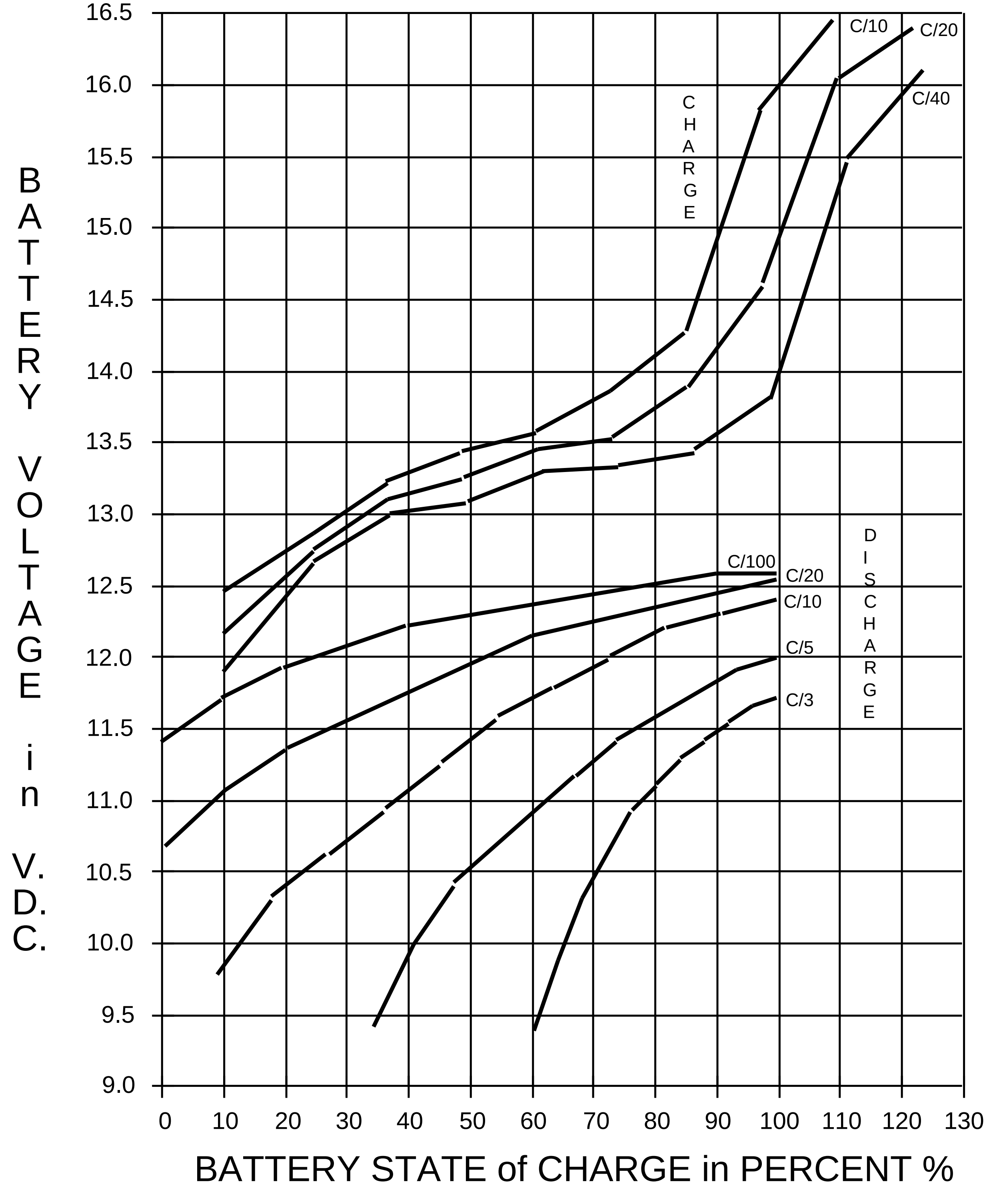
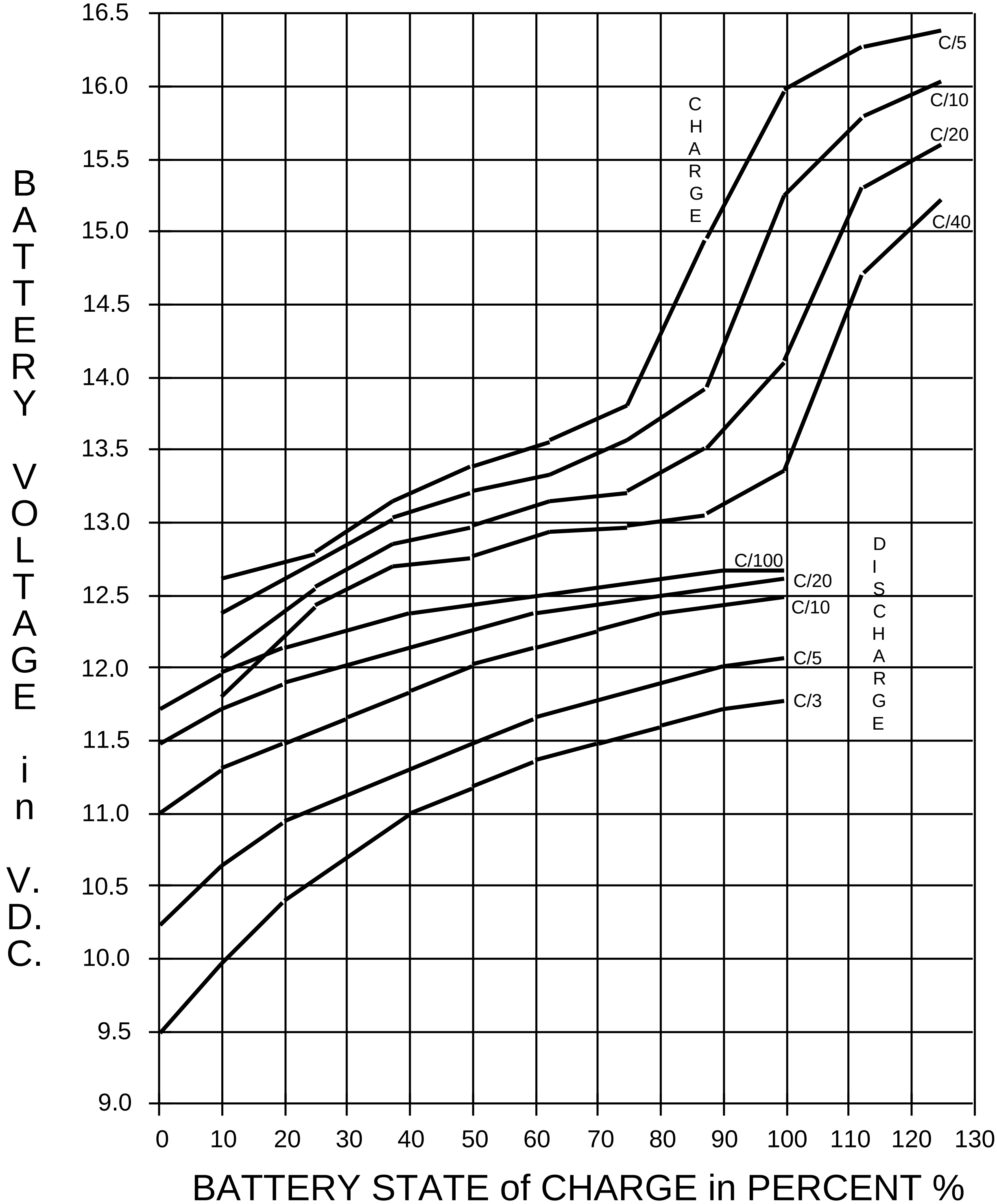
12 Volt Lead-Acid Battery Chart- 34°F.



