WHITE PAPER

MARINE ELECTRONICS

Battery Banks for Household Loads: Lithium

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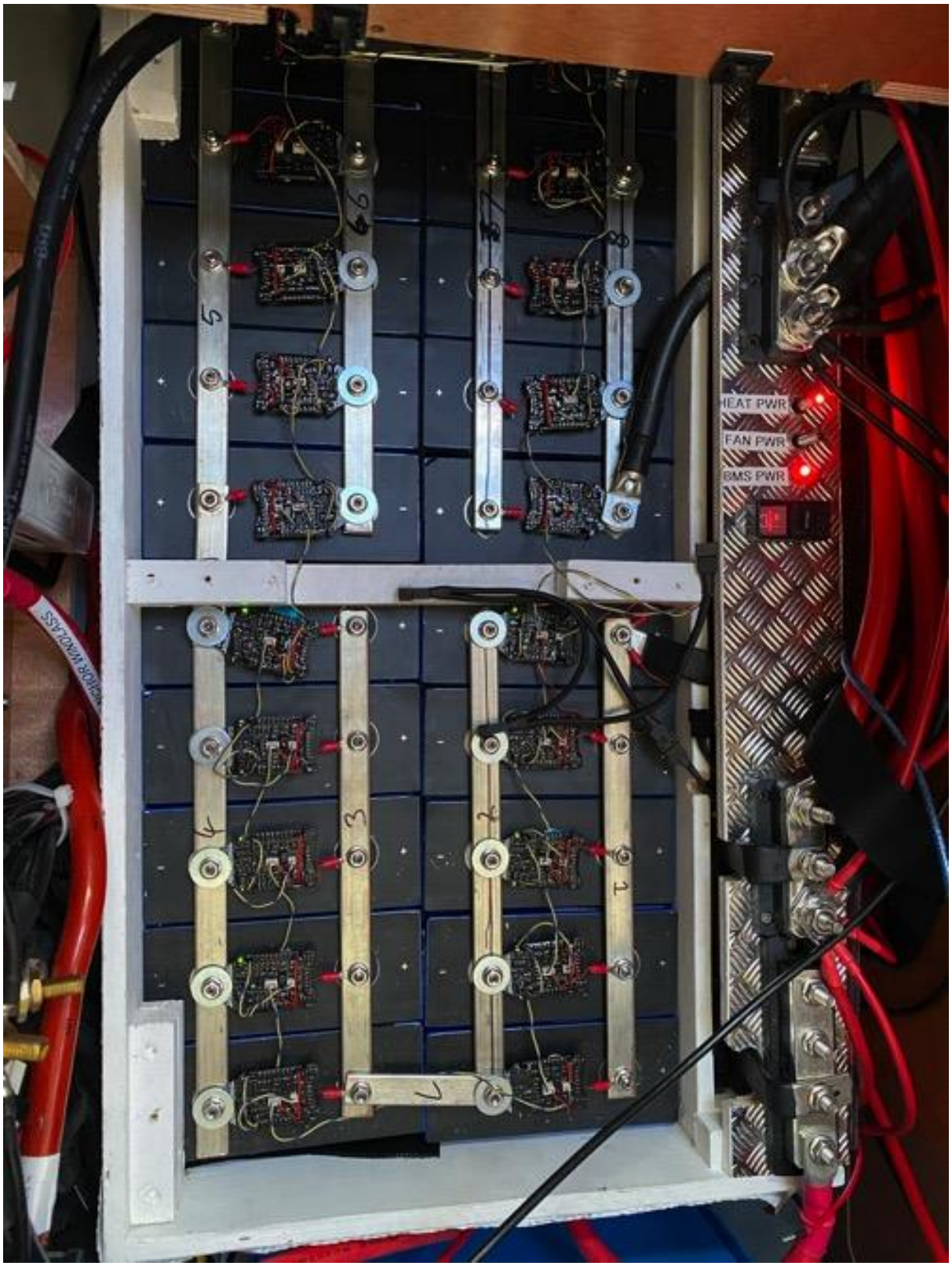

HEAT PWR
FAN PWR
BMS PWR

INTRODUCTION

Everyone wants to talk, positively or negatively about lithium and if we are not careful, we forget there are other options, and valid options at that.

To this point the first thing we'll do in this White Paper is discuss the advantages and disadvantages that come with several different options; effectively why is everyone excited about Lithium.

We'll also look at the safety and issues that might be perceived or real with Lithium or for that matter Lead Acid.

The bottom line is that batteries just do a job for us on our boats. There should be no emotional bias other than what is the best option at doing what we need them to do.

This White Paper is called 'Battery Banks for **Household Loads'** and that is the use we will look at directly.

