



Lithium-ion 101

Author: J. Andrew Lerma
Flux Power Product Support Physicist

8/8/19
990922 v1.1



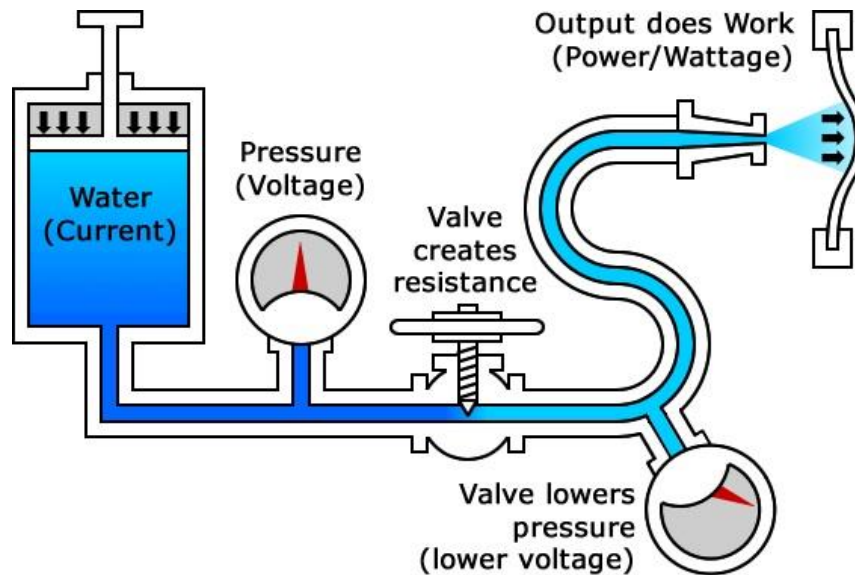
Overview

- 1. Electricity Basic**
- 2. Battery Basic**
- 3. Lithium-ion versus Lead-acid**
- 4. Lithium-ion Basics**

Electricity Basics

Electricity = flow of electrons
Like the flow of water!

Think of water in a pipe. The water pump is the battery. The water pressure is the Voltage, the speed of the water flow is the amperage, and the output of the system is the work.



Water Pressure -> **V=Voltage** -> **volts** (joule/coulomb)

Flow speed -> **I=Current** -> **amperes** (coulomb/sec)

Power -> **W=Watt** -> **volts*amperes** (joule/sec)

Work -> **kWh** = Power*Time -> **watts*sec** (joule)

What's a coulomb???

1 coulomb = 6.241x10¹⁸ electrons



Electricity Basics

Electricity is the flow of Electrons

Flow is measured in amps: 1 amp = 1 coulomb/second

So what is Energy?

Energy = Work = Power x Time

Energy (work) is measured in joules, kilowatt-hours, or calories.

1 calorie = 4.184 joules

1 kilowatt-hour = 3.6×10^6 joules

They are all the same thing, just different scales!

100 Ah battery * 25.6V nominal = 2560 Wh = 2.56 kWh



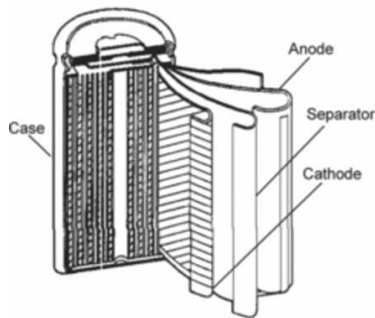
Battery Basics

Chemistry	Voltage	Capacity
<p>There are many different battery chemistries for many different uses. The most common battery chemistries are lead, nickel and lithium. There are many different lithium chemistries with different properties. The most common are Lithium Cobalt Oxide(LCO), Lithium Nickel Manganese Cobalt(NMC), and Lithium Iron Phosphate(LFP). Flux Power uses LFP due its thermal stability and overall safety.</p>	<p>Batteries are marked with nominal voltage; however, the open circuit voltage (OCV) on a fully charged battery is 5–7 percent higher. Chemistry and the number of cells connected in series provide the OCV. The closed circuit voltage (CCV) is the operating voltage. Always check for the correct nominal voltage before connecting a battery.</p>	<p>Capacity represents specific energy in ampere-hours (Ah). Ah is the discharge current a battery can deliver over time. You can install a battery with a higher Ah than specified and get a longer runtime; you can also use a slightly smaller pack and expect a shorter runtime. Chargers have some tolerance as to Ah rating (with same voltage and chemistry); a larger battery will simply take longer to charge than a smaller pack, but the Ah discrepancy should not exceed 25 percent.</p>

Cell Formats

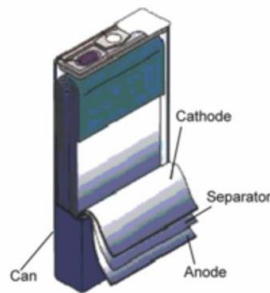
Cylindrical

Very popular format for batteries. It is very easy to manufacture and has good mechanical stability. Most forklifts and GSEs have square or rectangular battery compartment. A cylindrical format would make it more difficult to organize.



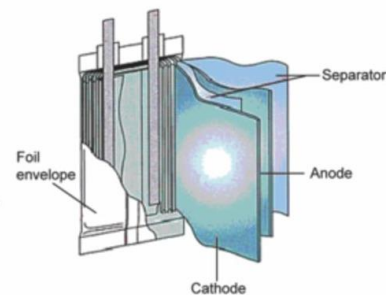
Prismatic

This newer format makes optimal use of space by using a layered approach. This format is very popular in hybrid vehicles. Flux Power uses a large version of this format.



Pouch

The pouch cell offers a simple, flexible and lightweight solution to battery design. Best used under light loads (Not suitable for material handling)



Lead Acid Batteries

Wet Cell / Flooded Batteries

Lead plates submerged in a liquid electrolyte. Must be kept upright.

Gel Cell - Lead plates with silica dust added to the electrolyte creating a putty-like gel electrolyte.

AGM - Absorbed Glass Mat. Fiberglass matrix which holds the electrolyte in place.

VRLA / SLA / Maintenance-Free - Valve Regulated Lead-Acid and Sealed Lead-Acid. Two types, Gel Cell and AGM.

VRLA/Sealed Batteries

1. Are less reliable than flooded lead acid.
2. Have shorter recharge time than flooded lead-acid.
3. Cannot tolerate overcharging: overcharging leads to premature failure.
4. Have shorter useful life, compared to properly maintained wet-cell battery.
5. Discharge significantly less hydrogen gas, as it's mostly recombined within the battery.
6. More expensive.

