The subject of batteries could take up many pages. All we have room for here is a basic overview of batteries commonly used with photovoltaic power systems. These are nearly all various variations of Lead-Acid batteries. For a very brief discussion on the advantages and disadvantages of these and other types of batteries, such as NiCad, NiFe (Nickel-Iron), etc. go to our Batteries for Deep Cycle Applications page. These are sometimes referred to as "deep discharge" or "deep cell" batteries. The correct term is deep cycle.

A printable version of this page will be available in Adobe PDF format when we finish updating this page for downloading and printing: Most of the charts have small images for faster downloading. To see the full size picture, just click on the small one.

Battery History

Although Alessandro Volta in Italy is usually credited with being the inventor of the modern battery (Silver-Zinc), ancient cells have been discovered in Sumerian ruins, origin around 250 BC.

The first evidence of batteries comes from archaeological digs in Baghdad, Iraq. This first "battery" was dated to around 250 B.C. and may have been used in simple operations to electroplate objects with a thin layer of metal, much like the process used now to plate inexpensive gold and silver jewelry. Possibly one of the first uses for batteries, although there is some dispute among scholars. Wikipedia entry for Baghdad Battery.

Batteries were re-discovered much later by Alessandro Volta after which the unit of electrical potential was named, the volt. The jar was found in Khujut Rabu just outside Baghdad and is composed of a clay jar with a stopper made of asphalt. Sticking through the asphalt is an iron rod surrounded by a copper cylinder. When filled with vinegar - or any other electrolytic solution - the jar produces about 1.1 volts.

What is a Battery?

A battery, in concept, can be any device that stores energy for later use. A rock, pushed to the top of a hill, can be considered a kind of battery, since the energy used to push it up the hill (chemical energy, from muscles or combustion engines) is converted and stored as potential kinetic energy at the top of the hill. Later, that energy is released as kinetic and thermal energy when the rock rolls down the hill. Not real practical for everyday use though.

Common use of the word, "battery" in electrical terms, is limited to an electrochemical device that converts chemical energy into electricity, by a galvanic cell. A galvanic cell is a fairly simple device consisting of two electrodes of different metals or metal compounds (an anode and a cathode) and an electrolyte (usually acid, but some are alkaline) solution. A "Battery" is two or more of those cells in series, although many types of single cells are usually referred to as batteries - such as flashlight batteries.

As noted above, a battery is an electrical storage device. Batteries do not make electricity, they store it, just as a water tank stores water for future use. As chemicals in the battery change, electrical energy is stored or released. In rechargeable batteries this process can be repeated many times. Batteries are not 100% efficient - some energy is lost as heat and chemical reactions when charging and discharging. If you use 1000 watts from a battery, it might take 1050 or 1250 watts or more to fully recharge it.

Internal Resistance

Part - or most - of the loss in charging and discharging batteries is due to internal resistance. This is converted to heat, which is why batteries get warm when being charged up. The lower the internal resistance, the better. There is a good explanation and demonstration of **Internal Resistance here** (YouTube)

Slower charging and discharging rates are more efficient. A battery rated at 180 amp-hours over 6 hours might be rated at 220 AH at the 20-hour rate, and 260 AH at the 48-hour rate. Much of this loss of efficiency is due to higher internal resistance at higher amperage rates - internal resistance is not a constant - kind of like "the more you push, the more it pushes back".

Typical efficiency in a lead-acid battery is 85-95%, in alkaline and NiCad battery it is about 65%. True deep cycle AGM's (such as Concorde) can approach 98% under optimum conditions, but those conditions are seldom found so you should figure as a general rule about a 10% to 20% total power loss when sizing batteries and battery banks.

Practically all batteries used in PV and all but the smallest backup systems are Lead-Acid type batteries. Even after over a century of use, they still offer the best price to power ratio. A few systems use NiCad, but we do not recommend them except in cases where extremely cold temperatures (-50 F or less) are common. They are expensive to buy, and very expensive to dispose of due the the hazardous nature of Cadmium.

We have had almost no direct experience with the NiFe (alkaline) batteries, but from what we have learned from others we do not not recommend them - one major disadvantage is that there is a large voltage difference between the fully charged and discharged state. Another problem is that they are very inefficient - you lose from 30-40% in heat just in charging and discharging them. Many inverters and charge controls have a hard time with them. It appears that the only current source for new cells seems to be from Hungary. In the past they were often used by railroads as backup power, but nearly all have now changed over to newer types.

An important fact is that ALL of the batteries commonly used in deep cycle applications are Lead-Acid. This includes the standard flooded (wet) batteries, gelled, and AGM. They all use the same chemistry, although the actual construction of the plates etc varies.

NiCads, Nickel-Iron, and other types are found in a few systems, but are not common due to their expense, environmental hazards, and/or poor efficiency.

