Solar Photovoltaic Introduction

Do It Yourself (DIY) Instructions

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Remember…Safety First!

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Introduction

In this guide we will be taking a look at the ever-evolving world of Solar Photovoltaic, or PV for short and how the Do It Yourself movement is changing the upfront costs associated with PV. In essence, we will be examining how we have learned to take the sun’s energy and convert that into electricity in a low cost manner.

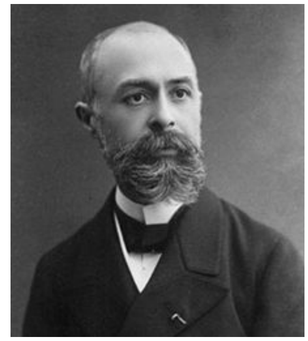
The sun has an enormous amount of energy, evident by the sunburns we have all put ourselves through. Humans have learned to passively harness this energy for thousands of years, using the sun’s rays to warm their homes or dry their food and clothing.

Not until the latter part of the 19th century, however, did we discover how to convert those powerful rays of sunlight into usable energy in the form of direct current (DC) electricity. This important breakthrough will be discussed, with the various types of solar cells that have been developed and the pros and cons of each.

The main components of a solar electric system will be identified and discussed, and, finally, we will discuss the steps towards constructing your own solar PV panel to harness the sun’s full potential.

PV History

The roots of photovoltaic can be traced all the way back to 1839 when 19 year old physicist Alexandre Edmond Becquerel was experimenting with an electrolytic cell made up of two metal electrodes and stumbled upon the photovoltaic concept.



Forty years later, in 1873, Willoughby Smith discovered the photoconductivity of selenium, and in 1883 Charles Fritts, an American inventor, described the first solar cell derived from selenium wafers.

Even Nikola Tesla and Albert Einstein got into the concept of photovoltaic in the early years. Tesla received a US patent for the "method of utilizing, and apparatus for the utilization of, radiant energy" and Einstein received the Nobel Prize for a 1904 paper on the photoelectric effect.

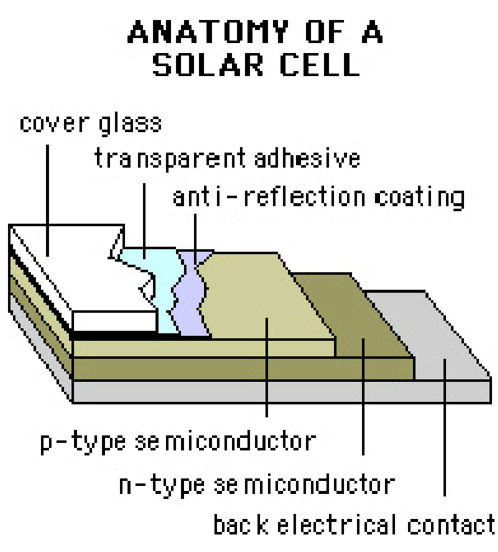
Then, in 1954 Bell Labs exhibited the first high-power silicon PV cell. Based upon the momentum of the photovoltaic sciences, the *New York Times* forecasted that solar cells will eventually lead to a source of "limitless energy of the sun".

This was done even though the cells back then were only about 5.5% efficient – compare that to the 20%+ efficient cells now! And the commercial age of photovoltaic has really just begun and we can expect some of the biggest technological breakthroughs yet to come.

The Science of Solar Electricity

The sun's rays are comprised of many tiny photons of light. These photons possess energy. These little balls of energy multiplied many times over strike the surface of the solar panel and cause the necessary commotion to knock electrons free in the solar cell. Solar cells are typically made up of high grade silicon as a semiconductor, but this alone is not sufficient to create an efficient solar cell. However, if a doping agent is introduced, commonly boron and phosphorus, it causes an unbalanced chemical structure, with a surplus of electrons in the silicon-phosphorus layer on the front surface of the cells.

