# General Information on Batteries

Deep Cycle Batteries are the key component in various types of renewable energy systems that require the storage of electricity. A battery is essentially a storage vessel for electricity. It is a critical component heavily relied upon by the system as a whole. A battery bank can provide a relatively constant source of power when the grid is down, or during periods when your photovoltaic system is not producing power. Although batteries are not one hundred percent efficient, they are predictable and stable enough for reliable long-term service.

**Think of Your Batteries Like a Bucket of Energy**

Batteries are basically the only method to store direct current (DC) power produced from sources like solar panels, wind generators, micro-hydro or generators. Think of your batteries like a bucket of energy, where the voltage is equal to pressure, and amperage equates to flow rate. Imagine that we are slowly pouring water into a bucket that has a small hole on the bottom. As we pour the water into the bucket, its slow leak will mean that you'll probably use 12 gallons of water to fill a 10 gallon bucket by the time it is full. In the same way, it takes more energy to charge a battery than it will actually store. The size of your bucket is analogous to the amp hour capacity of the battery bank. Amp hour is the unit of measurement used to express the storage capacity of deep cycle batteries. The Amp hour rating, written as Ah, will tell you how much amperage is available when discharged evenly over a 20-hour period. Twenty hours has been the standard time length for rating batteries, although shorter or longer time variables may be used depending on the application.

**Battery Components**

Battery technology has not changed much in the last 100 years. The standard construction method involves flooding lead plates in sulfuric acid. The chemical reaction between the positively charged lead plate and the negatively charged acid allows the battery to store and "give" electricity. The thickness of the lead plate is closely related to the lifespan of the battery because of a factor called "Positive Grid Corrosion". The positive lead plate gradually wears away over time. Thicker plates are used in deep cycle batteries. This usually translates to a longer battery life. Although plate thickness is not the only factor related to longer lifespan, it is the most critical variable

**Battery Lifespan**

Most of the loss incurred in charging and discharging batteries is due to internal resistance, which is eventually wasted as heat. Efficiency ratios are relatively high considering that most lead acid batteries are 85 to 95 percent efficient at storing the energy they receive. Deep cycle batteries used in renewable energy applications are designed to provide many years of reliable performance with proper care and maintenance. Proper maintenance and usage play a major role in battery lifespan. Toiling over your battery bank daily with complex gadgets and a gallon of distilled water, however, is not necessary. The most common causes of premature battery failure include loss of electrolyte due to heat or overcharging, undercharging, excessive vibration, freezing or extremely high temperatures, and using tap water among other factors.

**Charging 101**

There are three basic stages in charging a battery: Bulk, Absorption, and Float. These terms signify different voltage and current variables involved in each stage of charging.

**Bulk Charge:**

In the first stage of the process, current is sent to the batteries at the maximum safe rate they will accept until voltage is brought up to nearly 80-90 percent full charge level. There are limits on the amount of current the battery and/or wiring can take.

**Absorption Charge:**

In the second stage, voltage peaks and stabilizes and current begins to taper off as internal resistance rises. The charge controller puts out maximum voltage at this stage.

**Float Charge:**

This can also be referred to as trickle charging or a maintenance charge. In this stage, voltage is reduced to lower levels in order to reduce gassing and prolong battery life. The main purpose of this stage is basically to maintain the battery's charge in a controlled manner. In Pulse Width Modulation (PWM) the charger sends small, short charging cycles or "pulses" when it senses small drops in voltage.

**Environmental Factors**

Fortunately most of what goes into a battery is recyclable. Over ninety five percent of lead-acid cells used under the hood of vehicles will most likely end up being recycled into another battery. Europe takes the lead in efficiency by recycling nearly one hundred percent of their starter batteries.

**Determining battery state of charge**

There are a few ways to determine the state of charge on a battery, each with their own level of accuracy. As there is no direct method to measure a battery's state of charge, there are numerous ways to go about it. One way to gauge a battery is by measuring its static voltage and comparing it to a standardized chart. This is the least accurate method, but it only involves an inexpensive digital meter. Another method of gauging the battery involves measuring the density or specific gravity of the sulfuric acid electrolyte. This is the most accurate test, yet it is only applicable to the flooded types. This method involves measuring the cell's electrolyte density with a battery hydrometer. Electrolyte density is lower when the battery is discharged and higher as the cells are charged. The battery's chemical reactions affect the density of the electrolyte at a constant rate that is predictable enough to get a good indication of the cell's state of charge. Using an amp-hour meter one can also obtain an accurate indication of the battery's state of charge. Amp-hour meters keep track of all power moving in and out of the battery by time, and the state of charge is determined by comparing flow rates.

