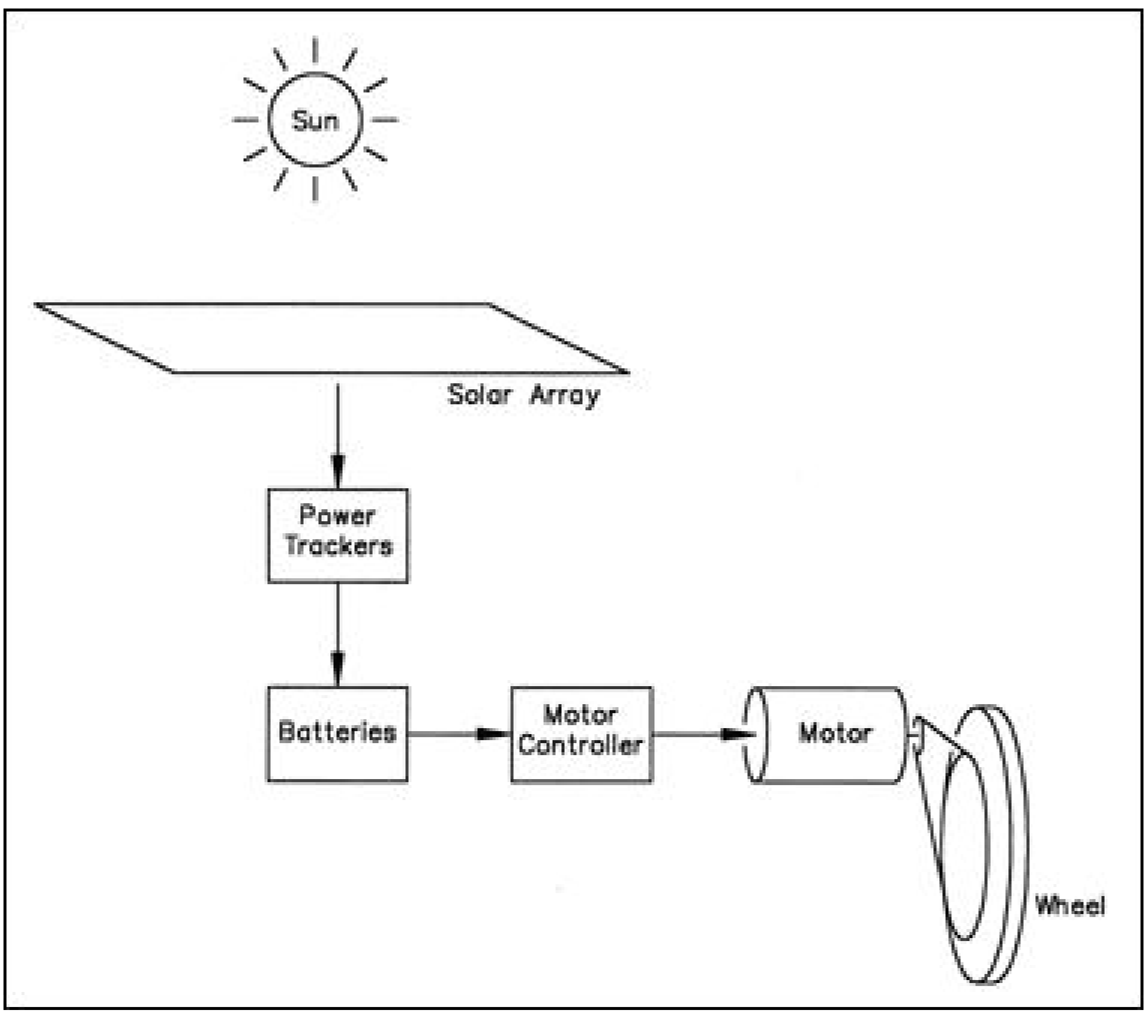
Please read and re-read as many times needed in order to understand the inner workings of the solar car. The info in this section before Advanced is from William Shih, Northview Solar Racing Team, and is available on the Solar Car Challenge website.

Solar cars are powered by the sun's energy. The main component of a solar car is its solar array, which collects the energy from the sun and converts it into usable electrical energy. The solar cells collect a portion of the sun's energy and stores it into the batteries of the solar car. Before that happens, power trackers converts the energy collected from the solar array to the proper system voltage, so that the batteries and the motor can use it. After the energy is stored in the batteries, it is available for use by the motor & motor controller to drive the car. The motor controller adjusts the amount of energy that flows to the motor to correspond to the throttle. The motor uses that energy to drive the wheels.



