FAQ List for Solar Cells

1. What is photovoltaics?

Photovoltaics is the direct conversion of sunlight into electricity using the physical mechanism called the photovoltaic effect.

2. How is photovoltaics different than other solar energy conversion technologies?

There are a variety of ways to convert sunlight into useful energy. One method used for many centuries is to convert sunlight into heat, which can then be used for building heating or water heating. Two common examples of solar energy into heat are solar pool heating and solar water heaters. There are also two ways to convert sunlight into electricity. One is solar thermal electricity generation, which uses much of the technology from conventional utility electricity generation. In most utility electricity generation, heat is generated by burning a fuel such as coal or by a nuclear reaction, and this heat is turned into electricity. In solar thermal generating systems, the heat is created by focusing sunlight onto a spot rather than burning fuels, but the remainder of the electricity generation process is the same as conventional utility generation. Photovoltaics is another mechanisms for converting sunlight into electricity. Photovoltaics, (also called solar electricity, solar batteries or solar cells) are fundamentally different in that they convert sunlight directly into electricity without intermediate steps.

3. How does a solar cell work?

Solar cells (or photovoltaic devices) directly convert light into electricity, and usually use similar physics and technology as that used by the microelectronics industry to make computer chips. The first step in the conversion of sunlight into electricity is that light must be absorbed in the solar cell. The absorbed light causes electrons in the material to increase in energy, at the same time making them free to move around in the material. However, the electrons remain at this higher energy for only a short time before returning to their original lower energy position. To collect the carriers before they lose the energy gained from the light, a *pn* junction is typically used.

A pn junction consists of two different regions of a semiconductor material (usually silicon), with one side called the p-type region and the other the n-type region. In p-type material, electrons can grain energy when exposed to light but also readily return to their original low energy position. However, if they move into the n-type region, then they can no longer go back to their original low energy position and remain at a higher energy. The process of moving a light-generated carrier from where it was originally generated to the other side of the pn junction where it retains its higher energy is called collection.

Once a light generated carrier is collected, it can be either extracted from the device to give a current, or it can remain in the device and gives rise to a voltage. The generation of a voltage due to the light generated carriers is called the photovoltaic effect. Typically, some of the light generated carries are used to give a current, while others are used to create a voltage. The combination of a current and voltage give rise to a power output from the solar cell. The electrons that leave the solar cell as current give up their energy to whatever is connected to the solar cell, and then re-enter the solar (in the n-type region) at their original low energy level. Once back in the solar cell, the process begins again: an electron absorbs light and gains energy, the electron is collected by the pn junction, it leaves the device to dissipate its energy in a load, and then re-enters the solar cell.

4. What is solar cell efficiency and why do numbers of efficiency appear to vary so widely?

Solar cells are often characterised by the percentage of the incident power that they convert into power, called the power conversion efficiency or just efficiency. The efficiency is given by a percentage. The efficiency of a solar cell is determined by the material from which it is made and by the production technology used to make the solar cell. Efficiencies for commercially available solar cells range from about 5% to about 17%. The bulk of the commercial market consists of bulk silicon solar cells, and the research or laboratory efficiency of these is close to 25%. Space applications, where efficiency is more important, often use a different solar cell technology and may consist of solar cells made from different materials stacked on top of one another. The efficiency of these solar cells is up to 33%. The theoretical efficiency limit of solar energy conversion given completely idealized conditions and materials is 86%, but given present technology, solar cells that can potentially be made have a theoretical conversion efficiency closer to 50%.

In addition to the power conversion efficiency, other methods to characterise solar cells also contain the word efficiency and are also given by a percentage. For example, the quantum efficiency measures, at a given wavelength of light, how much of the incident light is turned into current – **not** power. Quantum efficiency is a chiefly a method of analyzing devices used by specialists in the area and does not simply or directly relate its power conversion efficiency. For solar cells that have **power conversion efficiencies** of 15%, the **quantum efficiencies** may routinely reach over 90%. For newer or experimental solar cells, the quantum efficiency is often much lower, about 30%, and the power conversion efficiency is often less than 10%. The quantum efficiency and power conversion efficiency are sometimes confused in press or non-specialist articles, leading to apparent claims of very high solar cell efficiencies.

5. What are the different solar cell technologies?

Solar cell technologies differ from one another based firstly on the material used to make the solar cell and secondly based on the processing technology used to fabricate the solar cells. The material used to make the solar cell determines the basic properties of the solar cell, including the typical range of efficiencies.