This creates a negative charge and is referred to as the N-layer. Boron is often added to the back layer of the cells, creating a silicon-boron mixture that has a positive charge and can easily accept extra electrons, often referred to as the P-layer. In between the two is a positive/negative junction, or P/N junction. This middle junction between the other two layers has a neutral charge and will only allow the flow of electrons in one direction; from the P-layer to the N-layer.



Inherently, electrons like to move from negative to positive charges, and the only pathway for the electrons to return to the P-layer from the N-layer is through the conductor, which offers them very little resistance and allows them to flow out of the surface of the solar cell.

It then returns to the solar cell through the completed circuit into the P-layer. By taking this flow of electrons, or electricity, and attaching a load to its circuit you make the electrons do the work and have usable, renewable energy.

When each photon hits the cell it carries enough energy from the sun with it to excite one electron in the cell into the movement that creates the electricity. That is where the importance of the sun comes in. Without an outside energy source, the circuit would not flow.

However, when there is enough sunlight, the electrons from the P-layer leave their unbalanced atom and leave holes behind, which are easily filled by new electrons in the N-layer returning from their work in the circuit.

This process happens until the sun sets for the day and then they lay in wait for a new day. A blocking diode on the positive lead out of the panel prevents any current from flowing back into the cells at night and draining the batteries.

When wired together, the solar cells form a solar panel. When solar panels are wired together they form a solar array.

Types of Solar Cells

Solar cells are typically comprised of one of three solid types: monocrystalline, polycrystalline, and amorphous cells. While many different materials are used to make the solar cells, the most common element used for the monocrystalline and polycrystalline cells is silicon.

Silicon, while the second most abundant element on the Earth's crust, must be of the highest grade to be used in solar cell production. It must be cleaned of any impurities and superheated to form the ingots that are then thinly cut into the crystalline solar cells. Amorphous, or thin film, cells are comprised of many different elements: commonly cadmium, telluride or indium, among others. These cells are typically applied to a flexible substrate such as aluminum, certain plastics or even glass by evermore technically advanced methods.

Monocrystalline cells are the most efficient while polycrystalline cells are a close second. Amorphous cells, while considerably less efficient tend to cost only a fraction of what the crystalline cells do. The two types of crystalline cells comprise the panels that are typically used in residential installation.

Because they are so much more efficient than the amorphous cells, you do not need as much roof or ground space. However, due to amorphous panels' low costs they tend to be preferred for many commercial applications, since space is not an issue in many cases.

Calculating Volts, Amps & Watts

Solar cells output power can be measured in Volts and Amps. To compare this concept to water, the Voltage of a device can be related to the pressure of the water, while the Current (measured in Amps) can be compared to the amount of water flowing. This is an important concept to remember.

When you know both the Voltage and Current (or Amps) of a solar cell you can multiply them together to find its rating in Watts. Completed solar panels are rated in Watts, so it's important to understand this formula. Knowing just two parts of the formula, you can also derive the third component.

Volts X Amps = Watts

For example, understanding the basic formula V (volts) x A (amps) = W (watts) allows us to derive the amps from a 100 Watt 18 Volt panel:

V x A = W or W/V=A

100w / 18v = 5.55 Amps that the panel will deliver

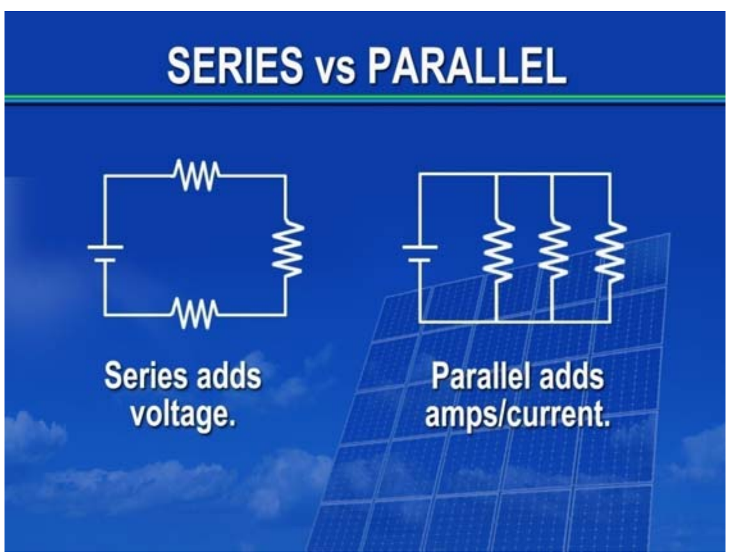
The best way to measure the output from the cells is to use a *multimeter* and touch the positive and negative leads to the positive and negative conductors on the solar cell under full sun. Once you know the Voltage and Amperage of your solar cells you can begin to wire them together to form the solar panel.