Solar Array and Power Trackers

Solar cells should be wired in series on a panel and should be divided into several zones. For example, if you have 750 solar cells, you might want to wire 3 sets of 250 cells, each zone producing about 125 volts. If one zone fails, two other zones are still producing power. The solar array voltage does not need to match the system voltage of the motor if you use power trackers. Power trackers convert the solar array voltage to the system voltage. They are essential in a solar car. Be sure to verify with the power tracker vendor the necessary array voltage to feed the power trackers. If the car drives underneath shade, the power trackers automatically adjusts the power to match system voltage, allowing the system to run as efficient as possible.
There are 3 types of trackers- boost, buck and boost/buck. Boost will step up voltage, buck will step down voltage, and boost/buck will do both.

Another thing to consider when creating solar arrays is shading. Not only does shading reduce power output by reducing the amount of sunlight hitting the panels, it will

Batteries

The batteries store energy from the solar array and makes them available for the motor's use. Many different types of batteries are sold. Lead acids are a popular choice because of their relative inexpensive price, however that comes at the price of weight. Lithium ion batteries are much lighter, but much more expensive. Another choice teams must make is running with flooded-cell batteries or gel-cell batteries. Flooded-cell batteries are the standard automotive batteries filled with liquid sulfuric acid. They are preferred because they can be overcharged without risk of blowing up, but they weigh more than gel-cell batteries. Gel-cell are sealed and lightweight, but when charging the batteries, check the battery voltage often.
The number of batteries to choose depends on the motor (system) voltage. E.g. if the system voltage is 72 volts, you will need 6 12-volt batteries. Buy a battery system with as many watt-hours as allowed by the rules to maximize the amount of energy you can store.

Motor & Controller

DC brushed permanent magnet motors are inexpensive and easy to hook up which makes these motors are desirable for high school teams with little financial support. Expect a maximum efficiency of 80-90%. For teams with more money, brushless motors increase the efficiency of the motor to the 94-99% range. Also, some motor and controller setups allow for regenerative braking, which allows the solar car to put energy back into the batteries when going downhill. For the beginning team, DC brushed motors would be sufficient to get a solar car up and running. Another variable in choosing a motor is how much power it has. We have found that there is little need to have more than 5hp continuous power output on our motors. Controllers usually drive a particular motor. Once you choose the motor that suits your needs, the same vendor would most likely have a matching controller.

Instrumentation/Telemetry

One of the most important pieces of instrumentation is a state-of-charge meter. A state-of-charge meter gives information about system voltage, amp draw, battery energy remaining, and estimates how much time remains until the battery is out of energy. Voltage is measured using a volt-meter and amperage is measured using a shunt resistor. Remaining battery capacity is measured using voltage and the percentage is calculated based off nominal battery voltage. Another instrument that may be useful is a speedometer. Instead of using a regular speedometer drive, use magnetic contact speedometers, found in many sports equipment stores. This option does not add drag to your car. To ensure that your batteries are running properly, you may invest in getting a voltmeter for each of your batteries. A failed battery may show the proper voltage when the car is not running, but while the battery is under load, the voltmeter will show a lower than normal battery voltage.

Another thing to consider is wireless transmission of telemetry. Many teams will have a method of wireless transmission of data (e.g. voltage level, speed, etc) so that they can tell the car to slow down or speed up. The transmission, processing, and communication of this data is just as crucial as any other part of the car as it could mean the difference between a charged car, and a car that has no charge and has to be trailered off the track.

Steering & Suspension

We strongly recommend front wheel steering as it tends to be more stable and safer. A solar car uses energy frugally if it is to be competitive. If there are two front wheels, it is therefore advisable to work out the geometry so that they run parallel when the car is going straight ahead, but when the car is turning, the front wheels turn at different radii. If the car is turning left, the left front tire is making a smaller circle than the right front tire. If the tires remain parallel while turning, they will cause unnecessary drag, decreasing tire life and overall performance.

The only advice we can offer with respect to suspension is that it should be soft enough to protect the car and solar array from unnecessary jolts and firm enough to provide a stable ride.

