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Lithium-ion Battery Overview and Safety

ICE - International Cleaning Equipment

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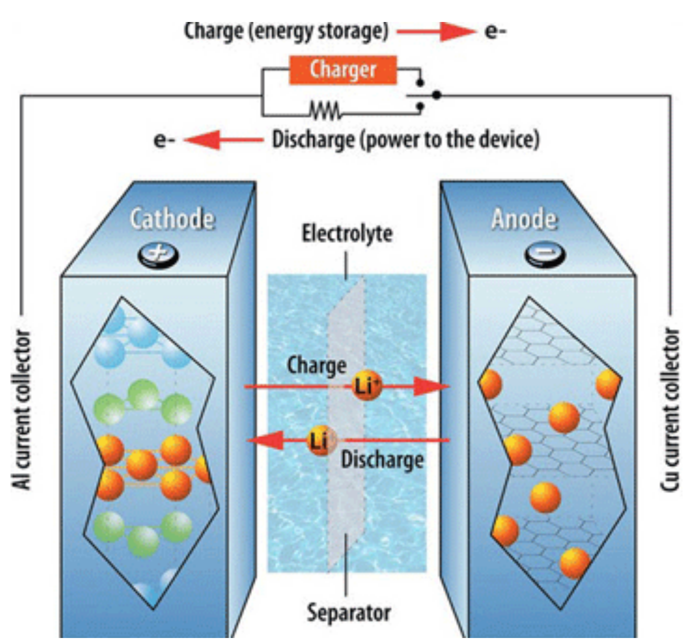
OVERVIEW of Lithium-ion Batteries

What is a Lithium-ion (Li-ion or LIB) Battery?

It is a rechargeable electrochemical device which stores and releases energy. Lithium is ideal because it is the lightest metal. It also has the highest electrochemical potential. Within the battery cells, lithium ions move from the negative electrode (anode) to the positive electrode (cathode) during discharge and in the opposite direction when charging. Figure A below shows how a LIB is constructed.

FIGURE A: The Lithium-Ion Battery



Source: http://nuclear-news.net/2012/08/24/new-fast-lithium-ion-battery-for-electric-cars/

BENEFITS OF THE LIB

- **Higher Energy Density.**
    - A typical LIB can store 150 watt-hours electricity per kg of battery compared to 100 watt-hours in a nickel-metal hydride (NiMH) battery and only 25 watt hours in a lead-acidy battery.
- **Low Maintenance.** There isNo *Memory Effect*,* no periodic discharge needed.
    - LIBs only use approximately 5% of their charge each month compared to 20% loss per month for NiMH batteries
- **More Charge/Discharge Cycles.** (LIB: 2000-5000 cycles vs. LAB: 500-1000)
- **Fast & Efficient Charging.** They take a fraction of the time to charge.
- **Low *Self-Discharge*.****
- **Lighter in Weight.**
- **Very Little Wasted Energy.** (LIB charge at nearly 100% efficiency vs. 85% of LAB.)
- **Less Hazardous.** There are no poisonous metals used: lead, mercury, or cadmium

**Memory Effect*: "The property of nickel-cadmium (NiCad) batteries that causes them to lose their capacity for full recharging if they are discharged repeatedly the same amount and then recharged without overcharge before they have fully drained. The term derives from the fact that the battery appears to have a *memory* for the amount of charging it can sustain." http://www.webopedia.com/TERM/M/memory_effect.html

***Self-Discharge*: "This is a phenomenon in batteries in which internal chemical reactions reduce the stored charge of the battery without any connection between the electrodes. Self-discharge decreases the shelf-life of batteries and causes them to initially have less than a full charge when actually put to use." https://en.wikipedia.org/wiki/Self-discharge

