GREEN CUBES
THE POWER TO PERFORM

Lithium
SAFEFLEX

Lower Total Cost of Ownership with Li-ion Batteries and Chargers

Overview

Lithium-ion (Li-ion) batteries are rapidly being adopted as the power technology of choice for material handling equipment. The environmental benefits are clear and there is legislation and government incentives that spur interest, but the low total cost of ownership is driving adoption in advance of these initiatives. The low total cost of ownership is tied up in a few factors that tie into efficiency: low maintenance, less infrastructure, improved safety and improved charging and process efficiency.

Workplace injuries are all too common in the warehouses; battery maintenance for material handling equipment is a typical culprit. The ongoing maintenance required to keep flooded lead acid batteries running presents a danger to the workers tasked with charging, watering and changing batteries. Li-ion batteries eliminate most of these issues because they are self-contained and maintenance-free. Use of Li-ion batteries eliminates the need for the battery watering room, showers, eye-wash stations and other expensive maintenance and safety infrastructure.

Li-ion batteries are safer and more environmentally friendly than lead-acid batteries and can be opportunity charged resulting in improved operational cost and smaller infrastructure investment.

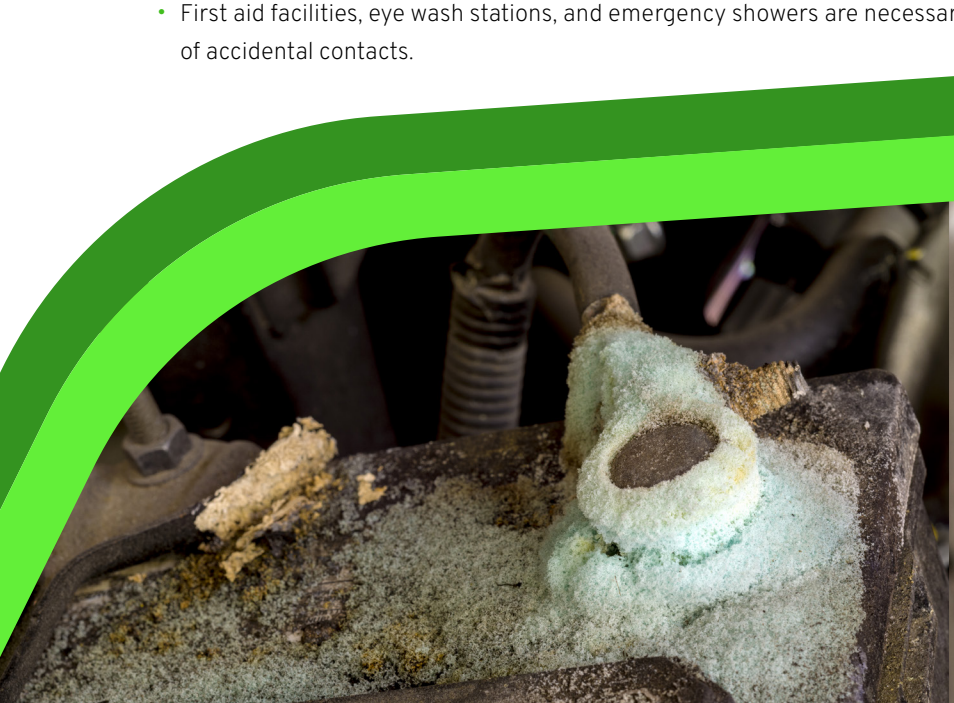
Charging Overview

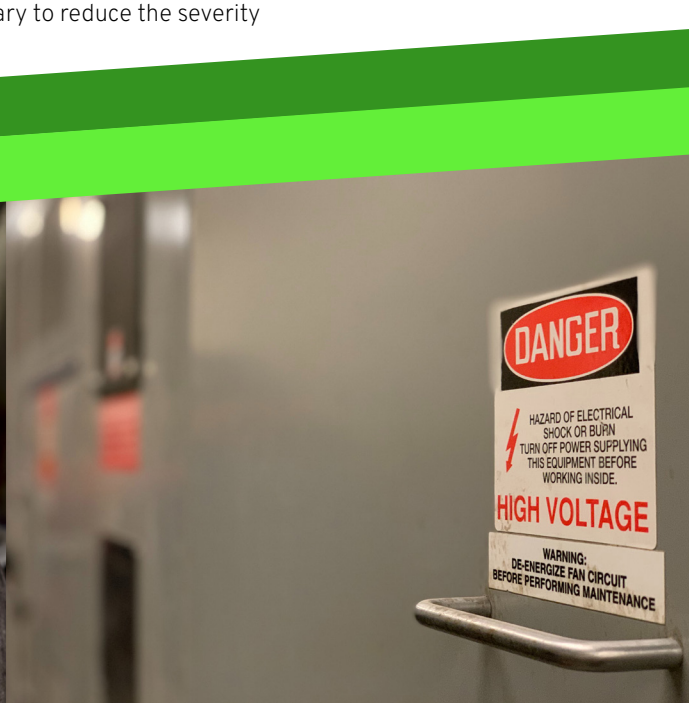
Fast charging is a key differentiator for Li-ion batteries. Because the chemistry allows fast charging without damaging cycle life, Li-ion batteries can be charged opportunistically during breaks and don't require battery swaps. Green Cubes' state-of-the-art chargers employ high-frequency technology for the most compact, efficient for the widest voltage range available on the market today. Multiple outputs and automatic voltage detection via CAN communication enable simultaneous charging of multiple trucks with a single utility connection. The modular design allows an entire fleet, from pallet jacks to forklifts, to be serviced, opportunity charging around the clock.