Types of Batteries

Batteries are divided in two ways, by application (what they are used for) and construction (how they are built). The major applications are automotive, marine, and deep-cycle. Deep-cycle includes solar electric (PV), backup power, traction, and RV and boat "house" batteries. The major construction types are flooded (wet), gelled, and AGM (Absorbed Glass Mat). AGM batteries are also sometimes called "starved electrolyte" or "dry", because the fiberglass mat is only 95% saturated with Sulfuric acid and there is no excess liquid.

Flooded may be standard, with removable caps, or the so-called "maintenance free" (that means they are designed to die one week after the warranty runs out). All AGM & gelled are sealed and are "valve regulated", which means that a tiny valve keeps a slight positive pressure. Nearly all sealed batteries are "valve regulated" (commonly referred to as "VRLA" - Valve Regulated Lead-Acid). Most valve regulated are under some pressure - 1 to 4 psi at sea level.

Battery Lifespan

The lifespan of a deep cycle battery will vary considerably with how it is used, how it is maintained and charged, temperature, and other factors. In extreme cases, it can vary to extremes - we have seen L-16's killed in less than a year by severe overcharging and water loss, and we have a large set of surplus telephone batteries that sees only occasional (10-15 times per year) heavy service that were just replace after 35+ years. We have seen gelled cells destroyed in one day when overcharged with a large automotive charger. We have seen golf cart batteries destroyed without ever being used in less than a year because they were left sitting in a hot garage or warehouse without being charged. Even the so-called "dry charged" (where you add acid when you need them) have a shelf life of 18 months at most. (They are not totally dry - they are actually filled with acid, the plates formed and charged, then the acid is dumped out).

These are some typical (minimum - maximum) typical expectations for batteries **if used in deep cycle service**. There are so many variables, such as depth of discharge, maintenance, temperature, how often and how deep cycled, etc. that it is almost impossible to give a fixed number.

- Starting: 3-12 months
- Marine: 1-6 years
- Golf cart: 2-7 years
- AGM deep cycle: 4-8 years
- Gelled deep cycle: 2-5 years
- Deep cycle (L-16 type etc): 4-8 years
- Rolls-Surrette premium deep cycle: 7-15 years
- Industrial deep cycle (Crown and Rolls 4KS series): 10-20+ years.
- Telephone (float): 2-20 years. These are usually special purpose "float service", but often appear on the surplus market as "deep cycle". They can vary considerably, depending on age, usage, care, and type.
- NiFe (alkaline): 5-35 years
- NiCad: 1-20 years

Starting, Marine, or Deep-Cycle Batteries

Starting (sometimes called SLI, for starting, lighting, ignition) batteries are commonly used to start and run engines. Engine starters need a very large starting current for a very short time. Starting batteries have a large number of thin plates for maximum surface area. The plates are composed of a Lead "sponge", similar in appearance to a very fine foam sponge. This gives a very large surface area, but if deep cycled, this sponge will quickly be consumed and fall to the bottom of the cells. Automotive batteries will generally fail after 30-150 deep cycles if deep cycled, while they may last for thousands of cycles in normal starting use (2-5% discharge).

Deep cycle batteries are designed to be discharged down as much as 80% time after time, and have much thicker plates. The major difference between a true deep cycle battery and others is that the plates are SOLID Lead plates - not sponge. This gives less surface area, thus less "instant" power like starting batteries need. *Although these can be cycled down to 20% charge, the best lifespan vs cost method is to keep the average cycle at about 50% discharge.* Unfortunately, it is often impossible to tell what you are really buying in some of the discount stores or places that specialize in automotive batteries. The golf car battery is quite popular for small systems and RV's. The problem is that "golf car" refers to a **size** of battery case (commonly called GC-2, or T-

105), not the type or construction - so the quality and construction of a golf car battery can vary considerably - ranging from the cheap off brand with thin plates up to true deep cycle brands, such as Crown, Deka, Trojan, etc. In general, you get what you pay for.

Marine batteries are usually a "hybrid", and fall between the starting and deep-cycle batteries, though a few (Rolls-Surrette and Concorde, for example) are true deep cycle. In the hybrid, the plates may be composed of Lead sponge, but it is coarser and heavier than that used in starting batteries. It is often hard to tell what you are getting in a "marine" battery, but most are a hybrid. Starting batteries are usually rated at "CCA", or cold cranking amps, or "MCA", Marine cranking amps - the same as "CA". Any battery with the capacity shown in CA or MCA may or may not be a true deep-cycle battery. It is sometimes hard to tell, as the term deep cycle is often overused - we have even seen the term "deep cycle" used in automotive starting battery advertising. CA and MCA ratings are at 32 degrees F, while CCA is at zero degree F. Unfortunately, the only positive way to tell with some batteries is to buy one and cut it open - not much of an option.