BATTERY COMPARISON FOR HOUSEHOLD BANK DUTIES

Batteries need to provide power at an affordable cost. The other measures which we can use to compare batteries are:

- Useable power to weight ratio
- Cost/Kwh
- Charge/Discharge Rates
- Expected Lifespan

Battery Type	Power/ Weight Ratio	Useable Power Ratio	Cost/ Kwh	Charge/ Discharge Rate	Lifespan/Cycles	Temperature range	Safety Rating
Traditional Lead Acid	30W/Kg	50%	131	0.2C	200-1000	0-30c	Safe
AGM Lead Acid	40W/Kg	50%	221	0.3C	200-650	0-30c	Safe
Lithium Life4po	130W/Kg	80%	530*	1C	1000-4000	0-50c	Safe

As you can see from the table above, lithium considerably outperforms LA or AGM batteries both in day-to-day operation but also in lifespan.

'Cost' is the trade-off. They are more expensive but are coming down in price rapidly and like so many "new" technologies you pay a premium for ready-made solutions based on Lithium.

These costs can be avoided with self-builds. Of course, this is not a choice for everyone.

What the numbers don't make obvious

The really big difference with lithium batteries is not the usable density. You could always add more batteries, but that also means more weight, so it's a significant a trade-off.

The really big difference that is not entirely obvious from the tables figures is:

- the Charge/Discharge rate
- the voltage sag and
- safety

Yes, Safety!!! There is a lot of talk about lithium batteries being dangerous, but the truth in real world operation is, like your House Bank, LIFEPO4 chemistry (I'm careful here, this is not what is in your iPhone battery or even your Tesla, it's a safer chemistry) can be much safer.

Charge/Discharge rate

Charge discharge rate is how fast you can charge or discharge the battery and is expressed in terms of Amps/Amp-hours. i.e., a 1C rate means you can charge a 100AH battery at 100amps maximum charge rate.

NOTE: Important Concept, the reason one battery type may have a higher charge rate is because of a factor called 'internal resistance'. Electrical resistance, creates heat, heat kills things and makes them break down, so high resistance limits the charging rate safety limit.

This has a major impact on both how efficient your system is and how much power you can use.

A working example might be my own boat. Let's do a quick comparison on my setup, first with Lithium and then with lead acid.

Lithium Set Up

- 2200w Solar array will produce 1500w quite normally on a sunny day
- 1400AH of lithium batteries can potentially be charged at 1400A (1C), but I limit it to 220A (0.15C). As you can see, I am very conservative and could have A LOT more solar and not have it go to waste, still being within a safe charging rate.
- 1500w = Circa 115A of charge, so the battery absorbs everything that the solar can generate.
- My inverter is 5kw and can draw 400A from the battery pack under full load.
- I limit this to 600A, but the battery system easily accommodates the full power of the inverter.
- On a sunny day averaging 1500W I will recharge my battery bank to 100%, including day loads being taken care of, by midday or just after.

Comparing to Lead Acid Set Up

- 2200w Solar would produce 1500w of power
- 1400AH of lead acid would only be able to safely accept 280A, if below 80% charge so the 115A from the solar would be absorbed well to start with but would rapidly drop off for safety, even at 115A it would generate quite a lot of heat. A danger.
- The inverter at full load would want to draw 400A from the battery bank but I would have to limit that to half for safety and would still run into heat related safety issues if there was prolonged use, such as cooking.
- The battery bank would take all day to charge as although 280A seems fine, this would reduce rapidly as the battery charged and so the power of the solar would go to waste (or household uses) as it throttles back.

You can see that if I had a smaller AH battery bank, I could be waiting for a long time to charge it as the maximum Amps would be quite a bit smaller.

- 600AH bank would struggle with 120A (would really be getting dangerous at this stage)
- 400AH bank would be limited to 80A and I would be wasting half the solar.

Whereas with the Lithium I could add more solar safely, and vastly reduce waste. In fact, I could double the capacity of my solar and still be safe, charging at a C rate that would not create much heat at all in the batteries.

Voltage Sag

The next big thing is voltage sag. As you put a load onto a battery the voltage that that battery can provide will sag i.e., reduce because of load.

With lead acid batteries this is significant, but with lithium batteries this is not significant at all.

The result is 12V equipment, like inverters, are designed to work with 12V Direct Current.

This means that they work with voltages from 14V to 12V. This is called 12v Nominal.

But if the voltage drops below (sags) the minimal voltage required for the device, in this case your inverter, then it will shut down for safety, shutting off your 240V (or 110V) power in the boat, because of voltage sag.

Lithium, because of it having a much higher C rating and lower voltage sag, are much better suited to House Bank loads than Lead Acid where the C rating and sag can cause safety and shut off issues relatively easily.

Before I moved to Lithium, I could not install an inverter because it would not reliably be able to run much without shutting down because of voltage sag. Whereas with the lithium I never experience voltage sag, but do from time to time exceed the maximum rate of the inverter and it shuts down, i.e., my battery is safe, but I could do with bigger inverters!!!

ARE LITHIUM BATTERIES SAFE

First things first: ‘Lithium batteries’ is a generic term and refers to several different chemistries all of which have different characteristics and safety envelops.

I WOULD NOT EVER PUT ANY LITHIUM BATTERIES INTO MY BOAT THAT WERE NOT LIFEPO4 CHEMISTRY.

I make this statement because LifePo4 (Lithium (Li) Iron (fe) Phosphate) batteries are as safe if not safer than Lead Acid batteries. Other Lithium battery chemistries are NOT anywhere near as safe.

