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Market Status/Overview

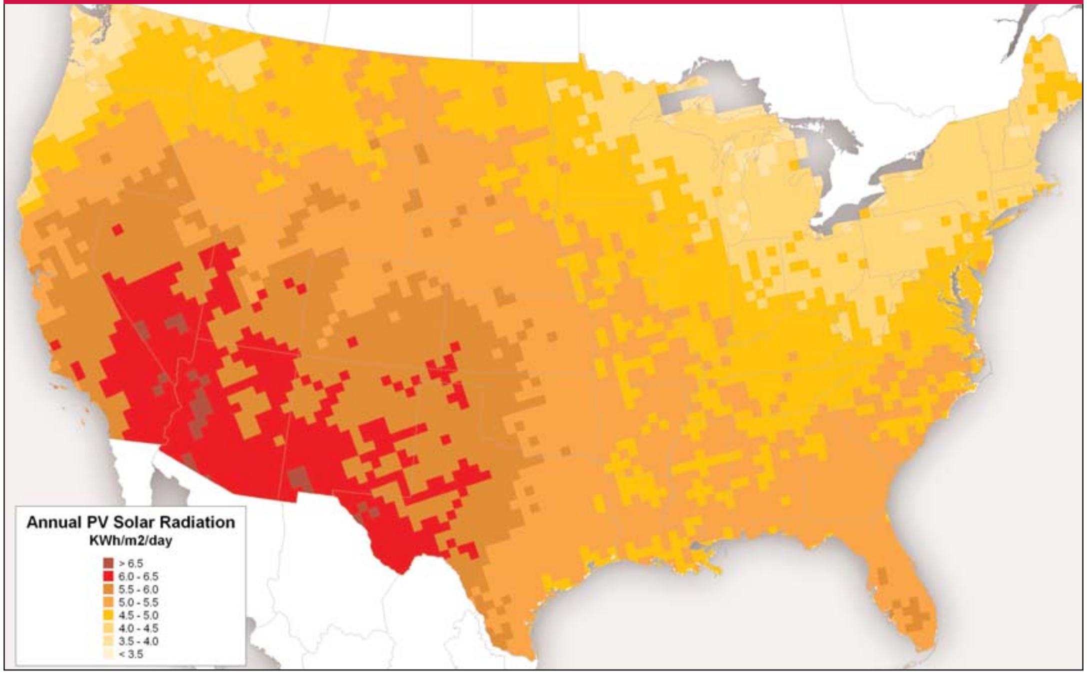
Photovoltaic (PV)-based electricity generation is growing by 25% to 35% per year worldwide and is expected to continue this rapid growth. The U.S. market is driven largely by state-level regulations and subsidies, such as solar set-asides in state Renewable Portfolio Standards (RPS) and buy-downs funded through system benefit charges. Details vary by state, but in some cases co-ops are not subject to RPS requirements and co-op members are not eligible for buy-downs. As a result, PV is still quite expensive for co-op members, costing between 28 cents and 50 cents per kWh.

PV's numerous technical advantages, however, can in some cases allow the technology to overcome its steep entry price. It is technically straightforward: easy to install, simple to operate, and requiring little or no maintenance. It is scalable and can supply power requirements from tens of watts to hundreds of kilowatts. It is easy to site—systems can be put on roofs and, therefore, it has little visual impact. And it will produce electricity anywhere the sun shines. It's the technology of choice for remote, off-grid applications. Additionally, it is finding a small niche market in supplying peak power to grids facing summer air-conditioning peak demands.

Photovoltaic Resource Assessment

Unlike wind turbines, which typically require wind speeds of 8 to 9 mph before they even start turning, PVs will generate some electricity even on a heavily overcast day in winter. The more light, however, the more electricity. So, the question of whether PVs will "work" in a

Annual PV Solar Radiation



U.S. solar resources are abundant. This maps provides monthly average daily total solar resource information on grid cells of approximately 40 km by 40 km in size. The insolation values represent the resource available to a flat plate collector, such as a photovoltaic panel, oriented due south at an angle from horizontal to equal to the latitude of the collector location.

specific geographic location is one of economics and cost-effectiveness, not technical feasibility.

There are a number of online maps and other resources that will provide good estimates of insolation (sunlight) in a given geographic area, and even the amount of electricity one can expect from PV systems in a specific location. The NREL Renewable Resource Data Center provides maps of U.S. solar resource availability under a number of variables, including month, tilt angle, tracking systems (east-west and north-south), and technology (flat plate or concentrator). See http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas. Estimates of the kilowatt-hour production from a system in a specific geographic location can be found at http://rredc.nrel.gov/solar/codes_algs/PVWATTS.

Unlike wind maps, these maps are quite accurate even when considering a specific location, because insolation (sunlight) does not vary with small changes in location. Because the online resources, such as those listed above, are very good, it is not necessary to collect insolation data before installing a PV system. There is one important caveat, however: These tools are reasonably accurate at predicting annual or even monthly kilowatt-hour output, but they are less well suited for predicting daily output curves. Therefore, the peak reduction capability of PVs is more difficult to predict accurately.