12 Volt Lead-Acid Battery Chart- 78°F.



Lead-Acid Batteries for Home Power Storage

Richard Perez

In 1970, we moved to the Mountains. The only desirable property we could afford was in the outback. Everything was many miles down a rough dirt road, far from civilized conveniences like electricity. We conquered the bad roads with a 4WD truck and countless hours of mechanical maintenance. The electrical power problem was not so easy to solve. We had to content ourselves with kerosene lighting and using hand tools. The best solution the marketplace could then offer was an engine driven generator. This required constant operation in order to supply power, in other words, expensive. It seemed that in America one either had power or one didn't.

We needed inexpensive home power. And we needed it to be there 24 hours a day without constantly running a noisy, gasoline eating, engine. At that time, NASA was about the only folks who could afford PVs. We started using lead-acid batteries to store the electricity produced by a small gas engine/generator. We'd withdraw energy from the batteries until they were empty and then refill them by running a lawnmower engine and car alternator. Since we stored enough energy to last about 4 days, we discharged and recharged the batteries about 100 times a year. Over years of this type service, we have learned much about lead-acid batteries-- how they work and how to best use them. The following info has been hard won; we've made many expensive mistakes. We've also discovered how to efficiently and effectively coexist with the batteries that store our energy. Batteries are like many things in Life, mysterious until understood.