This includes your mobile phone (usually something like **Lithium Nickel Manganese Cobalt Oxide (LiNiMnCoO2)** is much more unstable, but still viewed as safe enough, mostly because of size. Does anybody remember not being allowed to fly with your Samsung phone?

Your electric car is probably using **Lithium Cobalt Oxide (LiCoO2)** also rather unstable unless well managed and God forbid you managed to damage the battery in an accident, the resulting fire could take days to put out.

Both these chemistries have much higher C ratings and power densities which you, as a consumer, demand from your phones and cars. But trade off safety. LifePo4 has a lower power density and lower C ratings as well but are much safer.

But don't' take my word for it, a picture is worth a thousand words, look at https://www.youtube.com/watch?v=Qzt9RZ0FQyM .

From real world experience, I personally have woken in the middle of the night to the smell of smoke and found one of my starter batteries (Lead Acid) had developed an internal short and was heating up to the "could cause a fire" point. Even after a day of sitting on the dock it was still too hot to touch. Lesson: Lead Acid is not completely safe either.

But why might Lifepo4 batteries be safer than Lead Acid? The answer is 'C Rating'.

The Charge/Discharge rating of a battery is limited by the internal resistance of that battery and therefore the heat that is generated through charging/discharging. C ratings are given to batteries chemistries based on the safe heat generation that a given C rating creates.

Because LifePo4 batteries have a C rating 5X higher than a Lead acid battery they produce far less heat and are much more within their safe parameters during use as a House Battery where the loads can be high and lengthy.

NOTE: Lead Acid starter batteries often have what is called a CCA which is very high. (Cold Cranking Amps) but this is a momentary delivery of discharge and reading the fine print will inform you that full CCA should never be maintained for more than a few seconds at a time. This is to allow the battery to dissipate the heat generated by that load.

BATTERY CHEMISTRY CONCLUSIONS

Lead acid batteries are fine for many applications and even better in many situations than Lithium. Starter batteries for your engines for instance are a perfect match for Lead acid batteries and the cost return is about right.

When it comes to house bank batteries though, there is a real advantage to Lithium and contrary to many statements they may even be safer (almost definitely are) than Lead Acid under the same conditions.

The problem then becomes cost. They are still quite expensive compared to Lead Acid batteries but there are ways to mitigate this to some degree.

The question should, perhaps, not be one of "should I move to a LifePo4 house bank?", but rather "how can I make them affordable?"

WHAT DO I NEED TO KNOW ABOUT BATTERIES TO MOVE TO LITHIUM?

There are some things you need to understand. I should point out that the only reason you think you don't need to know these for Lead Acid is that you already have a well-designed (one would hope) lead acid environment that you have not had to consider.

Moving to Lithium the rules change, you get bigger C ratings for a start, and they require a slightly different supporting environment to Lead Acid batteries.

Can I just buy "Drop in Lithium" batteries and be done with it

The answer is no, any more than you could if we were going in the other direction, from a Lithium battery environment and adding Lead Acid. Batteries fit into a supporting environment, and it all needs to line up.

So unfortunately to move to lithium you need to understand how you must adjust your environment to fit the new batteries requirements or things can go wrong.

What changes with Lithium compared to Lead Acid?

The two most important changes are:

- Charge/Discharge rates i.e., internal resistance of the batteries
- Charge Profile (style if you like) of the different chemistries.

The second one is important because Lead Acid and Lithium require slightly different charging techniques.

You might not be aware, but your battery chargers currently are charging your batteries according to a pattern that is best for your Lead Acid batteries. This is not good for your Lithium batteries in the long term and will slow down their charging greatly in the short term.

So, either your chargers will be able to be re-programmed (presuming you are not keeping any Lead Acid batteries around) or you might need new chargers.

If you get this wrong, the whole thing won't blow up, it just won't last as long or take advantage of one of the benefits of Lithium, which is fast charging.

Things can go *bang* if you don't understand

The C rating (Charge/Discharge rate) is a much more important factor to consider.

Lead Acid batteries have a much higher internal resistance, and therefore their charging rate is much lower.

Some of the components of your electrical system may well depend on this fact to protect them. Your alternators on your engines for instance; if they are not regulated and many perhaps most, are not, then they will attempt to provide as much current as the battery demands.

They can get away with this because they are designed to work with the maximum C rating of a lead acid battery, but if you suddenly put a Lithium battery in there and it now demands 5 X the current from the alternator, if it doesn't have some external regulator, it will simply get too hot and burn out.

Again, a picture is worth a thousand words, so take a look at https://www.youtube.com/watch?v=jgoIocPgOug kindly provided by Victron to educate us.

This is the reason that putting "Drop In Lithium" batteries is not such a good idea.

If you want to geek out, or learn a little bit, consider this….

