How Solar Cells Work

by Jessika Toothman and Scott Aldous

Browse the article **How Solar Cells Work**

Renewing the Grid Image Gallery

This is one place you're probably used to seeing solar cells, but they'll be popping up more as the years go by. See more renewing the grid pictures.
©iStockphoto.com/blackred

UP NEXT

- Solar Cell Quiz
- How Solar Thermal Power Works
- How Thin-film Solar Cells Work

Introduction to How Solar Cells Work

You've probably seen calculators with solar cells -- devices that never need batteries and in some cases, don't even have an off button. As long as there's enough light, they seem to work forever. You may also have seen larger solar panels, perhaps on emergency road signs, call boxes, buoys and even in parking lots to power the lights.

Although these larger panels aren't as common as solar-powered calculators, they're out there and not that hard to spot if you know where to look. In fact, **photovoltaics** -- which were once used almost exclusively in space, powering satellites' electrical systems as far back as 1958 -- are being used more and more in less exotic ways. The technology continues to pop up in new devices all the time, from sunglasses to electric vehicle charging stations.

The hope for a "solar revolution" has been floating around for decades -- the idea that one day we'll all use free electricity from the sun. This is a seductive promise, because on a bright, sunny day, the sun's rays give off approximately 1,000 watts of energy per square meter of the planet's surface. If we could collect all of that energy, we could easily power our homes and offices for free.

In this article, we will examine solar cells to learn how they convert the sun's energy directly into electricity. In the process, you will learn why we're getting closer to using the sun's energy on a daily basis, and why we still have more research to do before the process becomes cost-effective.

GOING SOLAR, GOING GREEN
Adding solar panels to an existing home can be expensive -- but there are lots of other ways to make your home greener. Learn more about what you can do to protect the environment at Discovery Channel's Planet Green.

UP NEXT

- Solar Cell Quiz
- How Solar Thermal Power Works
- How Thin-film Solar Cells Work

Photovoltaic Cells: Converting Photons to Electrons

The solar cells that you see on calculators and satellites are also called photovoltaic (PV) cells, which as the name implies (photo meaning "light" and voltaic meaning "electricity"), convert sunlight directly into electricity. A module is a group of cells connected electrically and packaged into a frame (more commonly known as a solar panel), which can then be grouped into larger solar arrays, like the one operating at Nellis Air Force Base in Nevada.

Photovoltaic cells are made of special materials called semiconductors such as silicon, which is currently used most commonly. Basically, when light strikes the cell, a certain portion of it is absorbed within the semiconductor material. This means that the energy of the absorbed light is transferred to the semiconductor. The energy knocks electrons loose, allowing them to flow freely.

PV cells also all have one or more electric field that acts to force electrons freed by light absorption to flow in a certain direction. This flow of electrons is a current, and by placing metal contacts on the top and bottom of the PV cell, we can draw that current off for external use, say, to power a calculator. This current, together with the cell's voltage (which is a result of its built-in electric field or fields), defines the power (or wattage) that the solar cell can produce.

That's the basic process, but there's really much more to it. On the next page, let's take a deeper look into one example of a PV cell: the single-crystal silicon cell.

How Silicon Makes a Solar Cell

Silicon has some special chemical properties, especially in its crystalline form. An atom of silicon has 14 electrons, arranged in three different shells. The first two shells -- which hold two and eight electrons respectively -- are completely full. The outer shell, however, is only half full with just four electrons. A silicon atom will always look for ways to fill up its last shell, and to do this, it will share electrons with four nearby atoms. It's like each atom holds hands with its neighbors, except that in this case, each atom has four hands joined to four neighbors. That's what forms the **crystalline structure**, and that structure turns out to be important to this type of PV cell.

The only problem is that pure crystalline silicon is a poor conductor of electricity because none of its electrons are free to move about, unlike the electrons in more optimum conductors like copper.

President Barack Obama, Senate Majority Leader Harry Reid of Nevada, and Col. Howard Belote, checked out the solar panels at Nellis Air Force Base in Nevada in May of 2009.
AP Photo/Charles Dharapak

UP NEXT

- Solar Cell Quiz
- How Solar Thermal Power Works
- How Thin-film Solar Cells Work

To address this issue, the silicon in a solar cell has **impurities** -- other atoms purposefully mixed in with the silicon atoms -- which changes the way things work a bit. We usually think of impurities as something undesirable, but in this case, our cell wouldn't work without them. Consider silicon with an atom of phosphorous here and there, maybe one for every million silicon atoms. Phosphorous has five electrons in its outer shell, not four. It still bonds with its silicon neighbor atoms, but in a sense, the phosphorous has one electron that doesn't have anyone to hold hands with. It doesn't form part of a bond, but there is a positive proton in the phosphorous nucleus holding it in place.

