Technology to Optimize Total Cost of Ownership: TPPL vs Li-ion

Overview

As motive power technology advances and options proliferate for Material Handling Equipment (MHE), decision makers feel overwhelmed by choice. From Internal Combustion Engines (ICE) to traditional Flooded Lead Acid (FLA) to Lithium-ion (Li-ion) to hydrogen fuel cells, and beyond, there are several different battery types that may suit your warehouse or distribution operation's needs. Getting the best Total Cost of Operation (TCO) depends on an understanding of first, the usage model, and second, which technology best fits the way MHE is used.

Each enterprise and often, each facility may need different types of power systems depending on the type of equipment (forklift vs pallet jack), the environmental conditions (indoor vs outdoor), and any sustainability considerations (including relevant vouchers and government credits). For many operations ICE is falling out of favor. It is excluded for most indoor applications and there is government legislation and incentives to drive the electrification of MHE. FLA has several disadvantages- primarily the need for regular maintenance and watering and the subsequent need for safety equipment, specialized facilities and high water usage. Therefore, many operations find that they are choosing between a Thin Plate Pure Lead (TPPL) option and a Li-ion option. In this white paper, you will learn about the different kinds of lead acid batteries and Li-ion batteries and how to determine which has the best TCO for your usage.

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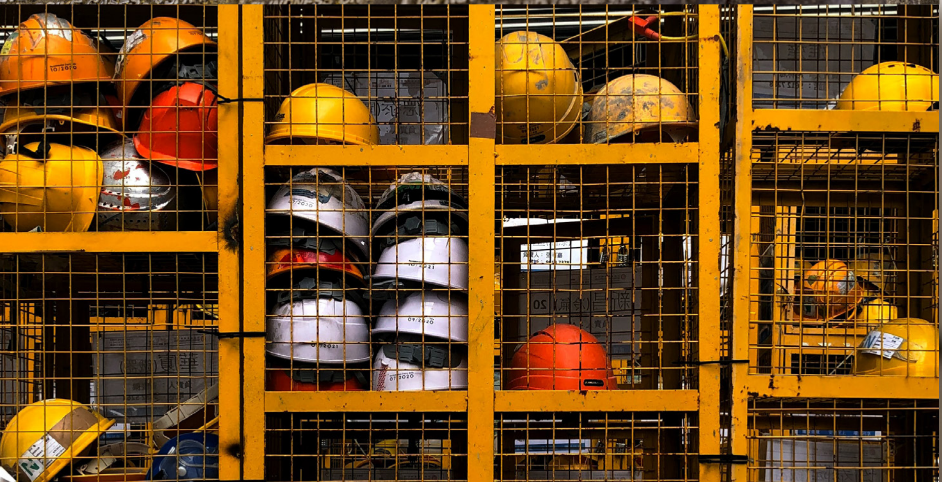
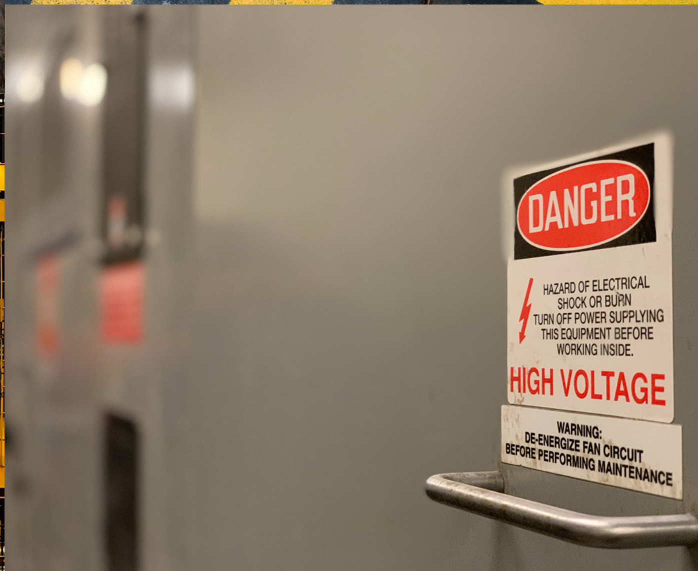
Lead Acid Batteries