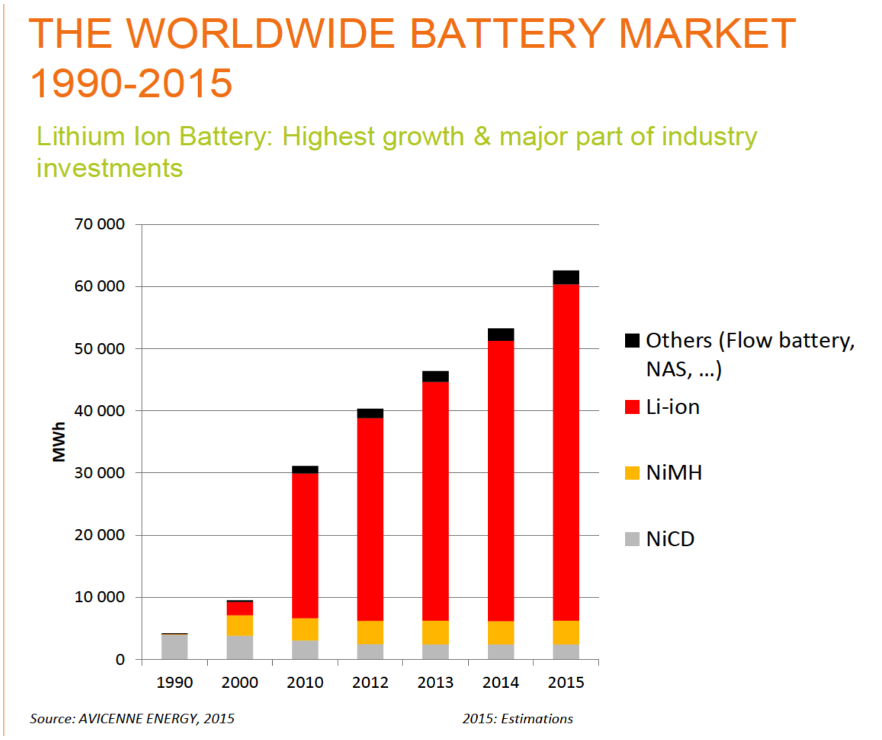
DRAWBACKS OF THE LIB

- **Short Life.** LCO, LNO, NMC, and LMO batteries currently last for only 2-3 years from the date of manufacture, regardless of whether they are used or not. However, manufacturers are constantly improving LIBs. New chemical combinations are being introduced almost monthly which makes it difficult to assess how long these updated LIBs will last.
- **Temperature Sensitivity.** Higher temperatures lead to a faster degradation rate than normal.
- **Transportation restrictions.** Shipment of larger quantities are subject to regulations.
- **Comparatively Expensive.**
- **Needs Circuit Protection.** If the LIB pack fails there is a risk that it could burst open into flame in certain cases.

POPULARITY OF THE LIB

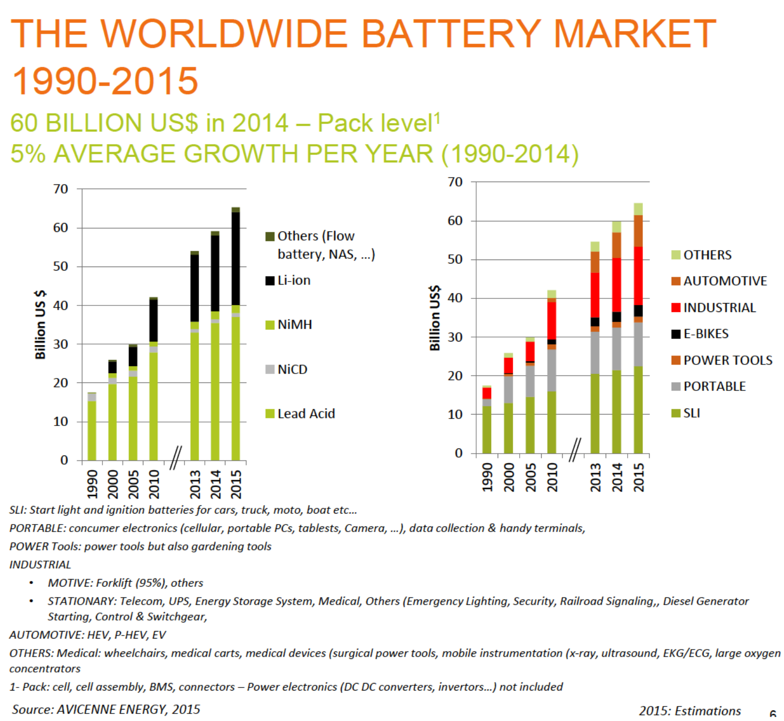
Due to the many benefits of LIB batteries, they are rapidly growing in popularity especially with portable consumer electronics (cell phones, computers, power tools, and tablets). Other industries are quickly adopting this technology and the global market is estimated at $11 billion and predicted to grow to $60 billion by 2020, according to Nexeon, Inc. Because LIB produce the highest energy density, experts estimate they will eventually dominate the world market. See Graphs 1 and 2.