Lead acid batteries: Hazards, Precautions and Maintenance

The charging of lead-acid batteries is hazardous, but many workers may not remember this since the activity is so routine. The three most common risks are from hydrogen gas formed when the battery is being charged, the sulfuric acid in the battery fluid- with exposure from spills and leaks, and physical injuries from the batteries' weight. Repetitive use injuries, such as sprains and strains are common, but unfortunately the highly corrosive electrolytes in batteries can cause respiratory irritation, eye damage, skin irritation, and it can even erode tooth enamel. The sheer size of material handling batteries means that crush injuries also occur during battery changes. The corrosive electrolyte material is shown in the first image below of a damaged lead acid battery. This is an overview of the risky maintenance for lead-acid batteries:

- The fluid level is extremely important and a safe level requires regular watering. Overwatering and underwatering can both damage the battery. If too much water was added before charging, the electrolyte levels will expand and cause the battery to overflow and damage the battery.
- Conventional batteries contain a liquid "electrolyte" which is a mixture of sulfuric acid and water. The plates in a lead battery contain an active material that should be continuously bathed in electrolytes while oxygen and hydrogen gas are released during charging.
- When batteries are being recharged, they generate hydrogen gas that is explosive in certain concentrations in the air, so the ventilation system must provide enough fresh air to prevent an explosion.
- The electrical voltage created by batteries can ignite flammable materials and cause severe burns. Workers have been injured and killed when loose or sparking battery connections ignited gasoline and solvent fumes during vehicle maintenance.
- Wear personal protection equipment such as protective eyewear and gloves when working on batteries. To avoid splashing acid, personal protective equipment such as chemical splash goggles and a face shield must be worn.
- First aid facilities, eye wash stations, and emergency showers are necessary to reduce the severity of accidental contacts.





Features of SAFEFlex Batteries

Ease of Use

- 30 kWh, 48V 600Ahr battery can be fully charged in less than 1 hour at 320 amps
- Configurable dot matrix battery discharge indicator provides critical battery information along with errors or other important runtime data
- No change to truck required, CAN communication for lithium ready equipment
- Utilizes existing 4/0 cabling
- No Maintenance
- No Watering
- No Equalization Charging
- No Battery Washing Needed
- Utilizes Lithium Iron Phosphate battery chemistry for increased safety and stability
- Voltage, Current, and Temperatures are continuously monitored by Green Cubes Technology's custom Battery Management System (BMS) which controls the internal safety contactors or disconnects the fuse
- Constructed from UL approved components

Safety Features of Li-ion batteries

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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 flooded lead acid 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. It is a critical decision which not only impacts how well the product will operate but also how safely it can operate. Factors such as how much power is required, the time required to charge, operating temperatures, operating environment, packaging dimensions, and weight are all examples of key parameters that must be considered.

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 utilized in 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 actually needed for the counterbalance systems. 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.

The physical construction of the cell also 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. The safest Li-ion cells incorporate ceramic 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 material handling equipment. The fact that the battery is virtually maintenance free over the life-time of the truck, eliminates the possibility for user error and greatly reduces the risks in the workplace.

LFP VS. NMC

Parameter	Lithium Iron Phosphate (LFP)	Nickel Manganese Cobalt (NMC)	Comparison
Voltage	3.2 V	3.7 V	NMC Batteries are lighter and more compact
Weight Energy Density	90-120 Wh/Kg	150-250 Wh/Kg	
Volume Energy Density	300-350 Wh/L	500-700 Wh/L	
Max Discharge Rate	30C	2C	LFP Batteries provide more power over a shorter period, and can be charged faster
Max Charge Rate	10C	0.5C	
Typical Cycle Life (@80%)	3000+ Cycles	500-1000 Cycles	LFP Batteries will deliver more cycles over a longer calendar life
Calendar Life (@80%)	8-10 Years	**4-5 Years	
Thermal Runaway Onset*	~195 °C	~170 °C	NMC Batteries have lower thermal runaway thresholds and will burn hotter
Thermal Runaway Increase*	210 °C	500 °C	

* Royal Society of Chemistry, 2014

** With derated charge voltage

Charging Li-ion Batteries

Li-ion batteries are preferably charged using a Constant Current / Constant Voltage (CC/CV) charge regime, but most MH equipment batteries are designed to accept both CC/CV and FLA charge regimens. Regardless of the state-of-charge of the battery when connected to the charger, the battery will efficiently accept the power and increase its state-of-charge. **Whether the battery has been connected to the charger for 15 minutes or two hours, that battery can be immediately discharged and used by the MH equipment as there is no need to cool or rest a Li-ion battery after charging.**

The Li-ion cell chemistry has numerous chemical variants. Lithium Iron Phosphate (LFP) chemistry is the predominant chemistry used to power MH equipment: LFP features:

- exceptionally long cycle life (2000 - 4000 cycles to reach 80% of the original capacity)
- high power capabilities for both charge and discharge
- lower energy/density than other Li-ion variants.