Lead Acid Batteries



Battery Corrosion



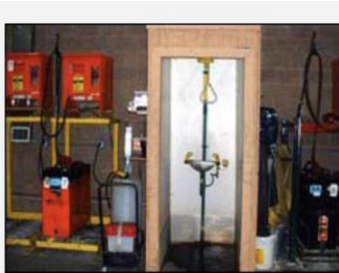
Detail



Battery Watering /
Watering Systems



Battery Room Ventilation

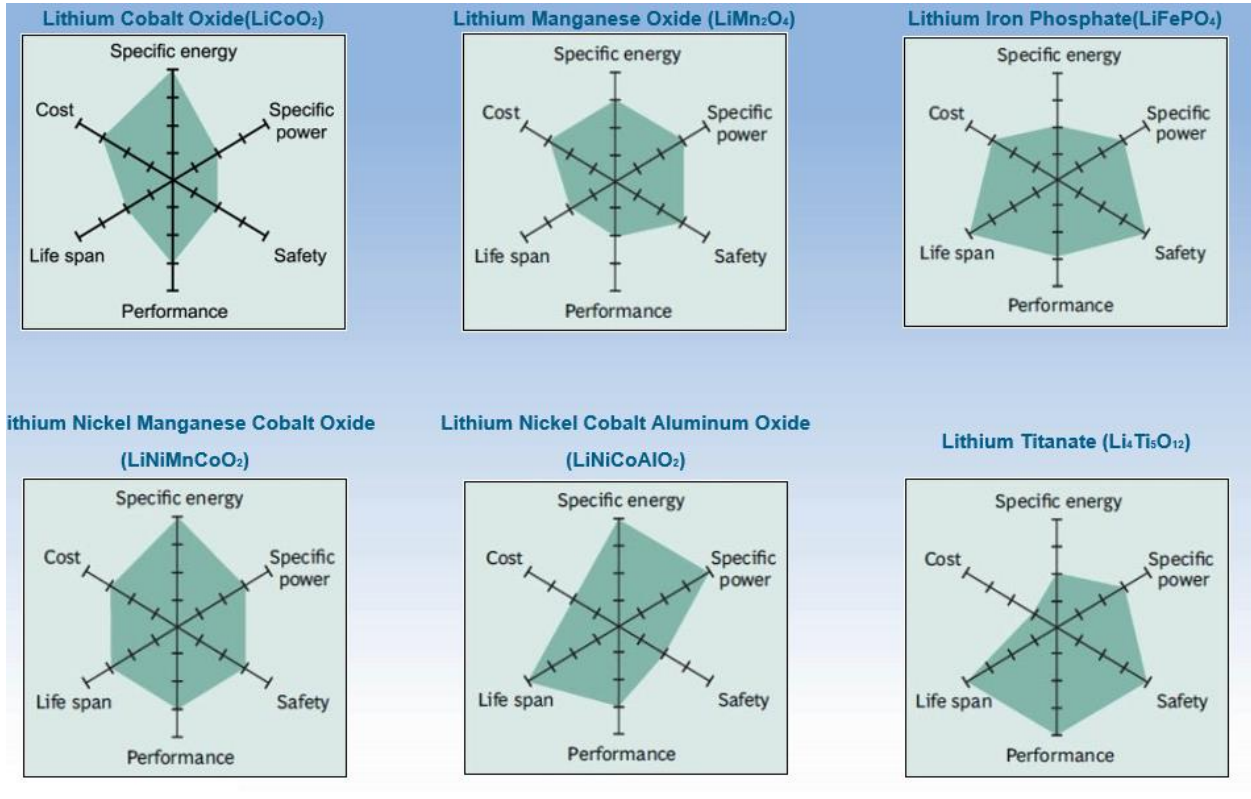


Battery Charging Area OSHA Safety
Requirements

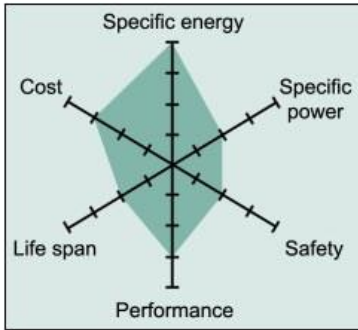


Lead-Acid Spill
Kits

Lithium-Ion Chemistries and Benefits

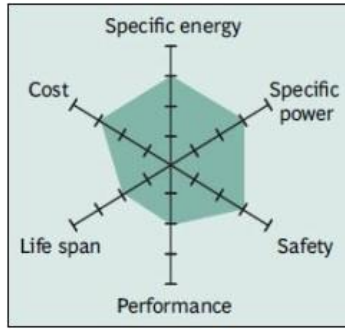


Lithium Cobalt Oxide (LiCoO₂)

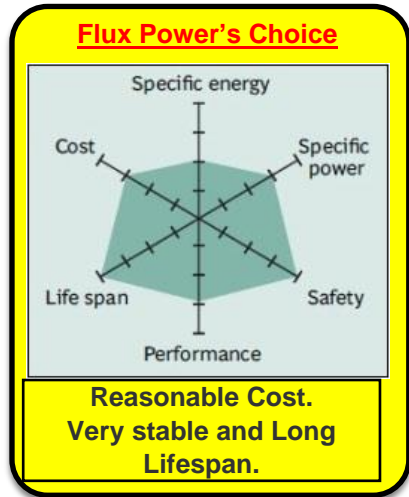


High Capacity
Cell Phones, Laptops, etc.

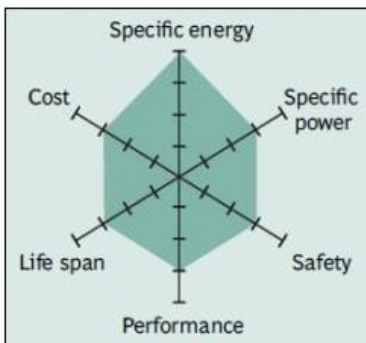
Lithium Manganese Oxide (LiMn₂O₄)



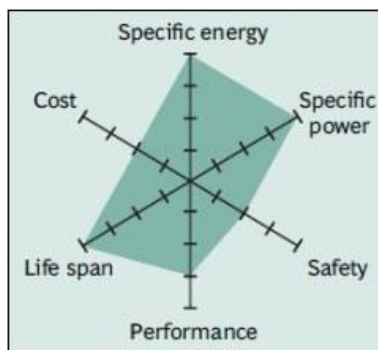
Lithium Iron Phosphate (LiFePO₄)



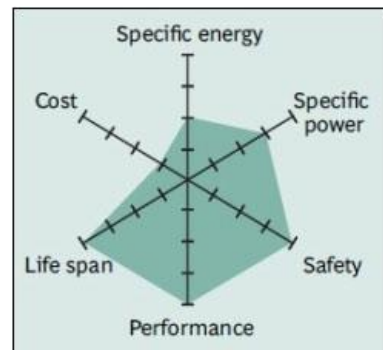
Lithium Nickel Manganese Cobalt Oxide (LiNiMnCoO₂)



Lithium Nickel Cobalt Aluminum Oxide (LiNiCoAlO₂)