Before we can effectively communicate about batteries, we must share a common set of terms. Batteries and electricity, like many technical subjects, have their own particular jargon. Understanding these electrical terms is the first step to understanding your batteries.

Electrical Terms

Voltage

Voltage is electronic pressure. Electricity is electrons in motion. Voltage is the amount of pressure behind these electrons. Voltage is very similar to pressure in a water system. Consider a water hose. Water pressure forces the water through the hose. This situation is the same for an electron moving through a wire. A car uses 12 Volts, from a battery for starting. Commercial household power has a voltage of 120 volts. Batteries for renewable energy are usually assembled into packs of 12, 24, 32, or 48 volts.

Current

Current is the flow of electrons. The unit of electron flow in relation to time is called the Ampere. Consider the water hose analogy once again. If voltage is like water pressure, then current is like FLOW. Flow in water systems is measured in gallons per minute, while electron flow is measured in Amperes. A car tail light bulb consumes about 1 to 2 Amperes of electrical current. The headlights on a car consume about 8 Amperes each. The starter uses about 200 to 300 Amperes. Electrical current comes in two forms-- direct current (DC) and alternating current (ac). In DC circuits the electrons flow in one direction ONLY. In ac circuits the electrons can flow in both directions. Regular household power is ac. Batteries store electrical power as direct current (DC).

Power

Power is the amount of energy that is being used or generated. The unit of power is the Watt. In the water hose analogy, power is can be compared to the total gallons of water transferred by the hose. Mathematically, power is the product of Voltage and Current. To find Power simply multiply Volts times Amperes. The amounts of power being used and generated determine the amount of energy that the battery must store.

Battery Terms

A Cell

The cell is the basic building block of all electrochemical batteries. The cell contains two active materials which react chemically to release free electrons (electrical energy). These active materials are usually solid and immersed in a liquid called the "electrolyte". The electrolyte is an electrically conductive liquid which acts as an electron transfer medium. In a lead acid cell, one of the active materials is lead dioxide (PbO_2) and forms the Positive pole (Anode) of the cell. The other active material is lead and forms the Negative pole (Cathode) of the cell. The lead acid cell uses an electrolyte composed of sulphuric acid (H_2SO_4).

During discharge, the cell's active materials undergo chemical reactions which release free electrons. These free electrons are available for our use at the cells electrical terminals or "poles". During discharge the actual chemical compositions of the active materials change. When all the active materials have undergone reaction, then the cell will produce no more free electrons. The cell is now completely discharged or in battery lingo, "dead".

Some cells, like the lead-acid cell, are rechargeable. This means that we can reverse the discharge chemical reaction by forcing electrons backwards through the cell. During the recharging process the active materials are gradually restored to their original, fully charged, chemical composition.

The voltage of an electrochemical cell is determined by the active materials used in its construction. The lead-acid cell develops a voltage of around 2 Volts DC. The voltage of a cell has no relationship to its physical size. All lead acid cells produce about 2 VDC regardless of size.

In the lead acid cell, the sulphuric acid electrolyte actually participates in the cell's electrochemical reaction. In most other battery technologies, like the nickel-cadmium cells, the electrolyte merely transfers electrons and does not change chemically as the cell discharges. In the lead-acid system, however, the electrolyte participates in the cell's reaction and the H_2SO_4 content of the electrolyte changes as the cell is discharged or charged. Typically the electrolyte in a fully charged cell is about 25% sulphuric acid with the remaining 75% being water. In the fully discharged lead-acid cell, the electrolyte is composed of less than 5% sulphuric acid with the remaining 95% being water. This happy fact allows us to determine how much energy a lead-acid cell contains by measuring the amount of acid remaining in its electrolyte. Figure 1 illustrates the electrochemical workings of a lead acid cell.

A Battery

A battery is a group of electrochemical cells. Individual cells are collected into batteries to either increase the voltage or the electrical capacity of the resulting battery pack. For example, an automotive electrical system requires 12 VDC for operation. How is this accomplished with a basic 2 VDC lead-acid cell? The cells are wired together in series, this makes a battery that has the combined voltages of the cells. A 12 Volt lead-acid battery has six (6) cells, each wired anode to cathode (in series) to produce 12 VDC. Cells are combined in series for a voltage increase or in parallel for an electrical capacity increase.