**Amp-Hour Rating & Capacity**

All deep cycle batteries are classified and rated in amp-hours. Amp-hours is the term used to describe a standardized rate of discharge measuring current relative to time. It is calculated by multiplying amps and hours. The generally accepted rating time period for most manufacturers is 20 hours. This means that the battery will provide the rated amperage for about 20 hours until it is down to 10.5 volts or completely dead. Some battery manufacturers will use 100 hours as the standard to make them look better, yet it can be useful in long-term backup calculations.

**Types of Batteries**

There are three main types of batteries that are commonly used in renewable energy systems, each with their own advantages and disadvantages. Flooded or "wet" batteries are the most cost efficient and the most widely used batteries in photovoltaic applications. They require regular maintenance and need to be used in a vented location, and are extremely well suited for renewable energy applications. Sealed batteries come in two varieties, the gel cell and Absorbed Glass Mat (AGM) type. The gel cell uses a silica additive in its electrolyte solution that causes it to stiffen or gel, eliminating some of the issues with venting and spillage. The Absorbed Glass Mat construction method suspends the electrolyte in close proximity with the plate's active material. These batteries are sealed, requiring virtually no maintenance. They are more suitable for remote applications where regular maintenance is difficult, or enclosed locations where venting is an issue.

**Flooded Lead Acid**

Flooded Lead Acid batteries are the most commonly used batteries, and have the longest track record in solar electric systems. They usually have the longest life and the lowest cost per amp-hour of any of the other choices. The downside is that they do require regular maintenance in the form of watering, equalizing charges and keeping the terminals clean. These cells are often referred to as "wet" cells, and they come in two varieties: the serviceable, and the maintenance-free type (which means they are designed to die as soon as the warranty runs out). The serviceable wet cells come with removable caps, and are the smarter choice, as they allow you to check their status with a hydrometer.

**Gelled Electrolyte Sealed Lead Acid**

Gel sealed batteries use silica to stiffen or “gel” the electrolyte solution, greatly reducing the gasses, and volatility of the cell. Since all matter expands and contracts with heat, batteries are not truly sealed, but are "valve regulated". This means that a tiny valve maintains slight positive pressure. AGM batteries are slowly phasing out gel technology, but there still are many applications for the gel cells. The recharge voltage for charging Gel cells are usually lower than the other styles of lead acid batteries, and should be charged at a slower rate. When they are charged too fast, gas pockets will form on the plates and force the gelled electrolyte away from the plate, decreasing the capacity until the gas finds its way to the top of the battery and recombines with the electrolyte.

**Sealed Absorbed Glass Mat (AGM)**

Absorbed Glass Mat (AGM) is a class of valve-regulated lead acid battery (VLRA) in which the electrolyte is held in glass mats as opposed to freely flooding the plates. This is achieved by weaving very thin glass fibers into a mat to increase surface area enough to hold sufficient electrolyte for the lifetime of the cell. The advantages to using the AGM batteries are many, yet these batteries are typically twice the cost of their flooded-cell counterpart. On the plus side, these cells can hold roughly 1.5 times the amp hour capacity of a similar size flooded battery due to their higher power density. Another factor that improves their efficiency is the higher lead purity used in AGM cells. Because of their sandwich construction, each plate no longer has to support its own weight. Their low internal resistance allows them to be charged and discharged much faster than other types. AGM cells function well in colder temperatures and are highly resistant to vibration. There are many advantages to using the AGM cells over their flooded counterpart that are beyond the scope of this article.

