar panel. Shade can be caused by trees, nearby buildings, roof equipment such as HVAC systems and vents, or structural features such as chimneys.
- It is best to orient fixed-mount panels due south in the northern hemisphere. Siting panels so that they face east or west of due south will decrease efficiency. However, that effect varies by location and could be minimal.

  In the area of San Francisco, California, for example, the losses due to orientation are about 10% for a panel facing 45 degrees east of south and about 4% for one facing 45 degrees west of south. A key assumption is that there is no loss of efficiency for a system facing due south.[6] While an orientation east or west of south is not ideal because of the resulting reduction in efficiency, it may be necessary due to the roof or building configuration.

- In the United States, the optimal tilt angle for achieving the highest performance from a fixed-mount PV panel is a tilt angle equal to the latitude of a location, for locations in latitudes less than 20 degrees north. At higher latitudes, the correlation is not valid. Christensen and Barker (2001) analyzed the annual solar resource data for different latitudes.[7] At a location of 40° north latitude, an optimal tilt varies from 30° to 35° to maximize the annual energy production.

  Fixed-mount solar panels can be flush- or tilt-mounted on roofs, pole-mounted on the ground, or can be integrated into building materials, such as into roofs, windows, and awnings. However, a tilt angle equal to latitude is not always feasible because of factors such as roof pitch, wind, or snow loading considerations. It is possible to install panels at a different angle. The impact of a non-ideal tilt angle varies by location, and could be minimal.

  In San Francisco, for example, the losses due to tilting a panel 10 degrees greater than latitude are 3%, but there are no losses due to tilting 10 degrees less than latitude. It is assumed that there is no loss of efficiency for a system oriented at latitude.[8]

- The size and nature of an electric load must be well understood to properly select and size a PV system. PV systems can be designed to provide power simultaneously with the utility (grid-connected); independent of the utility (stand-alone, with batteries); or to do either

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[6] Analysis in PVWATTS. Assuming: location = San Francisco, CA; tilt=latitude (37.6 deg); DC to AC derate factor =0.77.

[7] Christensen, C.; Barker, G. (2001). “Effects of Tilt and Azimuth on Annual Incident Solar Radiation for United States Locations.” Presented at 2001 Solar Energy Forum, Washington, D.C.

[8] Analysis in PVWATTS. Assuming: location = San Francisco, CA; orientation = 180 deg (south); DC to AC derate factor =0.77.

(dual mode). The systems can be designed to power any percent of an electric load, from a very small percentage to over 100% of the load, depending on available area for the panels, availability of the sun, and depending on what is allowed by the interconnecting utility. When considering a system that will be tied to the utility grid, or grid-connected, it is essential to understand the applicable net metering rules and interconnection standards for the serving electric utility company.

For electric customers who generate their own electricity, net metering allows for the flow of electricity both to and from the customer typically through a single, bi-directional meter. When a customer's generation exceeds the customer's usage, electricity flows back onto the grid. This effectively offsets electricity consumed by the customer at a different time during the same billing cycle or is carried over as a credit on future billing cycles. Many state rules allow a credit to be carried for 12 months, with a resulting electricity credit resulting in either a check to the customer or a forfeiture of the value of the excess electricity produced at the end of the 12 month period. Net metering is required by law in most U.S. states, but these policies vary widely.[9] Some net metering programs reimburse customers for excess generation at the wholesale rate, while others reimburse at the retail value. Some policies specify a limit on the capacity of PV systems that can participate in the net metering program.

Interconnection standards specify the technical and procedural process by which a customer connects a PV system to the grid. Such standards include the technical and contractual arrangements by which system owners and utilities must abide. State public utilities commissions typically establish standards for interconnection to the distribution grid, however, Federal Energy Regulatory Commission (FERC) has adopted interconnection standards for small generators interconnected to the distribution system that sell power in the wholesale market. Additionally, FERC has adopted standards for interconnection to the transmission system. Many states have adopted interconnection standards, but some states' standards apply only to investor-owned utilities—not to municipal utilities or electric cooperatives. Several states have adopted interconnection guidelines, which are weaker than standards and generally only apply to net-metered systems.[10]

- Since PV modules have different efficiencies, it is important to consider the efficiency versus the available or required area of the PV system. Fewer modules made of a higher efficiency cell (such as single crystalline) would be needed for approximately the same power output as more modules made of a lower efficiency cell (such as thin film). Therefore, if a project location is space-constrained, a higher efficiency, and potentially higher cost, module may make the most sense. However, if a project has an abundance of space, a lower efficiency, less costly module may be most practical.