Deep Cycle Battery as a Starting Battery

There is generally no problem with this, providing that allowance is made for the lower **cranking amps** compared to a similar size starting battery. As a general rule, if you are going to use a true deep cycle battery (such as the Concorde SunXtender) also as a starting battery, it should be **oversized** about 20% compared to the existing or recommended starting battery group size to get the same cranking amps. That is about the same as replacing a group 24 with a group 31. With modern engines with fuel injection and electronic ignition, it generally takes much less battery power to crank and start them, so raw cranking amps is less important than it used to be. On the other hand, many cars, boats, and RV's are more heavily loaded with power sucking "appliances", such as megawatt stereo systems etc. that are more suited for deep cycle batteries. We have used the Concorde SunXtender AGM batteries in some of our vehicles with no problems.

It will not hurt a deep cycle battery to be used as a starting battery, but for the same size battery they cannot supply as much cranking amps as a regular starting battery and is usually much more expensive.

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What Batteries Are Made Of

Nearly all large rechargeable batteries in common use are Lead-Acid type. (There are some NiCads in use, but for most purposes the very high initial expense, and the high expense of disposal, does not justify them). A few Lithium-Ion types are starting to make their appearance, but are much more expensive than Lead-Acid and most charge controllers do not have the correct setpoints for proper charging.

The acid is typically 30% Sulfuric acid and 70% water at full charge. NiFe (Nickel-Iron) batteries are also available - these have a very long life, but rather poor efficiency (60-70%) and the voltages are different, making it more difficult to match up with standard 12v/24/48v systems and inverters. The biggest problem with NiFe batteries is that you may have to put in 100 watts to get 70 watts of charge - they are much less efficient than Lead-Acid. What you save on batteries you will have to make up for by buying a larger solar panel system. NiCads are also inefficient - typically around 65% - and very expensive. However, NiCads can be frozen without damage, so are sometimes used in areas where the temperatures may fall below -50 degrees F. Most AGM batteries will also survive freezing with no problems, even though the output when frozen will be little or nothing.

Industrial Deep Cycle Batteries

Sometimes called "fork lift", "traction" or "stationary" batteries, are used where power is needed over a longer period of time, and are designed to be "deep cycled", or discharged down as low as 20% of full charge (80% DOD, or Depth of Discharge). These are often called traction batteries because of their widespread use in forklifts, golf carts, and floor sweepers (from which we get the "GC" and "FS" series of battery sizes). Deep cycle batteries have much thicker plates than automotive batteries. They are sometimes used in larger PV systems because you can get a lot of storage in a single (very large and heavy) battery.

Plate Thickness

Plate thickness (of the Positive plate) matters because of a factor called "**positive grid corrosion**". This ranks among the top 3 reasons for battery failure. The positive (+) plate is what gets eaten away gradually over time, so eventually there is nothing left - it all falls to the bottom as sediment. Thicker plates are directly related to longer life, so other things being equal, the battery with the thickest plates will last the longest. The negative plate in batteries expands somewhat during discharge, which is why nearly all batteries have separators, such as glass mat or paper, that can be compressed.

Automotive batteries typically have plates about .040" (4/100") thick, while forklift batteries may have plates more than 1/4" (.265" for example in larger Rolls-Surrette) thick - almost 7 times as thick as auto batteries. The typical golf cart will have plates that are around .07 to .11" thick. The Concorde AGM's are .115", The Rolls-Surrette L-16 type (CH460) is .150", and the US Battery and Trojan L-16 types are .090". The Crown L-16HC size has .22" thick plates. While plate thickness is not the only factor in how many deep cycles a battery can take before it dies, it is the most important one.

Most industrial (fork lift) deep-cycle batteries use Lead-Antimony plates rather than the Lead-Calcium used in AGM or gelled deep-cycle batteries and in automotive starting batteries. The Antimony increases plate life and strength, but increases gassing and water loss. This is why most industrial batteries have to be checked often for water level if you do not have Hydrocaps. The **self discharge** of batteries with Lead-Antimony plates can be high - as much as 1% per day on an older battery. A new AGM typically self-discharges at about 1-2% per month, while an old one may be as much as 2% per week.

<u>Sealed Batteries</u>

Sealed batteries are made with vents that (usually) cannot be removed. The so-called Maintenance Free batteries are also sealed, but are not usually leak proof. Sealed batteries are not totally sealed, as they must allow gas to vent during charging. If overcharged too many times, some of these batteries can lose enough water that they will die before their time. Most smaller deep cycle batteries (including AGM) use **Lead-Calcium** plates for increased life, while most industrial and forklift batteries use **Lead-Antimony** for greater plate strength to withstand shock and vibration.

Lead-Antimony (such as forklift and floor scrubber) batteries have a much higher self-discharge rate (2-10% per week) than Lead or Lead-Calcium (1-5% per month), but the Antimony improves the mechanical strength of the plates, which is an important factor in electric vehicles. They are generally used where they are under constant or very frequent charge/discharge cycles, such as fork lifts and floor sweepers. The Antimony increases plate life at the expense of higher self discharge. If left for long periods unused, these should be trickle charged to avoid damage from sulfation - but this applies to ANY battery.

As in all things, there are trade offs. The Lead-Antimony types have a very long lifespan, but higher self discharge rates.