Battery Capacity

Battery capacity is the amount of energy a battery contains. Battery capacity is usually rated in Ampere-hours (A-h) at a given voltage. Watt-hours (W-h) is another unit used to quantify battery capacity. While a single cell is limited in voltage by its materials, the electrical capacity of a cell is limited only by its size. The larger the cell, the more reactive materials contained within it, and the larger the electrical capacity of the cell in Ampere-hours.

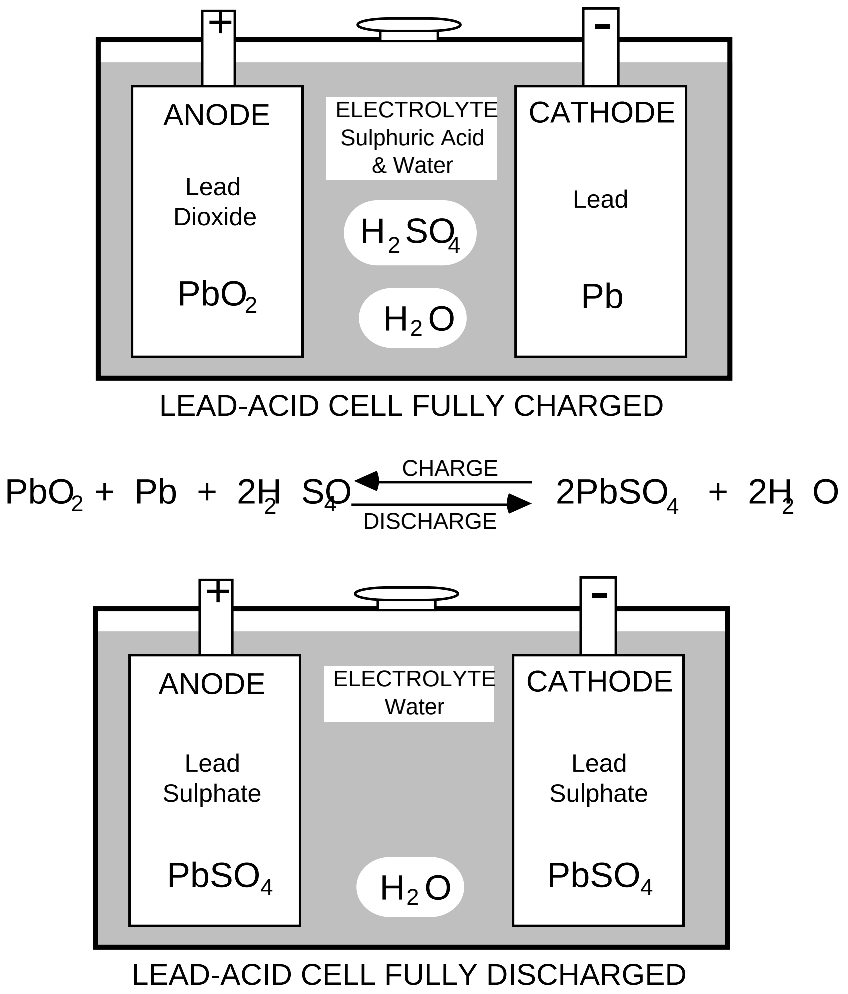


Figure 1- An electrochemical schematic of the lead-acid cell.

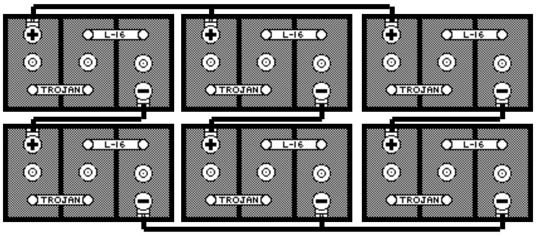
A battery rated at 100 Ampere-hours will deliver 100 Amperes of current for 1 hour. It can also deliver 10 Amperes for 10 hours, or 1 Ampere for 100 hours. The average car battery has a capacity of about 60 Ampere-hours. Renewable energy battery packs contain from 350 to 4,900 Ampere-hours. The specified capacity of a battery pack is determined by two factors-- how much energy is needed and how long the battery must supply this energy. Renewable energy systems work best with between 4 and 21 days of storage potential.

