FACT SHEET
Agriculture and Natural Resources

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Photovoltaic Systems for Solar Electricity Production

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Photovoltaics (PV) is a solar power technology that uses solar cells to convert light from the sun directly into electricity. An individual PV cell is usually quite small, typically producing about 1 or 2 watts of power. To produce more power, cells can be interconnected and encapsulated to form PV modules, which is the product usually sold to the customer (Figure 1). The PV modules can in turn be combined and connected to form PV arrays of different sizes and power output.

In addition to the modules, a PV system also includes an inverter to transform DC current into AC current, rechargeable batteries (when storage is needed), a mechanical structure to mount the modules, and wiring. These remaining elements are commonly referred to as Balance-of-System (BOS). The PV system can meet a particular energy demand, such as powering a water pump or the appliances and lights in a home.

Solar cells (PV cells) can be made from various types of semiconductor materials. The first type is crystalline form of silicon (c-Si) or amorphous silicon (a-Si). The second type is polycrystalline thin-film semiconductors, including copper indium gallium diselenide (Cu(InGa)Se2 or CIGS), and cadmium telluride (CdTe) and thin film silicon. The third type is single-crystalline thin films including gallium arsenide (GaAs).

PV systems can be classified into two general categories: flat-plate systems or concentrator systems. Flat-plate PV modules are the most common array design. These modules can either be fixed in place or allowed to track the movement of the sun. Concentrator systems operate under concentrated sunlight using lenses or mirrors as concentrators. It allows a small solar cell to capture the solar energy shining on a fairly large area. This saves on the number of expensive semiconductors needed but adds complexity to the system.

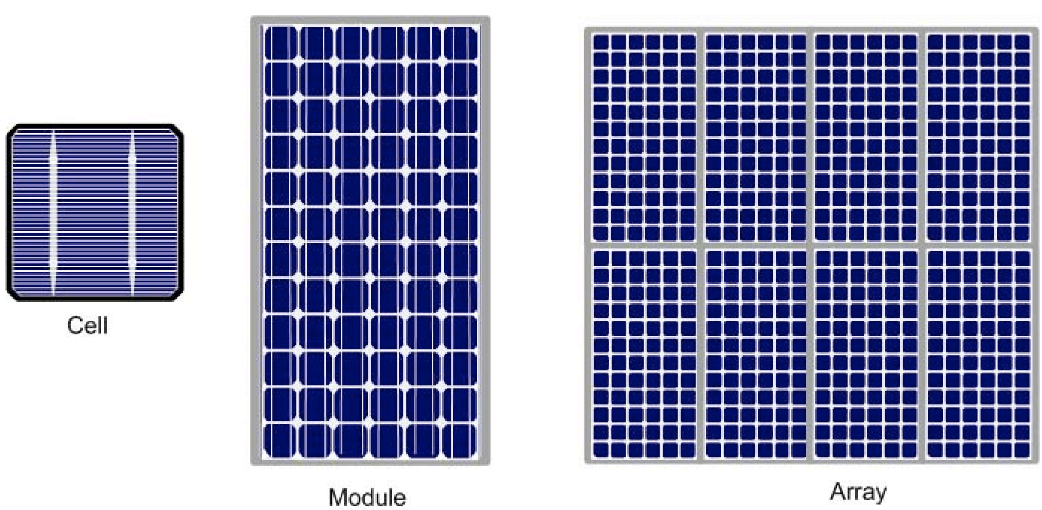

Figure 1. Solar cell, module, and array.

Grid-independent photovoltaic systems

PV systems with batteries for storage are excellent for supplying electricity in areas where utility power is unavailable or utility line extension would be too expensive. It can be designed to power equipment that requires DC or AC electricity. As AC electricity is required for typical appliances and lights, an inverter is required between the batteries and the load. Although a small amount of energy is lost in converting DC electricity to AC, an inverter makes it possible to operate ordinary AC appliances and lights (Figure 2).

In PV systems with batteries, the PV modules are connected to a battery, and the battery, in turn, to the load. During the day, the PV modules charge the battery, and then the battery supplies power to the load as needed. A simple electrical device called a charge controller keeps the battery charged properly and helps prolong its life by protecting it from overcharging or from being completely drained.

Nickel-cadmium rechargeable batteries are used in most PV powered appliances, but lead-acid batteries and capacitors can also be used. The batteries used in PV systems are similar to car batteries, but they are built somewhat differently to allow more of their stored energy to be used each day. Batteries designed for PV projects pose the same risks and demand the same caution in handling and storage as automotive batteries. The fluid in unsealed batteries must be checked periodically and the battery protected from extremely cold weather.