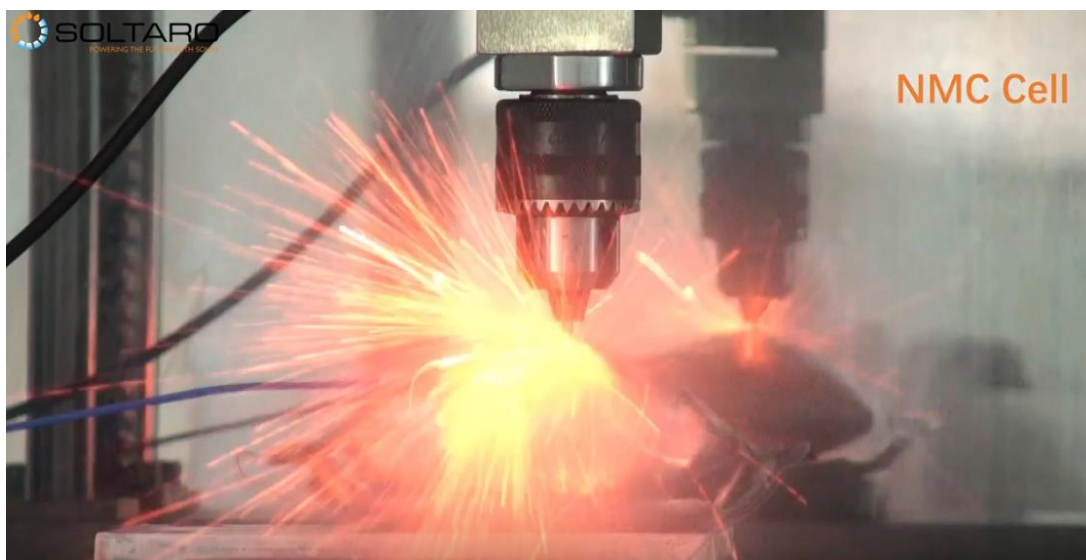
Lithium Titanate (Li₄Ti₅O₁₂)



LFP vs. NMC Puncture Test

Watch This Video to see what happens between puncturing a LFP cell compared to a NMC cell.

<https://www.youtube.com/watch?v=bnzxrnS0JkE>





Amp-Hour Ratings

Forklift batteries are rated in **amp-hours (Ah)** at the 6-hour discharge rate.

What does this mean???

A 180 amp-hour battery is capable of producing 30 amp current for 6 hours.

While Ah is used as an “indicative” measure of energy, it is NOT energy.

The ENERGY in a batter is $Ah \times \text{voltage}$, ie kWh.



Amp-Hour Ratings

Forklift Batteries are rated in **amp-hours (Ah)** at the 6-hour discharge rate.

What does this mean???

180 amp-hours battery is capable of producing:

30 amp current for **6 hours**

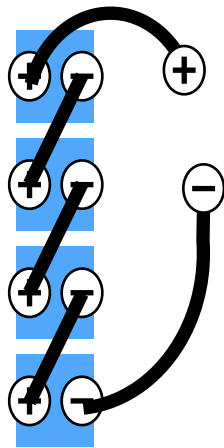
Whilst Ah is used as an 'indicative' measure of energy, it is NOT energy.

The ENERGY in a battery is Ah x voltage, ie kWh.

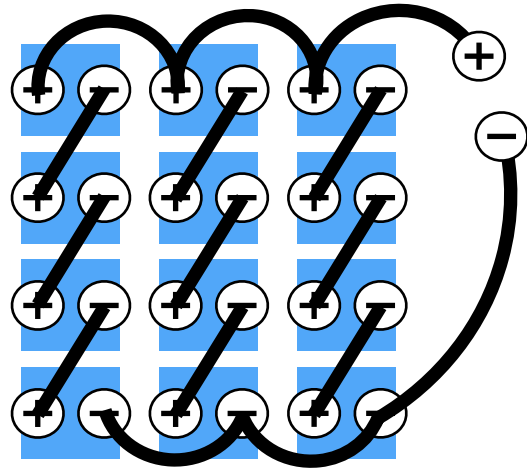
Sample Battery

Build a **12 volt, 60 amp-hour battery** from **20 amp-hour LiFePo4 pouch cells**.