A battery is similar to a bucket. It will only contain so much electrical energy, just as the bucket will only contain so much water. The amount of capacity a battery has is roughly determined by its size and weight, just as a bucket's capacity is determined by its size. It is difficult to water a very large garden with one small bucket, it is also difficult to run a homestead on an undersized battery. If a battery based renewable energy system is to really work, it is essential that the battery have enough capacity to do the job. Undersized batteries are one of the major reasons that some folks are not happy with their renewable energy systems.

Battery capacity is a very important factor in sizing renewable energy systems. The size of the battery is determined by the amount of energy you need and how long you wish to go between battery rechargings. The capacity of the battery then determines the size of the charge source. Everything must be balanced if the system is to be efficient and long-lived.

State of Charge (SOC)

A battery's state of charge is a percentage figure giving the amount of energy remaining in the battery. A 300 Ampere-hour battery at a 90% state of charge will contain 270 Amperes-hours of energy. At a 50% state of charge the same battery will contain 150 Ampere-hours. A battery which is discharged to a 20% or less state of charge is said to be "deep



Lead- Acid Battery-- 12 VDC at 1,050 Ampere-hours.
6 each Trojan L-16W (6 VDC at 350 Ampere-hours)
Each L-16 CELL contains 350 Ampere-hours at 2 VDC, and the L-16 battery has 3 cells(in series) within its case.

cycled". Shallow cycle service withdraws less than 10% of the battery's energy per cycle.

Lead-Acid Batteries

Lead-acid batteries are really the only type to consider for home energy storage at the present time. Other types of batteries, such as nickel-cadmium, are being made and sold, but they are simply too expensive to fit into low budget electrical schemes. We started out using car batteries.

Automotive Starting Batteries

The main thing we learned from using car batteries in deep cycle service is **DON'T**. Automotive starting batteries are not designed for deep cycle service; they don't last. Although they are cheap to buy, they are much more expensive to use over a period of several years. They wear out very quickly.

Car Battery Construction

The plates of a car battery are made from lead sponge. The idea is to expose the maximum plate surface area for chemical reaction. Using lead sponge makes the battery able to deliver high currents and still be as light and cheap as possible. The sponge type plates do not have the mechanical ruggedness necessary for repeated deep cycling over a period of many years. They simply crumble with age.

Car Battery Service

Car batteries are designed to provide up to 300 Amperes of current for very short periods of time (less than 10 seconds). After the car has started, the battery is then constantly trickle charged by the car's alternator. In car starting service, the battery is usually discharged less than 1% of its rated capacity. The car battery is designed for this very shallow cycle service.

Car Battery Life Expectancy & Cost

Our experience has shown us that automobile starting batteries last about 200 cycles in deep cycle service. This is a very short period of time, usually less than 2 years. Due to their short lifespan in home energy systems, they are more than 3 times as expensive to use as a true deep cycle battery. Car batteries cost around $60. for 100 Ampere-hours at 12 volts.

Beware of Ersatz "Deep Cycle" Batteries

After the failure of the car batteries we tried the so called "deep cycle" type offered to us by our local battery shop. These turned out to be warmed over car batteries and lasted about 400 cycles. They were slightly more expensive, $100. for 105 Ampere-hours at 12 volts. You can spot these imitation deep cycle batteries by their small size and light weight. They are cased with automotive type cases. Their plates are indeed more rugged than the car battery, but still not tough enough for the long haul.

True "Deep Cycle" Batteries

After many battery failures and much time in the dark, we finally tried a real deep cycle battery. These batteries were hard to find; we had to have them shipped in as they were not available locally. In fact, the local battery shops didn't seem to know they existed. Although deep cycle types use the same chemical reactions to store energy as the car battery, they are very differently made.

Deep Cycle Physical Construction

The plates of a real deep cycle battery are made of scored sheet lead. These plates are many times thicker than the plates in car batteries, and they are solid lead, not sponge lead. This lead is alloyed with up to 16% antimony to make the plates harder and more durable. The cell cases are large; a typical deep cycle battery is over 3 times the size of a car battery. Deep cycle batteries weigh between 120 and 400 pounds.

We tried the Trojan L-16W. This is a 6 Volt 350 Ampere-hour battery, made by Trojan Batteries Inc., 1395 Evans Ave., San Francisco, CA (415) 826-2600. The L-16W weighs 125 pounds and contains over 9 quarts of sulphuric acid. The "W" designates a Wrapping of the plates with perforated nylon socks. Wrapping, in our experience, adds years to the battery's longevity. We wired 2 of the L-16Ws in series to give us 12 Volts at 350 Ampere-hours.

