Battery Technologies

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Summary:

If you have decided to use LFP batteries in your system. Then simply read the LFP section below. Congratulations because your world, at least related to support, is easy to understand. Training issues are minimized.

If you have decided to go with Lead-Acid batteries in your system, then indeed read this section, because there are a host of complicated issues concerning the proper care and feeding of Lead-Acid batteries. Not exceeding a maximum depth of discharge (ever) is a major issue. Proper training is important with some controllers.

Lithium Ferrous Phosphate (LFP) Batteries

The explosive growth of hybrid and all electric automobiles has the industry racing to make enough of these batteries. Tesla is about to complete it's "Giga factory" in anticipation of volume sales of Lithium Ion batteries. This means that LFP and the other Lithium chemistries continue to drop in price as production volumes ramp up.

LFP Batteries are Not Really more Expensive

At first it appears that an given size LFP battery is more expensive to purchase, but this is not really the case. It seems that way because the intital purchase is higher, BUT for a given physical size, the capacity of these batteries is much higher, and the life-time longevity is much greater. If the lead-acid battery expires on a solar system because it can only handle 600 cycles in it's lifetime, but in comparison the LFP battery can do 3000 to 5000 cycles... then the LFP battery could last longer than 10 years in service. Which chemistry is really the less expensive option? As of this writing, solar systems in PNG based on LFP are now three years old, and show no signs of capacity degradation, at all. They are performing well.

The other problem with the initial cost comparison is the user not being fair about the specification. If a 100 Wh Lead-Acid battery can only be discharged to 70% full capacity (30% DoD) without greatly shortening it's lifetime, but a 100Wh LFP battery can be safely discharged to 20% full capacity (80% DoD), every day.... then the TRUE capacity of the former is really 30 Wh and the latter is really 80 Wh. So the LFP battery is really less expensive than the Lead-Acid by a factor of 2.6 times... if cost per wattage based on usable capacity is the same. This is the capacity that matters, not the label on the battery in the store.

So to put this in tangible perspective. The 72 Wh (usable 58 Wh) Bioenno LFP battery pack at 12 volts costs $80. The equivalent usable capacity, 240 Wh (72 Wh usable) Lead Acid battery would be $40. So it would appear that the cost is 2x for LFP during intial installation. BUT.... the size and weight of the LFP is 1/6 the size (literally) and maybe 1/4 the weight (literally). What would be the additional cost of flying the two batteries to a remote location by the kilogram?

Later in the programme.... what's the additional cost of perhaps replacing the Lead-Acid battery up to three more times, plus transport cost? What the physical replacement cost worth? (An intangible item).

Or to put that in other terms: If I want 100 Wh for my application. I need 120Wh purchased of LFP battery, but I would need 260 Wh for the equivalent storage capacity on the Lead-Acid side. Again, which is REALLY more expensive?

Comparison Chart with Lead-Acid:

Brief Summary LFP vs Pb Features

Feature	**Lead Acid**	**LiFePO4 (LFP)**
Cycle Life	60 at 30% DoD	3000 at 80% DoD

Feature	Lead Acid	LiFePO4 (LFP)
Depth of Discharge w/o Damage	30% (70% SoC)	80% (20% SoC)
Relative Weight	3x (10 kg)	1x (3.3 kg)
Environmental Impact	Toxic Breakdown	Non-Toxic Breakdown
Maintenance	AGM type - Sealed	Always Sealed
Fire Hazard	Relatively Safe	Relatively Safe
Cost of Deployment (Lifetime Cost)	High	Low
Initial Cost at Installation	1x	2x

A major problem with Lead-Acid batteries by design: they must always be fully charged, and then occasionally used, but with an immediate recharge back to full charge. Examples are automobiles and security emergency light systems in office buildings. Most of their life, these batteries are fully charged as they live.

Solar applications are not like this. If you run down the battery in the beginning of the night, then you have to wait hours for the sunrise the next day. If you run down the batteries today, perhaps tomorrow there is little solar radiation to recharge, and you have to wait until the next day for a very good recharge cycle. Or maybe you have a total week of bad sunshine. LFP batteries in the field have been known to be totally discharged way beyond what is reasonable, or what the manufacturer says is "allowed", only to snap back into service even after a very long period of down time. They are simply more robust and can take a lot of abuse, at least the solar kind of abuse. Lead-Acid batteries can be called "fragile" in relation to solar power.