Connecting in Series or Parallel

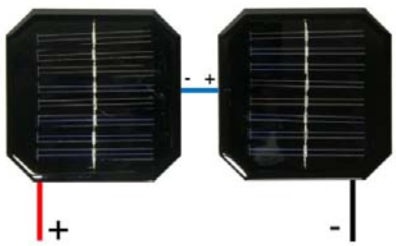
The solar cells are wired together with conductors, commonly tab ribbon. This allows us to take the single solar cell and pair it with similar cells to create a solar panel with customizable power outputs.

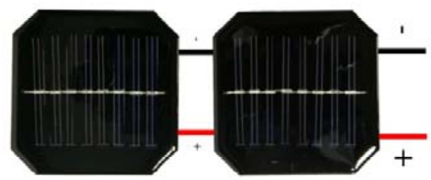
There are two ways to connect the cells together. The first is in a "Series" connection, where the positive electrode from the cell is connected to the negative electrode of the next cell.

The second way is with a "Parallel" connection. This circuit takes the positive electrodes from the cells and connects it to the positive electrodes from the adjacent cell.



When you wire two cells together in Series you add the Voltage and the Current/Amps remains constant, while when you wire two cells together in Parallel you add the Current/Amps and the Voltage remains constant. This concept allows us to construct solar panels with customizable outputs.





Wired in "Series"

(Volts are added & Amps stay constant)

Wired in "Parallel"

(Amps are added, Volts stay constant)

Since most solar cells, regardless of size, will have an output of about 0.5 Volts, wiring the cells together in Series increases the Voltage a solar panel can achieve. And since the solar cells physical size determines the Current output (assuming the same type of cells are being used) we can create Parallel strings of cells to achieve the proper Current.

For example, if you have a 0.5 Volt X 3.5 Amp solar cell and you wire 20 of them in Series, this would give us about 10 Volts when exposed to the sun, while still outputting the original 3.5 Amps. On the other hand, if you take the same cells with 0.5 Volts and 3.5 Amps and wire 20 of them together in Parallel you would have a panel with 35 Amps but still just 0.5 Volts.

The same concept applies when wiring multiple panels together. Many larger solar inverters have a “voltage window,” usually between about 150-450 Volts (depending on the inverter size and manufacturer).

In order to kick the inverter on we would have to wire enough solar panels together to raise the Voltage high enough for the inverter to operate properly.

You can also wire multiple solar panels together to achieve a higher Current/Amps, but take care not to raise the Current too high as it becomes dangerous and you may have a hard time finding fuses that can handle the higher Current levels.