Brakes

Disc brakes are desirable as they are predominantly hydraulic. Having hydraulic lines running to the wheels can be easier than mechanical brake arrangements. The most significant problem with disc brakes is that the brake pads do not back away from the brake rotors when pressure is released, they just relieve braking pressure. Because the pads don't normally back away from the rotors, they continue to have a small amount of drag. While this drag may not be noticeable on the family car, it is very inefficient on solar cars. Go kart shops now have brake calipers that are spring loaded to move the pads away from the rotors. We have found these very worthwhile.

Tires & Hubs

Tire selection will affect rolling resistance which affects how far the solar car will travel with the energy available. Tires with thicker rubber and wider tread tend to have higher rolling resistance (a bad thing). Thinner tires with higher pressure have less rolling resistance, but are more susceptible to flats. They are very thin and operate at over one hundred pounds/inch pressure.

Unfortunately, they need to be mounted on specially made wheels and require custom made hubs. On the good side, these tires and wheels are very light. Some college teams have experimented with bicycle tires but report limited success (bicycle tires, rims and spokes are not designed for the forces placed on them by non-tilting vehicles that weigh several hundred pounds). Motorcycle tires tend to have more resistance, although there may be high pressure tires with low resistance that we don't know about yet.

Bearing resistance can be reduced by light minimal lubrication. Bearing seals can be cut away at the contact lip to leave most of the seal protection while removing most if not all seal drag. It is a good idea to get the rolling chassis operational months before your schedule gets critical. Run the chassis as many miles as possible to prove that your bearings, axles, steering and suspension can survive.

Advanced

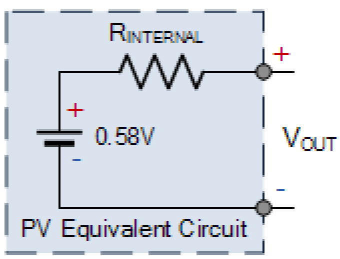
How Solar Cells Work

**Read the following section after reading "Electrical Information Solar Car"*

Solar cells are made from layers of silicon semiconductor materials. One layer of silicon is treated with a substance to create an excess of electrons. This becomes the negative or N-type layer. The other layer is treated to create a deficiency of electrons, and becomes the positive or P-type layer similar to transistors and diodes. When assembled together with conductors, this silicon arrangement becomes a light-sensitive PN-junction semiconductor. In fact photovoltaic solar cells or PV's as they are more commonly called, are no more than big, flat photo sensitive diodes.

Photovoltaic solar cells convert the photon light around the PN-junction directly into electricity without any moving or mechanical parts. PV cells produce energy from sunlight, not from heat. In fact, they are most efficient when they are cold!. For each change in degree from a certain temperature, the efficiency of the panel will change a certain amount, which is called the temperature coefficient, which tells you how much efficiency the panel will lose for each degree above 25 degrees C. E.g. a panel with an efficiency of 17%, and a temperature coefficient of -0.45 will have it's efficiency fall to 16.7% at 30 degrees C.

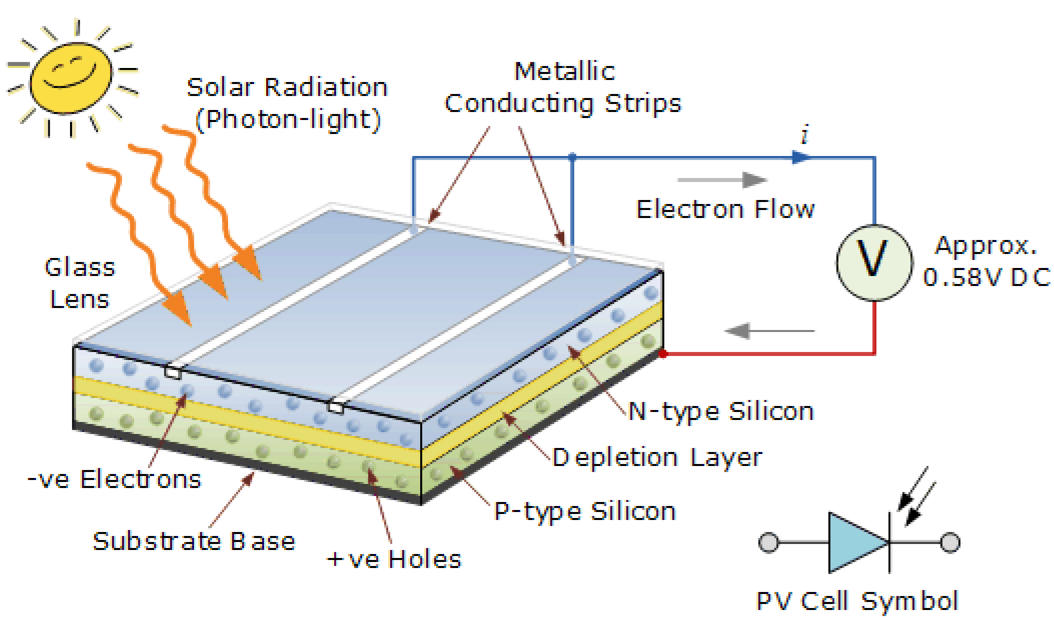
When exposed to sunlight (or other intense light source), the voltage produced by a single solar cell is about 0.58 volts DC, with the current flow (amps) being proportional to the light energy (photons). In most photovoltaic cells, the voltage is nearly constant, and the current is proportional to the size of the cell and the intensity of the light.