> *A Lead Acid battery bank can only be charged at 0.2 C until it approaches 80% charged. Then the internal resistance will reduce the rate at which the batteries can be charged because of the increasing internal resistance.*
>
> *So, a 125Amp alternator would be at maximum capacity if the battery bank had 625AH of free space left before it got to 80%. This would mean that the battery bank because you should not discharge below 50% for Lead Acid, would have to be over 1500AH and almost fully drained to draw 125A from the alternator.*
>
> *But a Lithium battery, which could accept 1C of charge right up to 100% would only need a battery of 125AH that was partially drained (just a little) to draw the same current. Imagine how much a slightly empty 600AH battery would try to draw from that 125A alternator (600A would be the answer).*

In Conclusion

You cannot "just drop in" a Drop in Lithium battery because you need to consider what impact your chargers might have on it and what impact it might have on components in your system, like your alternators.

To give you an idea, using my own system.
I live on a Catamaran and that Catamaran, having two engines, had two alternators, both 125A.

It also had two mains power chargers, which were setup for Lead Acid of course.

The starter and House Bank batteries were Lead Acid, and all connected to the charging circuit, which was powered by the alternators and battery chargers (if plugged into the shore power).

I left Lead Acid batteries as the engine starter batteries and simply disconnected the charging circuit from the House Bank. This meant that the alternators were only ever charging starter batteries and so were the shore power chargers.

This meant the alternators and chargers could remain the same and I needed a different charging strategy for the new Lithium battery bank, which of course would all be setup for Lithium.

NOTE: *There was a bit more I did to allow some of this charge to safely go to the Lithium, but for this purpose let's keep it simple.*

This is only one solution you might have to the issue of getting lithium working with your existing system, there are others, and better ones depending on your needs.

I had a lot of solar going on and an 11kw generator that I could use to charge the lithium, so my main need for the alternators and chargers was to maintain the starter batteries. BUT if you needed to use your engine as a generator you might opt to replace your alternators with high output "externally regulated" alternators that would give the lithium batteries their full amps without blowing up.

NOTE: in the above regulated alternator setup, you still need to ensure that your BMS can control the alternators directly so that overcharging cannot occur with the batteries. Most of the better externally regulated alternators do have this facility, it does need to be connected. So, you protect both the alternators and batteries.

These considerations should NOT put you off installing lithium. It might seem like you have a lot to learn, but just think of it as the things you don't understand about how your Lead Acid system works. It can add cost and this needs to be considered.

Remember if you are wanting to do this and need help, call me.

WHAT'S THIS THING CALLED A BMS?

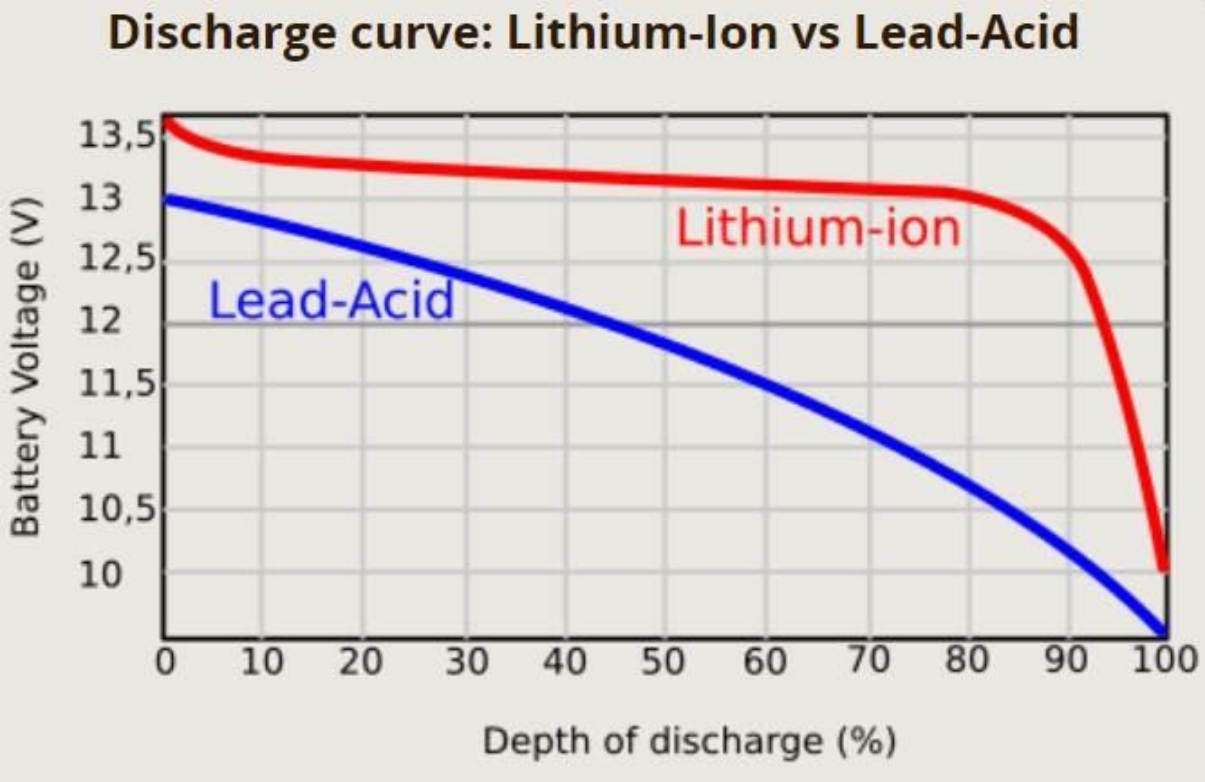
Firstly, why do we need a BMS with Lithium?