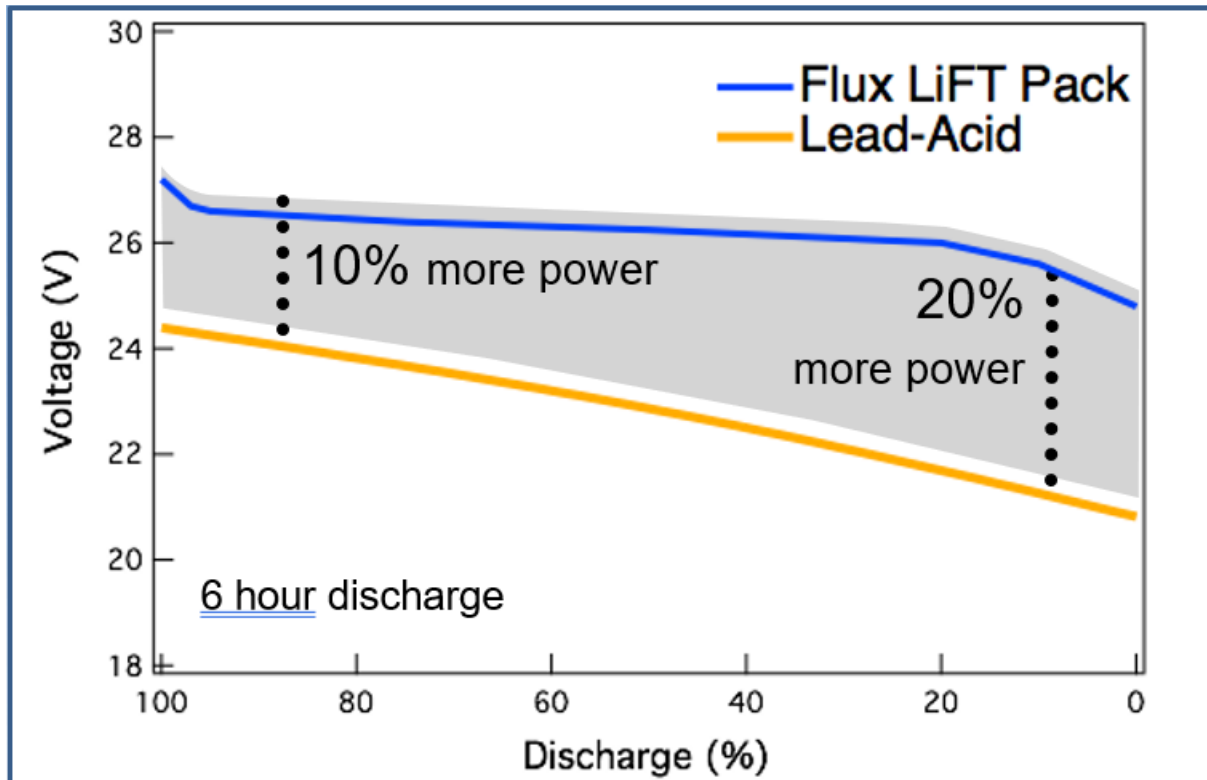
12.8 volt battery



12.8 volt 60 amp-hour battery



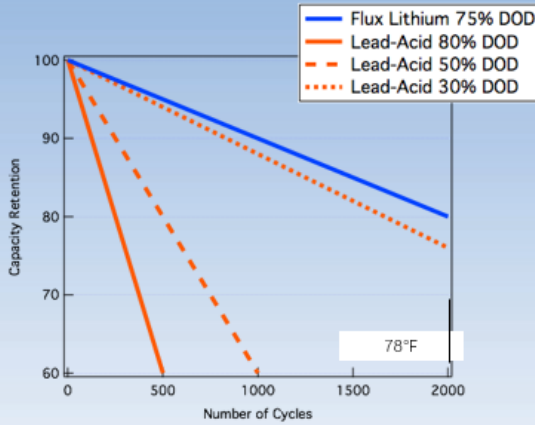
Benefit of Higher Operating Voltage



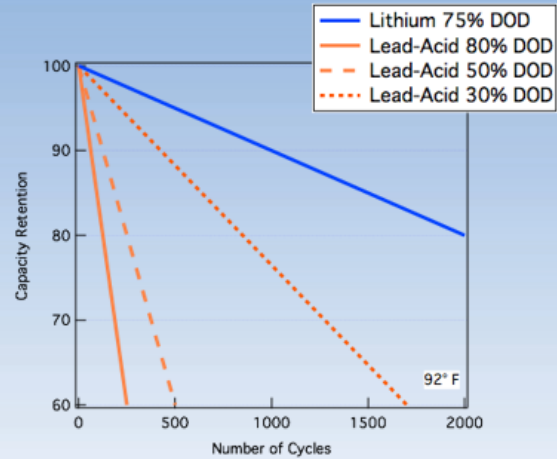
- Lithium Voltage starts at a higher level than Lead Acid and doesn't decay during discharge like Lead Acid.
- ENERGY in a Li cell is HIGHER than for the same Ah rated Lead Acid cell
- POWER output is similarly higher, which can improve vehicle performance

Cycle Life

Cycle Life is dependent on depth of discharge (DOD) and operating temperature



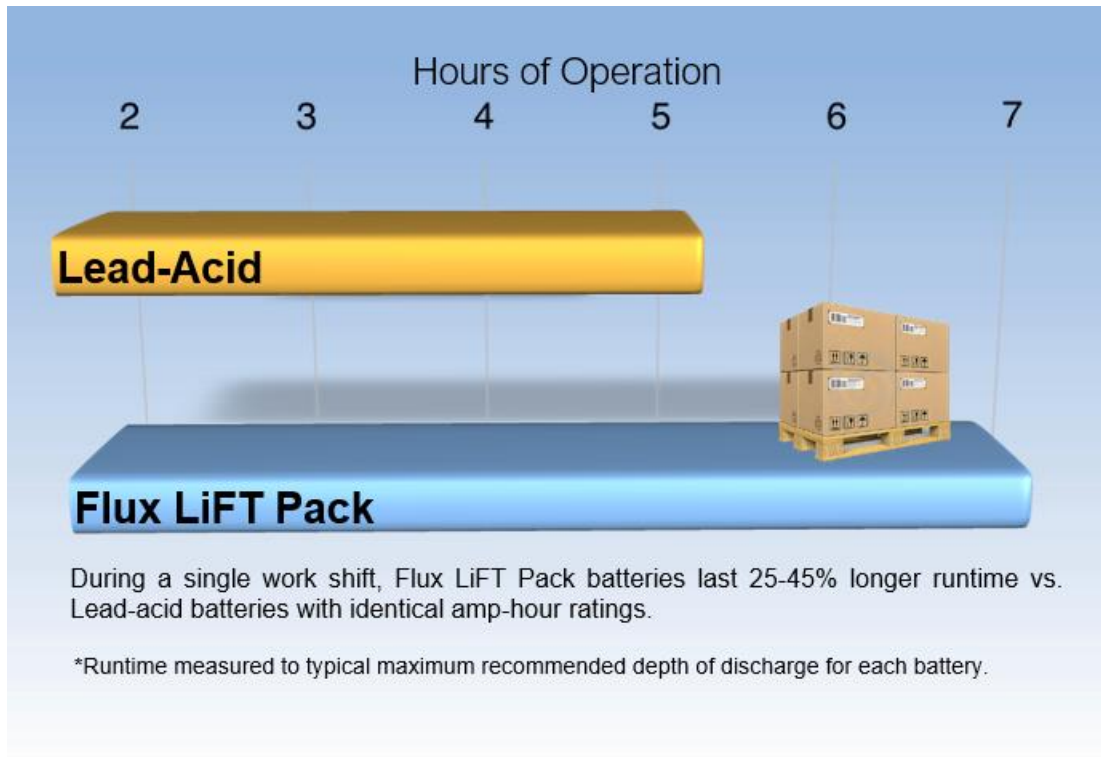
Moderate



Hot

At operating temperatures above 92°F lead-acid must be replaced twice as often as normal, while Li-ion is unaffected.

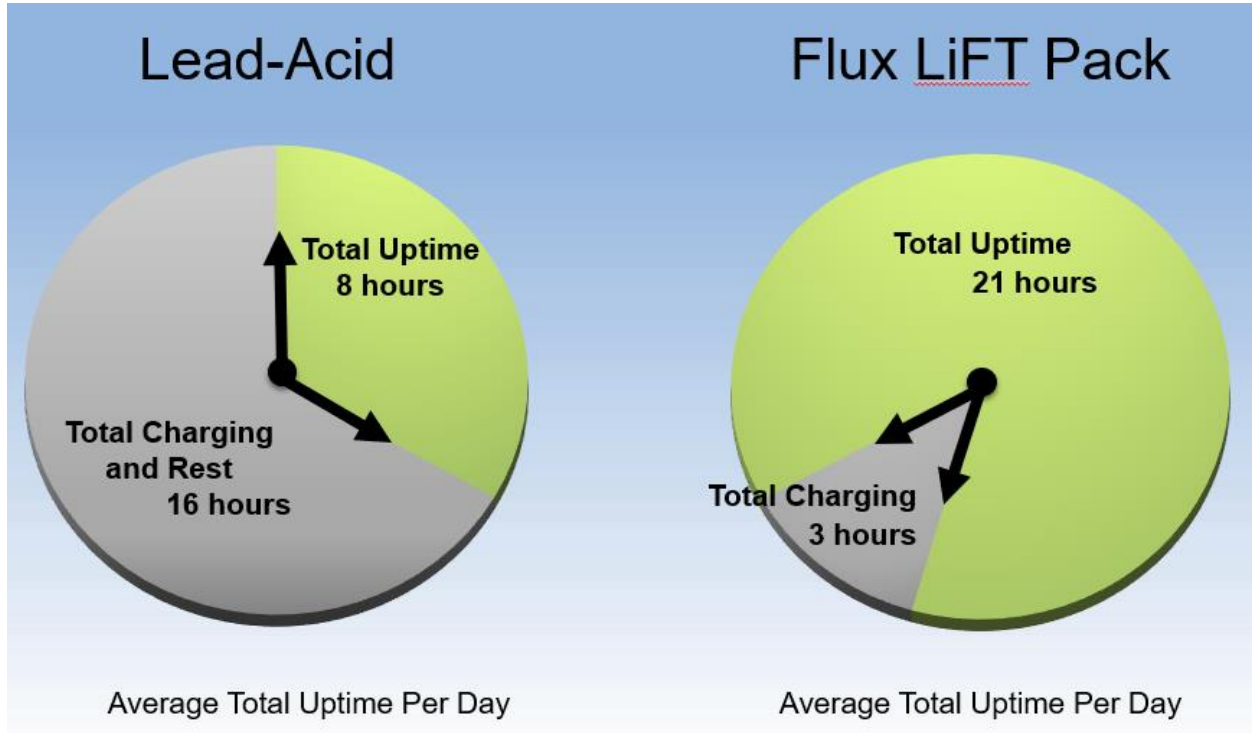
Longer Run Time



During a single work shift, Flux LiFT Pack batteries last 25-50% longer runtime vs. Lead-acid batteries with identical amp-hour ratings. There are many reasons why the runtime of lithium is longer, here are a couple reasons:

1. The depth of discharge for lithium-ion is 80%, while most lead acid DoD is 50% this means that only 50% of the battery's capacity is actually used.
2. Lithium-ion and specifically LFP has a very flat discharge curve compared to lead acid. This means it requires the same current output the whole time the battery is used. In lead acid towards the end of the cycle it takes more current to provide the same amount of power which makes the battery's capacity significantly drop.
3. LFP can handle large spikes in currents without any significant capacity loss. Lead-acid can not handle these spikes.

More Uptime



Does not need a rest period like lead-acid.

Almost doubles uptime and means fewer batteries are needed for 24/7 shifts.



Energy Efficiency












- Lithium accepts a charge more efficiently compared to lead acid (10%).
- Lithium does not require the equalization charge needed by lead-acid batteries for balancing and to reverse sulfation.
- Lithium batteries weigh less than lead-acid. Less weight being carried by the pallet truck at all times, means less power needed to run the truck.
- The higher nominal operating voltage of lithium (25.6V) compared to lead-acid (24V), translates to lower currents which means less energy is wasted as heat. Less heating of components also means longer equipment lifetimes.
- Save 20-40% on energy from the wall with Lithium-ion.
- Flux controlled testing confirms 33% less energy delivered 'out of the wall' for same work done.



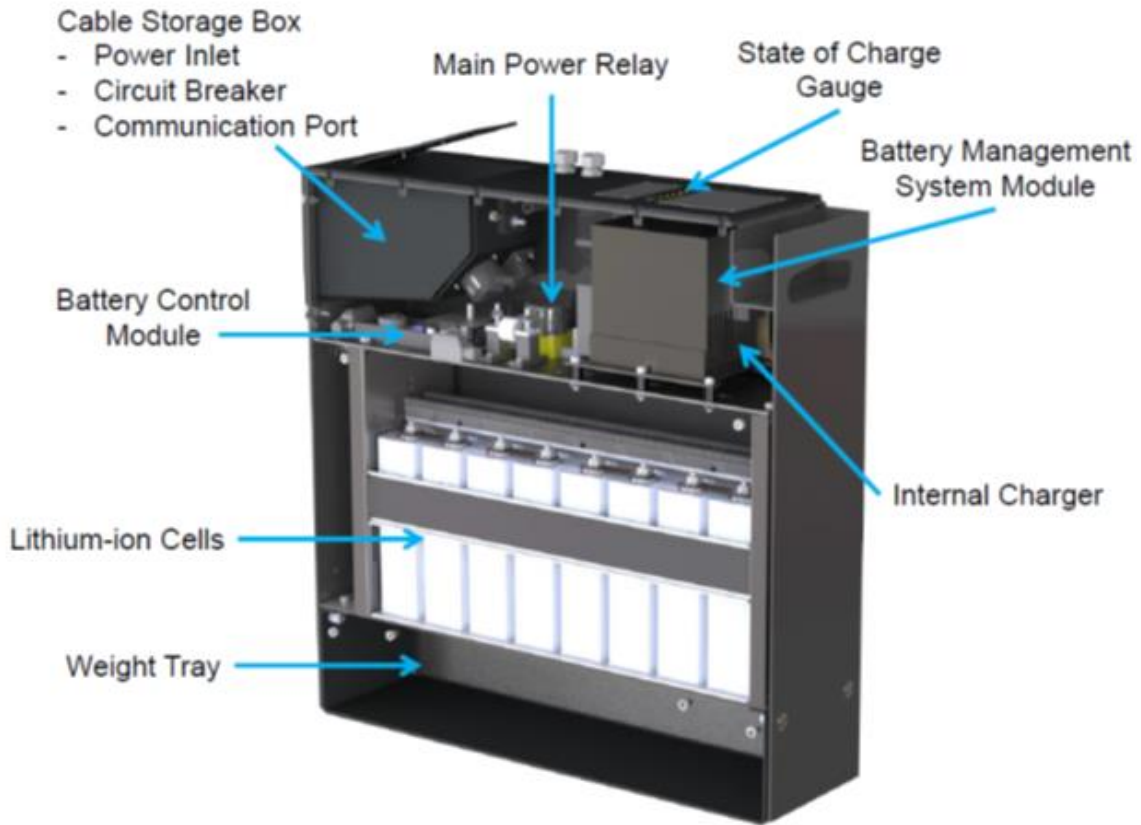
Recycling

- Lead-acid - Mature industry recycles ~96% of each battery.
- LiFePO_4 – Recycling is in its infancy and evolving rapidly.
- Japan, the US, and the EU all fund recycling research plants (Texco is involved with Tesla and the US government).
- Batteries are highly recyclable, but it is not economically favorable (yet). Economy of scale. Massive number of phone batteries, electric car batteries etc. feeding into system.
- China requires use of LFP in high population areas.
- Lithium lasts 3-5 times longer than lead-acid. The carbon footprint of recycling and producing 5 lead-acid batteries must be considered.