Developed in the 1850s, FLA have been the go-to pick for indoor MHE. Inside the case of a lead-acid battery are positively and negatively charged lead plates, joined by lead connectors, immersed in an electrolyte solution of sulfuric acid. As the battery discharges, the sulfur in the electrolyte coats the lead plates, and in the process gives up electrons that become the electricity that powers the equipment. As the sulfate ions coat the lead plates, the electrolyte solution becomes more dilute. At the same time, the lead sulfate coating the plates acts as an insulator, impacting the battery's performance. Charging reverses this process. FLA batteries must be charged at a rate of C/5 at most for the constant current phase and then the constant voltage phase starts at 80% for a total charge time of about 8 hours, the charging efficiency is in the 75% range. This means the amount of electricity paid for is not the same amount that ends up in the battery itself. This inefficiency in the charging process creates heat and necessitates a prolonged cooling period between uses. There are many limitations including the need for a weekly equalization charge. For applications running multiple shifts, lead-acid batteries often require a dedicated battery changing and maintenance room for watering which takes up space and resources. For a three shift operation, each truck gets three batteries which are swapped out- one in operation, one charging and one cooling.





Thin Plate Pure Lead Batteries

Thin Plate Pure Lead (TPPL) Batteries are similar to or could be considered a subset of Absorbed Glass Mat batteries (AGM). The highly absorbent glass structure used in AGM is slightly under-saturated so there are voids present and it is possible for generated oxygen to travel to the negative electrode and the battery can be sealed and doesn't require watering. Over time, delivery capabilities increases AGM replacing FLA in many industries. Early successes for TPPL were in the avionics and defense industries, but it was the telecom industry that spurred widespread adoption because its high cycle capabilities are appropriate for back up grid applications. Development of carbon-enhanced TPPL enabled use in hybrid telecom power applications and carbon enhanced TPPL batteries were brought into MHE applications recently.

In some ways, TPPL has advantages that sound similar to Li-ion batteries that will be outlined in the next section. TPPL plates have a thickness of a third to a quarter of standard batteries', so more plates can be accommodated. This provides a large reactive surface area and low internal resistance, with power densities hence boosted. Consequently, TPPL batteries can be recharged within a short period of time and they can deliver high current peaks, without a large voltage dip (as compared to FLA). They have a long cycle life, especially when subject to repeated short cycles of discharging followed by partial opportunity charging. Low self-discharge rates allow battery storage for extended periods.

TPPL batteries don't require watering like FLA. However, they do need to be brought up to a full state of charge at least once weekly and they will need to be periodically checked for cell imbalances. This means a TPPL battery can charge quickly up to 70-80%- the constant current phase is a higher charge rate, but it takes long time to get it to the fully charged state because the constant voltage phase is unchanged. The total time it takes for a TPPL battery to reach its full charge is reduced, however TPPL batteries need to be brought to full charge to limit sulfation. In addition, they cannot be discharged fully, so the operating range is narrow. TPPL batteries are about 30% more expensive than lead acid batteries. The life expectancy of a TPPL battery is two to four years, depending on many application-specific variables.

TPPL Challenges:

- They suffer from sulfation (the formation of lead sulfate crystals over the active material of the battery) that impedes a battery's usable capacity, and ultimately decreases its cycle life.
- Lead acid batteries require routine maintenance, and failure to adhere to a rather strict schedule can lower a battery's lifespan. If the battery isn't equalized, the lead sulfate crystals can harden on the lead plates, permanently reducing performance.
- While lead acid batteries can be opportunity charged, there are strict limitations. Discharging a TPPL battery beyond 40% state of charge damages the battery and reduces cycle life.
- TPPL can be opportunity charged within a small window, which makes it only suitable for single shift, low usage situations and highly subject to operator error.

Li-ion Batteries

Li-ion batteries are becoming more and more common because of their long cycle life and short charge times, but they also greatly reduce the risk to the workforce when they are implemented in a warehouse environment. Li-ion batteries are made up of cells, just like lead-acid batteries. Large format Li-ion cells, used to manufacture batteries used for motive applications, are shown in the picture. The cells have an anode and a cathode with a separator and electrolyte in between. Unlike FLA cells, the li-ion cells are sealed and have many safety factors designed in them. The cathode material is the main determining factor in the cell's performance. In the battery power market today, there is a myriad of available battery cathode chemistries to choose from. While lithium-ion batteries require no regular maintenance from operators, they do still need to be inspected so that they can be serviced as needed.

The physical construction of the cell affects its safety. All lithium batteries contain a critical component called the separator, which is placed in between the anode and cathode layers in the electrode. The separator limits the chemical reaction of the electrode and helps to prevent thermal runaways by closing its porous structure at high temperatures. Most li-ion cells incorporate ceramic coated separators. The ceramic material is resilient at high temperatures and helps prevent the breakdown of the separator that occurs during a thermal runaway event.