With Lead Acid batteries they tend to get charged in one of two ways, via a charger or via an alternator directly.

Battery Chargers

A good way to think of Battery chargers is a device pushing out current to the battery. 'Pushing' being the operative word. This is not exactly how they work but they do raise the voltage to 'push' the expected current into the battery.

The chargers turn off the charging as the voltage climbs. Lead Acid has a reliable voltage to State of Charge (SOC) curve, and their resistance goes up accordingly. So, a charger can literally monitor the batteries voltage and decide how charged the battery is and slow down the charge rate (current). Easy!! (Lithium DOES NOT HAVE A RELIABLE VOLTAGE TO SOC CURVE).



Alternators

A good way to "think" about alternators is as 'responding' to demand on current. 'Responding' being the operative word

Alternators on the other hand, unlike chargers, don't deliver current at a fixed rate but according to resistance and as the batteries charge their resistance increases and so the current slows down from the alternator. THIS DOES NOT HAPPEN WITH LITHIUM.

Why Do Lead Acid Batteries Not Need a BMS?

Lead Acid battery environments tend to self-regulate because of the reliable SOC curve and the internal resistance of the batteries.

Strictly speaking we could do with a BMS (Battery Management System) with Lead Acid because we could prevent things happening to the battery that might damage it, over discharging, over charging (should a charger fail to slow down the current) or overheating etc. All things that routinely kill our Lead Acid batteries and can result in extreme circumstances with a fire.

We don't because it is perceived we don't need them. Whereas in the lithium world we started with much more volatile chemistries and the batteries became quite dangerous if not properly managed. So BMS's systems were invented.

The reason your Tesla just doesn't blow up or your phone (most of the time) just catch fire, is because they have sophisticated BMS systems built into them to prevent this.

With LifePo4 a BMS is less necessary, and you can run a system without one, but you can also damage an expensive battery system by mistake (just as you can with Lead Acid and over discharging or over charging).

So, What's a BMS

BMS's are BATTERY MANAGEMENT SYSTEMS designed to keep your batteries safe but also protected from damaging usage that might shorten their life.

Investing in a good one, is both a safety measure and a longevity measure. You might also argue, successfully that your LifePo4 battery system is MUCH SAFER than a LA battery system BECAUSE it has a BMS looking after it.

A BMS can literally disconnect the battery if there is too much charge, discharge, heat, cold etc. or a smart one can "talk" to the chargers and consumers limiting the input and output without disconnecting.

To be clear: You could overcharge, charge whilst too cold, over discharge and abuse your LifePo4 batteries without a BMS and you might kill them, but they are highly unlikely to kill you. Just like Lead Acid. But a BMS will make sure they are well managed despite any failure on your part or the systems other components.

BMS features you should want

- Critical Disconnect ability (THE MOST IMPORTANT).
- State of charge calculations.
- Cell over-voltage and under-voltage protection.
- Battery cell balancing (passive or active).
- Battery charger control logic.
- Battery Consumer (Inverter) control logic
- Pack or Cell temperature monitoring for
    - Over temperature
    - Under temperature
- Current limit protection for both

- Charging
- Discharging

You might also want features like the ability to control cooling or heating for your battery, live monitoring software for all your parameters (as above).

PASS THROUGH BMS AND CONTROLLING BMS

The only other thing you should be aware of is how the BMS controls the batteries connection to the outside world.

In cheaper BMS's the disconnect is built into the BMS and the amount of current that it can reliably handle is limited. More importantly as you get into higher and higher current draws that current must pass through your BMS and as current produces heat (via resistance) pass through BMS's are not suitable for high current applications.

On the other hand, a controller BMS sits to one side and monitors the battery and cells and controls a disconnect "switch" which all the current passes through. This means that the BMS is NOT subjected to the full current or stress of the battery pack and is isolated from the load itself. These types of BMS are more expensive and require more setup on your part BUT are more suitable for any reasonable size House Bank setup.

CHOSING LITHIUM BATTERIES TO PUT INTO YOUR BOAT

Ok, first things first, for safety lets be sure the message has got through: DON'T USE ANYTHING OTHER THAN LifePo4 LITHIUM IN YOUR BOAT. THIS MEANS DON'T USE RECYCLED TESLA BATTERIES, OR 18650 CELLS TO BUILD A BATTERY.

LifePo4 ONLY

So, given that, what other choices do you have?

"Drop in" Lithium replacement batteries.

"Drop in" replacement batteries on the face of it seem like a perfect solution.

Drop ins are Lithium batteries built into a Lead Acid form factor that look and have the same basic shape and voltage etc. as the lead Acid batteries they are designed to replace.