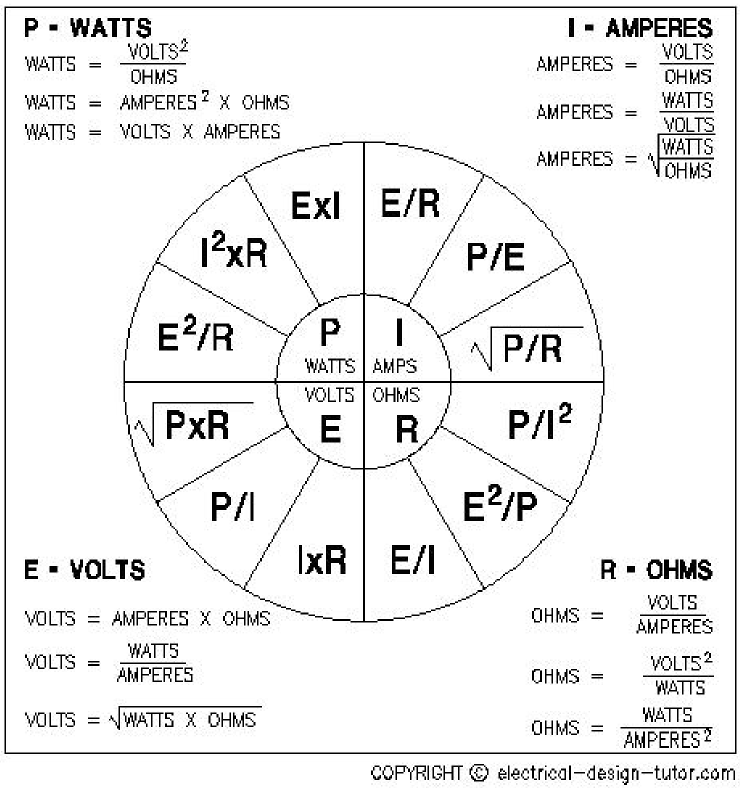
Voltage Drop

Every solar system will always start at the solar panel. This is where the energy starts, and from there it must enter some conductor to reach its destination. This conductor is typically an insulated copper wire. The amount of energy and the distance of the wire will determine what size wire to use.

In electrical circuits, Ohm's law states that the current through a conductor between two points is directly proportional to the potential difference or voltage across the two points, and inversely proportional to the resistance between them. The mathematical equation that describes this relationship is:

$$I = \frac{V}{R}$$

“V” is the potential difference measured across the resistance in units of volts; “I” is the current through the resistance in units of amperes (amps) and R is the resistance of the conductor in units of ohms. A more thorough diagram to express the relationship between these units is shown below.



Typically you will want no more than 2% loss through your DC wire runs. There are several online calculators for determining this, or you may choose to do the math yourself using the table below.

Voltage Drop per 100 FT Run of Paired Wire

GAUGE (AWG)	.5 AMPS - Load Current	1 AMP - Load Current	2 AMPS - Load Current	4 AMPS - Load Current	10 AMPS - Load Current
10	0.10	0.20	0.40	0.80	2.00
11	0.13	0.25	0.50	1.01	2.52
12	0.16	0.32	0.64	1.27	3.18
13	0.20	0.40	0.80	1.60	4.00
14	0.25	0.50	1.01	2.02	5.04
15	0.32	0.64	1.27	2.54	6.35
16	0.40	0.80	1.60	3.20	8.00
17	0.50	1.01	2.02	4.03	10.08
18	0.64	1.27	2.54	5.08	12.71
19	0.80	1.60	3.20	6.40	16.01
20	1.01	2.02	4.03	8.07	20.17
21	1.27	2.54	5.08	10.17	25.42
22	1.60	3.20	6.40	12.81	32.02

For example; given a load current of 4 amps, and using 14 AWG wire, how much voltage drop can we expect at the load end for a 250 foot run of paired wire?

Using the chart, we match the row for 14 AWG and the column for 4 amps and determine that voltage drop per 100 feet is 2.02 Volts. By dividing the paired wire length by 100, we get the factor by which we need to multiply voltage drop per 100 feet to determine total voltage drop.

Therefore, 250 feet divided by 100 equals 2.5. Multiply 2.5 by 2.02 volts drop per 100 feet to get your total voltage drop. Thus the total voltage drop is 2.5 times 2.02, or 5.05 voltage drop for 250 feet. If your system voltage is 250 volts or more this may be acceptable loss. Note that the higher the voltage the lower the current, as they are inversely related.