**Lithium-Ion**

A relative newcomer to the field, li-ion batteries were first developed in the 1970s and have seen increasingly common use in the consumer world, being omnipresent in consumer electronics like cell phones and laptops. Lately, they've also begun to make an entrance in the renewables field, such as with the Tesla Powerwall home backup power systems. Compared to all lead-acid acid batteries, lithium ion:

Is physically smaller and lighter for a given capacity
Shows better performance characteristics, including a greater depth of discharge and less self-discharge
If properly sized and managed, can survive more charge cycles (i.e., can have a greater lifespan)
Requires less user maintenance

**So what are the downsides?**

Chiefly, price. Lead-acid batteries are in extremely common use for household backup power and are manufactured by many different vendors. Lithium-ion doesn't have the same market yet and are relatively expensive compared to tried-and-trued lead-acid. As lithium ion production ramps up, such as with Tesla's new "gigafactories", increased competition should bring down the price. As of 2015, however:

Compared to regular (unsealed) lead-acid batteries, li-ion is more expensive, period.
Compared to sealed lead-acid batteries, li-ion is more expensive upfront (i.e. at initial purchase), but end up being comparable over its lifetime because of its greater longevity. The specifics, however, depend on environmental conditions such as ambient temperatures.

**Deep Cycle versus Shallow Cycle**

Lead acid batteries are designed to absorb and give up electricity by using a reversible chemical reaction. In battery lingo, a cycle on a battery occurs when you discharge your battery and then charge it back to the same level. How deep a battery is discharged is referred to as Depth of Discharge (DOD).

**Starting Lighting and ignition**

Automotive starting, lighting, and ignition batteries (SLI) have a short or “shallow” depth of discharge, as they are designed to produce a high amount of current in a very short time. These batteries are not recommended for use in a photovoltaic system, as they would quickly be ruined by the deep cycles required for extended use.

**Deep cycle**

Deep cycle batteries are designed with thicker lead plates, which have less overall surface area than their thinner SLI counterpart. Because of the reduced availability of surface area for chemical reactions, deep cycle batteries produce less current than an SLI type battery, yet they produce that current for longer periods of time. Deep cycle batteries can be discharged up to 80 percent DOD without damage depending on the model. In order to increase battery life, manufacturers recommend discharging deep-cycle batteries only down to 50 percent in order to increase battery life.

**Maintenance & Monitoring**

Proper maintenance and monitoring will greatly extend the life of your batteries. Flooded batteries need to be checked regularly to make sure electrolyte levels are full. The chemical reaction releases gases, as water molecules are split into hydrogen and oxygen. This, in turn, consumes water and creates the need to replace it regularly. Only distilled water should ever be used in batteries, and you should never add any kind of acid solution. The connections from battery to battery and to the charging and load circuits should always be kept clean and free of corrosion. Corrosion is created upon charging, when a slight acid mist forms as the electrolyte bubbles. Corrosion buildup will create a good deal of electrical resistance, eventually contributing to a shortened battery life and malfunctions. A good way to keep up on the terminals is to regularly clean them with a baking soda solution

**Future Trends**

Companies world-wide are quickly adjusting to the increased global market for solar systems by developing batteries that are better suited for photovoltaic systems. At some distant point in the future, it is likely that lead-acid batteries will become extinct, as newer technologies in lithium ion and Nickel metal hydride continue to evolve. Because lead-acid batteries are under the hood of virtually every car, advancements in lead-acid technology, however are still being made. New developments in lead-acid technology usually originate in the auto industry. Efficiency ratings are constantly going up, as new sensors and improved materials are helping batteries achieve longer lifespan.

The Trojan battery company, one of the world's leading manufacturer of deep-cycle batteries, is deeply involved in the research and development of renewable energy (RE) applications for deep cycle batteries. Trojan recently set up a web page dedicated solely to the RE market, and keep expanding their AGM product line.

How much storage you would like your battery bank to provide? Base this on the number of days your system will have to provide power without solar input. How many cloudy days in a row are typical for your location? Do you have an alternate source of power—grid intertie or generator—during these days?

Getting the right size battery. It's not good for batteries to be completely drained (ever), nor is it good for them to be consistently undercharged. It is best to size your battery bank so that it gets regularly charged to capacity.

If you are installing a system for a weekend home you may want to consider a larger battery bank, because your system will have all week to charge and store energy. Alternatively, if you are adding an array as a supplement to a generator-based system, your battery bank can be slightly undersized since the generator can be operated if needed for recharging.

When you sized your solar panel array you were dealing with watts per hour that you need to produce. Now you will be dealing with amps per hour that you need to store. Remember watts = volts X amps. Now grab a calculator and do the math..........

**Deep Cycle Batteries: How to Keep Them Alive for Years and Years**

Lead-acid deep cycle batteries are often considered to be the "weak link" in renewable energy systems. However, today's renewable energy batteries are better than ever, and so are the devices that regulate and protect them. Battery failures are rarely the fault of the batteries themselves! Follow these guidelines to avoid the vast majority of all battery problems.