The equivalent circuit of a PV, shown on the left, is that of a battery with a series internal resistance, $R_{INTERNAL}$, similar to any other conventional battery.

When sunlight shines on a photovoltaic cell, photons of light strike the surface of the semiconductor material and liberate electrons from their atomic bonds. During manufacture certain doping chemicals are added to the semiconductors composition to help to establish a path for the freed electrons. These paths creates a flow of electrons forming an electrical current which starts to flow over the surface of the photovoltaic solar cell.

Metallic strips are placed across the surface of a photovoltaic cell to collect the electrons which form the positive (+) connection of the cell. The back of the cell, the side away from the incoming sunlight consists of a layer of aluminium or molybdenum metal which forms the negative (–) connection to the cell. Then a photovoltaic solar cell has two electrical connections for conventional current flow, one positive, and one negative, as shown.



The type of solar power produced by a photovoltaic solar cell is DC the same as from a battery. Most photovoltaic solar cells produce a “no load” open circuit voltage of about 0.5 to 0.6 volts when there is no external circuit connected. This output voltage (VOUT) depends very much on the load current (I) demands of the PV cell.

For example on very cloudy or dull day the current demand would be low and so the cell could provide the full output voltage, but at a reduced output current. But as the current demand of the load increases a brighter light (solar radiation) is needed at the junction to maintain a full output voltage, VOUT

However, there is a physical limit to the maximum current that a single photovoltaic solar cell can provide no matter how intense or bright the suns radiation is. This is called the maximum deliverable current and is symbolised as IMAX

The IMAX value of a single photovoltaic solar cell depends upon the size or surface area of the cell (especially the PN-junction), the amount of direct sunlight hitting the cell, its efficiency of converting this solar power into a current and of course the type of semiconductor material that the cell is manufactured from either silicon, gallium arsenide, cadmium sulphide or cadmium telluride etc