And finally there are transportation costs. For many in remote third-world settings the only way to transport goods is by aircraft and one pays by the kilogram. The Lead-Acid battery is rather heavy, and the LFP is amazingly light. One could say "feather-weight" by comparison and the volume size (packaging) might be a third as large, physically for the same usable Wh capacity.

In this picture, the LFP battery is much smaller, and also about the third of the weight of the Lead-Acid battery and yet the two batteries have almost the same **usable** capacity.

Where to purchase complete LFP systems? Consider the GTIS store GTIS Home Page and some other manufacturers of solar parts, such as the excellent Fosera Solar Systems line from Germany (if you can find them in your country).

Are Lead-Acid batteries still viable? Yes, if there are good ones available nearby where you live. But at whatever the cost to you, be prepared to replace them within 2 years. If you go to a city to purchase a "new" Lead-Acid battery, be sure to ask the store owner if they have been on the shelf, for the last 6 months waiting, on a trickle charger in the intervening time before sale. If not, then consider asking for a discount- such batteries are no longer "new". They already have a reduced capacity.

LFP has Superior Capacity

Unlike the Lead-Acid battery (see discussion, next section) the stated capacity of the purchased battery is actually close to the real usable energy capacity of the battery. For example, since the Depth of Discharge (DoD) is allowed to be 80%, that is near the 100% of the manufacturer's specification for the given battery system, using LFP technology. So, unlike the Lead-Acid battery (30% useable capacity) the 80% useable capacity is enormously larger. This ultimately reflects in the cost of purchase, since you really far less battery than in a typical Lead-Acid installation.

The reason for this is that LFP technology can be discharged to 80% (DoD) or down to 20% "State of Charge" (20% of 100% capacity) and not damage the battery. The battery can remain in a discharged state for hours or days without problems (unlike the fragile Lead-Acid battery). DoD does affect the overall lifetime however. See next section.

The main point here is that LFP is not fragile in the field. As of this writing we have solar LFP systems that were deployed in 2012 and now it is the year 2016. There is no sign yet, of capacity degradation in some of these systems that were properly treated and working well, each and every day in the field. And there is every indication that they are on their way to living lifetimes greater than 10 years.

LFP has Superior Lifetime Use

The Depth of Discharge issues DOES have a bearing on cycle times however. The battery that is consistently discharged 80% each day is going to have a greatly reduced lifetime, but we are talking an eye-popping 3000 cycles on some manufactuer's charts! That's "only" 3000 / 365 days = 8.2 years! But our design and recommendation for LFP systems in this paper is around 50% DoD (that 4 hours of work on a netbook during the night). At 50% DoD, the charts often state a whopping 5000 cycles for the lifetime of the battery. That's 13.7 years!

So you can see that "around 10 years" of useful service is not unrealistic for our systems. This translates to greatly reduced deployment costs, wtih less maintenance (replacement) over the lifetime of the project if the project runs 10 years or more. This is very typical of our translation and language development efforts in the field.

LFP is Safe - No "Flame Outs"

Some people are concerned or fearful to deploy any kind of Lithum battery because of the world-famous "flame out" stories of Boeing Aircraft and whole fleets that were grounded due to an electrical fire on board one aircraft, or the famous early model Tesla automobiles that caught fire.

Guess what? There are at least five kinds of Lithum compound batteries in manufacture and probably more coming. The "bad guy" here is called **Lithium Cobalt**. This is the lightest weight and most energy dense package you can make for storing energy, and on aircraft and cars a very sophisticated electronic controller has to monitor the battery state at all times. The issue is thermal runaway problems that then can lead to fires. The Boeing scenario was really a failed battery charging controller on board the one single aircraft.

LFP is actually the **"least of these"** in terms of **energy storage by weight**. It's far better than Lead-Acid, but not the most energy dense technology that can be made with Lithum. As a result it does not "flame out" even with a direct short. We even have a video in Chinese (link?) where a man places a direct-short, heavy gauge wire across the battery terminals, similar to the old Villager-N series (240 Wh), and then he stands back. The footage goes for minutes and all that happens is the wire insulation melts away. The battery body itself does nothing really.

Having said the above, there is still another way to burn your village house down, and that would be related to a sustain electrical arcing across two points that are close together, but not touching. Such an electric spark could cause wood to combust and lead to a fire. But that's why we have fuses and circuit breakers in our systems. You could start a fire with a 100 watt solar panel by itself under the right conditions.