Deep Cycle Service

The deep cycle battery is designed to have 80% of its capacity withdrawn repeatedly over many cycles. They are optimized for longevity. If you are using battery stored energy for your home, this is the only type of lead-acid battery to use. Deep cycle batteries are also used for motive power. In fact, many more are used in forklifts than in renewable energy systems.

Deep Cycle Life Expectancy & Cost

A deep cycle battery will last at least 5 years. In many cases, batteries last over 10 years and give over 1,500 deep cycles. In order to get maximum longevity from the deep cycle battery, it must be cycled properly. All chemical batteries can be ruined very quickly if they are improperly used. A 12 Volt 350 Ampere-hour battery costs around $440. Shipping can be expensive on these batteries. They are corrosive and heavy, and must be shipped motor freight.

Deep Cycle Performance

The more we understood our batteries, the better use we made of them. This information applies to high antimony, lead-acid deep cycle batteries used in homestead renewable energy service. In order to relate to your system you will need a voltmeter. An accurate voltmeter is the best source of information about our battery's performance. It is needed in answering the two questions of battery operation-- when to charge & when to stop charging.

Voltage vs. Current

The battery's voltage depends on many factors. One is the rate, in relation to the battery's capacity, that energy is either being withdrawn from or added to the battery. The faster we discharge the battery, the lower its voltage becomes. The faster we recharge it, the higher its voltage gets. Try an experiment- hook the voltmeter to a battery and measure its voltage. Turn on some lights or add other loads to the battery. You'll see the voltage of the battery is lowered by powering the loads. This is perfectly normal and is caused by the nature of the lead-sulphuric acid electrochemical reaction. In homestead service this factor means high powered loads need large batteries. Trying to run large loads on a small capacity battery will result in very low voltage. The low voltage can ruin motors and dim lights.

Voltage vs. State of Charge

The voltage of a lead-acid battery gives a readout of how much energy is available from the battery. Figure 2, on page 26, illustrates the relationship between the battery's state of charge and its voltage for various charge and discharge rates. This graph and its companion, Fig.3, are placed in the center of the magazine as a tearout so you can put them on your wall if you wish. This graph is based on a 12 Volt lead-acid battery at room temperature. Simply multiply the voltage figures by 2 for a 24 Volt system, and by 4 for a 48 Volt system. This graph assumes that the battery is at room temperature 78°F. Use the C/100 discharge rate curve for batteries at rest (i.e. not under charge or discharge).

Temperature

The lead-acid battery's chemical reaction is sensitive to temperature. See the graph, Figure 3 on page 25, which shows the same info as Figure 2, but for COLD lead-acid batteries. Note the voltage depression under discharge and the voltage elevation under charge. The chemical reaction is very sluggish at cold temperatures. Battery efficiency and usable capacity drop radically at temperatures below 40° F. At 40°F., a lead acid battery has effectively lost about 20% of its capacity at 78°F. At 0°F., the same battery will have effectively lost 45% of its room temperature capacity. We keep our batteries inside, where we can keep them warm in the winter. Batteries banished to the woodshed or unheated garage will not perform well in the winter. They will be more expensive to use and will not last as long. The best operating temperature is around 78° F..

The situation with temperature is further complicated by the lead-acid system's electrolyte. As the battery discharges the electrolyte loses its sulphuric acid and becomes mostly (≈95%) water. IT WILL FREEZE. Freezing usually ruptures the cell's cases and destroys the plates. Lead-acid batteries at < 20% SOC will freeze at around 18°F. If you're running lead acid batteries at low temperatures, then keep them fully charged to prevent freezing on very cold nights.

Determining State of Charge with a Hydrometer

A hydrometer is a device that measures the density of a liquid in comparison with the density of water. The density of the sulphuric acid electrolyte in the battery is an accurate indicator of the battery's state of charge. The electrolyte has greater density at greater states of charge. We prefer to use the battery's voltage as an indicator rather than opening the cells and measuring the electrolyte's specific gravity. Every time a cell is opened there is a chance for contamination of the cell's inards. Lead- acid batteries are chemical machines. If their cells are contaminated with dirt, dust, or other foreign material, then the cell's life and efficiency is greatly reduced. If you insist on using a hydrometer, make sure it is spotlessly clean and temperature compensated. Wash it in distilled water before and after measurements.