<u>Battery Size Codes</u>

Batteries come in all different sizes. Many have "group" sizes, which is based upon the ***physical size*** and terminal placement. It is NOT a measure of battery capacity. Typical BCI codes are group U1, 24, 27, and 31. Industrial batteries are usually designated by a part number such as "FS" for floor sweeper, or "GC" for golf cart. Many batteries follow no particular code, and are just manufacturers part numbers. Other standard size codes are 4D & 8D, large industrial batteries, commonly used in solar electric systems.

Some common battery size codes used are: (ratings are approximate)

U1	34 to 40 Amp hours	12 volts
Group 24	70-85 Amp hours	12 volts
Group 27	85-105 Amp hours	12 volts
Group 31	95-125 Amp hours	12 volts
4-D	180-215 Amp hours	12 volts
8-D	225-255 Amp hours	12 volts
Golf Cart & T-105	180 to 225 Amp hours	6 volts
L-16, L16HC etc.	340 to 415 Amp hours	6 volts

Gelled Electrolyte

Gelled batteries, or "Gel Cells" contain acid that has been "gelled" by the addition of Silica Gel, turning the acid into a solid mass that looks like gooey Jell-O. The advantage of these batteries is that it is impossible to spill acid even if they are broken. However, there are several disadvantages. One is that they must be charged at a slower rate (C/20) to prevent excess gas from damaging the cells. They cannot be fast charged on a conventional automotive charger or they may be permanently damaged. This is not usually a problem with solar electric systems, but if an auxiliary generator or inverter bulk charger is used, current **must be limited** to the manufacturers specifications. Most better inverters commonly used in solar electric systems can be set to limit charging current to the batteries.

Some other disadvantages of gel cells is that they must be charged at a lower voltage (2/10th's less) than flooded or AGM batteries. If overcharged, voids can develop in the gel which will never heal, causing a loss in battery capacity. In hot climates, water loss can be enough over 2-4 years to cause premature battery death. It is for this and other reasons that we no longer sell any of the gelled cells except for replacement use. The newer AGM (absorbed glass mat) batteries have all the advantages (and then some) of gelled, with none of the disadvantages.

AGM (Absorbed Glass Mat) Batteries

A newer type of sealed battery uses "Absorbed Glass Mats", or AGM between the plates. This is a very fine fiber Boron-Silicate glass mat. These type of batteries have all the advantages of gelled, but can take much more abuse. We sell the Concorde (and Lifeline, made by Concorde) AGM batteries. These are also called "starved electrolyte", as the mat is about 95% saturated rather than fully soaked. That also means that they will not leak acid even if broken.

AGM batteries have several advantages over both gelled and flooded, at about the same cost as gelled:

Since all the electrolyte (acid) is contained in the glass mats, they cannot spill, even if broken. This also means that since they are non-hazardous, the shipping costs are lower. In addition, since there is no liquid to freeze and expand, they are practically immune from freezing damage.

Nearly all AGM batteries are "**recombinant**" - what that means is that the Oxygen and Hydrogen recombine INSIDE the battery. These use gas phase transfer of oxygen to the negative plates to recombine them back into water while charging and prevent the loss of water through electrolysis. The recombining is typically 99+% efficient, so almost no water is lost.

The charging voltages are the same as for any standard battery - no need for any special adjustments or problems with incompatible chargers or charge controls. And, since the internal resistance is extremely low, there is almost no heating of the battery even under heavy charge and discharge currents. The Concorde (and most AGM) batteries have no charge or discharge current limits.

AGM's have a very low self-discharge - from 1% to 3% per month is usual. This means that they can sit in storage for much longer periods without charging than standard batteries. The Concorde batteries can be almost fully recharged (95% or better) even after 30 days of being totally discharged.

AGM's do not have any liquid to spill, and even under severe overcharge conditions hydrogen emission is far below the 4% max specified for aircraft and enclosed spaces. The plates in AGM's are tightly packed and rigidly mounted, and will withstand shock and vibration better than any standard battery.

Even with all the advantages listed above, there is still a place for the standard flooded deep cycle battery. AGM's will cost about 1.5 to 2 times as much as flooded batteries of the same capacity. In many installations, where the batteries are set in an area where you don't have to worry about fumes or leakage, a standard or industrial deep cycle is a better economic choice. AGM batteries main advantages are no maintenance, completely sealed against fumes, Hydrogen, or leakage, non-spilling even if they are broken, and can survive most freezes. Not everyone needs these features.

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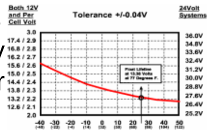
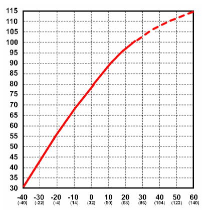
Temperature Effects on Batteries

Battery capacity (how many amp-hours it can hold) is reduced as temperature goes down, and increased as temperature goes up. This is why your car battery dies on a cold winter morning, even though it worked fine the previous afternoon. If your batteries spend part of the year shivering in the cold, the reduced capacity has to be taken into account when sizing the system batteries. The standard rating for batteries is at room temperature - 25 degrees C (about 77 F). At approximately -22 degrees F (-27 C), battery AH capacity drops to 50%. At freezing, capacity is reduced by 20%. Capacity is increased at higher temperatures - at 122 degrees F, battery capacity would be about 12% higher.