If you have a long wire and have low system voltage you have 3 main choices. The first is to buy very thick wire, although the cost of copper these days may prohibit this. The second is to reduce the wire run by situating your solar array closer to your load. The third option is to increase the voltage by wiring more panels in series or by inverting the DC power to AC power at the site instead of the point of contact with the load. This may require putting the batteries closer to the array in an enclosure separate from your residence, but can result in some big savings since you will be running AC power at 120 or 240 volts instead of 12 volts.

$$\frac{350}{100} \times 1.27 = 4.45 \text{ Volts}$$

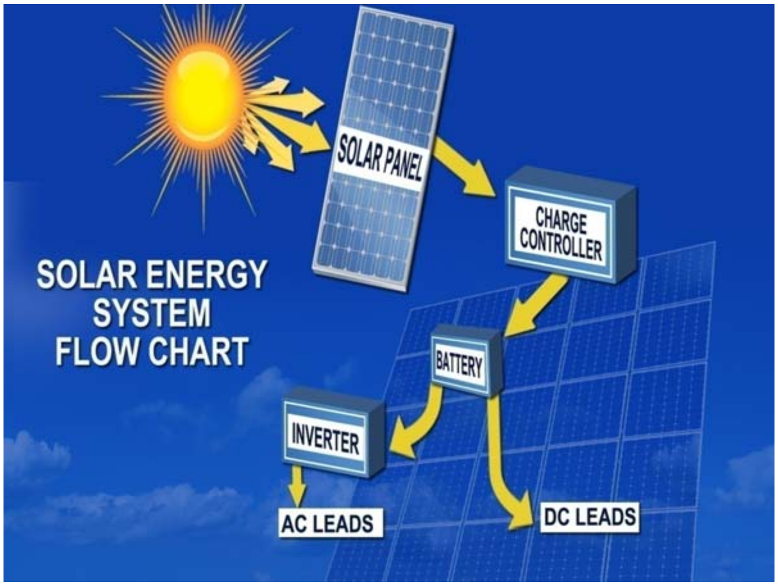
Solar Electric System Components

There are three main types of solar electric systems: off-grid, grid-tied, or grid-tied with battery backup. Off grid systems typically use batteries as their form of energy storage and have been around for many decades. These systems typically rely on a back-up power source like a generator for when the sun does not shine for prolonged periods.

Grid-tied systems have only gained popularity in recent years as utility, state, and federal incentives have made the solar system much more cost competitive with its dirty rivals: the fossil fuels. These grid-tied systems use the utility grid (the network of wires and cables that span every city and town in the US) to store their energy, sending excess energy into the grid during the day and pulling from it at night. A good resource to check to see what incentives are available in your locality is www.dsireusa.org.

There are numerous permitting and electrical codes that must be adhered to when connecting to the city grid and non-UL listed homemade solar panels absolutely can not be used in a grid-tied system.

In an off-grid application, the energy from the sun typically flows through these components:



Solar Panel:

As mentioned before there are different types of solar cells and methods of wiring them together to create the ideal Amps and Volts. When combining multiple solar panels together, you create a solar array that will create the power for a house or commercial application. This energy then must go through a series of components before finally being consumed.

Charge Controller:

From the solar panel the electrical current flows into a charge controller. This unit is in essence a regulator of energy. It is a customizable unit that regulates the flow of energy “to the batteries” and prevents energy being pulled “from the batteries” at nighttime or in cloudy weather. Depending on the size of the solar array you may spend anywhere from about $25 to over $100 USD for your charge controller(s).

The charge controller can be programmed to stop flow from the batteries when they reach a certain depth of discharge (DOD). The DOD is typically no less than 50% of the battery’s capacity. The further you discharge a battery on a regular basis the shorter the life span of a battery will be.

Controllers are available in a variety of sizes and appearances.

Battery:

The batteries are a crucial component of your off-grid system. This is what will be powering your appliances when the sun goes down or behind clouds. Most batteries now are lead-acid batteries, although as more funding is being put into the R&D of batteries the chemistry is constantly evolving and becoming more efficient. For solar applications you will want to use deep cycle batteries. Wired together, they form a battery bank.

Batteries are also available in unsealed and sealed types. The unsealed types are much more common due to their lower cost. However, they do require ongoing maintenance to keep their electrolyte levels above the plates inside the battery. The sealed batteries come at a premium, but do not require the maintenance, since the electrolyte is usually in a gel substance.