LFP is Environmental Friendly in the Third-World

A lot has already been said by others as the atrocities of the Western world and the exploitation of third-world countries. If you are a guest in another country, one should really be a "good citizen" in that host country, and this includes teaching by example with the disposal of high tech equipment and depleted batteries in general. Obviously for most third-world countries are no organized re-cycling and battery deposit centers around, for the most part, and even in cities.

The good news is that the chemistry of LFP, should the battery enter a land-fill and be buried, breaks down into several inert and safe-for-human chemicals. This is totally the opposite of Lead-Acid where the Lead is entirely toxic to humans and Lead-Acid batteries normally must be disposed of carefully. There is a similar situation with the lead used in printed circuit boards upon their disposal as well.

Summary: Purchase a Modern LFP Battery Solar System

What's not to like here. Relative low actual cost; long lifetimes; more robust in times of abuse; can be deep discharged and get far more real capacity; sealed an no-maintenance; doesn't flame out when shorted; very light weight and perfect for air transport. Practically no user training issues in the classroom. If you can get this technology into your country, than do so.

Lead-Acid Batteries

If you are reading this section and below it means you are interested in a Lead-Acid Battery deployment for your upcoming solar system. There could be good reasons for this, but you will notice that this section is quite long. Why? Because Lead-Acid batteries have quite a few "issues" if you want them to give you good service, and the issues are rather complicated here to express. If you want simplicity and a system that simple "just works" and for a very long time, say over 10 years of service. Then read through the LFP section above, a second time.

Obviously training costs are going up, as you invest the time to teach the solar user all the technical issues of using Lead-Acid batteries. In the PNG context, this cost is quite high, because the user typically doesn't understand these issues well enough, or there are significant village and family social pressures that lead to battery abuse, and then a failed solar system.

AGM or Absorbed Glass Mat Batteries

For a more in depth discussion about Lead-Acid batteries see the Advanced Topics section.

if you must use Lead-Acid batteries in your system, then consider that not all Lead-Acid batteries are the same. The typical "car battery" is shown above, but it is a high-maintenance battery since water in the electrolyte solution readily evaporates over time and then it 6 cells must be topped up with new, distilled water periodically. What happens if the water has impurities.... it fails sooner. What happens if you allow the acid solution to fall down and expose the Lead plates inside the battery.... they sulfate, and break, and capacity is reduced. What happens if the acid spills out? It will corrode metal objects and cause damage, and is considered hazardous cargo in aircraft. In short, you can purchase these batteries, but your training costs are much higher for the end user. There are many points of failure here.

A newer type of sealed battery uses “Absorbed Glass Mats”, or AGM between the plates. This is a very fine glass mat composed of Boron-Silicate fiber. These type of batteries have all the advantages of gelled, but can take much more abuse. Panasonic, Lifeline, PowerSonic, Yuasa and all the rest manufacture 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 - very important to the aviation industry, and therefore considered “non-hazardous” cargo. Therefore they are more easily transported.

AGM batteries have several advantages over both gelled and flooded (liquid filled), and were more expensive than gelled in the past. But recently prices have fallen such that now they are completely replacing gelled altogether, and rapidly closing in on “flooded” batteries.

They are still Lead-Acid in chemistry, however, and fragile when used in solar systems. They are easily damaged by a 50% discharge of full capacity. A "State of Charge" (SoC) of 50%.

Advantages of AGM over Liquid "Flooded" Batteries

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, which is admittedly more important in northern Canada, not sub-Sahara Africa.

AGM's have a very low self-discharge rates - 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. AGM batteries can be almost fully recharged (95% or better) even after 30 days of being totally discharged (but please don't do this, nonetheless, as discussed more fully in this paper).

There is still a place for the standard flooded deep cycle battery. AGM's will sometimes cost 2 to 3 times as much as flooded batteries of the same capacity, although recently we have seen a dramatic price reduction. 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.

No Equalization Charging. Unlike the more “Flooded” type batteries, equalization charging to extend the life-time of the batteries that some charge controllers allow for “automatically” are not to be used. In fact, this will decrease the lifetime of AGM batteries due to electrolyte loss via the vented valves supplied. Once electrolyte is expelled it is lost forever. Not having to perform the equalization, is one less maintenance headache that the user has to concern themselves with. Plus there is no need to ever refill the batteries with distilled water, for the lifetime of the battery.