Most commercial solar cells for use in terrestrial applications (i.e., for use on earth) are made from wafers of silicon. Silicon wafer solar cells account for about 85% of the photovoltaic market. Silicon is a semiconductor used extensively to make computer chips. The silicon wafers can either consist of one large singe crystal, in which case they called single crystalline wafers, or can consist of multiple crystals in a singe wafer, in which case they are called multicrystalline silicon wafers. Single crystalline wafers will in general have a higher efficiency than multicrystalline wafers. Silicon wafers used in commercial production allow power conversion efficiencies of close to 20%, although the fabrication technologies at present limit them to about 17 to 18%. Multicrystalline silicon wafers allow power conversion efficiencies of up to 17%, with present fabrication achieving between 13 to 15%.

The efficiency achieved by a solar cell depends on the processing technology used to make the solar cell. The most commonly used technology to make wafer-based silicon solar cells is screen-printed technology, which achieves efficiencies of 11-15%. Higher efficiency technologies are the buried contact or buried grid technology, which achieves efficiencies op up to 18% and has been in production for about a decade.

Although silicon solar cells are the dominant material, some applications – particularly space applications – require higher efficiency than is possible from silicon or other solar cell technologies. Solar cells made from GaAs or related materials (called III-V materials since they are ingeneral made from groups III and V of the periodic table) have a higher efficiency than silicon solar cells, particularly for the spectrum of light that exists in space. GaAs solar cells have efficiencies of up to 25% measured under terrestrial conditions. To further increase these efficiencies, solar cells made from different kinds of materials are stacked on top of one another. Such devices are called tandem or multijunction solar cells (the term multijunction applies to other types of structures as well). Such solar cells have efficiencies of up to 33% (under concentration, see below).

A final class of solar cell materials is called thin film solar cells. These solar cells can be made from a variety of materials, with the key characteristic being that the thickness of the devices is a fraction of other types of solar cells. Thin film solar cells may be made either from amorphous silicon, cadmium telluride, copper indium diselenide or thin layers of silicon. The efficiencies of thin film solar cells tend to be lower than those of other devices, but to compensate for this the production cost can also be significantly lower. Of these technologies, amorphous silicon is the best developed, and laboratory efficiencies are between 10 to 12%, with commercial efficiencies just over half these efficiencies. The other thin film technologies are still the subject of development, although commercial products exist. The efficiency of these devices is about 6% to 10% efficient.

Most solar cells will theoretically operate with a higher efficiency under intense sunlight than under the conditions encountered on earth. Concentrator solar systems exploit this effect, by focusing sunlight into a concentrated spot or line. Concentrator systems exist for both silicon and III-V solar cells. Silicon concentrator systems have reached efficiencies of 28% while III-V based systems have reached about 33%.

6. What is the difference between a solar cell and a photovoltaic panel or array?

A solar cell is a single device. A photovoltaic or solar panel consists of multiple solar cells connected together into a single unit to protect the solar cells and increase the voltage and power above that of a single solar cell. Typically, you cannot buy solar cells, only photovoltaic panels. “Photovoltaic panel” and “photovoltaic array” are sometimes used interchangeably, but a photovoltaic array refers to all of the photovoltaic panels in particular systems that are connected together.

7. What type of electricity is produced by a PV panel?

PV panels produce DC power, which stands for direct current. This is the same type of power as in a battery, but is different to that produced by the utility company, which is AC power. “AC” stands for “alternating current”. DC power is converted into AC power via an inverter, which may be incorporated into some types of PV modules, such that these modules produce AC power.

8. How much power is produced by a PV panel and what does the standard rating mean?

A PV panel is rated in terms of the power it would produce under standard light intensity conditions called AM1.5 and at room temperature. For most locations, the standard light intensity rating is about the amount of light produced at noon in summer on a sunny day. (Locations close the equator or at higher altitudes may exceed this at certain times of the year, while locations far away from the equator will not reach this level). For climates at latitudes of about 30° above or below the equator, you can multiply the rating of the panel by 5 to get the amount of kWhr produced per day to get a rough estimate of the energy produced. For higher latitudes, multiply the rated power of the panel by about 3.

9. How much photovoltaic power do I need for a given application?

Detailed calculations and system designs are often calculated using computer programs, but rough estimates can be determined by a simple rule of thumb. The rule of thumb for locations around 30° above or below the equator is:

$$\text{PV power needed} = \frac{\text{Total daily load in kWhr}}{4}$$

The total daily load in kWhr can be determined from either your utility bill (which will usually lists your daily energy consumption in kWhr), or by finding the power used by the appliance in kilowatts (1 kW = 1,000 Watts) and multiplying by the number of hours used. The power used by an appliance is often listed on either the box or somewhere on the appliance. An apartment will usually have a load of about 10 kWhr per day. Large variations from this number can be experienced in the daily load if the dwelling or the water heater uses electric heating. Heating loads are very energy intensive, and in a system using PV-generated electricity, such heating loads would be switched to solar (ie., not solar electric), gas or oil heating. For locations at higher latitudes, the load in the above equation should be divided by a lower number (3 is often a reasonable estimate), while locations closer to the equator or in high sunlight desert regions can use higher numbers (5 to 6).