**Size a battery bank and PV array properly**

A battery bank should be sized (as a minimum) to a capacity of 5 days of load. Energy use in most home power systems increases over time, so consider sizing larger than that. Why? After 1 year of service, it is NOT advisable to enlarge a battery bank by adding new batteries to it, because batteries' voltage response changes with age. Stray currents flow, causing losses and failure to equalize. A PV array, if it is the primary energy source, should be sized to produce (on average) 30% more energy than the load requires. This compensates for battery losses and for less-than-average charging conditions. Luckily, a PV array can be expanded at any time.

Buy high-quality batteries, selected for your needs

You get what you pay for! Good deep-cycle batteries can be expected to last for 5 to 15 years, and sometimes more. Cheap batteries can give you trouble in half that time. Buy from a reputable source.

**Avoid multiple parallel strings**

The ideal battery bank is the simplest, consisting of a single series of cells that are sized for the job. Higher capacity batteries tend to have thicker plates, and therefore greater longevity. Having fewer cells will reduce the chance of randomly occurring defects, and reduces maintenance. Suppose for example, that you require a 700 Amp-Hour bank. You can approximate that by using 3 parallel strings of golf-cart batteries (220 AH), or 2 strings of the larger L-16 style batteries (350 AH) or a single string of larger, industrial batteries.

Under no circumstances is it advisable to install more than three parallel battery strings. The resulting bank will tend to lose its equalization, resulting in accelerated failure of any weak cells. Weak cells will be difficult to detect because they will "steal" from the surrounding cells, and the system will suffer as a whole and will cost you more in the long run.

Here are some precautions to take when wiring two or more strings of batteries in series-parallel. The goal is to maintain all of the cells at an equal state of charge. Cells that tend to receive less charge are likely to fail prematurely. This can take years off of the effective life of the battery bank. A fraction of an ohm of added resistance in one battery string can reduce the life of the entire string.

(1) Connect the two main cables to opposite corners of the battery bank, and maintain symmetry in wire size and lengths. This will help to distribute current evenly through the bank.

(2) Arrange batteries to maintain even temperature distribution throughout the bank. Avoid uneven exposure to heat sources. Leave at least 1/2 inch of air space around each battery, to promote even cooling.

(3) Apply a finish charge at least every 3 weeks (bring every cell to 100% charge).

**Prevent corrosion**

In flooded battery installations, corrosion of terminals and cables is an ugly nuisance that causes resistance and potential hazards. Once corrosion gets hold, it is hard to stop. The good news -- it is easy to prevent! Apply a non-hardening sealant to all of the metal parts of the terminals BEFORE ASSEMBLY. Completely coat the battery terminals, the wire lugs, and the nuts and bolts individually. A sealant applied after assembly will not reach all around every junction. Voids will remain, acid spatter will enter, and corrosion will begin as soon as your installation is finished.

Special compounds are sold to protect terminals, but you can have perfectly good results using common petroleum jelly (Vaseline). It will not inhibit electrical contact. Apply a thin coating with your fingers, and it won't look sloppy. If wire is exposed at a terminal lug, it should be sealed airtight, using either adhesive-lined heat-shrink tubing or submersible rubber splice tape. You can also seal an end of stranded wire by warming it gently, and dipping it in the petroleum jelly to liquefy, and wick it into the wire.

It also helps to put the batteries over a floor drain, or in a space without a floor, so that they can be rinsed with water easily. Washing the battery tops (about twice per year) will remove accumulated moisture (acid spatter) and dust.

This will further reduce corrosion, and will prevent stray currents from stealing energy. Batteries that we have protected by these measures show very little corrosion, even after 10 years without terminal cleaning.

**Moderate the temperature**

Batteries lose approximately 25% of their capacity at a temperature of 30°F (compared to a baseline of 77°F). At higher temperatures, they deteriorate faster. Thus, it is desirable to protect them from temperature extremes. If no thermally-stable structure is available, consider an earth-sheltered enclosure. Where low temperature cannot be avoided, get a larger battery bank to make up for the loss of capacity in the winter. Avoid direct radiant heat sources that will cause some batteries to get warmer than others.

**Use temperature compensation**

When batteries are cold, they require an increase in the charge voltage limit, in order to reach full charge. When they are warm, they require a reduction in the voltage limit in order to prevent overcharge. Temperature compensation is a feature in many charge controllers and power centers, as well as in the back-up chargers in some inverters. To use this feature, order the accessory temperature probe for each charging device, and attach it to any one of the batteries.