Battery charging **voltage** also changes with temperature. It will vary from about 2.74 volts per cell (16.4 volts) at -40 C to 2.3 volts per cell (13.8 volts) at 50 C. This is why you should have temperature compensation on your charger or charge control if your batteries are outside and/or subject to wide temperature variations. Some charge controls have temperature compensation built in (such as Morningstar) - this works fine if the controller is subject to the same temperatures as the batteries. However, if your batteries are outside, and the controller is inside, it does not work that well. Adding another complication is that large battery banks make up a large **thermal mass**.

Thermal mass means that because they have so much mass, they will change internal temperature much slower than the surrounding air temperature. A large insulated battery bank may vary as little as 10 degrees over 24 hours internally, even though the air temperature varies from 20 to 70 degrees. For this reason, external (add-on) temperature sensors should be attached to one of the POSITIVE plate terminals, and bundled up a little with some type of insulation on the terminal. The sensor will then read very close to the actual internal battery temperature.

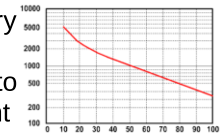


Even though battery capacity at high temperatures is higher, battery *life* is shortened. Battery capacity is reduced by 50% at -22 degrees F - but battery LIFE increases by about 60%. Battery life is reduced at higher temperatures - for every 15 degrees F over 77, battery life is cut in half. This holds true for ANY type of Lead-Acid battery, whether sealed, gelled, AGM, industrial or whatever. This is actually not as bad as it seems, as the battery will tend to average out the good and bad times. *Click on the small graph to see a full size chart of temperature vs capacity.*

One last note on temperatures - in some places that have extremely cold or hot conditions, batteries may be sold locally that are NOT standard electrolyte (acid) strengths. The electrolyte may be stronger (for cold) or weaker (for very hot) climates. In such cases, the specific gravity and the voltages may vary from what we show.

Cycles vs Lifespan

A battery "cycle" is one complete discharge and recharge cycle. It is usually considered to be discharging from 100% to 20%, and then back to 100%. However, there are often ratings for other depth of discharge cycles, the most common ones are 10%, 20%, and 50%. You have to be careful when looking at ratings that list how many cycles a battery is rated for unless it also states how far down it is being discharged. For example, one of the widely advertised telephone type (float service) batteries have been advertised as having a 20-year life. If you look at the fine print, it has that rating only at 5% DOD - it is much less when used in an application where they are cycled deeper on a regular basis. Those same batteries are rated at less than 5 years if cycled to 50%. For example, most golf cart batteries are rated for about 550 cycles to 50% discharge - which equates to about 2 years.



Battery life is directly related to how **deep** the battery is cycled each time. If a battery is discharged to 50% every day, it will last about twice as long as if it is cycled to 80% DOD. If cycled only 10% DOD, it will last about 5 times as long as one cycled to 50%. Obviously, there are some practical limitations on this - you don't usually want to have a 5 ton pile of batteries sitting there just to reduce the DOD. The most practical number to use is 50% DOD on a regular basis. This does NOT mean you cannot go to 80% once in a while. It's just that when designing a system when you have some idea of the loads, you should figure on an **average** DOD of around 50% for the best storage vs cost factor. Also, there is an upper limit - a battery that is continually cycled 5% or less will usually not last as long as one cycled down 10%. This happens because at very shallow cycles, the Lead Dioxide tends to build up in clumps on the the positive plates rather in an even film. The graph above shows how lifespan is affected by depth of discharge. The chart is for a Concorde Lifeline battery, but all lead-acid batteries will be similar in the shape of the curve, although the number of cycles will vary.

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Battery Voltages

All Lead-Acid batteries supply about 2.14 volts per cell (12.6 to 12.8 for a 12 volt battery) when fully charged. Batteries that are stored for long periods will eventually lose all their charge. This "leakage" or self discharge varies considerably with battery type, age, & temperature. It can range from about 1% to 15% per month. Generally, new AGM batteries have the lowest, and old industrial (Lead-Antimony plates) are the highest. In systems that are continually connected to some type charging source, whether it is solar, wind, or an AC powered charger this is seldom a problem. However, one of the biggest killers of batteries is sitting stored in a partly discharged state for a few months. A "float" trickle charge should be maintained on the batteries even if they are not used (or, **especially** if they are not used). Even most "dry charged" batteries (those sold without electrolyte so they can be shipped more easily, with acid added later) will deteriorate over time. Max storage life on those is about 18 to 30 months.