GRAPH 1. LIB Highest Growth Battery



Source: Avicienne Energy, 2015

GRAPH 2. Worldwide Battery Market



Source: Avicienne Energy, 2015

COMPARISON OF LIB COMPONENTS

There are several types of Lithium-ion batteries. The type of battery technology depends on the application requirements for power, safety, lifetime, and cost. Table 3 and 4 below compare the major components that are currently available on the market.

TABLE 3. The Major Components of Lithium-ion Batteries and Their Properties

Name	LCO	LNO	NCA	NMC	LMO	LFP	LTO
Items	Lithium Cobalt Oxide	Lithium Nickel Oxide	Lithium Nickel Cobalt Aluminium Oxide	Lihium Nickel Manganese Cobalt Oxide	Lithium Manganese Spinel	Lithium Iron Phosphate	Lithium Titanate
Cathode	$LiCoO2$	$LiNiO2$	Li(Ni0,85Co0,1 Al0,05)O2	Li(Ni0,33Mn0, 33Co0,33)O2	$LiMn2O4$	$LiFePO4$	e.g.: LMO, NCA, …
Anode	Graphite	Graphite	Graphite	Graphite	Graphite	Graphite	$Li4Ti5O12$
Cell voltage	3,7 - 3,9V	3,6V	3,65V	3,8 - 4,0V	4,0V	3,3V	2,3 – 2,5V
Energy density	150mAh/g	150Wh/kg	130Wh/kg	170Wh/kg	120Wh/kg	130Wh/kg	85Wh/kg
Power	+	o	+	o	+	+	++
Safety	-	o	o	o	+	++	++
Lifetime	-	o	+	o	o	+	+++
Cost	--	+	o	o	+	+	o

Source: Daimler Analysis, Nationale Plattform Elektromobilität, 2010

TABLE 4. Comparison Data Among Various Lithium Base Batteries

FEATURES	LiFePO4	LiCoO2	LiMn2O4	NIMH
SAFETY AND ENVIRONMENTAL CONCERNS	Safest: no explosion, no smoke, no fire under abused working condition and the most environmentally friendly. Non-toxic, no rare metal, fire resistant, easily disposed of	Not stable very dangerous	Acceptable but also be explosive and on fire under abused working condition	Not stable will be on fire even just under high temperature
CYCLE LIFE	Best among all the listed groups-Up to 2000 times (80% DOD condition)	Acceptable (< 500 times)	Unacceptable (around 300 times)	Below 500 times
POWER WEIGHT DENSITY	Acceptable 65% weight of NIMH	Best	Acceptable	Low
LONG TERM COST	Most Economical	High	Acceptable	High
THERMAL PERFORMANCE	Excellent (-45℃~ -70℃)	Decays beyond +55℃ ~ -20℃	Decays extremely fast over +50℃	Decays faster in high temperature

Source: CellTech Energy Systems, www.celltech.dk

SAFETY of Lithium-ion Batteries

Relating to ICE Lithium Iron Phosphate ($LiFePO_4$) Batteries

By now you are aware of what can happen when a Lithium-ion battery (LIB) gets damaged and overheats. Because LIB is the best battery technology available today and widely used, it is the responsibility of the manufacturer to mitigate this risk. At ICE-International Cleaning Equipment, safety is #1. ICE has gone above and beyond to ensure safe operation of their Lithium-Ion batteries. ICE has incorporated rigorous safety standards into their LIB technology used in their floor care equipment.

ICE LIBs are extremely safe based on the following:
❶ Battery Properties and Construction
❷ Battery Management System (BMS)
❸ Charger
❹ required certifications and standards.

❶ Battery Properties & Construction

Manufacturers have a variety of factors to consider when designing a battery for their product including its chemistry, size, power, cost, and safety. For ICE safety has always been the highest priority. **ICE uses Lithium Iron Phosphate ($LiFePO_4$) batteries in their products because they are the safest LIB available.** According to Battery University, "Li-phosphate offers good electrochemical performance with low resistance. The key benefits are high current rating and long cycle life, besides good thermal stability, enhanced safety and tolerance if abused. Li-phosphate is more tolerant to full charge conditions and is less stressed than other lithium-ion systems if kept at high voltage for a prolonged time."
Refer to Tables 3, 4 and 5.