**Use low-voltage disconnects**

Discharging a battery to exhaustion will cause immediate, irreversible loss of capacity and life expectancy. Your system should employ low voltage disconnect (LVD) in the load circuits. Most dc to ac power inverters have this feature, and so do many charge controllers and power centers. Don't depend on human behavior to prevent over-discharge. It can be caused easily by accident or by an irresponsible user. Again, most inverters have LVD built-in but if there are DC loads on the system, please incorporate an LVD device.

**Bring batteries to a full state-of-charge at least every 3 weeks**

Bring the batteries to a full state-of-charge (SOC) at least every 3 weeks. This reduces internal corrosion and degradation, and helps to insure equalization, so that any weaker cells do not fall continually farther behind. A full SOC may occur naturally during most of the year, but do not hesitate to run a generator when necessary, to bring the batteries up. Information like this should be posted at the power center. For more details, refer to the instructions for the inverter/charger and for the batteries.

**How do you know when a battery is 100% charged?**

The "charged" indicator on most PV charge controllers means only that battery voltage is relatively high. The SOC may be approaching full, but is not necessarily near 100% A voltmeter reading gets you closer, but it is not a certain indicator. It varies too much with current flow, temperature and time, to give a clear indication.

For flooded batteries, a hydrometer is the definitive indicating device, although not a convenient one. With it, you can measure every cell individually. Obtain one from a battery or automotive supplier. Even the cheapest hydrometer is fine. Rinse it after use, and keep it clean.
An amp-hour meter is the most informative and user-friendly way to monitor SOC. For sealed batteries, it is the ONLY definitive method. See next paragraph.

**Install a System Monitor**

Would you drive a car with no dashboard? Metering is not just "bells and whistles". It is necessary to help you to read the status of the system. Many charge controllers have indicator lights and readouts built-in. For a full-scale remote home, consider the addition of a digital monitor, like Trace TM-500, Tri-Metric, E-Meter or Omni-Meter. These devices monitor voltage and current, record amp-hours, and accurately display the state-of-charge of the battery bank. They also record more detailed information that can be useful for troubleshooting. The monitor may be mounted in another room or building, for handy viewing.

**How to Read a Hydrometer**

A hydrometer will help you to determine whether the battery bank is getting fully charged, and whether any individual cells are falling behind. You should be aware that a hydrometer will give you false readings under the following conditions.

(1) After adding water: For pure water to mix throughout the cell, it takes time and some bubbling during finish charge. A hydrometer will show a greatly reduced reading until the fluid mixes.

(2) Low temperature: As battery temperature drops, the fluid becomes more dense. A temperature compensating hydrometer is best. Otherwise, for every 10°F below 70°F, subtract 3.5 points from the reading.

(3) Time lag during recharge: As the battery recharges, the fluid becomes more dense down between the plates. The hydrometer reads the fluid above the plates. You will get a delayed reading until the fluid is mixed by the movement of bubbles during finish charge. The voltage will rise steadily, providing an indication that something is happening.

During discharge, you will get a true hydrometer reading because the fluid becomes less dense and will circulate to the top. Any time a hydrometer indicates a fully charged cell, you KNOW it is fully charged.

**WARNING**

BATTERY ACID IS HAZARDOUS

When working around batteries, wear safety glasses. Get a rugged plastic bottle to keep with your service tools, and fill it with a sodium bicarbonate (baking soda) and water. Use it to neutralize accidental splash or spills and to clean normal acid spatter from battery tops. Finally, don't wear your favorite blue jeans!

**Just add water**

Note: This applies only to "flooded batteries", not to "sealed batteries". The plates of every cell in your battery bank must be submerged at all times. Never add any fluid to a battery except distilled water, deionized water, or very clean rainwater collected in plastic containers. Most batteries require addition of water every 6 to 12 months. There is no need to fill them more frequently than needed to submerge the plates. Fill them only to the level recommended by the manufacturer, generally about an inch below the top, otherwise they may overflow during finish-charging.

**Conclusion**

Deep cycle batteries are the heart of your power system. They may demand your attention occasionally, but your relationship with them need not be a struggle. With a proper installation, a little understanding and some simple maintenance, your batteries will live a long and healthy life.