Rates of Charge/Discharge

Rates of charge and discharge are figures that tell us how fast we are either adding or removing energy from the battery. In actual use, this rate is a current measured in Amperes. Say we wish to use 50 Amperes of current to run a motor. This is quite a large load for a small 100 Ampere-hour battery. If the battery had a capacity of 2,000 Ampere-hours, then the load of 50 Amperes is a small load. It is difficult to talk about currents through batteries in terms of absolute Amperes of current. Battery people talk about these currents in relation to the battery's capacity.

Rates of charge and discharge are expressed as ratios of the battery's capacity in relation to time. Rate (of charge or discharge) is equal to the battery's capacity in Ampere-hours divided by the time in hours it takes to cycle the battery. If a completely discharged battery is totally filled in a 10 hour period, this is called a C/10 rate. C is the capacity of the battery in Ampere-hours and 10 is the number of hours it took for the complete cycle. This capacity figure is left unspecified so that we can use the information with any size battery pack.

For example, consider a 350 Ampere-hour battery. A C/10 rate of charge or discharge is 35 Amperes. A C/20 rate of charge or discharge is 17.5 Amperes. And so on... Now consider a 1,400 Ampere-hour battery. A C/10 rate here is 140 Amperes, while a C/20 rate is 70 Amperes. Note that the C/10 rate is different for the two different batteries; this is due to their different capacities. Battery people do this not to be confusing, but so we can all talk in the same terms, regardless of the capacity (size) of the battery under discussion.

Let's look at the charge rate first. For a number of technical reasons, it is most efficient to charge deep cycle lead-acid batteries at rates between C/10 and C/20. This means that the fully discharged battery pack is totally recharged in a 10 to 20 hour period. If the battery is recharged faster, say in 5 hours (C/5), then much more electrical energy will be lost as heat. Heating the battery's plates during charging causes them to undergo mechanical stress. This stress breaks down the plates. Deep cycle lead-acid batteries which are continually recharged at rates faster than C/10 will have shortened lifetimes. The best overall charging rate for deep cycle lead-acid batteries is the C/20 rate. The C/20 charge rate assures good efficiency and longevity by reducing plate stress. A battery should be completely refilled each time it is cycled. This yields maximum battery life by making **all** the active materials participate in the chemical reaction.

We often wish to determine a battery's state of charge while it is actually under charge or discharge. Figure 2, on page 25, illustrates the battery's state of charge in relation to its voltage for several charge/discharge rates. This graph is based on a 12 Volt battery pack at room temperature. For instance, if we are charging at the C/20 rate, then the battery is full when it reaches 14.0 volts. Once again the digital voltmeter is used to determine state of charge without opening the cells and risking contamination. Figure 3, on page 24, offers the same information as Figure 2, but in Figure 3 the information pertains to a lead-acid battery at 34°F. Note the depression of voltage under discharge and the voltage elevation under charge. This reflects an actual change in the batteries internal resistance to electrical flow. The colder the battery becomes, the higher its internal resistance gets, and the more radical the voltage swings under charge and discharge become.

The Equalizing Charge

After several months, the individual cells that make up the battery may differ in their states of charge. Voltage differences greater than 0.05 volts between the cells indicate it is time to equalize the individual cells. In order to do this, the battery is given an equalizing charge. **An equalizing charge is a controlled overcharge of an already full battery. Simply continue the recharging process at the C/20 rate for 5 to 7 hours after the battery is full.** Batteries should be equalized every 5 cycles or every 3 months, whichever comes first. Equalization is the best way to increase deep cycle lead-acid battery life. Battery voltage during the equalizing charge may go as high as 16.5 volts, especially if the battery's temperature is < 40°F.. This voltage is too high for many 12 Volt electronic appliances. Be sure to turn off all voltage sensitive gear while running an equalizing charge.

Wind machines and solar cells are not able to recharge the batteries at will. They are dependendent on Mama Nature for energy input. We have found that most renewable energy systems need some form of backup power. The engine/generator can provide energy when the renewable energy source is not operating. The engine/generator can also supply the steady energy necessary for complete battery recharging and equalizing charges. The addition of an engine/generator also reduces the amount of battery capacity needed. Wind and solar sources need larger battery capacity to offset their intermittent nature. Home Power #2 discusses homebuilding a very efficient and supercheap 12 Volt DC source from a lawnmower motor and a car alternator.