Table 5: Lithium Iron Phosphate

Lithium Iron Phosphate: $LiFePO_4$	
Voltages	3.20, 3.30V nominal; typical operating range 2.5–3.65V/cell
Specific energy (capacity)	90–120Wh/kg
Charge (C-rate)	1C typical, charges to 3.65V; 3h charge time typical
Discharge (C-rate)	1C, 25C on some cells; 40A pulse (2s); 2.50V cut-off (lower that 2V causes damage)
Cycle life	1000–2000 (related to depth of discharge, temperature)
Thermal runaway	270°C (518°F) **Very safe battery even if fully charged**
Applications	Portable and stationary needing high load currents and endurance
Comments	Very flat voltage discharge curve but low capacity. **One of safest Li-ions.** Used for special markets. Elevated self-discharge.

Source: Battery University, BU-205: Types of Lithium-ion, last updated 2/21/2016,
http://batteryuniversity.com/learn/article/types_of_lithium_ion

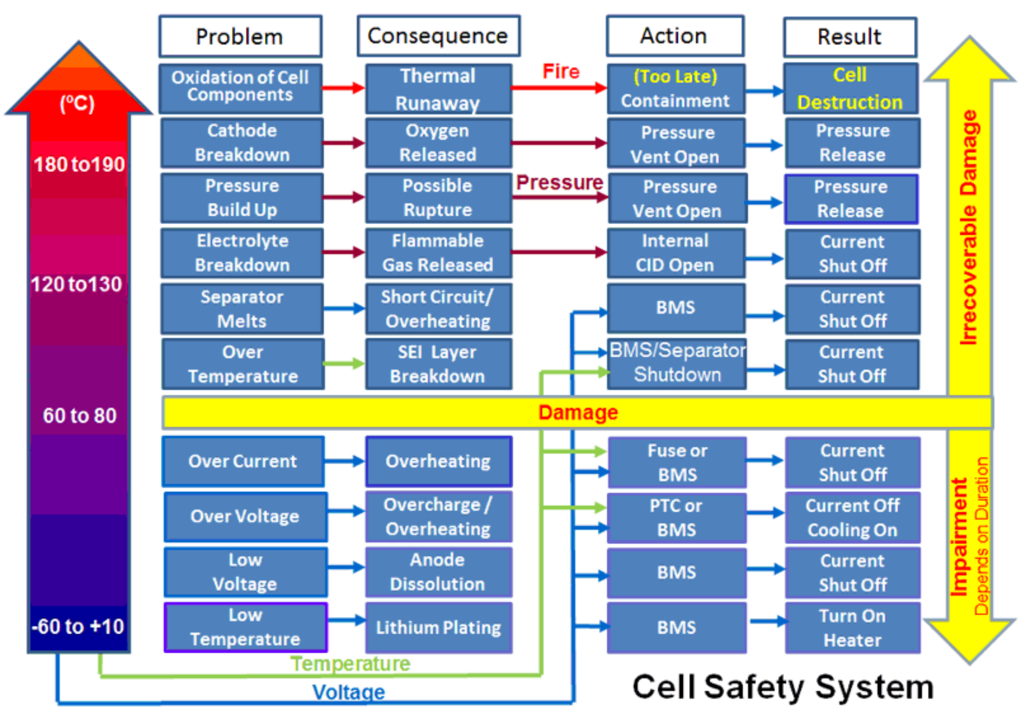
ICE batteries were **constructed with maximum thermal stability** in mind:

- By adding flame retardant into the electrolyte of the battery cells, the risk of fire is greatly reduced even when temperatures are very high.
- Battery cells come with an explosion-proof valve on the cover. In the event the internal voltage exceeds the acceptable limit, the explosion-proof valve will break to release pressure avoiding an explosion.
- On the battery cell, there is a septum that will close when the temperature reaches 266°F. The insulation between the cathodes of cells prevents direct contact of cathode.

❷Battery Management System (BMS) Safety

The Battery Management System that ICE uses in it's floor cleaning equipment is another key feature to ensuring safe operation. The BMS is the brains of the battery pack. It measures and reports crucial data regarding the operation of the battery and protects the battery from damage during various operating conditions. The most valuable function of the BMS is cell protection. If cells are overcharged they can overheat and potentially explode or catch fire. If cells are discharged below their limits it could permanently reduce their capacity. The second most important function of the BMS is energy management. The BMS will indicate how much charge is left, the rate of energy consumption, and how much runtime is left before the battery needs to be recharged.