Batteries self-discharge faster at higher temperatures. Lifespan can also be seriously reduced at higher temperatures - most manufacturers state this as a 50% loss in life for every 15 degrees F over a 77 degree cell temperature. Lifespan is increased at the same rate if below 77 degrees, but capacity is reduced. This tends to even out in most systems - they will spend part of their life at higher temperatures, and part at lower. Typical self discharge rates for flooded are 5% to 15% per month.

Myth: The old myth about not storing batteries on concrete floors is just that - a myth. This story has been around for 100 years, and originated back when battery cases were made up of wood and asphalt. The acid would leak from them, and form a slow-discharging circuit through the now acid-soaked and conductive floor.

State of Charge

State of charge, or conversely, the depth of discharge (**DOD**) can be determined by measuring the voltage and/or the specific gravity of the acid with a hydrometer. This will NOT tell you how good (capacity in AH) the battery condition is - only a sustained **load test** can do that. Voltage on a fully charged battery will read 2.12 to 2.15 volts per cell, or 12.7 volts for a 12 volt battery. At 50% the reading will be 2.03 VPC (Volts Per Cell), and at 0% will be 1.75 VPC or less. Specific gravity will be about 1.265 for a fully charged cell, and 1.13 or less for a totally discharged cell. This can vary with battery types and brands somewhat - when you buy new batteries you should charge them up and let them sit for a while, then take a reference measurement. Many batteries are sealed, and hydrometer reading cannot be taken, so you must rely on voltage. Hydrometer readings may not tell the whole story, as it takes a while for the acid to get mixed up in wet cells. If measured right after charging, you might see 1.27 at the top of the cell, even though it is much less at the bottom. This does not apply to gelled or AGM batteries.

"False" Capacity

A battery can meet the voltage tests for being at full charge, yet be much lower than it's original capacity. If plates are damaged, sulfated, or partially gone from long use, the battery may give the **appearance** of being fully charged, but in reality acts like a battery of much smaller size. This same thing can occur in gelled cells if they are overcharged and gaps or bubbles occur in the gel. What is left of the plates may be fully functional, but with only 20% of the plates left... Batteries usually go bad for other reasons before reaching this point, but it is something to be aware of if your batteries seem to test OK but lack capacity and go dead very quickly under load.

On the table below, you have to be careful that you are not just measuring the surface charge. To properly check the voltages, the battery should sit at rest for a few hours, or you should put a small load on it, such as a small automotive bulb, for a few minutes. The voltages below apply to ALL Lead-Acid batteries, except gelled. For gel cells, subtract .2 volts. Note that the voltages when **actually charging** will be quite different, so do not use these numbers for a battery that is under charge.

Amp-Hours - What Are They?

All deep cycle batteries are rated in amp-hours. An amp-hour is one amp for one hour, or 10 amps for 1/10 of an hour and so forth. It is **amps x hours**. If you have something that pulls 20 amps, and you use it for 20 minutes, then the amp-hours used would be 20 (amps) x .333 (hours), or 6.67 AH. The generally accepted AH rating time period for batteries used in solar electric and backup power systems (and for nearly all deep cycle batteries) is the "**20 hour rate**". (Some, such as the Concorde AGM, use the 24 hour rate, which is probably a better real-world rating). This means that it is discharged down to 10.5 volts over a 20 hour period while the total actual amp-hours it supplies is measured. Sometimes ratings at the **6 hour rate** and **100 hour rate** are also given for comparison and for different applications. The 6-hour rate is often used for industrial batteries, as that is a typical daily duty cycle. Sometimes the 100 hour rate is given just to make the battery look better than it really is, but it is also useful for figuring battery capacity for long-term backup amp-hour requirements.

Why amp-hours are specified at a particular rate:

Because of something called the Peukert Effect. The Peukert value is directly related to the internal resistance of the battery. The higher the internal resistance, the higher the losses while charging and discharging, especially at higher currents. This means that the faster a battery is used (discharged), the LOWER the AH capacity. Conversely, if it is drained slower, the AH capacity is higher. This is important because some manufacturers and vendors have chosen to rate their batteries at the 100 hour rate - which makes them look a lot better than they really are. Here are some typical battery capacities from the manufacturers data sheets:

Battery Type	100 hour rate	20 hour rate	8
Trojan T-105	250 AH	225 AH	n/a
US Battery 2200	n/a	225 AH	181 AH
Concorde PVX-6220	255 AH	221 AH	183 AH

Surrette S-460 (L-16)	429 AH	344 AH	282 AH
Trojan L-16	400 AH	360 AH	n/a
Surrette CS-25-PS	974 AH	779 AH	639 AH

State of Charge

Here are no-load typical voltages vs state of charge

(figured at 10.5 volts = fully discharged, and 77 degrees F). Voltages are for a 12 volt battery system. For 24 volt systems multiply by 2, for 48 volt system, multiply by 4. VPC is the volts per individual cell - if you measure more than a .2 volt difference between each cell, you need to equalize, or your batteries are going bad, or they may be sulfated. These voltages are for batteries that have been at rest for 3 hours or more. Batteries that are being charged will be higher - the voltages while under charge will not tell you anything, you have to let the battery sit for a while. For longest life, batteries should stay in the green zone. Occasional dips into the yellow are not harmful, but continual discharges to those levels will shorten battery life considerably. It is important to realize that ***voltage measurements are only approximate***. The best determination is to measure the specific gravity, but in many batteries this is difficult or impossible. Note the large voltage drop in the last 10%.