10. What are common PV applications?

PV products are used in many different applications, covering a power range from 0.0001 Watts to 2,000,000 Watts. Traditionally, the most common application of PV has been for electrical loads that cannot be easily plugged into the electricity grid, either because they should be transportable – such as solar calculators, watches etc – or because the electricity grid does not exist at a particular location. When the grid is located far away from a particular application, PV is being used to provide "remote power". Examples of these applications are houses not connected to grid power, telecommunications, remote villages, water pumping and space. However, a recent and rapidly growing application for photovoltaics is for residential or building integrated which are connected to the electricity grid. During the day, power is used from photovoltaics, and at night power is used from the electricity grid. A final application is utility-scale photovoltaics, in which a utility company installs a large amount of photovoltaic power. These larger systems, which are far less common than other applications, are typically installed to achieve a specific technical goal.

11. Do solar cells produce more energy than is used during their manufacture?

Yes. The amount of time it takes for a technology to produce more energy than was used in their manufacture is called the energy payback time. Solar cells have an energy payback time ranging from a few months to 6 years, depending on the type of materials, the type of solar cell and where it is used. Solar cells have warranties well in excess of these numbers, typically 20 years. The origin of the popular myth that solar cells do not produce enough energy in their lifetime to recover the energy in making them is unknown, as every published study has shown that solar cells produce more energy in their lifetime than the energy used in production.

12. How much does PV power cost?

To buy a photovoltaic panel in small consumer quantities presently costs about $5/Watt. This number can vary widely depending on the amount of photovoltaic panels bought. Furthermore, installation and other component costs can up to double this number. An estimate for the installed price of a residential system is about $7/Watt, for a remote system up to $10/Watt. Although less common, a PV panel may also be priced in $/m². When priced in this way, it is difficult to compare to other panels priced in $/Watt, since the conversion factors depend on the panel efficiency, which is usually not given. It can however, be possibly determined by the power produced and the module area.

13. Is photovoltaics economically viable?

This question depends completely on the application for which you are trying to use PV – PV is clearly the lowest cost power source in some cases but in other it may be one of the more expensive options. In general, PV becomes more economic as the size of the load becomes smaller and farther away from grid power. If grid power is not available and the load is that of a typical household or less, a PV system is usually the lowest cost option. Similarly, for consumer appliances, PV is usually a factor of 10 to 100 cheaper than battery power. For cases where reliable grid power is readily available, PV is usually not the lowest cost option, unless other considerations such as environmental impact or different financing schemes are factored in. However, even in these cases, the economic viability of PV varies widely. PV is typically not technically or economically suited to the provision of large base-load power for utilities, but may be suited to power production for individual houses in locations with high peak electricity prices occurring during the day. For grid-connected applications, the costing of a PV system for a particular location and application needs to be considered on a case-by-case basis or at least region-by-region basis.

14. How does the cost of PV electricity compare to electricity generated by other means?

This is a complex question, and requires a fairly lengthy answer. To ignore the explanation and reasons why it is difficult, skip to the last paragraph in this section.

Comparing the cost of renewable energy technologies to conventional electricity sources is inherently difficult. PV panels, in common with other renewable energy technologies, are most commonly sold or prices quoted in terms of ***power*** (***Watts W or kilo-Watts kW***)– which does not have a time component – whereas utility companies or batteries usually quote electricity prices in terms of ***energy (kilo-Watt-hours or kWhr)***, which is power × time. This difference is inherent due to the fundamental differences between renewable and conventional energy technologies. In renewable energy technologies, the major cost is incurred at the initial purchase of the system. Since there are no fuel costs, the price essentially stays the same regardless of the time over which it is used. Hence power, which has no time component, makes most sense in quoting prices. However, for conventional generating systems, where the time of operation is a major cost component, electricity prices must include the time over which power is used and hence utility companies quote prices for energy (power × time), not just power. When comparing electricity costs for renewable and conventional electricity generation, this time component must be accounted for.

The energy costs of a renewable energy system can calculated by determining the energy it will produce in its 20+ year lifetime life and the total cost over its lifetime. However, comparing these costs to conventional electricity prices can be tricky. One issue is that this comparison is for the cost of PV over the *next* 20 years, while the electric prices are *present* prices, usually based on a plant that has been existence for a long time. Correcting for this factor involves estimating what conventional electricity prices will do over the next 20 years, which is notoriously difficult. Even determining the true *present* conventional electricity costs can be difficult due to the debate on the level of subsidies provided to electricity generation and hence its true cost. An additional problem is that the costs tend to be highly sensitive to the assumptions made in the analysis. For example, costs associated with borrowing money for the photovoltaic system can double the cost of the PV system. Also, the costs are sensitive to the assumptions about the amount of sunlight and the location of the PV system. Locations with high sunlight will have a lower PV electricity cost, although the cost of the system is the same. Finally, renewable energy systems may also receive subsidies when they are installed, but these vary from country to country and these effects cannot be easily generalized.