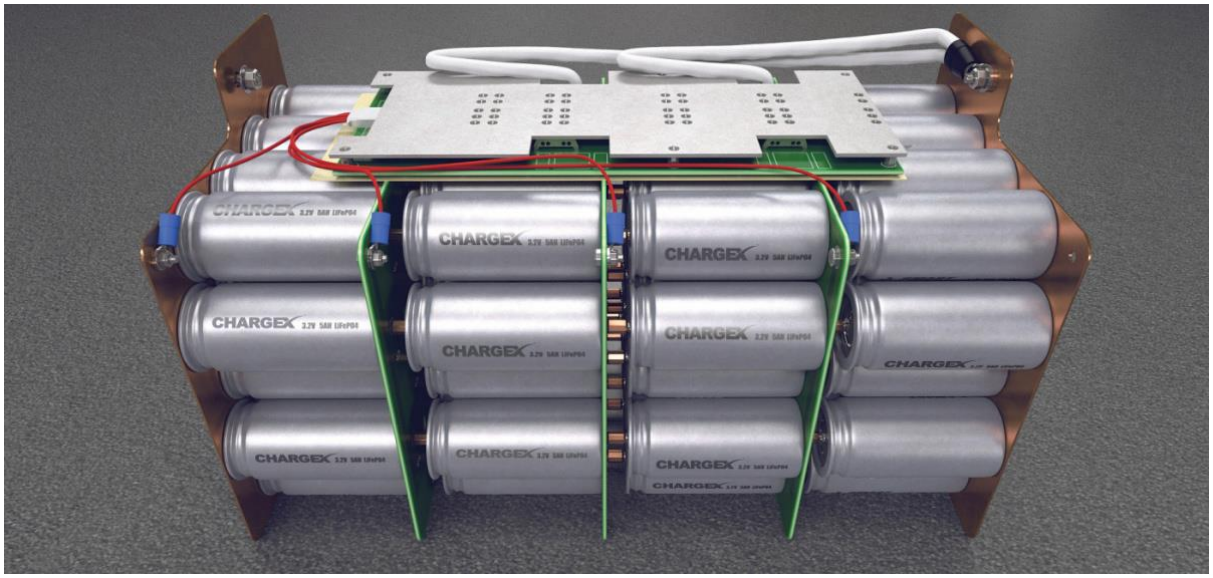
They should have a BMS built into the case along with the cells. The BMS and the internal build quality is something that needs to be examined closely. Many of these have limited features on their BMS and do not protect fully against things like low temperature cut-off.

Also, the BMS tends to be a pass-through design and in high load environments careful thought should be given to the appropriate design.

Because each battery has its own BMS and works in isolation you can get strange situations where a single battery will disconnect and interrupt your power supply.

Most of the time this is NOT an issue for these batteries, and they do, if sourced from reliable manufacturers, work very well and are an easy shortcut.

They also tend to have a large price tag associated with them as the builders are leveraging the new technology taking the risks on warranty and building a “low impact” replacement for lead acid batteries that don’t require you to build new mounts or holders.



Do be aware though that you STILL MUST ensure the chargers and alternators etc. are adapted as required for the Lithium environment.

Rack Mount batteries

Rack Mount batteries are a little like drop in replacements, but they are designed to be fitted to computer and office system racks. Therefore, their form factor is that of a rack dimension and their voltage does not tend to be a standard output 12V usually being 48V or higher.

This may sound like it should rule them out for boat use, however they have some strong advantages that should be considered and there are major benefits to creating a core Battery Bank system that is at a higher voltage and stepping down via a DC-DC device to support 12V or 24V boat systems.

Therefore, these may be highly appropriate if you are intending to build a new system and you can gain real advantages going to a 48V or even higher inverter system and MPPT

chargers etc. Working at a higher voltage mean greater safety and lower temperatures, cable dimensions at higher wattages.

The other main advantages of the Rack mount batteries are that they are designed from the start to be part of an overall management system and work in groups.

They usually come with industry standard CanBus connections (which is what your NMEA is based on) so that they can work together and also tend to have higher grade BMS with more features and separate non-passthrough disconnects. Effectively they tend to be a more robust and industrial style of battery at a reasonable price.

They also tend to be serviceable rather than sealed and therefore repairable and maintainable.

On top of this, they do tend to be lower in price for the capacity which is born out of competition in the industrial battery world.

In Summary: if you are intending to build a larger battery bank with all new chargers (MPPT etc.) and new Inverter/s then I would highly recommend you consider looking at the rack mount options and building a core Battery Bank working at 48V and stepping down to 12/24 for the main boat DC requirements.

NOTE: *if building again, this is the way I would go without question.*

Specific battery system implementations

There are now companies building specific battery systems designed for an electrical Ecosystem.

One of the best known of these is Victron (not sponsored!!!). Victron lithium batteries all connected using their Victron's network protocols (CanBus) and therefore are a plug and play, work together along with other Victron components.

There are others on the market and mostly they are from very reputable companies and give you a very reliable and easy to configure system that just plugs together. There are great design documents and advice, and they are well thought out.

