# Solar Explained

## Photovoltaics and Electricity

U.S. Energy Information Administration

### Photovoltaic cells convert sunlight into electricity

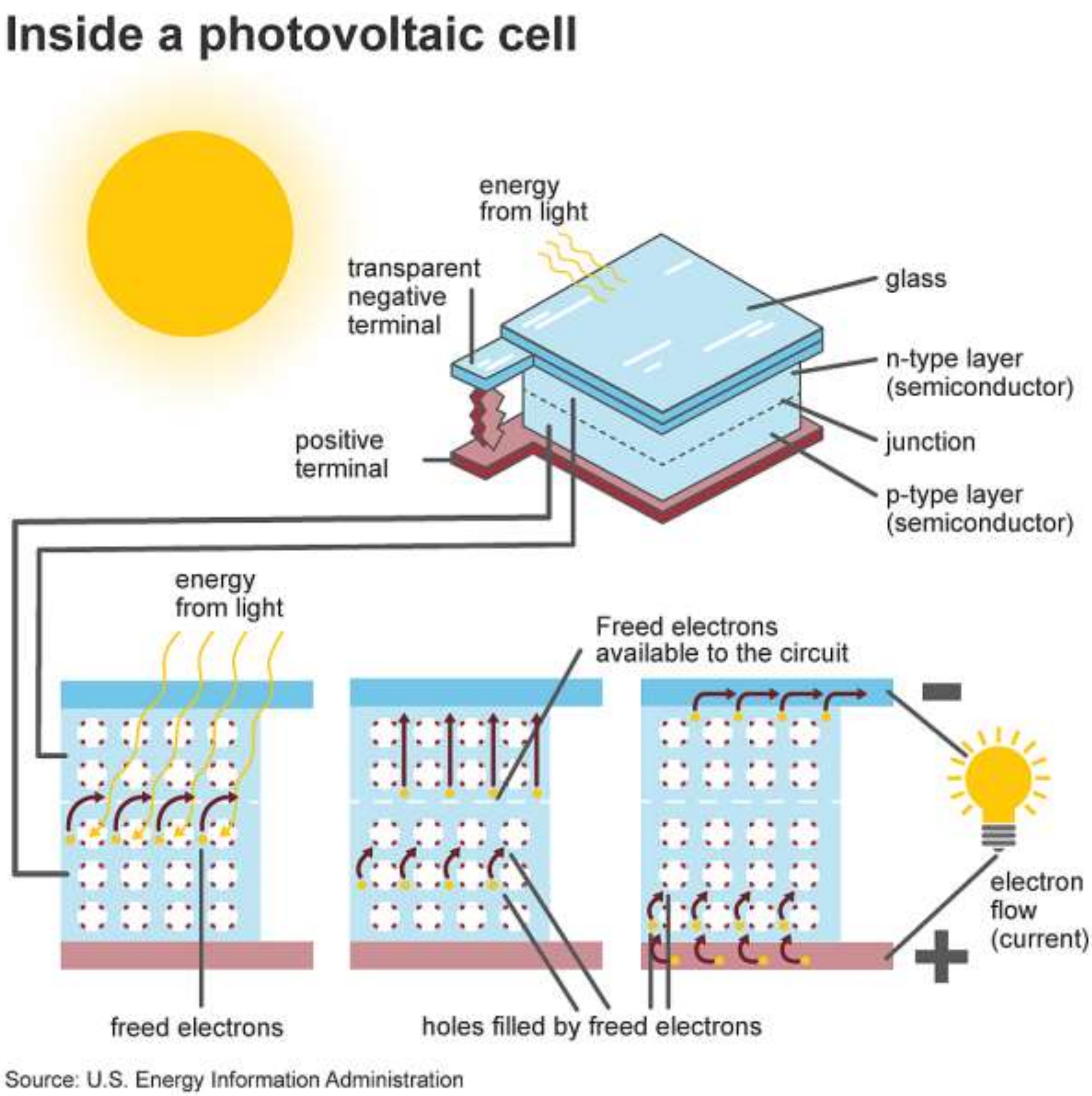
A photovoltaic (PV) cell, commonly called a solar cell, is a device that converts sunlight directly into electricity. Some PV cells can convert artificial light into electricity.

A PV cell is made of semiconductor material. When photons strike a PV cell, they may reflect off the cell, pass through the cell, or be absorbed by the semiconductor material. Only the absorbed photons provide energy to generate electricity. When the semiconductor material absorbs enough sunlight (solar energy), electrons are dislodged from the material's atoms. Special treatment of the material surface during manufacturing makes the front surface of the cell more receptive to the dislodged, or free, electrons so that the electrons naturally migrate to the surface of the cell.