With the above disclaimers, estimates of photovoltaic system energy cost that include all the costs of borrowing money but assume a reasonably optimum location (such as the desert regions of Southern California or other high sunlight regions) and do not include any rebates or subsidies usually arrive at numbers in the range of 20 to 40¢/kWhr. As a rough comparison, many customers in the US pay about 8 ¢/kWhr for their electricity. Recently, prices in California have reached 22 ¢/kWhr. Overseas, electricity prices tend to be higher. In Japan and Europe, electricity prices have historically been in the range of 15 to 25 ¢/kWhr (note that this number is complicated by exchange rate variations among currencies and is presently decreased by the high US dollar).

15. What companies make PV cells and products?

The following is a partial list of large PV manufacturers. In addition to other large PV companies, there are also numerous smaller local retailers do not fabricate solar cells, but rather sell PV system components and also provide design assistance, installation or maintenance. Check your local telephone listings for such services.
A good site that lists manufacturers is:
http://www.solarbuzz.com/CellManufacturers.htm

16. What are the advantages and disadvantages of photovoltaics?

Photovoltaic systems have many advantages. In many types of applications, PV systems have several important ***technical*** advantages that make them the best choice for electricity generation. PV panels are extremely reliable and require low maintenance, they can operate for long periods unattended, they are suitable for both large and small loads and additional generating capacity can be readily added. These characteristics make photovoltaics an ideal technical choice for both remote power and remote residential electricity applications. For such remote applications, a PV-based system is also usually the lowest cost system. There are a number of additional technical advantages, such as the distributed nature of PV power production and the low lead times to installation, which may be beneficial in grid-connected installations. In addition to its technical advantages, photovoltaics electricity generation is also environmentally benign, with arguably the lowest environmental impact of any of the electricity generating technologies.

The key disadvantage of photovoltaics is its relatively high cost compared to many other large-scale electricity generating sources. This disadvantage applies mainly to the use of PV for applications that are already tied to the electricity grid. Another disadvantage is that the power density of sunlight is relatively low. This means PV tends to be less suited to applications that are physically small compared to the amount of power they require. This affects primarily transport applications. Although solar cars, solar trains, solar planes and solar boats have all been made and used, in general these applications are difficult for PV or other solar-based systems.

17. What do you do for power at night?

A photovoltaic stand-alone system (i.e., no other generating components) will include some storage system – usually batteries – is power is needed at night. For residential systems that are connected to the utility grid, the power is used from the electricity grid at night.

18. How long to does a photovoltaic system last?

Photovoltaic systems are very robust and reliable, since there are no moving parts. A photovoltaic system would be expected to last in excess of 20 years. Many manufacturers have 20-year warranties on the photovoltaic modules. The electronic components can also be made reliable, since again there are no moving parts, but the warranties on these systems tend to be lower, about 5 years. If the photovoltaic system contains batteries (most stand-alone systems to and residential grid-connected do not), then the batteries will need to be replaced every 5 to 10 years.

19. What are the components of a photovoltaic system?

The possible components of a PV system are a power conditioning sub-system, a storage mechanism, and other general components called “balance of system” components. The power conditioning sub-system serves of two basic functions. One component of a power sub-system is often called a charge controller, which ensures that a battery in the system is correctly charged from the photovoltaic array. The second component is typically an inverter, which usually converts the low DC voltage of the photovoltaic system into the same type of power (higher voltage AC) produced by the utility company. In the US, the utility company produces 120 V at 60 Hz. Depending on the type of application, the inverter may also serve several other functions, such as battery charging or may disconnect the system from the utility when necessary. Another possible component of a photovoltaic system is the storage system. When included, this is usually battery storage, consisting of lead-acid batteries modified from those in cars in order to allow large amounts of energy to be drawn from them. Other system components are usually grouped under the term “balance of system (or BOS) components” and include the wiring of the photovoltaic array, the array mounting, battery housing, etc.

The actual components of a photovoltaic system depend on what the system will be used to power. For example, if the load is DC, then the inverter (which converts AC to DC) is not needed. Similarly, if the system is connected to the utility grid, the storage (and hence a charge controller) is not needed, while the inverter is.

20. Is there enough sunlight to make a contribution to the world’s energy needs?

Yes. The earth receives more energy from the sun in just one hour than the world uses in a whole year.

21. How can I participate in renewable energy programs?

In addition to the installation of photovoltaics on your roof, each country typically has a variety of “green energy” programs in place, by which you but electricity generated from renewable energy sources.