Figure B: BMS Scope and Failure Consequences



Source: Electropaedia, Battery Management Systems (BMS)

The BMS has to protect the battery and the user under all of the conditions outlined in Table 6.

Table 6: Safety Systems of the BMS

Multi Level Safety System
The BMS is part of a multi level safety system with the following objectives and safeguards

1. **Intrinsically Safe cell chemistry**
    - Cell technical design audit
2. **Cell Supplier and Production Audit**
    - Technical competence of staff
    - Process controls (Installed and working)
3. **Cell level (internal) safety devices**
    - Circuit Interrupt Device (CID) Cuts circuit if internal pressure limits exceeded
    - Shut down separator
    - Pressure vent
4. **External circuit devices**
    - PTC resistors (Low power applications only)
    - Fuses
    - Cell and battery isolation. Electrical and mechanical separation (Contactors and physical separation) to prevent event propagation
5. **BMS Software**
    - Monitoring of all key indicators coupled to control actions. (Cooling, Power disconnect, Load management)
    - Control actions or switch off in case of out of limits condition
6. **BMS Hardware - Fail safe back-up**
    - Hardware switch off in case of software failure. Set to slightly higher limits
    - Battery switch off in case low voltage BMS power supply fails
7. **Containment**
    - Robust outer container with controlled venting
    - Physical barriers between cells

Source: Electropaedia, Battery Management Systems (BMS)

The ICE BMS has **built-in electronic sensors that protect the batteries from extreme temperatures**. If the temperature exceeds 149°F, the BMS will shut down the battery from usage and charging. If charging under low temperatures, the BMS will shut down the battery when it is below 23°F.

The ICE BMS provides the following:

- **Cell protection.** In the event of overheating, ICE's BMS will automatically shut down the battery pack. If there is a wiring short circuit, the BMS will shut down the battery pack.
- **Charge control.** Charger safety protection kicks in when voltage and current exceeds the acceptable limits. It strictly regulates against current abnormality.
    - State of the Charge (SOC): When battery capacity drops to only 5%, the BMS will shut down the battery to protect it.

- **State of Health** (SOH, capability to deliver specified output). BMS will generate data on the percentage of power in the battery, cycle times, and capacity of fully charged battery.
- **Cell balancing.** The ICE i-Synergy system will send a warning if the groups within the battery are not balanced.
- **History** (number of cycles, maximum and minimum voltage, temperature, maximum charging and discharging). BMS will record the cycle times, current voltage, internal temperature, charging current, and working current. This information is very useful for future required maintenance.
- **ID** (date of manufacture, serial no, traceability). Each BMS has its own ID. This will help trace the BMS's manufactured date, delivery date, and the serial number of the machine.
- **Communication** between the battery and the charger. The BMS can provide the immediate charging current as the battery is being charged.

❸ Charger Safety

The third key safeguard ICE has designed into their products are specially-designed battery chargers. The following features are unique to ICE Lithium-ion battery chargers:

- An operator can not use any charger NOT specified or approved by ICE. It may lead to damaging the battery or the BMS will shut down the battery if it detects any irregularity when charging.
- An **ICE charger will automatically shut down if thermal limits are exceeded** when charging: the upper limit is 149°F and the lower limit is 23°F.

❹ Certifications and Standards

ICE batteries have received the following certifications and have met the following standards to ensure safety during transport and use:

- **UL 1642** certification for battery cells (dated March 13, 2012 including revision date of July 30, 2013)
  UL certificate was issued November 7, 2014, #20141107-MH49498
- **IEC 62133** Standard
- **2006/66/EC** and amendment **2013/56/EU**, Directives on batteries and accumulators on heavy metal content
- Compliance with EMC Standards**, EN 61000-6-1:2007, EN 61000-6-3: 2007+A1: 2011**
  Date received: January 18, 2016
- **MSDS** sheets are available upon request. The chemical components used are: lithium iron phosphate, NMP, PVDF, SBR, electrolyte, and graphite. Note: there is no spillage or hazardous gas with LIB.
- ICE has **applied for UL 2271** certification for battery assembly. The testing is underway and UL approval is expected by Summer, 2016.

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