Grid-connected photovoltaic systems

PV systems can be connected to the public electricity grid via a suitable inverter. Energy storage is not necessary in this case. The electricity produced by the PV system is used first to meet any electric requirements (e.g., appliances, lights) in the home. If more electricity is produced from the PV system than the family needs, the excess energy is sold back to the utility through net metering. When more electricity is required than the PV system is generating (for example, in the evening or cloudy days), the house draws its power from the grid (Figure 3). At the end of the month, a credit for electricity sold is deducted

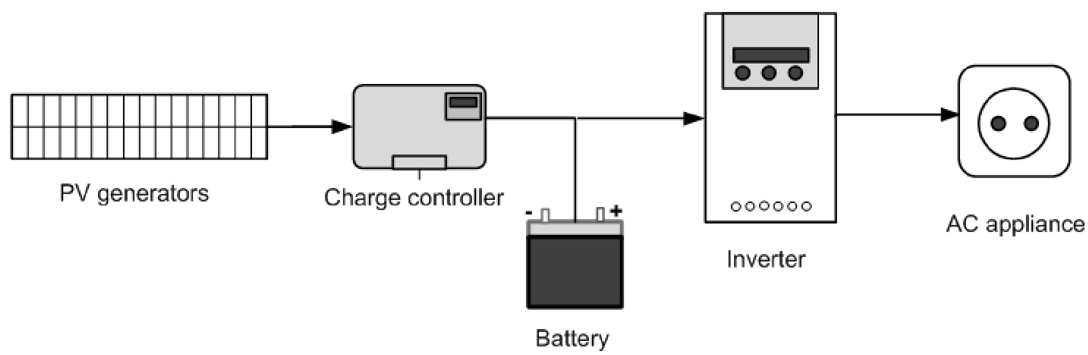

Figure 2. Components of grid-independent photovoltaic systems.

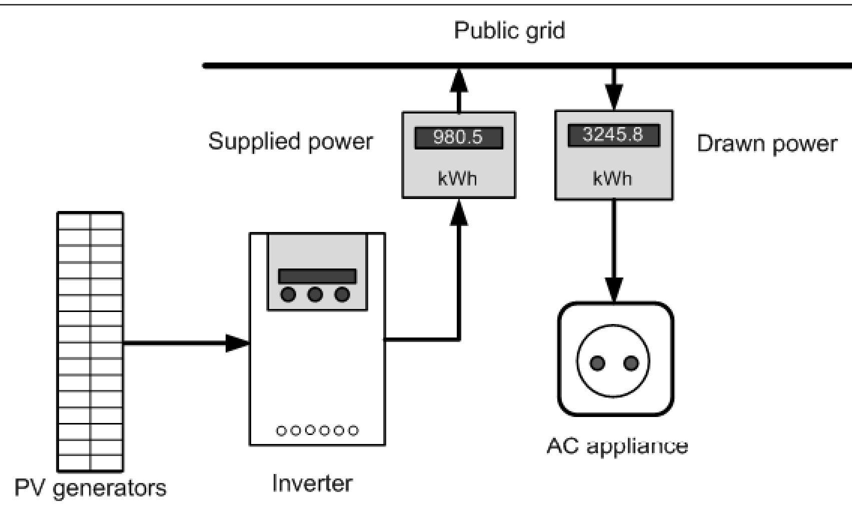

Figure 3. Components of grid-connected photovoltaic systems.

from charges for electricity purchased. The PV system reduces the amount of electricity purchased from the utility each month.

PV systems operating parallel to the grid have technological potential, but are not yet financially competitive without subsidies.

Net metering is a policy that allows customers to receive the full credit for the electricity produced by their solar energy system. Under federal law, utilities must allow independent power producers to be interconnected with the utility grid, and utilities must purchase any excess electricity they generate. Many states have gone beyond the minimum requirements of the federal law by allowing net metering for customers with PV systems.

Electricity yield of the photovoltaic systems

The electricity yield of the PV system is determined by the available solar energy and the electrical characteristics of the PV modules under Standard Test Conditions (STC) (Irradiance: 1000 W/m^2; Spectrum: AM1.5; and Cell Temperature: 25°C), as provided by its manufacturers.

The real efficiency of the PV module installed at home may only have about 70% of the STC efficiency shown in the manufacturer's information. Accumulation of dust and variance of ambient temperature are major reasons for the low real efficiency. As shown in Table 1, the conversion efficiency of crystalline silicon PV panel is 13–17%, while the conversion efficiency of amorphous silicon PV panel is about 5–7%.

Table 1. Conversion efficiency of PV module.