The electronics of the li-ion battery also provide protection against safety events, with incorporated fuses and protection against over- charge, over-discharge and high and low temperature charging. These battery "smarts," combined with the long cycle life and short charge time seamlessly integrate with the MHE.

Advantages of Li-ion batteries:

- **Low maintenance:** They are sealed and do not require maintenance watering and the associated infrastructure.
- **Charging:** Li-ion batteries can be charged at a 1C rate with very negligible time in the constant voltage phase so the total charge time is a little over an hour.
- **Charging efficiency:** Li-ion batteries have a low impedance with very little loss to waste heat. They are 98% electrically efficient.
- **Operating state of charge:** unlike TPPL, Li-ion batteries are not damaged by usage outside the middle state of charge.
- **Operating temperature:** Li-ion has a wider operating temperature range than lead acid from -40C to 60C.
- **Cycle life:** Li-ion batteries have a cycle life of more than 3000 full cycles.
- **Communication:** Li-ion batteries offer CAN communication with the truck and charger.
- **Low self-discharge:** Li-ion batteries can be stored for long periods.

Types of Li-ion Batteries

Lithium batteries for MHE are available in two main types with different cathode chemistry: Nickel Manganese cobalt oxide (NMC) batteries and Lithium Iron Phosphate (LFP) batteries. The pros and cons of each type vary by application, but in general, lithium-ion batteries offer the following characteristics:

While higher energy li-ion chemistries are available, Lithium iron phosphate (LFP) is safest with the longest cycle life due to its stable chemical make-up. A demonstration of how much more stable the LFP chemistry is compared to the high energy Lithium Cobalt Oxide (LCO), used in consumer electronics, is to compare the thermal runaway temperatures- the high temperatures at which the chemistries begin to become unstable and volatile. LCO has a much lower thermal runaway temperature of 150°C (302°F) compared to LFP's thermal runaway temperature of 270°C (518°F). This large difference shows LFP to be the much safer of the two lithium chemistries. High energy density is important for battery systems which need to be smaller and lightweight. A more modern cathode chemistry than LCO is Nickel Manganese Cobalt (NMC). NMC is the result of an attempt to balance safety and performance. A version of NMC is the chemistry is utilized in most automotive EV battery systems today. EV batteries utilize higher voltages and with the higher energy available, additional safety measures and control must be implemented. The cells heat up quicker, so proper charging is critical.

With larger industrial, motive power battery systems, space is available for the larger batteries, and weight is needed for the counterbalance systems. Fast charging is critical and LFP accommodating lead acid charging helps with systems safety. Cycle life and safety is prioritized. The lower voltage of LFP is good match for Lead Acid replacement. This and the tolerance of Lead Acid charging systems make LFP the safest backward compatible option for material handling batteries.

Li-ion Battery Components:

- **Electrolyte:** Allows the lithium ions to pass between the cathode and anode.
- **Anode:** During discharge, the anode releases positively charged lithium ions into the electrolyte, and releases electrons through the circuit of the device being powered.
- **Cathode:** As the battery discharges, the cathode absorbs positive lithium ions and receives electrons from the device's circuit.
- **Separator:** A separator allows the lithium ions to pass through and insulates the anode and cathode preventing shorts.
- **Batter Management System (BMS):** Li-ion batteries require intelligent management for safety, temperature sensors, balancing and state of charge. The BMS communicates to the truck and charger with CANBus.