When energy is added to pure silicon, in the form of heat for example, it can cause a few electrons to break free of their bonds and leave their atoms. A hole is left behind in each case. These electrons, called **free carriers**, then wander randomly around the crystalline lattice looking for another hole to fall into and carrying an electrical current. However, there are so few of them in pure silicon, that they aren't very useful.

But our impure silicon with phosphorous atoms mixed in is a different story. It takes a lot less energy to knock loose one of our "extra" phosphorous electrons because they aren't tied up in a bond with any neighboring atoms. As a result, most of these electrons do break free, and we have a lot more free carriers than we would have in pure silicon. The process of adding impurities on purpose is called **doping**, and when doped with phosphorous, the resulting silicon is called **N-type** ("n" for negative) because of the prevalence of free electrons. N-type doped silicon is a much better conductor than pure silicon.

The other part of a typical solar cell is doped with the element boron, which has only three electrons in its outer shell instead of four, to become P-type silicon. Instead of having free electrons, **P-type** ("p" for positive) has free openings and carries the opposite (positive) charge.

On the next page, we'll take a closer look at what happens when these two substances start to interact.

UP NEXT

- Solar Cell Quiz
- How Solar Thermal Power Works
- How Thin-film Solar Cells Work

Anatomy of a Solar Cell

Before now, our two separate pieces of silicon were electrically neutral; the interesting part begins when you put them together. That's because without an **electric field**, the cell wouldn't work; the field forms when the N-type and P-type silicon come into contact. Suddenly, the free electrons on the N side see all the openings on the P side, and there's a mad rush to fill them. Do all the free electrons fill all the free holes? No. If they did, then the whole arrangement wouldn't be very useful. However, right at the **junction**, they do mix and form something of a barrier, making it harder and harder for electrons on the N side to cross over to the P side. Eventually, equilibrium is reached, and we have an electric field separating the two sides.

This electric field acts as a **diode**, allowing (and even pushing) electrons to flow from the P side to the N side, but not the other way around. It's like a hill -- electrons can easily go down the hill (to the N side), but can't climb it (to the P side).

When light, in the form of photons, hits our solar cell, its energy breaks apart electron-hole pairs. Each photon with enough energy will normally free exactly one electron, resulting in a free hole as well. If this happens close enough to the electric field, or if free electron and free hole happen to wander into its range of influence, the field will send the electron to the N side and the hole to the P side. This causes further disruption of electrical neutrality, and if we provide an external current path, electrons will flow through the path to the P side to unite with holes that the electric field sent there, doing work for us along the way. The electron flow provides the **current**, and the cell's electric field causes a **voltage**. With both current and voltage, we have **power**, which is the product of the two.

There are a few more components left before we can really use our cell. Silicon happens to be a very shiny material, which can send photons bouncing away before they've done their job, so

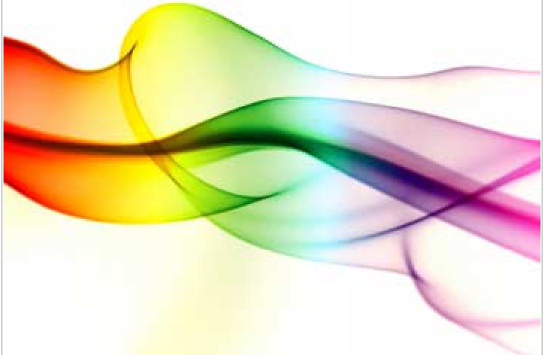
an **antireflective coating** is applied to reduce those losses. The final step is to install something that will protect the cell from the elements -- often a **glass cover plate**. PV modules are generally made by connecting several individual cells together to achieve useful levels of voltage and current, and putting them in a sturdy frame complete with positive and negative terminals.

How much sunlight energy does our PV cell absorb? Unfortunately, probably not an awful lot. In 2006, for example, most solar panels only reached efficiency levels of about 12 to 18 percent. The most cutting-edge solar panel system that year finally muscled its way over the industry's long-standing 40 percent barrier in solar efficiency -- achieving 40.7 percent [source: U.S. Department of Energy]. So why is it such a challenge to make the most of a sunny day?

Energy Loss in a Solar Cell

Visible light is only part of the electromagnetic spectrum. Electromagnetic radiation is not monochromatic -- it's made up of a range of different wavelengths, and therefore energy levels. (See How Light Works for a good discussion of the electromagnetic spectrum.)