So when considering solar systems for our national colleagues to use, if the choice is Lead-Acid, then combinations of increased safety, easier transport, no-refilling and no equalization charging are considered great advantages, and that much less we have to train the inexperienced person.

Consider Manufacturing Date Codes

Each manufacturer of lead-acid batteries has their own system of stamping on the unit the date of manufacture. This becomes important for AGM style batteries especially as their capacity generally degrades in time “just sitting around” on the shelf. This can be an important factor in a third-world setting, where the supplier in a port town, has had stock sitting around for a very long time, and the store-reseller has not taken the time to maintain a trickle charge of the batteries while waiting for sale.

If possible, contact the manufacturer of the given part directly on email and convince them (if possible) to tell you their system of date code stamping. Then you can easily verify the claim that the given stock you are about to purchase indeed has been manufactured recently. If in your town, the store owner/ reseller cannot show you that they maintained a trickle charge on their "new" batteries while waiting six months to sell their inventory... then proceed to another store, or suggest a discount price before purchase. These batteries are no longer "new" even though they have not been put into service. Such is life with Lead-Acid batteries.

Amp-Hour Capacity as Listed on Battery Labels.

This topic is covered in far greater details in the Advanced Topics section.

Technically a Watt-Hour is a unit of energy (Wh). I represent how much work you can get done. If 100 Watt-Hours of energy is required to raise a 100 kg bucket of water 100 meters, or an electric pump to do the same... it represents work what you are able to accomplish with electricity as the source. It doesn't matter how much time it takes to accomplish this task, or how fast you work to get this done. I could take minutes, it could take hours, it could take days. But if 100 kgs of water moved, takes 100 Wh or energy or work. It will take another 100 Wh or energy to do the task again.

In relation to Watts, the standard formula is Watts = Volts x Amps, or W = V x A.

Energy is stored in batteries. But in the case of automotive style batteries, they are all normally 12 volt batteries. So technically a 100 Ah battery for your car, is really 12v x 100Ah or 1200 Wh. But all the batteries are 12 volt batteries. They are the same 12 volt chemistry. So capacity is erroneously stated as in Amp-Hours, since all the batteries are 12 volt batteries, as a "unit of comparison" from one car battery to the next. Amp-Hours then yield an overall indication of energy capacity.

So, when comparing the energy capacity of one Lead-Acid battery in the store, over the next one, when the label says 200 Ah, it has twice the storage capacity as the 100 Ah model.

However, this lazy "Amp-Hour" nomenclature for "capacity" totally breaks down in comparison to devices that might be consuming energy. For example, most of the notebooks we use in life, are 19 volt systems and not 12 volt systems. Therefore you cannot make comparisons or calculations based purely on Ah ratings. You need to be talking about Wh, in the strictest and correct sense about units of energy. This is really an issue for all batteries, not just Lead Acid batteries.

Lead-Acid Battery Life Issues

Depth of Discharge affect Useable Capacity

This topic is discussed in more detail in the Advanced Topics section.

A very important factor for battery lifetime is the average level of discharge over the lifetime of the project. Basically lead-acid batteries are designed to be fully charged at all times. While using the batteries, **unlike the design of LFP batteries, the overall level of discharge should be keep to a minimum,** and still achieve daily work goals that are practical for the given work conditions.

This means that for practical applications of Lead-Acid batteries and to maintain a long life, you want to only use about 10% or their capacity or down to 90% State of Charge (SoC). The other way to describe this is the "Depth of Discharge" of only 10%, yielding a SoC of 90% full capacity of the Lead-Acid battery. Note that this condition works well for automobile starters, and for emergency lighting in office buildings, because most of the lifetime of the battery it sits there at 100% charge. The battery is always full, and always "happy".

But solar is not like this. Solar condtions on a day-to-day level are not this way at all. Hence Lead-Acid batteries are actually the worst kind of chemistry for solar applications. You could be discharging the battery 30% today, and worse, tomorrow, as a rainy day, did not allow you to recharge fully to 100%. Still worse is that likely you used the battery at early evening hours, and maybe discharged to 50%, but alas... now we must wait hours before the sun even rises the next morning. The waiting while discharged, damages the Lead-Acid battery further.