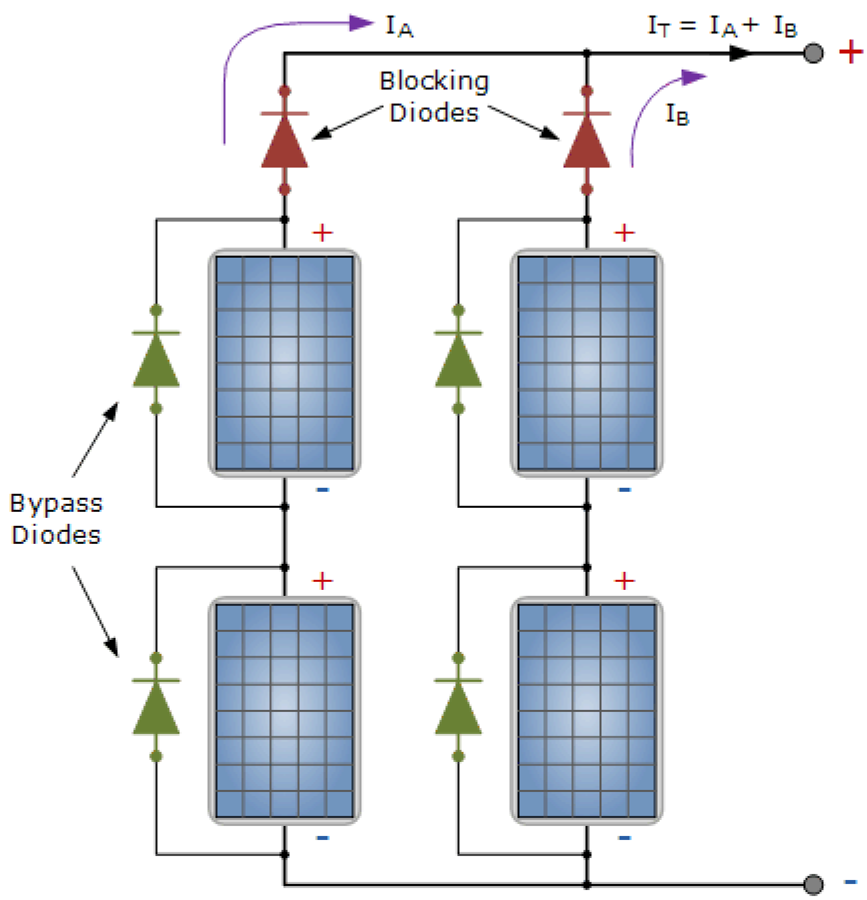
Diodes in Photovoltaic Arrays

The PN-junction diode acts like solid state one way electrical valve that only allows electrical current to flow through themselves in one direction only. The advantage of this is that diodes can be used to block the flow of electric current from other parts of an electrical solar circuit. When used with a photovoltaic solar panel, these types of silicon diodes are generally referred to as *Blocking Diodes*.

Bypass Diodes are used in parallel with either a single or a number of photovoltaic solar cells to prevent the current(s) flowing from good, well-exposed to sunlight solar cells overheating and burning out weaker or partially shaded solar cells by providing a current path around the bad cell. Blocking diodes are used differently than bypass diodes.

Bypass diodes in solar panels are connected in "parallel" with a photovoltaic cell or panel to shunt the current around it, whereas blocking diodes are connected in "series" with the PV panels to prevent current flowing back into them. Blocking diodes are therefore different than bypass diodes although in most cases the diode is physically the same, but they are installed differently and serve a different purpose. Consider our photovoltaic solar array below.

Bypass Diodes in Photovoltaic Arrays



As we said earlier, *diodes* are devices that allow current to flow in one direction only. The diodes coloured green above are "bypass diodes", one in parallel with each solar panel to provide a low resistance path. Bypass diodes in solar panels and arrays need to be able to safely carry this short circuit current.

The two diodes coloured red are referred to as the “blocking diodes”, one in series with each series branch. Blocking diodes are different than bypass diodes, but in most cases the two diodes are physically the same. However they are installed differently and serves a different purpose.

These blocking diodes, also called a series diode or isolation diode, ensure that the electrical current only flows in one direction “OUT” of the series array to the external load, controller or batteries.

The reason for this is to prevent the current generated by the other parallel connected PV panels in the same array flowing back through a weaker (shaded) network and also to prevent the fully charged batteries from discharging or draining back through the array at night. So when multiple solar panels are connected in parallel, blocking diodes should be used in each parallel connected branch.

Generally speaking, blocking diodes are used in PV arrays when there are two or more parallel branches or there is a possibility that some of the array will become partially shaded during the day as the sun moves across the sky. The size and type of blocking diode used depends upon the type of photovoltaic array.

Two types of diodes are available as bypass diodes in solar panels and arrays: the PN-junction silicon diode and the schottky barrier diode. Both are available with a wide range of current ratings. Most manufacturers include both blocking diodes and **bypass diodes** in their solar panels simplifying the design.

If panels are connected in series, and one is producing a lower amperage, then the whole string will only produce that low amperage, even if the other panels can produce more amperage.

How MPPT Works

This section covers the theory and operation of "Maximum Power Point Tracking" as used in solar electric charge controllers.

An MPPT, or maximum power point tracker is an electronic DC to DC converter that optimizes the match between the solar array (PV panels), and the battery bank or utility grid. To put it simply, they convert a higher voltage DC output from solar panels (and a few wind generators) down to the lower voltage needed to charge batteries.

(These are sometimes called "power point trackers" for short - not to be confused with PANEL trackers, which are a solar panel mount that follows, or tracks, the sun).