Light can be separated into different wavelengths, which we can see in the form of a rainbow. Since the light that hits our cell has photons of a wide range of energies, it turns out that some of them won't have enough energy to alter an electron-hole pair. They'll simply pass through the cell as if it were transparent. Still other photons have too much energy. Only a certain amount of energy, measured in electron volts (eV) and defined by our cell material (about 1.1 eV for crystalline silicon),



The familiar sight of a rainbow represents just a sliver of the greater electromagnetic spectrum.
©iStockphoto.com/nataq

UP NEXT

- Solar Cell Quiz
- How Solar Thermal Power Works
- How Thin-film Solar Cells Work

is required to knock an electron loose. We call this the **band gap energy** of a material. If a photon has more energy than the required amount, then the extra energy is lost. (That is, unless a photon has twice the required energy, and can create more than one electron-hole pair, but this effect is not significant.) These two effects alone can account for the loss of about 70 percent of the radiation energy incident on our cell.

Why can't we choose a material with a really low band gap, so we can use more of the photons? Unfortunately, our band gap also determines the strength (voltage) of our electric field, and if it's too low, then what we make up in extra current (by absorbing more photons), we lose by having a small voltage. Remember that power is voltage times current. The optimal band gap, balancing these two effects, is around **1.4 eV** for a cell made from a single material.

We have other losses as well. Our electrons have to flow from one side of the cell to the other through an external circuit. We can cover the bottom with a metal, allowing for good conduction, but if we completely cover the top, then photons can't get through the opaque conductor and we lose all of our current (in some cells, transparent conductors are used on the top surface, but not in all). If we put our contacts only at the sides of our cell, then the electrons have to travel an extremely long distance to reach the contacts. Remember, silicon is a semiconductor -- it's not nearly as good as a metal for transporting current. Its internal resistance (called **series resistance**) is fairly high, and high resistance means high losses. To minimize these losses, cells are typically covered by a metallic contact grid that shortens the distance that electrons have to travel while covering only a small part of the cell surface. Even so, some photons are blocked by the grid, which can't be too small or else its own resistance will be too high.

Now that we know how a solar cell operates, let's see what it takes to power a house with the technology.

Just as flowers are best aimed toward the beaming sun, so too are solar panels.
©iStockphoto.com/AndreasWeber

UP NEXT

- Solar Cell Quiz
- How Solar Thermal Power Works
- How Thin-film Solar Cells Work

Solar-powering a House

What would you have to do to power your house with solar energy? Although it's not as simple as just slapping some modules on your roof, it's not extremely difficult to do, either.

First of all, not every roof has the correct orientation or **angle of inclination** to take full advantage of the sun's energy. Non-tracking PV systems in the Northern Hemisphere should ideally point toward true south, although orientations that face in more easterly and westerly directions can work too, albeit by sacrificing varying degrees of efficiency. Solar panels should also be inclined at an angle as close to the area's latitude as possible to absorb the maximum amount of energy year-round. A different orientation and/or inclination could be used if you want to maximize energy production for the morning or afternoon, and/or the summer or winter. Of course, the modules should never be shaded by nearby trees or buildings, no matter the time of day or the time of year. In a PV module, if even just one of its cells is shaded, power production can be significantly reduced.

If you have a house with an unshaded, southward-facing roof, you need to decide what size system you need. This is complicated by the facts that your electricity production depends on the weather, which is never completely predictable, and that your electricity demand will also vary. Luckily, these hurdles are fairly easy to clear. Meteorological data gives average monthly sunlight levels for different geographical areas. This takes into account rainfall and cloudy days, as well as altitude, humidity and other more subtle factors. You should design for the worst month, so that you'll have enough electricity year-round. With that data and your average household demand (your utility bill conveniently lets you know how much energy you use every month), there are simple methods you can use to determine just how many PV modules you'll need. You'll also need to decide on a system voltage, which you can control by deciding how many modules to wire in series.

You may have already guessed a couple of problems that we'll have to solve. First, what do we do when the sun isn't shining?

UP NEXT

- Solar Cell Quiz
- How Solar Thermal Power Works
- How Thin-film Solar Cells Work

Solving Solar Power Issues

The thought of living at the whim of the weatherman probably doesn't thrill most people, but three main options can ensure you still have power even if the sun isn't cooperating. If you want to live completely off the grid, but don't trust your PV panels to supply all the electricity you'll need in a pinch, you can use a backup generator when solar supplies run low. The second stand-alone system involves energy storage in the form of batteries. Unfortunately, batteries can add a lot of cost and maintenance to a PV system, but it's currently a necessity if you want to be completely independent.