For either battery you will want to keep them away from any potential heat or fire sources. A shed or a well vented room in your home will work best. Try to avoid temperature extremes for your battery bank, as this will affect the performance negatively.

These may look very similar to car batteries, but they are only similar in appearance and greatly differ in their requirements. Car batteries are meant to be fully discharged and then rapidly recharged.

Solar deep cycle batteries are slowly charged throughout the day and then discharged slowly at night. Their energy input will vary throughout the day and the discharge will be sporadic at night, too.

A car battery used for a solar application would not be expected to last even one year, while a well maintained deep-cycle battery can be expected to last 6 years or more, depending on the depth of discharge level you have set and how often you keep the electrolyte levels maintained.

Inverter:

If you are using just direct current (DC) loads (appliances) you will not need an inverter and can just power the loads from the battery, assuming the voltages match up. However, the cost and availability of DC appliances remains an impediment to the solely DC home.

Alternating current (AC) appliances dominate the home landscape and require an inverter to change the DC current from the solar array to AC current for your refrigerator, TV, lights, etc. You should expect to spend around $0.50/watt or more depending on the size of the inverter needed. Typically, all but the largest residential solar systems will work fine on one inverter.

Inverters, like the charge controllers, will vary in shape and size depending upon the inverter's output rating and manufacturer.

You may be able to save some money on larger systems by purchasing an inverter that has a charge controller inside its circuitry. Check the spec sheets to determine this. Many of the larger manufacturers of inverters have solar string sizing programs available for free on their website, so you may want to reference this to determine what size inverter to use.

The inverter's input voltage window is the main determination to determine how many panels you can wire together in a series string, which is why they are often called string inverters.

You can get by with an inverter that is rated below the name plate rating of the array. For example, a solar array with a name plate rating of 3,300 watts (3.3 kilowatts) will work just fine with a 3,000 watt inverter, since you will typically lose up to 20% of the output from the panels from many factors. Among them, voltage losses in the wires, panel mismatch, dirt or pollen on the panels and the DC to AC inversion.

Disconnect Switches:

Disconnect switches are often times built into the inverters, but many municipalities require a separate disconnect switch for either the DC side or the AC side, or both. If you are planning on getting your system inspected by a licensed inspector or are going to connect your system to the grid check with your local laws to determine which disconnects you will need to install.

The National Electrical Code (NEC) book has set laws on mounting the equipment, such as how high off the ground, distance from batteries and other components, etc. Disconnect switches, depending on how many strings of panels you are creating may need to have an integrated fuse. These disconnects can be purchased at a local electrical supply or hardware store.

Putting it all together:

If you are constructing a small array, you may get away with just one battery, a small charge controller and a low wattage inverter, like the kind you can plug into your car adaptor. You can plug many AC electronics and appliances directly into the inverter, so long as the inverter is rated to handle the load requirements. For larger systems, you should opt to run the inverter AC wires directly into your homes breaker panel with breaker slots allotted for the inverter. A master electrician's services should be sought for this step.

To make sure your breaker panel can handle the backfed current take the busbar rating found on the inside cover, multiply it by 1.2 and then subtract your main breaker size. The max continuous output current of the inverter multiplied by 1.25 (depending on which NEC Code year you reference) must be below this number. For example, a 200 A breaker panel (standard in most new construction) with a 200 A main breaker will allow for 40 A to be backfed (200 x 1.2 – 200 = 40 A). You can typically fit up to about 7000 watts on a 200 A breaker panel since the max continuous output of a 7,000 watt inverter is usually close to 32 A. The max continuous output of the inverter is found in the spec sheet or by contacting the manufacturer. Reference the National Electrical Code (NEC) book for the latest requirements when sizing an electrical array.

Grid-tied systems substitute the utility grid for the batteries. Most homes that are connected to the grid opt for this service. If going this route, you will want your utility provider to install a net meter for you. This meter records the flow of electricity in both directions, essentially crediting your account for sending excess electricity into the grid. When the sun is out and your panels are producing more electricity than your home needs, your meter will spin backwards. When the sun goes down and the lights come on you begin to pull electricity from the grid and your meter spins forwards again.