Most PV panels are built to put out a nominal 12 volts. The catch is "nominal". In actual fact, almost all "12-volt" solar panels are designed to put out from 16 to 18 volts. The problem is that a nominal 12-volt battery is pretty close to an actual 12 volts - 10.5 to 12.7 volts, depending on state of charge. Under charge, most batteries want from around 13.2 to 14.4 volts to fully charge - quite a bit different than what most panels are designed to put out. Catch #1 is that it is rated at 130 watts at a particular voltage and current. The Kyocera KC-130 is rated at 7.39 amps at 17.6 volts. (7.39 amps times 17.6 volts = 130 watts).

Why 130 Watts does NOT equal 130 watts

Where did my Watts go?

So what happens when you hook up this 130-watt panel to your battery through a regular charge controller?

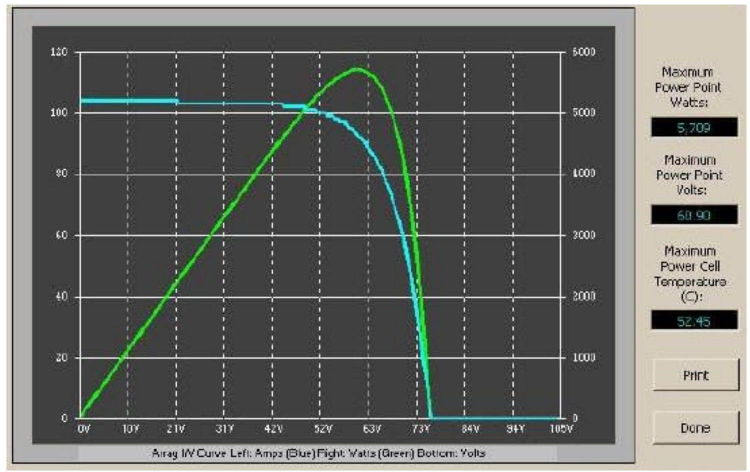
Unfortunately, what happens is not 130 watts.

Your panel puts out 7.4 amps. Your battery is sitting at 12 volts under charge: 7.4 amps times 12 volts = 88.8 watts. You lost over 41 watts - but you paid for 130. That 41 watts are not going anywhere, it just is not being produced because there is a poor match between the panel and the battery. With a very low battery, say 10.5 volts, it's even worse - you could be losing as much as 35% (11 volts x 7.4 amps = 81.4 watts. You lost about 48 watts. [technical note: that lost power is actually getting converted into heat. It's not actually missing, it's just not usable by the charge controller.]

Here is where the optimization or maximum power point tracking comes in. Assume your battery is low, at 12 volts. An MPPT takes that 17.6 volts at 7.4 amps and converts it down so that what the battery gets is now 10.8 amps at 12 volts. Now you still have almost 130 watts, and everyone is happy.

Ideally, for 100% power conversion you would get around 11.3 amps at 11.5 volts, but you have to feed the battery a higher voltage to force the amps in. And this is a simplified explanation - in actual fact, the output of the MPPT charge controller might vary continually to adjust for getting the maximum amps into the battery.

If you look at the green line, you will see that it has a sharp peak at the upper right - that represents the maximum power point. What an MPPT controller does is "look" for that exact point, then does the voltage/current conversion to change it to exactly what the battery needs. In real life, that peak moves around continuously with changes in light conditions and weather.



How a Maximum Power Point Tracker Works:

The Power Point Tracker is a high-frequency DC to DC converter. They take the DC input from the solar panels, change it to high-frequency AC, and convert it back down to a different DC voltage and current to exactly match the panels to the batteries. MPPT's operate at very high audio frequencies, usually in the 20-80 kHz range. The advantage of high-frequency circuits is that they can be designed with very high-efficiency transformers and small components. The design of high-frequency circuits can be very tricky because of the problems with portions of the circuit "broadcasting" just like a radio transmitter causing radio and TV interference. Noise isolation and suppression becomes very important.

The power point tracker (and all DC to DC converters) operates by taking the DC input current, changing it to AC, running through a transformer (usually a toroid, a doughnut looking transformer), and then rectifying it back to DC, followed by the output regulator. In most DC to DC converters, this is strictly an electronic process - no real smarts are involved except for some regulation of the output voltage. Charge controllers for solar panels need a lot more smarts as light and temperature conditions vary continuously all day long, and battery voltage changes.

Proper Solar Panel Techniques

Standard solar panel connectors- MC4 Connectors

The wires in between the individual cells- busbars

Solar panels, especially the flexible panels, are extremely fragile. So fragile in fact that even a light touch can damage the panel. This means that it is imperative that when handling these panels, that they are treated with extreme caution.