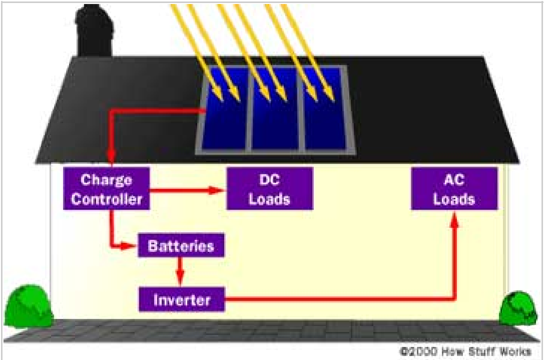
The alternative is to connect your house to the utility grid, buying power when you need it and selling it back when you produce more than you use. This way, the utility acts as a practically infinite storage system. Keep in mind though, government regulations vary depending on location and are subject to change. Your local utility company may or may not be required to participate, and the buyback price can vary greatly. You'll also probably need special equipment to make sure the power you're looking to sell the utility company is compatible with their own. Safety is an issue as well. The utility has to make sure that if there's a power outage in your neighborhood, your PV system won't continue to feed electricity into power lines that a lineman will think are dead. This is a dangerous situation called

islanding, but it can be avoided with an anti-islanding inverter -- something we'll get to on the next page.

If you decide to use batteries instead, keep in mind that they'll have to be maintained, and then replaced after a certain number of years. Most solar panels tend to last about 30 years (and improved longevity is certainly one research goal), but batteries just don't have that kind of useful life [source: National Renewable Energy Laboratory]. Batteries in PV systems can also be very dangerous because of the energy they store and the acidic electrolytes they contain, so you'll need a well-ventilated, nonmetallic enclosure for them.

Although several different kinds of batteries are commonly used, the one characteristic they should all have in common is that they are **deep-cycle batteries**. Unlike your car battery, which is a shallow-cycle battery, deep-cycle batteries can discharge more of their stored energy while still maintaining long life. Car batteries discharge a large current for a very short time -- to start your car -- and are then immediately recharged as you drive. PV batteries generally have to discharge a smaller current for a longer period of time (such as at night or during a power outage), while being charged during the day. The most commonly used deep-cycle batteries are **lead-acid batteries** (both sealed and vented) and **nickel-cadmium batteries**, both of which have various pros and cons.

On the next page, we'll dig a little deeper into the components that'll be needed for the sun to start saving you some cash.



This simple schematic shows how a residential PV system will often take shape.
HowStuffWorks 2000

UP NEXT

- Solar Cell Quiz
- How Solar Thermal Power Works
- How Thin-film Solar Cells Work

Finishing Your Solar Power Setup

The use of batteries requires the installation of another component called a **charge controller**. Batteries last a lot longer if they aren't overcharged or drained too much. That's what a charge controller does. Once the batteries are fully charged, the charge controller doesn't let current from the PV modules continue to flow into them. Similarly, once the batteries have been drained to a certain predetermined level, controlled by measuring battery voltage, many charge controllers will not allow more current to be drained from the batteries until they have been recharged. The use of a charge controller is essential for long battery life.

The other problem besides energy storage is that the electricity generated by your solar panels, and extracted from your batteries if you choose to use them, is not in the form that's supplied by your utility or used by the electrical appliances in your house. The electricity generated by a solar system is direct current, so you'll need an **inverter** to convert it into alternating current. And like we discussed on the last page, apart from switching DC to AC, some inverters are also designed to protect against islanding if your system is hooked up to the power grid.

Most large inverters will allow you to automatically control how your system works. Some PV modules, called **AC modules**, actually have an inverter already built into each module, eliminating the need for a large, central inverter, and simplifying wiring issues.

Throw in the mounting hardware, wiring, junction boxes, grounding equipment, overcurrent protection, DC and AC disconnects and other accessories, and you have yourself a system. You must follow electrical codes (there's a section in the National Electrical Code just for PV), and it's highly recommended that a licensed electrician who has experience with PV systems do the installation. Once installed, a PV system requires very little maintenance (especially if no batteries are used), and will provide electricity cleanly and quietly for 20 years or more.

Solar cells have long been a mainstay on satellites; where will they end up in the future?
©iStockphoto.com/iLexx

UP NEXT

- Solar Cell Quiz
- How Solar Thermal Power Works
- How Thin-film Solar Cells Work

Developments in Solar Cell Technology

We've talked a lot about how a typical PV system operates, but issues concerning cost-effectiveness (which we'll get into more on the next page) have spurred endless research efforts aimed at developing and fine-tuning new ways to make solar power increasingly competitive with traditional energy sources.