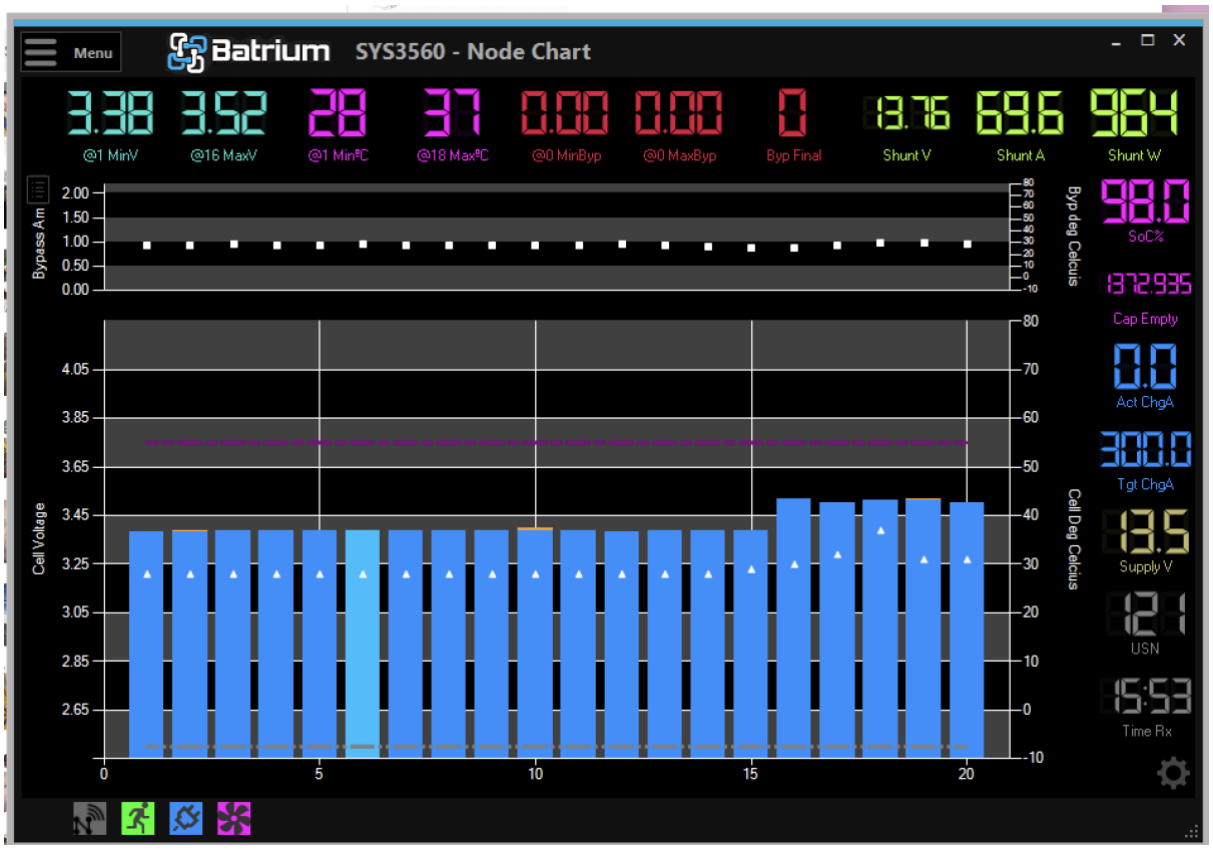
The trade-off is of course price. They can be extremely expensive compared to the market middle point.

If price is not an issue and support and ease of implementation is, then I would definitely recommend these options. Check what you are getting but they are generally very well thought out.

NOTE: *I have a lot of Victron gear on my boat, BUT not Victron batteries. I found them just too expensive and could not justify the cost. However, I built an equivalent battery system that connects 100% reliably to the rest of the Victron components and gives me more features and controllability. But you should know it took me a few weeks of effort to build and sort out. Cost/Effort benefit my battery cost me 10% of the Victron retail price.*