State of Charge	12 Volt battery	Volts per Cell
100%	12.7	2.12
90%	12.5	2.08
80%	12.42	2.07
70%	12.32	2.05
60%	12.20	2.03
50%	12.06	2.01
40%	11.9	1.98
30%	11.75	1.96
20%	11.58	1.93
10%	**11.31**	**1.89**
0	**10.5**	**1.75**

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Why 10.5 Volts?

Throughout this FAQ, we have stated that a battery is considered dead at 10.5 volts. The answer is related to the internal chemistry of batteries - at around 10.5 volts, the specific gravity of the acid in the battery gets so low that there is very little left that can do. In a dead battery, the specific gravity can fall below 1.1. Some actual testing was done recently on a battery by one of our solar forum posters, and these are his results:

I just tested a 225 ahr deep cycle battery that is in good working order..
I put a load on it 30a for 4 hrs it dropped its voltage to 11.2
I then let it cool down for 2 hrs

then put the load back on again in 1hr 42 mins it dropped to 10.3v
35 mins under 30a load 9.1v (273w)

10 mins later max output current 11.6a 8.5v (98.6w)
5 mins later max output current 5.2 amps 7.9v (41w)
3 mins later 7.6v and 2.3a (17.5w)

This shows after it gets below 10.3 v you only have 35 mins of anything useful available from the battery.

battery is now dead and most likely will not fully recover

Battery Charging

Battery charging takes place in 3 basic stages: *Bulk*, *Absorption*, and *Float*.

Bulk Charge - The first stage of 3-stage battery charging. Current is sent to batteries at the maximum safe rate they will accept until voltage rises to near (80-90%) full charge level. Voltages at this stage typically range from 10.5 volts to 15 volts. There is no "correct" voltage for bulk charging, but there may be limits on the maximum current that the battery and/or wiring can take.

Absorption Charge: The 2nd stage of 3-stage battery charging. Voltage remains constant and current gradually tapers off as internal resistance increases during charging. It is during this stage that the charger puts out maximum voltage. Voltages at this stage are typically around 14.2 to 15.5 volts. (The internal resistance gradually goes up because there is less and less to be converted back to normal full charge).

Float Charge: The 3rd stage of 3-stage battery charging. After batteries reach full charge, charging voltage is reduced to a lower level (typically 12.8 to 13.2) to reduce gassing and prolong battery life. This is often referred to as a maintenance or trickle charge, since it's main purpose is to keep an already charged battery from discharging. PWM, or "pulse width modulation" accomplishes the same thing. In PWM, the controller or charger senses tiny voltage drops in the battery and sends very short charging cycles (pulses) to the battery. This may occur several hundred times per minute. It is called "pulse width" because the width of the pulses may vary from a few microseconds to several seconds. Note that for **long term** float service, such as backup power systems that are seldom discharged, the float voltage should be around 13.02 to 13.20 volts.

Chargers: Most garage and consumer (automotive) type battery chargers are bulk charge only, and have little (if any) voltage regulation. They are fine for a quick boost to low batteries, but not to leave on for long periods. Among the regulated chargers, there are the voltage regulated ones, such as Iota Engineering, PowerMax, and others, which keep a constant regulated voltage on the batteries. If these are set to the correct voltages for your batteries, they will keep the batteries charged without damage. These are sometimes called "taper charge" - as if that is a selling point. What taper charge really means is that as the battery gets charged up, the voltage goes up, so the amps out of the charger goes down. They charge OK, but a charger rated at 20 amps may only be supplying 5 amps when the batteries are 80% charged. To get around this, Xantrex (and maybe others?) have come out with "smart", or multi-stage chargers. These use a variable voltage to keep the charging amps much more constant for faster charging.

We stock all of the **Iota Engineering** battery chargers.

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Charge Controllers

A charge controller is a regulator that goes between the solar panels and the batteries. Regulators for solar systems are designed to keep the batteries charged at peak without overcharging. Meters for Amps (from the panels) and battery Volts are optional with most types. Some of the various brands and models that we use and recommend are listed below. Note that a couple of them are listed as "power trackers" - for a full explanation of this, see our page on "Why 120 watts does not equal 120 watts".

Most of the modern controllers have automatic or manual equalization built in, and many have a LOAD output. There is no "best" controller for all applications - some systems may need the bells and whistles of the more expensive controls, others may not.

These are some of the charge controllers that we recommend, but almost any modern controller will work fine. Exact model will depend on application and system size, amperage and voltage.