For example, single-crystal silicon isn't the only material used in PV cells. Polycrystalline silicon is used in an attempt to cut manufacturing costs, although the resulting cells aren't as efficient as single crystal silicon. Second-generation solar cell technology consists of what's known as **thin-film solar cells**. While they also tend to sacrifice some efficiency, they're simpler and cheaper to produce -- and they become more efficient all the time. Thin-film solar cells can be made from a variety of materials, including amorphous silicon (which has no crystalline structure), gallium arsenide, copper indium diselenide and cadmium telluride.

Another strategy for increasing efficiency is to use two or more layers of different materials with different band gaps. Remember that depending on the substance, photons of varying energies are absorbed. So by stacking higher band gap material on the surface to absorb high-energy photons (while allowing lower-energy photons to be absorbed by the lower band gap material beneath), much higher efficiencies can result. Such cells, called **multi-junction cells**, can have more than one electric field.

Concentrating photovoltaic technology is another promising field of development. Instead of simply collecting and converting a portion of whatever sunlight just happens to shine down and be converted into electricity, concentrating PV systems use the addition of optical equipment like lenses and mirrors to focus greater amounts of solar energy onto highly efficient solar cells. Although these systems are generally pricier to manufacture, they have a number of advantages over conventional solar panel setups and encourage further research and development efforts.

All these different versions of solar cell technology have companies dreaming up applications and products that run the gamut, from solar powered planes and space-based power stations to more everyday items like PV-powered curtains, clothes and laptop cases. Not even the miniature world of nanoparticles is being left out, and researchers are even exploring the potential for organically produced solar cells.

But if photovoltaics are such a wonderful source of free energy, then why doesn't the whole world run on solar power?

Solar cells might still be a little pricey, but they're getting cheaper year by year.
©iStockphoto.com/acilo

UP NEXT

- Solar Cell Quiz
- How Solar Thermal Power Works
- How Thin-film Solar Cells Work

Solar Power Costs

Some people have a flawed concept of solar energy. While it's true that sunlight is free, the electricity generated by PV systems is not. There are lots of factors involved in determining whether installing a PV system is worth the price.

First, there's the question of where you reside. People living in sunny parts of the world start out with a greater advantage than those settled in less sun-drenched locations, since their PV systems are generally able to generate more electricity. The cost of utilities in an area should be factored in on top of that. Electricity rates vary greatly from place to place, so someone living farther north may still want to consider going solar if their rates are particularly high.

Next, there's the installation cost; as you probably noticed from our discussion of a household PV system, quite a bit of hardware is needed. As of 2009, a residential solar panel setup averaged somewhere between $8 and $10 per watt to install [source: National Renewable Energy Laboratory]. The larger the system, the less it typically costs per watt. It's also important to remember that many solar power systems don't completely cover the electricity load 100 percent of the time. Chances are, you'll still have a power bill, although it'll certainly be lower than if there were no solar panels in place.

Despite the sticker price, there are several potential ways to defray the cost of a PV system for both residents and corporations willing to upgrade and go solar. These can come in the form of federal and state tax incentives, utility company rebates and other financing opportunities. Plus, depending on how large the solar panel setup is -- and how well it performs -- it could help pay itself off faster by creating the occasional surplus of power. Finally, it's also important to factor in home value estimates. Installing a PV system is expected to add thousands of dollars to the value of a home.

Right now, solar power still has some difficulty competing with the utilities, but costs are coming down as research improves the technology. Advocates are confident that PV will one day be cost-effective in urban areas as well as remote ones. Part of the problem is that manufacturing needs to be done on a large scale to reduce costs as much as possible. That kind of demand for PV, however, won't exist until prices fall to competitive levels. It's a catch-22. Even so, as demand and module efficiencies rise constantly, prices fall, and the world becomes increasingly aware of the environmental concerns associated with conventional power sources, it's likely photovoltaics will have a promising future.

For more information about solar cells and related topics, check out the links on the next page.

UP NEXT

- Solar Cell Quiz
- How Solar Thermal Power Works
- How Thin-film Solar Cells Work

Lots More Information

Related HowStuffWorks Articles

- Solar Cell Quiz
- How Solar Thermal Power Works
- Are solar-powered vehicles still a possibility?
- Could luminescent solar concentrators make solar power more affordable?
- How Geothermal Energy Works
- How Batteries Work
- How Circuits Work
- How Semiconductors Work
- How a Microgrid Works
- How Power Grids Work
- Top 5 Solar-powered Gadgets
- Why is it so hard to cut dependence on gasoline?

More Great Links