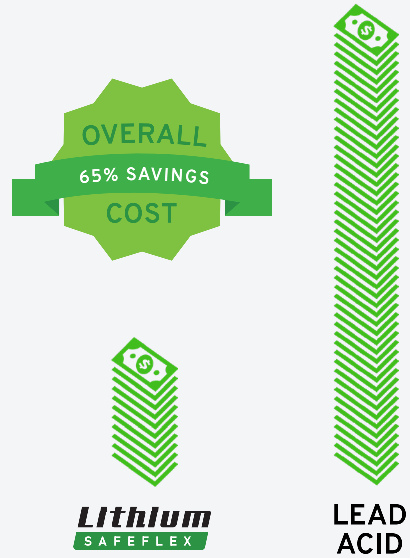
Summary Comparison

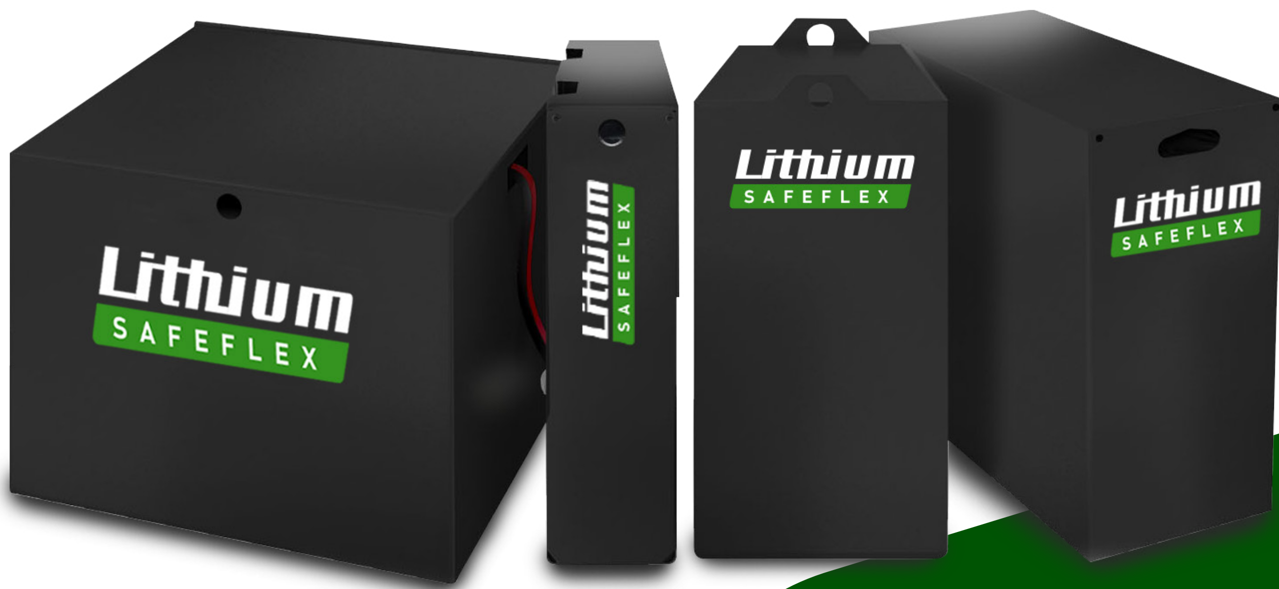
TPPL batteries can be a good solution for light usage single shift operations where production or break schedules allow for plugging up often and cost sensitivities are high, but they are not a good fit for higher usage and cost more than FLA. TPPL batteries can be charged much faster than standard lead acid batteries, but not as fast as Li-ion batteries, which can be fully charged in a little over an hour. Li-ion can be opportunity charged with little care to what range within the state of charge the battery is kept in, so there is less potential for operator error. With TPPL technology the batteries can only be discharged down to about 40% before their warranty is voided. The deeper a TPPL battery is discharged between charging, the lower the life expectancy of the battery. While the charging efficiency with TPPL batteries is significantly better than with FLA at about 85%, it is a less efficient process than with lithium ion, which is about 98%. This translates to an increased level of internal heat inside of the battery, causes a reduction in the life expectancy of TPPL batteries. When comparing TPPL batteries to lithium-ion batteries, in specific usage studies it becomes apparent that TPPL batteries need roughly double the nominal capacity to have the same amount of useful runtime/uptime. Even with the proper maintenance, TPPL is going to last about 2-4 years while Li-ion batteries will last 5-8 years, so the TCO for Li-ion is generally lower than TPPL.

YOUR NEXT STEP

Our engineers can help you identify areas of your operation where Lithium SAFEFlex can make the most impact, based on how you use your fleet:

1. We'll evaluate your facility to see where changing from Lead Acid to Li-ion will most impact your organization. Our analysis will cover number of vehicles, number of shifts, charging information, and major improvements you'd like to see.
2. We'll provide a quote to demonstrate that there will be a cost savings associated with the change to Li-ion and it's safety benefits, then we'll provide a trial system with monitoring software to validate the savings.





ABOUT GREEN CUBES TECHNOLOGY

Harnessing our 35 years of industry experience, Green Cubes Technology is committed to designing, manufacturing, and implementing Lithium-ion platforms that give you The Power to Perform. Our battery packs are sustainable, maintenance-free, environmentally friendly, and superior performing.

For more information, email **info@greencubes.com** or visit **greencubes.com.**

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