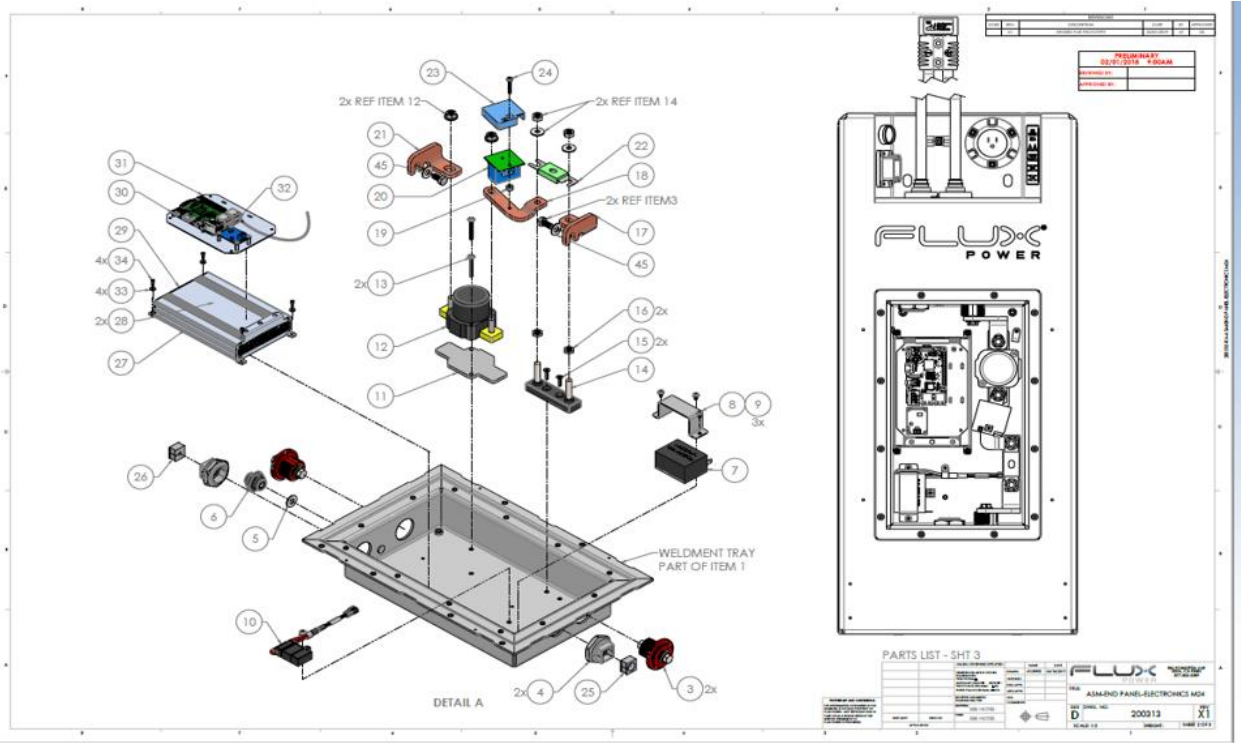
Products

FLUX POWER	S Series 24V 72, 100, 180Ah	M2 Series 24V 400Ah, 576Ah 600Ah, 864Ah	M3 Series 36V 600Ah, 864Ah	X Series 36V, 48V, 80V 600, 800Ah 300, 400Ah	G Series 80V 300 - 600Ah
Pricing is MSRP effective Feb 01 2019					
L x W x H	25.78" x 7.63" x 26.90"	30.5" x 13" x 30.9" 37.78" x 13" x 30.9"	37.78" x 13" x 30.9"	38.57" x 30" x 23.25"	44.16" x 14" x 22.48" 35.26" x 20" x 25.73" 35.26" x 26.26" x 25.73" 35.26" x 38.96" x 25.73"
Base Weight	200lbs / 322lbs	1000lbs	1140lbs	2400lbs	720lbs, 1200lbs, 1500lbs, 2100lbs
 Class 3 Walkie pallet Jack	72Ah: \$3,830 100Ah: \$4,495 180Ah: \$5,100				
 Class 3 Rider Pallet Jack		400Ah: \$10,500* 576Ah: \$13,500* On-Board charger: +\$1000 (Delta G, 1200W)			
 Class 2 Stock Picker		600Ah: \$15,000* 864Ah: \$19,250* Additional \$3/lb for weight			
 Class 2 Narrow Aisle			600Ah: \$21,500* 864Ah: \$27,000* Does not include Weight adaptor, \$3/lb		
 Class 1 Counterbalance Forklift				36V, 600Ah: \$23,500* 36V, 800Ah: \$28,500* 48V, 600Ah: \$28,500* 80V, 400Ah: \$28,500* Base weight 2400lbs, additional \$3/lb	
 Ground Support Equipment					80V, 200Ah: \$17,500* 80V, 300Ah: \$22,500* 80V, 400Ah: \$27,500* 80V, 600Ah: \$40,000*