Self-Discharge Rate vs. Temperature

All lead-acid batteries, regardless of type, will discharge themselves over a period of time. This energy is lost within the battery; it is not available for our use. The rate of self-discharge depends primarily on the battery's temperature. If the battery is stored at temperatures above 120° F., it will totally discharge itself in 4 weeks. At room temperatures, the battery will lose about 6% of its capacity weekly and be discharged in about 16 weeks. The rate of self-discharge increases with the battery's age. Due to self-discharge, it is not efficient to store energy in lead-acid batteries for periods longer than 3 weeks. Yes, it is possible to have too many batteries. If you're not cycling your batteries at least every 3 weeks, then you're wasting energy.

If an active battery is to be stored, make sure it is first fully recharged and then put it in a cool place. Temperatures around 35° F. to 40° F. are ideal for inactive battery storage. The low temperature slows the rate of self-discharge. Be sure to warm the battery up and recharge it before using it.

Battery Capacity vs. Age

All batteries gradually lose some of their capacity as they age. When a battery manufacturer says his batteries are good for 5 years, he means that the battery will hold 80% of its original capacity after 5 years of proper service. Too rapid charging or discharging, cell contamination, and undercharging are examples of improper service which will greatly shorten any battery's life. Due to the delicate nature of chemical batteries most manufacturers do not guarantee them for long periods of time. On a brighter note, we have discovered that batteries which are treated with tender love and care can last twice as long as the manufacturer's claim they will. If you're using batteries, it really pays to know how to treat them.

Battery Cables

The size, length, and general condition of your battery cables are critical for proper performance. While the battery may have plenty of power to deliver, it can't deliver it effectively through undersized, too long or funky wiring. Battery (and especially inverter) cables should be made of large diameter copper cable with permanent soldered connectors. The acid environment surrounding lead-acid system plays hell with any and all connections. Connectors which are mechanically crimped to the wire are not acceptable for battery connection. The acid gradually works its way into the mechanical joint resulting in corrosion and high electrical resistance. See Home Power #7, page 36, for complete instructions on home made, low loss, soldered connectors and cables.

Battery Safety

Location plays a great part in battery safety. A battery room or shed, securely locked & properly ventilated, is a very good idea. Children, pets, and anyone not aware of the danger should never be allowed access to battery areas. Lead-acid batteries contain sulphuric acid, and lots of it. For example, a medium sized battery of 12 VDC at 1,400 A-h will contain some 18 gallons of nasty, corrosive, dangerous acid. Such a battery pack is capable of delivering over 4,000 Amperes of 12 VDC for short periods. Direct shorts across the battery can arc weld tools and instantly cause severe burns to anyone holding the tool. Be careful when handling wrenches or any metallic object around batteries. If tools make contact across the batteries electrical terminals, the results can be instantly disastrous.

When a lead-acid battery is almost full and undergoing recharging, the cell's produce gasses. These gasses are mostly oxygen and hydrogen- a potentially explosive mixture. Battery areas should be well ventilated during recharging and especially during equalizing charges to dissipate the gasses produced. If a blower is used in ventilation, make sure that it employs a "sparkless motor". See Home Power #6, pg. 31, for info on venting lead-acid batteries.

Battery Maintenance

There is more to battery care than keeping their tops clean. Maintenance begins with proper cycling. The two basic decisions are when to charge and when to stop charging. Begin to recharge the battery when it reaches a 20% state of charge or before. Recharge it until it is completely full. Both these decisions can be made via voltage measurement, amperage measurement and the information in Figures 2 and 3.

A few suggestions for lead-acid battery use…

1. Don't discharge a deep cycle battery greater than 80% of its capacity.

2. When you recharge it, use a rate between C/10 and C/20.

3. When you recharge it, fill it all the way up.

4. Keep the battery as close to room temperature as possible.

5. Use only distilled water to replenish lost electrolyte.

6. Size the battery pack with enough capacity to last between 4 to 21 days. This assures proper

rates of discharge.

7. Run an equalizing charge every 5 charges or every 3 months, whichever comes first.

8. Keep all batteries and their connections clean and corrision free.

More detailed information on all types of batteries and their usage in renewable energy systems is available in The Complete Battery Book (ISBN# 0-8306-0757-9) by Richard A. Perez. This book is available from your local library, your local bookseller, or from Electron Connection Ltd., POB 442, Medford, OR 97501 for $19.45 first class postpaid.