Table 1: Area and Efficiencies Associated with 1 kW of PV of Various PV Module Types

Module Type	Module Efficiency	System Area (ft^2)
Single Crystal	19.3%	55 ft^2
Multi-Crystalline	15%	71 ft^2
Thin Film	9.5%	99 ft^2

[9] http://www.dsireusa.org/glossary/
[10] http://www.dsireusa.org/glossary/

Module efficiency in Table 2 is defined as the fraction of incident solar radiation converted to electricity. These values are established by testing under the standard rating conditions of 1000W/m^2 sun, 25°C temperature, and 1 m/s wind speed.

Incentives for Solar PV

Financial incentives offered by federal and state governments, local utilities and municipalities, and private organizations have a great effect on renewable energy project economics, including solar PV, and should be taken into account at all of the planning and feasibility stages. Potential incentives could include rebates, loans, tax incentives, grants, industry recruitment/support, bond programs, green building incentives, leasing/lease purchase programs and performance-based incentives. The Database of State Incentives for Renewables and Efficiency (DSIRE) website provides a listing of all applicable incentives for each potential project location.

Resources for Assessing Solar PV Potential

Many tools exist to help assess the technical and economic potential for solar PV at a specific location. These free tools can be used as a preliminary estimate of project potential by a property owner or project developer. However, a detailed feasibility study should be performed prior to making a decision.

- DSIRE: www.dsireusa.org

  The Database of State Incentives for Renewables and Efficiency (DSIRE) is a comprehensive database of federal, state, local, and utility incentives and policies relating to energy efficiency and renewable energy. DSIRE is funded by the U.S. Department of Energy and is updated by the North Carolina Solar Center and the Interstate Renewable Energy Council on a quarterly basis. Solar project planners should refer to DSIRE to determine ways in which to improve the value proposition of the project.

- IMBY: http://www.nrel.gov/eis/imby/

  The In My Backyard (IMBY) tool estimates the amount of electricity that can be produced with a solar PV array or wind turbine at a home or business. Homeowners, businesses, and researchers use IMBY to develop quick estimates of renewable energy production at locations throughout the continental United States, Hawaii, and northern Mexico.

  IMBY uses a map-based interface to allow users to choose the exact location of a PV array or wind turbine. Based on the location, system size, and other variables, IMBY estimates the expected electricity production for a system.[11]

- PVWATTS: http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/

  The PVWatts™ calculator determines the energy production and cost savings of grid-connected PV energy systems throughout the world. It allows homeowners, installers, manufacturers, and researchers to easily develop estimates of the performance of hypothetical PV installations.

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[11] http://www.nrel.gov/eis/imby/

The PVWatts calculator works by creating hour-by-hour performance simulations that provide estimated monthly and annual electricity production in kilowatts and energy value. The tool is user-friendly, robust, and reasonably accurate – and is widely used and referenced by most utilities. Users can select a site nearest to their location that has similar topography and choose to use default values or their own system parameters for size, electric cost, array type, tilt angle, and azimuth angle. In addition, the PVWatts calculator can provide hourly performance data for the selected location.[12]

- SAM: https://www.nrel.gov/analysis/sam/

  The System Advisor Model (SAM) is a performance and economic model designed to facilitate decision making for people involved in the renewable energy industry, ranging from project managers and engineers to incentive program designers, technology developers, and researchers.

  SAM makes performance predictions for grid-connected solar, small wind, and geothermal power systems and economic estimates for distributed energy and central generation projects. The model calculates the cost of generating electricity based on information provided about a project's location, installation and operating costs, type of financing, applicable tax credits and incentives, and system specifications. SAM also calculates the value of saved energy from a domestic solar water heating system.[13]

Monitoring of Photovoltaic Systems

Monitoring PV systems can be essential for reliable functioning and maximum yield of a system. It can be as simple as reading values such as produced AC power, daily kWh, and cumulative kWh locally on a LCD display on the inverter. For sophisticated monitoring and control purposes, environmental data – such as module temperature, ambient temperature, solar radiation, and wind speed – can be collected. Remote control and monitoring can be performed by various remote connections: Ethernet, internet, dial-up access, and via cellular data networks. Systems can send alerts and status messages to the control center or user via SMS (text message) service, cellular data networks, or fax. Data can also be stored in the inverter's memory or in external data loggers for further system analysis.