### The flow of electricity in a solar cell

The movement of electrons, each carrying a negative charge, toward the front surface of the solar photovoltaic cell creates an imbalance of electrical charge between the cell's front and back surfaces. This imbalance, in turn, creates a voltage potential like the negative and positive terminals of a battery. Electrical conductors on the cell absorb the electrons. When the conductors are connected in an electrical circuit to an external load, such as a battery, electricity flows through the circuit.

Sunlight is composed of photons - packets of solar energy - which contain different amounts of energy that correspond to the different wavelengths of the solar spectrum. When photons strike a PV cell, they may be reflected or absorbed, or they may pass right through.




The energy of an absorbed photon is transferred to an electron in an atom of the semiconductor device. This energy allows the electron to escape from its normal position associated with a single atom in the semiconductor device to become part of the current in an electrical circuit.

## Photovoltaic cells, panels, and arrays

The PV cell is the basic building block of a PV system. Individual cells can vary from 0.5 inches to about 4.0 inches across. However, one cell only produces 1 or 2 Watts, which is only enough electricity for small uses, such as powering calculators or wristwatches.

PV cells are electrically connected in a packaged, weather-tight PV panel (sometimes called a module). PV panels vary in size and in the amount of electricity they can produce. PV panel electricity-generating capacity increases with the number of cells in the panel or in the surface area of the panel. PV panels can be connected in groups to form a PV array. A PV array can be composed of as little as two to hundreds of PV panels. The number of PV panels connected in a PV array determines the amount of electricity the array can generate.

Photovoltaic cells generate direct current (DC) electricity. DC electricity can be used to charge batteries that power devices that use direct current electricity. Nearly all electricity is supplied as alternating current (AC) in electricity transmission and distribution systems. Devices called inverters are used on PV panels or in arrays to convert the DC electricity to AC electricity.

PV cells and panels will produce the most electricity when they are directly facing the sun. PV panels and arrays can use tracking systems that keep the panels facing the sun, but these systems are expensive. Most PV systems have panels in a fixed position that are usually facing directly south in the northern hemisphere—directly north in the southern hemisphere—and at an angle that optimizes the physical and economic performance of the system.

## The efficiency of photovoltaic systems

The efficiency at which PV cells convert sunlight to electricity varies by the type of semiconductor material and PV cell technology. The efficiency of commercially available PV panels averaged less than 10% in the mid-1980s, increased to around 15% by 2015, and is now approaching 25% for state-of-the art modules. Experimental PV cells and PV cells for niche markets, such as space satellites, have achieved nearly 50% efficiency.

## Applications of photovoltaic systems

The smallest photovoltaic systems power calculators and wristwatches. Larger systems can provide electricity to pump water, power communications equipment, supply electricity for a single home or business, or supply electricity to thousands of electricity consumers.

## Some advantages of PV systems are:

- PV systems can supply electricity in locations where electricity distribution systems (power lines) do not exist, and they can also supply electricity to an electric power grid.
- PV arrays can be installed quickly and can be any size.
- The environmental effects of PV systems located on buildings is minimal.

## History of photovoltaics

The first practical PV cell was developed in 1954 by Bell Telephone researchers. Beginning in the late 1950s, PV cells were used to power U.S. space satellites. By the late 1970s, PV panels were providing electricity in remote, or off-grid, locations that did not have electric power lines. Since 2004, most PV systems in the United States are grid-connected—they are connected to an electric power grid. They are installed on or near homes and buildings and at utility-scale power plants that have at least 1 megawatt of electric generation capacity. Technological advances, lower costs for PV systems, and various financial incentives and government policies have helped to greatly expand PV use since the mid-1990s. Hundreds of thousands of grid-connected PV systems are now installed in the United States.

Electricity generation at **utility-scale PV power plants** increased from 6 million kilowatt hours (kWh) (or 6,000 megawatt hours [MWh]) in 2004 to about 143 billion kWh (or 142,596,000 MWh) in 2022. About 59 billion kWh (or 58,512,000 MWh) were generated by small-scale, grid-connected PV systems in 2022, up from 11 billion kWh (or 11,233,000 MWh) in 2014.

**Small-scale PV systems** have less than 1,000 kilowatts of electricity generation capacity. Most small-scale PV systems are located on buildings and are sometimes called rooftop PV systems.

Last updated: May 26, 2023, with preliminary data for 2022 from the Electric Power Monthly, February 2023. ■

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U.S. Department of Energy
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