How Does PV Work?

PVs turn sunlight directly into electricity with no moving parts, no combustion, no noise, and no waste products. The photoelectric effect converts light into electricity at the atomic level. (For a tutorial on the physics of PV, see www.eere.energy.gov/solar/pv_physics.html.) The basic element, or building block, of a PV system is the solar cell, typically producing 1 or

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2 W of electrical power. Cells are assembled into modules (also called panels), with typical peak power outputs of 50 to 300 W. Modules can be assembled into arrays, which can vary from just two modules for a small residential system to hundreds of modules for a utility-scale system of 100 kW or more. The remaining equipment and structure in an installed PV system is called the balance of system (BOS).

There are many different types of PV modules. Most commercially available PV systems use crystalline silicon (C-Si) modules. C-Si modules were the first widely deployed PV technology and, to date, are the workhorses of the PV industry for the bulk of the PV cell market. In this design, silicon (which starts out as sand) is mixed with a small amount of a substance with a different number of electrons (such as boron or phosphorus). When light hits the PV material, electrons are dislodged. This movement of electrons creates an electric current. C-Si modules have reasonably high conversion efficiencies (typically 12% to 14%) and are made from readily available materials. Unfortunately, they are expensive to manufacture. C-Si modules come in two main types: monocrystalline and multicrystalline (also called polycrystalline). In general, monocrystalline modules have slightly higher efficiencies, and higher costs, than multicrystalline modules. C-Si modules are available for as little as $4.00 per W, although these prices do not include the BOS components needed to make an operating PV system.

Amorphous silicon modules (also known as "thin-film")—C-Si's closest competitor in customer-sited systems (although it accounts for less than 10% of the PV cell market)—have lower solar conversion efficiencies but use considerably less material, and their manufacturing processes are well suited for mass production. Costs for thin-film are about the same per watt as for C-Si, but because of lower efficiencies, more of these modules are required. This increases installation costs as well, because more space is needed for their installation.

Because of its size and flexibility, thin-film can be used in building products, such as roofing tiles and awnings; in this form, it is called building-integrated photovoltaic (BIPV). Functioning as both a construction element and power generator adds value to the PV, as it brings down the costs of construction. There are many types of thin-film modules, including amorphous silicon and various polycrystalline materials such as cadmium telluride (CdTe) and copper indium (gallium) diselenide. As of late 2005, prices for thin-film PV modules were just under $4.00 per W .

PV systems come in two main configurations: flat-plate and concentrating. Flat-plate systems are installed so that the PV cells face the sun directly, whereas concentrating systems use mirrors to focus or concentrate sunlight, which is then directed at the PV cells. In general, concentrating systems have higher first costs, but they can have higher efficiencies (defined as power output/power input) as well.

In addition to the cells themselves, other components (collectively called BOS) are required to make up an operating system. BOS components include the following:

- Mounting and supporting hardware for the PV modules
- Wiring
- A charge controller (also called a regulator) for off-grid systems
- A battery or batteries for off-grid systems
- An inverter for on-grid systems
- System monitoring and control hardware.

There are three main types of PV applications: utility-scale (also called central station), rooftop, and off-grid.

Utility-scale systems are typically 50 KW or larger and have the lowest cost per kilowatt-hour. There is a scattering of such systems. For example, one California utility installed a 500 kW PV system at a substation to help cope with summer afternoon peaking problems. However, such systems are in many cases not eligible for state subsidies or do not count toward RPS requirements. Even large PV systems cannot compete economically with wholesale power without these subsidies; as a result, there are few utility-scale PV systems.

The greatest growth in PV is in rooftop systems—typically 1 to 10 kW. A number of states—most notably California and New Jersey—have ambitious PV plans that are being met mostly by rooftop systems. Other states—

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such as Colorado, New Mexico, and Arizona—have solar set-aside requirements in their RPSs. The Colorado RPS, for example, requires that half the solar requirement be met with customer-sited PV systems. In some cases, co-ops are exempt from these RPS requirements, but the RPS increases interest and reduces costs in any case. Similarly, many states have public funds that can be used for rooftop PV installations. However, co-op eligibility for these funds varies. For a summary of state renewable policies and funds, see www.dsireusa.org.

PV can compete economically, even without public subsidy, for off-grid applications. Remote lighting, water pumping, communications, and other end uses can often be met with a PV/battery system at a lower cost than that of running new power lines. Such systems are often entirely DC, and thus avoid the expense and complications of DC-to-AC conversion. (These systems do, however, require a regulator—also called a charge controller.)

Wyoming is looking into greater use of off-grid PV systems for stock water pumps. Running distribution lines can cost $15,000 to $20,000 per mile, and repair costs can be quite high as well. As a result, off-grid PV can make economical sense for ranchers and co-ops. PV's intermittency may require that a backup generator be installed as well, which increases overall costs. However, when comparing these costs with those of running new lines, a remote PV system with backup may still be the less-expensive option.