Monitoring system data can facilitate outreach and education through publicly-available online displays, wall-mounted systems, or smart phone applications. Figure 4 illustrates a Web-based PV tracking system.

[12] http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/
[13] https://www.nrel.gov/analysis/sam/

Figure 4: Web-based PV Performance Display[14]

Tying PV Systems into the Curriculum

Implementing solar PV technologies on schools has a variety of benefits. These include the on-site production of sustainable, renewable electricity, a reduction in a school's greenhouse gas emissions and other toxic air contaminants, and a reduction in utility-purchased grid energy. An additional benefit is the educational opportunities associated with having a PV system installed on school grounds.

Renewable energy technologies can be incorporated into the curriculum from elementary through high school. The National Renewable Energy Laboratory (NREL) has developed a variety of educational resources, which are available at http://www.nrel.gov/education/educational_resources.html.

In Northern and Central California, Pacific Gas and Electric (PG&E) offers a Solar Schools programs, which aims to teach the value of renewable energy and energy efficiency to K-12 public schools. The program turns school buildings into engaging, "hands-on" science experiments, teaching students how their everyday energy choices can reduce their environmental impact.[15]

The PG&E Solar Schools Program includes a solar-curriculum training package and workshops for teachers and Bright Ideas grants. Since its inception in 2004, PG&E shareholders have contributed more than $9 million to the PG&E Solar Schools program. With over 125 schools participating throughout PG&E's service area, the program has trained more than 3,000 teachers, benefiting nearly 200,000 students.[16]

Barriers and Potential Solutions for School PV Installations

Solar PV systems comprise expensive components such as PV modules and inverters. They are frequently located in a highly visible location to ensure unimpeded solar access and to facilitate the education and outreach efforts associated with the PV system. Because of their exposed placement, PV systems on schools are particularly prone to vandalism and theft. Most vandalism acts are random and

[14] http://www.luciddesigngroup.com/kiosk/features.php
[15] http://www.pge.com/about/environment/pge/solarschools/
[16] http://www.pge.com/about/environment/pge/solarschools/

tend to occur in the evenings and on weekends. They also occur during the summer months when school is on break, the weather is warmer, and the days are longer.

Common anti-vandalism and -theft strategies include:

- **Install keyed fasteners at intermodule and end clamps.** These fasteners use a unique pattern, which are incompatible with standard wrenches and screwdrivers. The installer or owner keeps the key needed to unfasten the hardware. Although fasteners cost approximately $2-5 each, they are inexpensive relative to the cost of the modules.

Figure 7: Solar panel locks[17]

- **Install PV-specific alarm systems**, which tie into all PV modules, detect when a module is being disconnected, and send an alert to on-call staff or security.
- **Lock all panels together with heavy gauge, nylon coated wire** or other similarly designed systems. These essentially tie all panels together so that removal of individual panels is extremely difficult.
- **Check fences and gates for damage.** Make repairs as needed and keep gates locked.
- **Cut back weeds and other vegetation** around the campus to reduce fire risk and hiding places.
- **Keep surrounded areas clean.** Loose rocks that can be used by vandals should be removed.
- **Check all lighting on campus.** Replace all burned out bulbs. Install lighting in currently dark areas. Consider installing motion sensor lights.
- **Add or increase nightly patrols of campus**, especially during the summer months.
- **Install a reliable security camera system.** Post signage around the perimeter of the system alerting of the security systems in place.
- **Encourage neighbors to be concerned and watch for vandalism and theft.**
- **Engrave each system component** with the school name to deter reselling of stolen equipment.
- **Post warnings about potential hazards** and electric shocks from the system.

[17] http://www.solarpanelcleaningsystems.com

- **Educate the staff and students on the consequences of theft and vandalism** and create a sense of ownership of the PV system.