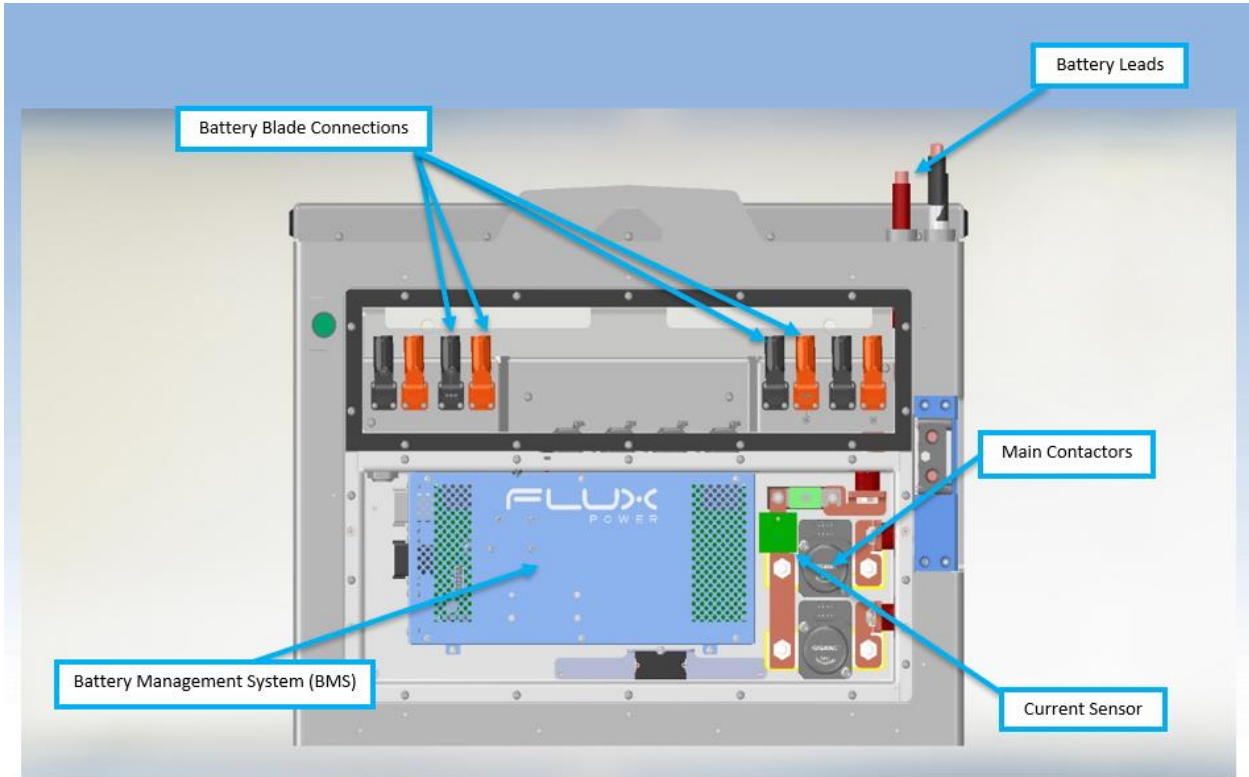
Flux Power LiFT Pack S8



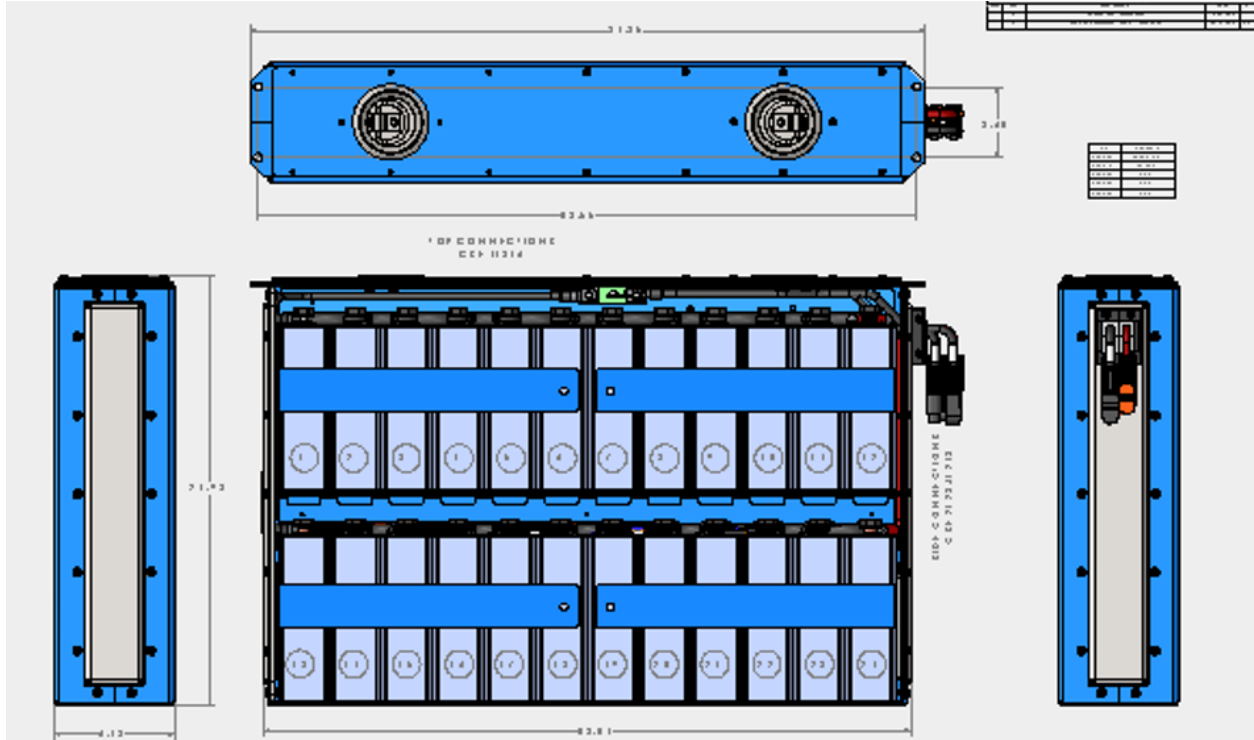
Flux Power LiFT Pack M24



Flux Power LiFT Pack X-Series



Flux Power Blade





Battery Management System

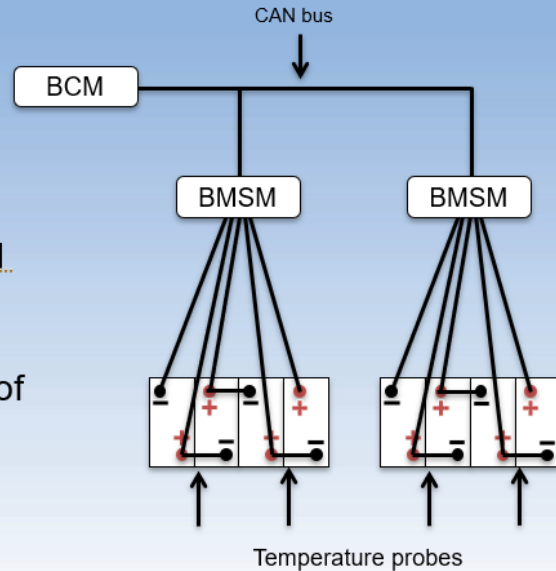
- Monitors cell voltages during charging and discharging
- Balances cells to maintain optimal battery life
- Prevents over-discharge (unless pack is completely neglected)
- Records a histogram of cell voltage, current, temperature, total Ah throughput, kilowatt-hour throughput

BMS Protective Functions

Fault Description	Cause and Required Duration to Cut Power	Fault Protection	LED Indicator	Service Required?	Fault Resolution
High Cell	>3.65V, 30 seconds	Contactors Opens	NONE	No	Wait 30 seconds until Contactor closes
Low Cell	<2.8V, 30 seconds	Contactors Opens	LED1	No	Connect Appropriate Charger
Over Temperature	>60C, 60 seconds	Contactors Opens	LED4	No	Allow pack to cool
Under Temperature	<-20C, 60 seconds	Contactors Opens	LED4	No	Allow pack to warm

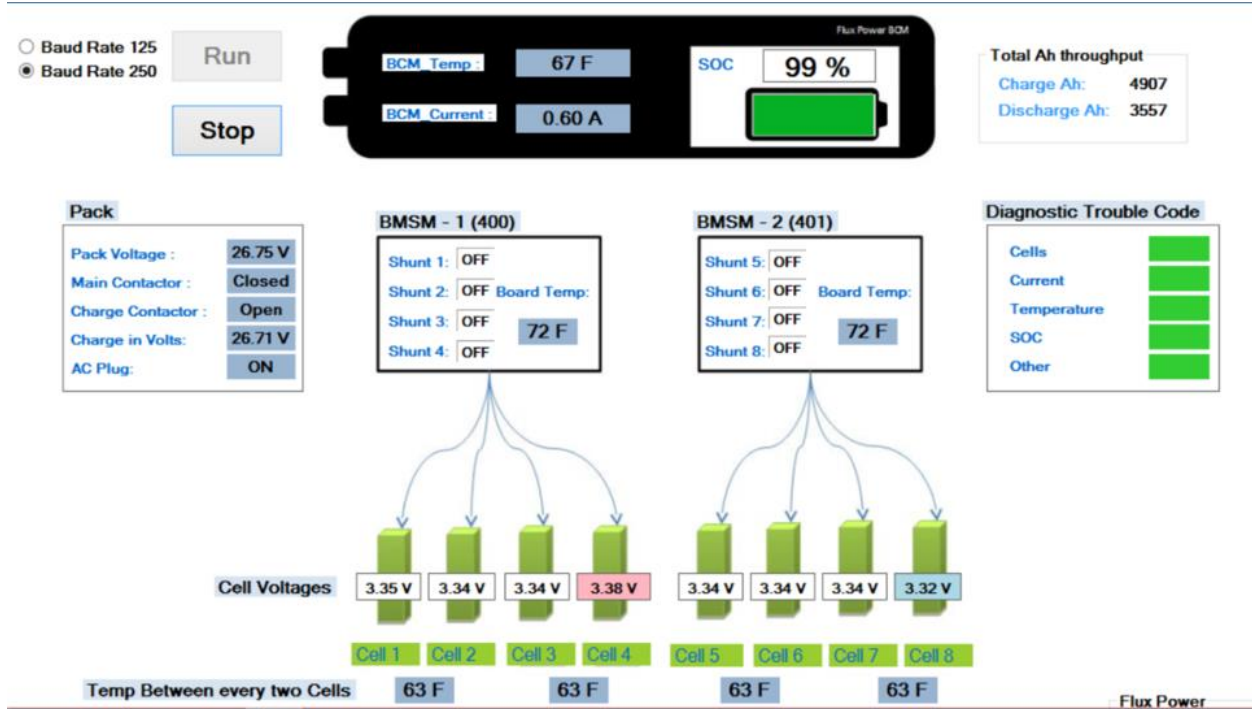
Cell Balancing Circuits (BMSM)

- The Battery Management System Modules (BMSMs) are charge balancing boards that intelligently monitor and maintain the life of the LiFePO₄ battery cells.
- Every BMSM manages four cells which provide a total of 12 volts.
- The BMSMs monitors the voltage and temperature of all 4 cells at all times (charging and discharging).
- The figure to the right is a schematic of two networked BMSM units on a 24 volt battery pack.
- Quantum balancing – A new cell balancing method that will shunt the high cells throughout the use of the battery.