So this leads to "battery lifetime" issues measured in the number of cycles you can discharge and recharge the battery over it's lifetime. If the manufacturer says the battery is designed for 1000 cycles (approx 3 years in a solar system= 1000 days), that is normally with a 10% DoD. If you go down to 30% DoD then the lifetime cycles will decrease to only 600 days. And if you are regularly falling to a 50% DoD, then maybe only 300 days of use. I think you can begin to see why we normally replace our Lead-Acid batteries in solar setups, in around two years. If you have a system that gets three years of service without replacement.... congratulate yourself... you are doing very well here. This of course, relates to overall costs for the user, which then go up upon battery replacement.

Panasonic and Yuasa and all the the other companies have technical specificcations in charts that tell the technician or engineer, what to expect.   There are curves with decreasing cycles as you increase the DoD.

The normal guideline for a Lead-Acid system is to try for a 30% DoD. But note too, for comparison purposes with LFP technologies discusses above. My total USEABLE capacity... the part that actually does the work is greatly reduced. If I have a 100 Ah battery (1200 Wh), but I only discharge or use, 30% of the stored energy, it means the energy available for work is only 30% of the listed total capacity. That's 100 Ah x 0.30 = 30 Ah (360 Wh). That quite a lot less than I thought I actually could use! If my computer demands 1000 Wh of energy each day, well, I have totally underspecified the battery size that i really need. I need much more, and that costs me a lot more to obtain in the field.

Capacity Monitoring - Batteries Age over Time

The goal of the solar controller is to protect the lead-acid battery, while allowing useful work to be done as required from the battery. As we have seen, the total number of solar cycles for the lifetime of the battery is dependent upon the average Depth of Discharge. The smart controller has a Low-Voltage Disconnect (LVD) that is set up properly protects the battey from over-use. “Capacity” or the total ability to store a given amount of energy is 100% for a newly acquired battery, but diminishes over time. Capacity can be monitored in the evenings for a “no load” situation. Using a Digital Voltmeter (DVM) at the battery terminals, turn off all loads including the netbook, any lights and anything else attached to the battery (you can leave the solar controller connected).

Generally speaking a good time to do this would be in the mornings before the sun rises, but before you turn on any village lights or the notebook computer. If a new battery had a terminal voltage of 12.9 volts, then on the average an terminal voltage of 12.6 or 12.5 volts would be an indication of a 30% Depth of Discharge. If you are seeing 12.4 volts as measured at the terminals, you are probably exceeding a 30% DoD and approach 40%.

If you brand new, rest state voltage was 12.8 volts instead of 12.9 volts when you first purchased your battery, then subtract 0.1 volts from the reference voltages listed above.

The other way to look at this "degradation of capacity" over time is to look at the terminal voltage in the early evening hours, with no loads connected. If the terminal voltage is no longer 12.9 volts as it was when it was new, but 12.8 or 12.7, then your total capacity of the battery is degrading over time (which is normal). It has “aged” that much, where age is a relative term here, and not based on the actual number of days of use. Note that temperature has an effect here too, but is beyond the scope of this particular paper.

Other Battery Chemistries

Nickel Metal Hydride

A very interesting technology, yet to be fully tried in field situations, are NiMH (Nickel Metal Hydride). They are considered far more expensive to implement than lead-acid chemistries, and are considered more expensive now that LFP given the volume production of such batteries for EV and Hybrid automobiles and home energy storage systems, like the Tesla home battery banks.

However, one must note that this chemistry can undergo a full, repeated and cycled deep discharge, up to a 1000 cycles and also discharge levels can be to practically the zero volt level without harm. Since lead-acid batteries must be “over-specified” to work successfully (LVD at 12.5 volts), and therefore greatly reduce their “working capacity”, it might be economically better to “under-specify” NiMH batteries since they have a much better “depth of discharge” capability. The same is true for LFP technologies.

In other words, we may be by-passing NiMH technologies because of an “apparent” cost differential that is perceived as way too high, when the reality is different for a given low power application. This would require further research and perhaps a different kind of solar controller. The only place we can see for simple NiMH tech might be as a "buffer" circuit for the "direct connect" solar option, helping the 5 volt regulator device. But for that discussion head over to the Tablets secion.

Iron-Air Batteries

An ancient and well understood battery chemistry. This design goes back the beginnigs of voltaic experiments, over 100 years ago. These batteries are commercially available and have the advantage of lifetimes on the order of 70 years or greater. Why don't we commonly see these batteries? They are VERY expensive to manufacture or at least they are sold at VERY exorbitant prices. People just don't trust that these batteries will really last a lifetime, but they do.