Material	Efficiency in lab	Efficiency in production
Mono-crystalline silicon	approx. 24%	14–17%
Poly-crystalline silicon	approx. 18%	13–15%
Amorphous silicon	approx. 13%	5–7%

Source: http://www.solarserver.de/wissen/photovoltaik-e.html

The energy generated by a PV system also depends on the solar radiation, which varies with location and climactic conditions. As shown in Table 2, the average solar radiation in several selected Ohio counties ranges from 1050 to 1300 btu/ft^2/day. Assuming the conversion efficiency of a solar panel is 10%, the electricity yields in the selected Ohio counties range from 3.2 to 4.3 kWh /ft^2/day. A solar array of 10 feet by 10 feet would average about 1120–1390 kilowatt-hours (kWh) per year depending on location in Ohio. The average household in America consumes 10,600 kWh per year, according to the U.S. Department of Energy.

Table 2. Average daily solar radiation of selected Ohio counties (1996–2006).

County	Solar radiation		PV electricity yield	
	kWh/m^2/day	btu/ft^2/day	kWh/m^2/day	btu/ft^2/day
Clark	3.5	1125	0.36	112
Jackson	3.6	1135	0.36	114
Delaware	4.1	1305	0.41	130
Wood	3.7	1180	0.37	118
Ashtabula	3.5	1100	0.35	110
Wayne	3.3	1050	0.33	105

There is a wide change in solar radiation through the year. Taking Clark County as an example, the yearly average solar radiation (1997–2006) was about 3.6 kWh/m^2/day (1100 btu/ft^2/day). As shown in Figure 4, the lowest solar radiation of 1.35 kWh/m^2/day (430 btu/ft^2/day) was obtained in December. The maximum solar radiation was obtained in July, which was about 5.7kWh/m^2/day (1800 btu/ft^2/day).

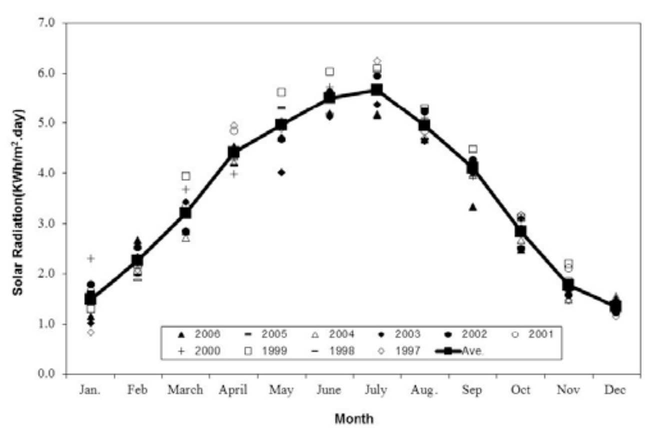

Figure 4. Average solar radiation in Clark County, Ohio (latitude: 39.86, longitude: -83.67).

Costs of photovoltaic systems

The current PV module cost of about \$4 to \$6/watt (W) is still too high to be competitive with other sources of electricity. Table 3 provides a comparison of the current cost of solar modules with different materials and manufacturers. The U.S. Department of Energy has set a target to lower unit price to \$0.33/W; but as the prices of coal, oil and gas rise, solar power will begin to look much more competitive.

Table 3. Cost of solar modules.*

Manufacturer	Wattage peak (watts)	Material	Unit price ($/watt)
Evergreen	51–115	Poly-crystalline silicon	5.6–6.6
ASE Americas	50–285	—	—
Astropower	45–120	Single-crystalline silicon	4.4–6.0
Photowatt	80–165	Poly-crystalline silicon	5.0–6.0
BP	20–160	Poly-crystalline silicon	15.0–5.0
Shell (SM, SP)	50–110	Single-crystalline silicon	7.0–6.6
Shell (ST)	5–40	thin-film (Copper Indium Diselenide)	15.0–8.0
Uni-solar (SSR)**	64–128	thin-film	7.2–7.1
Uni-solar (PVL)**	29–128	thin-film	6.4–5.8
Sharp	80–185	multi-crystalline silicon	5.6–5.4

*Source: http://www.advancedenergyonline.com/. Accessed on January 20, 2008.
**Building integrated photovoltaic modules, SSR = Standing Seam Roof, PVL = Peel and stick laminate for metal roofing.

Unlike electricity generated from fossil fuels, electricity generated by a PV system has no fuel costs, very low operating and maintenance costs, and a very high yearly capital amortization expense. The cost of solar electricity includes the plant's yearly capital amortization expense (84%) and the yearly fixed (15%) and variable (1%) operating and maintenance cost (Stavy, 2002). The solar electricity cost in the United States ranges from $0.38 (sunny climate, such as Arizona) to $0.80 (cloudy climate, such as Ohio) per kWh for a residential system. For a commercial system the cost ranges from $0.28 (sunny) to $0.60 (cloudy) (www.solarbuzz.com/solarindics.htm). The current price of electricity for residential use in Ohio is around $0.10 per kWh.

References

Stavy, M. 2002. A financial worksheet for computing the cost (c/kWh) of solar electricity generated at grid connected photovoltaic (PV) generating plants. *J. Solar Energy Engineering* 124: 319–321.

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