FluxConnect – Software

Diagnostics – cell voltage, current, temp sensors etc.

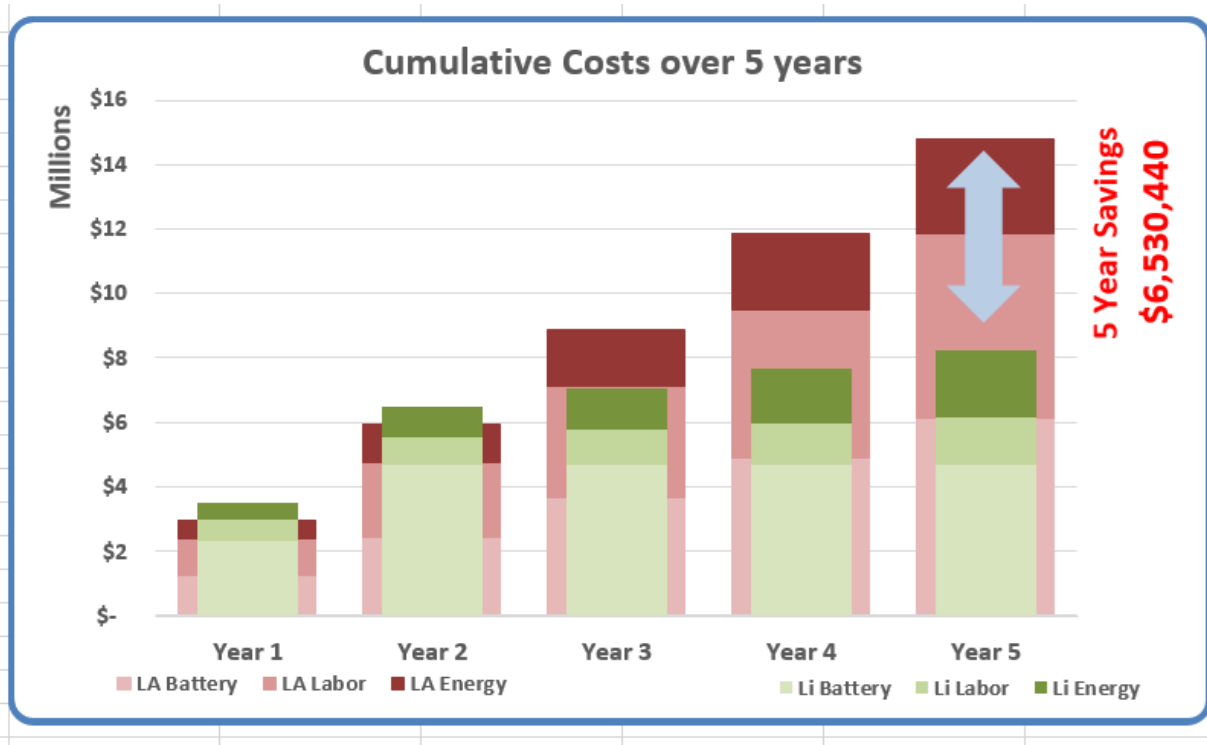




Flux Lithium is Safer **than Lead Acid...**

- The fuse and breaker protect from damage in the event of a short circuit.
- The BMS protects the cells from over-charge and over-temperature operation.
- Redundant backup systems ensure fail safe operation.
- Extensive shock and vibration testing in all 6 orientations.
- No dangerous gas generation during charging.
- Dangerous situations from electrical shorts, high temperatures, acid spills, and explosive gas generation are no longer a problem. The robust design, UL Listing and chemical makeup of our batteries make them among the safes in the industry.

40% lower cost of ownership



Savings driven by:

- Maintenance Elimination: no watering.
- Longer life – 5yr warranty, 2000cycles @ 80% DOD
- 30% reduced electricity costs
- No dedicated charging room or extraction etc.

Pay back within 2 years



Flux Advantage Safer Than Lead Acid

Flux LiFT Packs are one of the safest batteries available:

- The fuse and breaker protect from damage in the event of a short circuit.
- The BMS protects the cells from over-charge and over-temperature operation.
- Hard-wired backup systems provide additional temperature and voltage protection.
- Extensive shock and vibration testing in all 6 orientations.
- No dangerous gas generation during charging.
- The selected Lithium Chemistry is one of the most stable available
- No Cal / OSHA / EPA hazardous reporting requirements
- Dangerous situations from electrical shorts, high temperatures, acid spills, and explosive gas generation are no longer a problem.
- The robust design, UL Listing and chemical makeup of our batteries make them among the safest in the industry.



SUMMARY: LiFT-24V BENEFITS

Lithium-Ion Benefits		Lead-Acid
<ul style="list-style-type: none"> ✓ Longer run times <ul style="list-style-type: none"> • One battery can cover ~2 shifts • Battery can remain in forklift 	vs.	Power dissipates faster <ul style="list-style-type: none"> • Only 1 shift per 24 hours • Battery must be swapped out
✓ <u>5-7 year</u> lifespan	vs.	18-30 months
✓ More persistent power	vs.	Power dissipates faster
✓ 5-year warranty	vs.	x-year warranty
✓ Faster charging ~ as low as 1 hour	vs.	8 hours
✓ No cool down period required	vs.	8 hour cool down
✓ Opportunity charging	vs.	Reduces battery life
<ul style="list-style-type: none"> ✓ No watering or maintenance • Ventilated charging area not needed • No monthly regulatory reporting • No risk of acid spills 	vs.	Ongoing maintenance required <ul style="list-style-type: none"> • Required • Required • Ongoing risk.
✓ Lighter chemistry ~ 1/3 weight (flexible)	vs.	Heavy
✓ No heat challenges	vs.	Batteries heat (waste energy)
✓ <u>Six month</u> new battery shelf life	vs.	~35 days
✓ More efficient charging (use less power)	vs.	Less efficient (more costly)



Addressing Common Concerns

Fire

- Flux LiFT pack chemistry is one of the most stable Lithium chemistries.
- Thermal runaway temperature is significantly higher than other chemistries and Lead Acid.
- UL approval introduces several fire safety measures.

Safety

- Flux LiFT Prismatic cells have few power connections, making system inherently less complex than other competing technologies.
- No gases are emitted during charging, so no explosion risk.
- Power output is fused, so no 'meltdown' risk.

Up Front Cost

- Full Life cost can save 50% over 5 years, so investment should be justifiable.