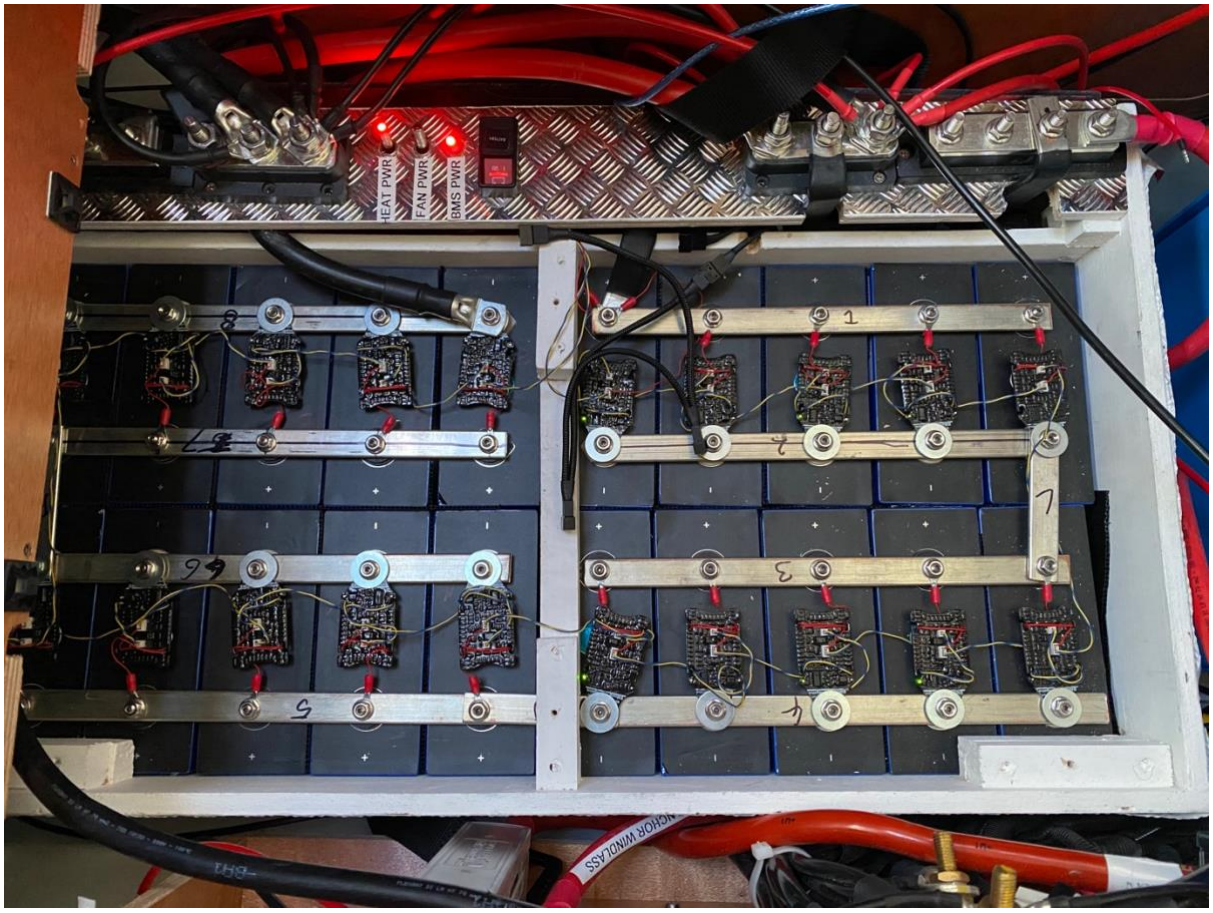
Build Your Own Battery

This sounds daunting but it is not as daunting as you might think.



There is a belief that you can't build a battery that is as good as a professional built battery. This is very wrong. The difference is knowledge not componentry. In fact, most commercial batteries are built to compete with their competitors and as such are built to a price.

Self-building can deliver you a saving but also a much better battery than you would get otherwise.



Even in my case, competing with Victron, who I have a lot of confidence and respect for, I was able to build a battery that is bigger, smarter with high quality components at a cheaper price (considerably) because building Lithium batteries is still a labour-intensive operation, and you pay for that all along the way. I should point out that I was able to integrate this battery fully into the Victron environment because of how open Victron is with their protocols and interfaces.

"How to build a battery pack" will be the subject of another White Paper for those that are interested. But for now, the information that is important is that you don't get an inferior product and it is not hard to do. It's just time consuming and you must learn quite a lot along the way to be able to do it. There are real savings, paid for out of your time and sweat equity.

NOTE: *I do like Victron, I am not in any way sponsored by them, but one reason I really like them is that they are very open with all their information, there is virtually zero proprietary practices and instead they compete by building systems that are high quality at prices that mean you may well not want to compete with them. I respect that. Most of the componentry in my own Lithium system is Victron from the MPPT's to Inverters, to Cerbo GX controllers and it all works faultlessly and is easy to integrate with. Very happy to call out their reputation is earned.*

KEY FINDINGS

- Lithium is better than Lead Acid for House Bank loads. BUT more expensive.
- You SHOULD NOT USE anything other than LifePo4 chemistry on a boat.
- “Drop In” replacement batteries are a bit misleading and can work but perhaps not your best option.
- You do need to ensure you understand how your electrical environment needs to change to fit Lithium. It’s not hard, just different and may come with hidden costs.
- There are a lot of battery options out there and the correct choice is between your time and knowledge vs another company’s time, knowledge, and support.
- The choice needs some thought and planning and can be the difficult part of moving to Lithium. I’m happy to help if you need advice on this.

CONCLUSION

Building a Lithium Battery System (battery bank, chargers, solar, etc. etc.) was the best thing I have added to the boat. It has radically changed our life onboard.

It does not need to be expensive, but it will always be costly, either via your time or your wallet.

You DO need to think about it as a system rather than just as batteries and plan for the outcomes you want.

I would highly recommend that you investigate Lithium (LifePo4) for Household Battery requirements, where they really do shine.

CONTACT DETAILS:

Feel free to contact me on GREG@ABBISS.CO.NZ or WhatsApp +447495739753

Good luck with your future boat projects.