How Much Do Photovoltaics Cost?

The costs of solar electricity have fallen dramatically over past decades because of technological improvements and increases in production and distribution economies. However, PV costs are still relatively high. In fact, prices have actually increased in the past two years due to the sharp rise in demand. Like other renewable energy technologies that don't have added fuel costs, the costs for solar power consist mostly of capital outlay followed by predictable payments for debt service and O&M. Capital costs vary depending on the chosen PV technology (e.g., C-Si or thin-film), installation specifics such as the type of roof and contractor costs, and the size of the system and the supplier's retail markup. PV modules are the fundamental components of a PV system and constitute roughly half of the installed capital costs. Other capital costs include the BOS components and site evaluation, permitting, and design and installation services.

As discussed above, PV modules are available for as little as $4.00 per W; however, average prices in the United States in late 2005 were about $5.30 per W. BOS prices depend on the specific application. For rooftop on-grid PV systems, for example, BOS components are typically $2.00 to $6.00 per W. This puts the total first cost for a rooftop PV system at $7.00 to $11.00 per W, excluding rebates or other public subsidies.

Green Power EMC's Sun Power for Schools Program (Tucker, GA) has installed the first 6 of 16 planned 1 kW systems on local schools, at a cost of about $8,000 per kW. This cost included BOS components, but the data collection and some site work paid by the local co-op totaled another $5,000. Holy Cross Energy (Glenwood Springs, CO) has 15 PV systems and is paying $8,000 to $10,000 per kW, installed.

O&M costs for PV systems are proportionately insignificant, at less than $0.01 per kWh. Fuel costs are zero. Scheduled maintenance consists mostly of washing the modules to remove dirt and dust. Technical failures of the modules themselves are rare. Inverters have historically been problematic, but they are showing improved reliability.

Life-cycle cost, also called levelized cost, is determined by spreading the assumed total costs (capital, debt service, and O&M) over the total expected output, in kilowatt-hours, during the lifetime of the system (about 25 years for most systems installed today). This cost is affected by financing details (notably interest rates), the solar resource, and other factors, and it can range from 28 cents to 50 cents per kWh.

Specific Questions to Ask When Considering Photovoltaics

1. How much will the system cost?

Quoted prices for PV may reflect the modules only, some but not all BOS components, or hardware-only costs—that is, not including permitting, installation, and so on. Make sure price quotes include *all* applicable costs. As noted above, the PV modules are typically about 50% of total costs—don't get misled by low module-only prices. For more details on what to ask PV system vendors, see www.solarbuzz.com/consumer/customertips3.htm.

2. What are the relevant siting, permitting, and electrical code requirements?

In many regions of the country, PV systems are still a new technology, and local land-use and building codes may not have procedures to deal with them. This can delay projects and increase costs.

3. What is the projected electrical output (kilowatt-hours) of a system over its lifetime?

PV systems are typically sold on the basis of peak capacity (kilowatts); however, what's of value to PV is the generation (kilowatt-hours). Vendors should provide estimates of annual output (kilowatt-hours per year), as well as peak output (kilowatts).

4. How will the system tie in to the distribution grid?

The system must have an easily accessible disconnect to protect line workers. The inverter and associated wiring and controls must be designed and installed to ensure safe operation. Electricians may not be familiar with PV system requirements; co-ops should require inspections of PV systems by their own personnel before allowing tie-in.

Also, It should be noted that PV proponents and some state regulators believe that such disconnects are unduly expensive, and unnecessary for safety because of the operation of line-commutated inverts. Be aware that any effort to require a disconnect could be controversial.

5. How might PV affect my system peak?

PV output is directly proportional to insolation (sunlight) as seen by the panel. It's therefore possible to affect output through system siting —for example, if the goal is to reduce summer afternoon peak, it might make sense to install PV systems facing southwest rather than due south. This can reduce total kilowatt-hour output but improve the match to system peak.

6. Who can help me take the next step?

A state-by-state database of solar system installers, manufacturers, and consultants can be found at www.solarbuzz.com/CompanyListings/UnitedStates.htm.

Outlook for Photovoltaics

A number of states (notably California) and now the federal government (via the Energy Policy Act of 2005, see Section 10) offer generous subsidies that, in effect, buy down the high capital costs of PV systems. (See www.dsireusa.org for the latest on state and federal subsidies.) Even with these subsidies, PV is more expensive than utility power. However, we expect to see annual 20% to 25% growth in PV installations, which offer numerous practical advantages (notably, the ability to be sited almost anywhere with essentially no maintenance requirements) that can overcome their cost disadvantages.

As of late 2005, the demand for PV was outstripping PV manufacturing capacity, which actually resulted in price increases. This problem is aggravated by shortages of C-Si, the main ingredient in PV panels. As a result, PV prices are expected to increase slightly or, at best, stay flat for the next two to three years. After that, they will likely resume a long-term decreasing trend.