The long cycle life means an LFP battery can be installed and remain in the equipment for 8-10 years. More importantly, since LFP chemistry can accommodate high power delivered to and from the battery, **a depleted LFP battery can accept a full charge in a little over one hour (i.e. 1 C rate) and it can be delivered throughout the shift when the operator has a break or lunch.** Li-ion is the optimal chemistry for opportunity charging.

Best Practices for Opportunity Charging

1. Do a power study where the battery activity is monitored. Based on the data, one can determine whether there are adequate opportunities for charging throughout the shift. If there is no down-time for the equipment throughout the shift, then the batteries will need to be charged for an hour before the shift.
2. Single shift vs. multi-shift operations can determine the value of opportunity charging. If the enterprise operates a single shift operation, a fully charged Li-ion (or FLA) battery should power that vehicle through the shift. When a second (or third) shift is needed, then opportunity charging can be used to recharge in increments and ensure that the equipment is powered through all the shifts.
3. Rather than charging FLA batteries in a centralized battery maintenance room, distribute the Li-ion charging stations near break rooms and heavy work areas. Decentralized charging stations eliminate the operator's travel time from their work area to battery maintenance room as well.
4. Assess existing FLA chargers to determine if they are compatible with the Li-ion batteries.
5. Assess the power output of the existing FLA and Li-ion charging infrastructure. The power rating on the charger must be much higher when opportunity charging.
6. Consider a multi-voltage charger if opportunity charging is desired but there is not adequate down-time within a shift.

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SAFEFlex Chargers

The Lithium SafeFlex Battery Charger is designed to operate with Material Handling (MH) and Ground Support Equipment (GSE) Lithium-ion batteries. This charger has universal AC power input, supports full Level 3 charging via a CANBus communications with the battery, has a touchscreen display, provides unity power factor with very low iTHD which results in very high charging efficiency, and has the smallest footprint in the MH and GSE charger industry.

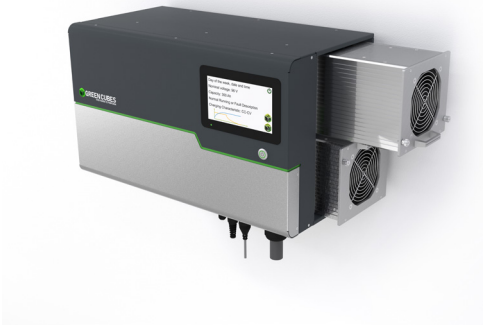
This charger is offered in 15 KiloWatt (kW) and 30 kW models. Each model supports up to three simultaneous charging ports, and performs voltage auto-detect for each of the charging ports. This charger is scalable down to 5 kW and up to 30 kW, while each module has a default power level of 15 kW.

This charger supports local and remote management with an embedded Internet of Things (IoT) processor which provides real-time performance information of each charge session with a Lithium-ion battery. Local support and remote administrative staff can review and manage charger/truck integration and overall fleet performance. Access to the Internet is supported via an Ethernet port, WiFi communications, or GSM cellular communications via Sim card slot.

With this charger connected to our Maestro cloud-based applications, fleet managers can monitor all critical charging performance parameters such as voltage, temperature, charge/discharge current, charge time connected to the battery, Kilo-Watts delivered per charge session and warnings errors.

Features

- Modular 15 kW and 30 kW models
- Level 3 charger with CANBus communications
- IoT Management via wireless and wired communications
- Real time performance monitoring via Maestro cloud-based application
- Easy configuration via touchscreen display
- Industry's highest energy density and efficiency, with smallest footprint.



YOUR NEXT STEP

Doosan Industrial Vehicle America Corp. and Green Cubes 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 DOOSAN INDUSTRIAL VEHICLE AMERICA CORP.

Leading the charge in the electric revolution, Doosan Industrial Vehicle America Corp. is a Top 5 material handling provider in North America with over 50 years of manufacturing vision and versatility. Boasting 90 product models ranging from 3,000 lbs. to 55,000 lbs., Doosan forklifts are powerful, efficient, and ready to lift your business into the future.

For more information, email. **Andre.Marshall@Doosan.com**, or visit **DoosanLift.com.**

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@greencubestech.com** or visit **greencubestech.com.**