Xantrex
Morningstar
Midnite Solar
Outback Power
Steca

Using any of these will almost always give better battery life and charge than "on-off" or simple shunt type regulators

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Battery Charging Voltages and Currents:

Most flooded batteries should be charged at no more than the "C/8" rate for any sustained period. While some battery manufacturers state a higher maximum charge rate, such as C/3, higher charge rates can result in high battery temperatures and/or excessive bubbling and loss of liquid. ("C/8" is the battery capacity at the 20-hour rate divided by 8. For a 220 AH battery, this would equal 26 Amps.) Gelled cells should be charged at no more than the C/20 rate, or 5% of their amp-hour capacity. The **Concorde and some other AGM** batteries are a special case - the can be charged at up the the Cx4 rate, or 400% of the capacity for the bulk charge cycle for a short period. However, since very few battery cables can take that much current, we don't recommend you try this at home. To avoid cable overheating, you should stick to C/4 or less.

Charging at 15.5 volts will give you a 100% charge on Lead-Acid batteries. Once the charging voltage reaches 2.583 volts per cell, charging should stop or be reduced to a trickle charge. Note that flooded batteries **MUST** bubble (gas) somewhat to insure a full charge, and to mix the electrolyte. Float voltage for Lead-Acid batteries should be about 2.15 to 2.23 volts per cell, or about 12.9-13.4 volts for a 12 volt battery. At higher temperatures (over 85 degrees F) this should be reduced to about 2.10 volts per cell.

Never add acid to a battery except to replace spilled liquid. Distilled or deionized water should be used to top off non-sealed batteries. Float and charging voltages for gelled batteries are usually about 2/10th volt less than for flooded to reduce water loss. Note that many shunt-type charge controllers sold for solar systems will NOT give you a full charge - check the specifications first. To get a full charge, you must continue to apply a current after the battery voltage reaches the cutoff point of most of these type of controllers. This is why we recommend the charge controls and battery chargers listed in the sections above. Not all shunt type controllers are 100% on or off, but most are.

Flooded battery life can be extended if an **equalizing charge** is applied every 10 to 40 days. This is a charge that is about 10% higher than normal full charge voltage, and is applied for about 2 to 16 hours. This makes sure that all the cells are equally charged, and the gas bubbles mix the electrolyte. If the liquid in standard wet cells is not mixed, the electrolyte becomes "stratified". You can have very strong solution at the bottom, and very weak at the top of the cell. With stratification, you can test a battery with a hydrometer and get readings that are quite a ways off. If you cannot equalize for some reason, you should let the battery sit for at least 24 hours and then use the hydrometer. AGM and gelled should be equalized 2-4 times a year at most - check the manufacturers recommendations, especially on gelled.

Battery Aging

As batteries age, their maintenance requirements change. This means longer charging time and/or higher finish rate (higher amperage at the end of the charge). Usually older batteries need to be watered more often. And, their capacity decreases while the self-discharge rate increases.

Mini Factoids

Nearly all batteries will not reach full capacity until cycled 10-30 times. A brand new battery will have a capacity of about 5-10% less than the rated capacity.

Batteries should be watered **after** charging unless the plates are exposed, then add just enough water to cover the plates. After a full charge, the water level should be even in all cells and usually 1/4" to 1/2" below the bottom of the fill well in the cell (depends on battery size and type).

In situations where multiple batteries are connected in series, parallel or series/parallel, replacement batteries should be the same size, type and manufacturer (if possible). Age and usage level should be the same as the companion batteries. Do not put a new battery in a pack which is more than 6 months old or has more than 75 cycles. Either replace with all new or use a good used battery. For long life batteries, such as the Surrette and Crown, you can have up to a one year age difference.

The vent caps on flooded batteries should remain on the battery while charging. This prevents a lot of the water loss and splashing that may occur when they are bubbling.

When you first buy a new set of flooded (wet) batteries, you should fully charge and equalize them, and then take a hydrometer reading for future reference. Since not all batteries have exactly the same acid strength, this will give you a baseline for future readings.

When using a small solar panel to keep a float (maintenance) charge on a battery (without using a charge controller), choose a panel that will give a maximum output of about 1/300th to 1/1000th of the amp-hour capacity. For a pair of golf cart batteries, that would be about a 1 to 5 watt panel - the smaller panel if you get 5 or more hours of sun per day, the larger one for those long cloudy winter days in the Northeast.

Lead-Acid batteries do NOT have a memory, and the rumor that they should be fully discharged to avoid this "memory" is totally false and will lead to early battery failure.

Inactivity can be extremely harmful to a battery. It is a **VERY** poor idea to buy new batteries and "save" them for later. Either buy them when you need them, or keep them on a continual trickle charge. The best thing - if you buy them, use them.

Only clean water should be used for cleaning the outside of batteries. Solvents or spray cleaners should not be used.

Some Peukert Exponent values (not complete, just for info). We don't have a lot of data. Trojan T-105 = 1.25; Optima 750S = 1.109; US Battery 2200 = 1.20.