Most states have now adopted net metering for renewable energy systems. If you don't get a net meter your old meter may actually charge you for energy consumed and energy produced!

Remember that homemade solar panels should never be hooked up to a grid-tied system. And always check your local laws and permitting requirements when working with electricity.

For Grid-Tied systems without battery backups, it is important to note that when you lose power from the grid, you won't be able to use the power from your solar array. This is a safety feature built into the inverters so that if you have a utility lineman working on the power lines in your front yard they can be confident there is no current in the lines. If your array were in the backyard feeding the grid and he was working in the front he would run the chance of having a bad electric shock.

A small percentage of homeowners opt for a grid-tied solar system with battery backup. This is more common in places with an unreliable utility connection like very remote areas or places with extreme weather conditions. You could pay up to 50% more on the total cost of an installed system by adding battery backup.

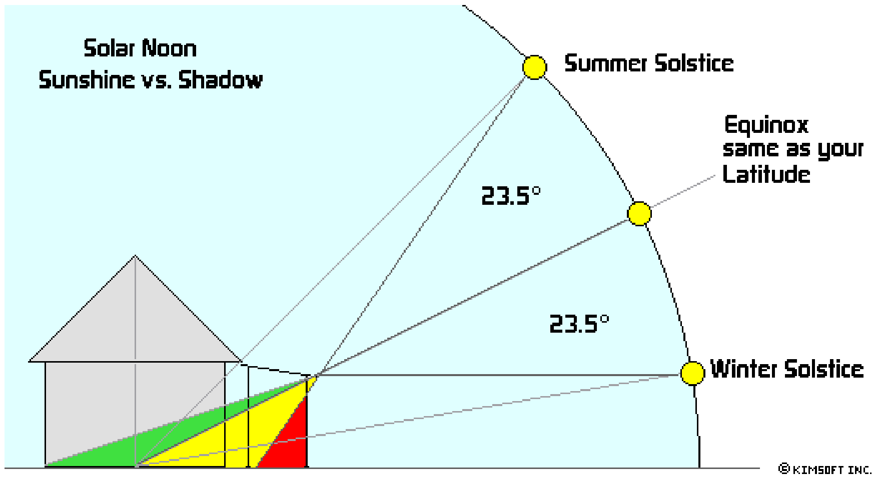
There are inverters out there that have grid-tied/battery backup capabilities, but you may need two inverters for this option. Having a crucial load subpanel is a good option for when the power goes down and you are drawing from the batteries. This isolates some of your electric loads on a separate breaker panel so that you won't pull down the battery's storage too fast by running unnecessary loads.

Site Determination

The biggest factor when determining the location is access to the sun. It is very important that your panels be located where they will get at least 6 hours of unobstructed sun per day. This 'solar window' is typically from 9am to 6pm, but may adjust to earlier or later in the day depending on the orientation of the panels.

The optimal pitch for the panels is equal to your latitude, although in many locations with cloudy winters, it may be optimal to subtract about 15 degrees from your latitude for optimal pitch. A solar pathfinder or Solmetric Sun Eyes are two popular options for determining the site's sun potential. They are useful tools that will show what shade issues you will have with a particular spot at all times of the year.

Shade is to be avoided at all costs since the cells and panels are mainly wired in series, and shading even one cell of a panel can wipe out a portion of the entire array.



The National Renewable Energy Laboratories (NREL) has developed a very useful online resource to determine the potential output of your array. The program is called PVWatts and is free to use online. It can be found online at: http://www.nrel.gov/rredc/pvwatts/. Simply input your array size in kilowatts, the orientation and angle of your panel and your zip code and the program will give you your estimated kilowatt hour (kWh) output for each month of the year.

If you cannot mount the panel to your roof, another consideration for site selection is to keep the array as close to your home as reasonably possible, since long wire runs will have higher power losses and will require thicker wires, increasing the cost of your system and requiring longer trenches.

Once you have determined the necessary size of you solar array, which components are needed and the location of your system, you are ready to begin your project.