Industrial batteries. Features Summary.

Chapter 3 – Lithium Ion battery types

Note:

To read Chapter 1, please visit: https://www.norwatt.es/noticia-industrial-batteries--features-summary---chapter-1---acronyms-es.html

To read Chapter 2, please visit: https://www.norwatt.es/noticia-industrial-batteries--features-summary--chapter-2---industrial-battery-types-es.html

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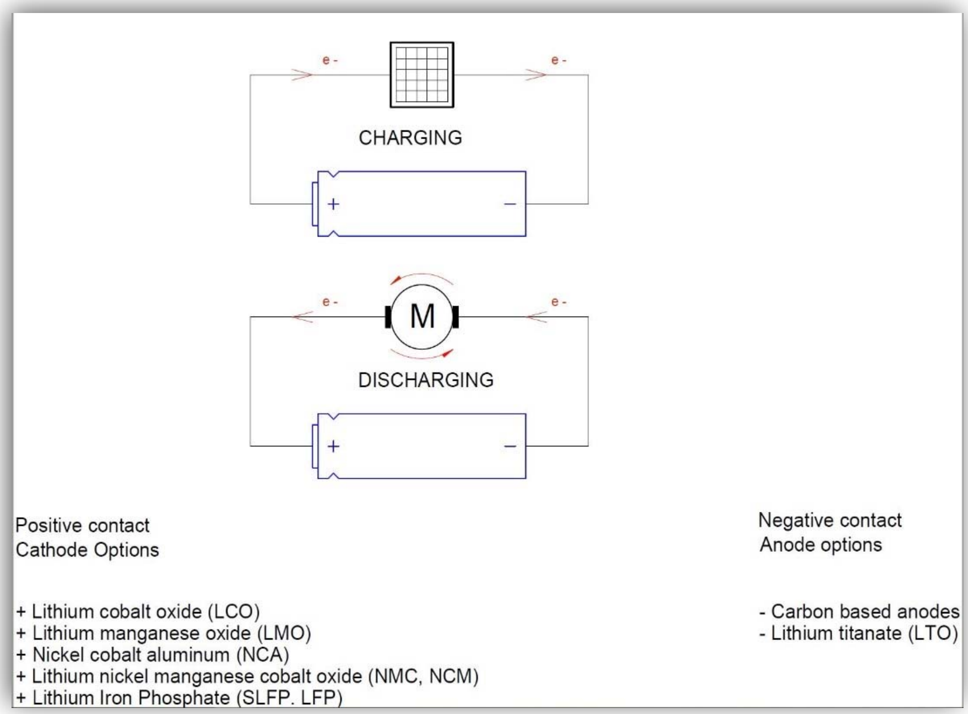
Commercially, there are five types of lithium-ion batteries depending on the cathode material and another two depending on the material of the anode material.

Working Principles



Cells convert chemical energy into electrical energy (and vice-versa). In Lithium ion batteries, during cell charge, the lithium ions flow from the cathode to the anode and they are stored there. During cell discharge, lithium ions disassociate from the anode and flow to the cathode through the electrolyte and electrons are transported by the external circuit to do an effective work.

A lithium ion battery has three functional layers: the positive electrode (cathode), the negative electrode (anode), and the separator.

The anode corresponds to the negative electrode. The electrons leave the battery through the anode; therefore, it must be made of a material with high electronic conductivity and great cycling capacity. Graphite is generally used. (70 to 250 micron)

The cathode corresponds to the positive electrode and must be capable of accepting and releasing lithium ions and electrons. Cathodes are generally made of metallic lithium oxide which can oxidize when lithium is removed.

For example: $LiMO_2$, (M = cobalt (Co), nickel (Ni), or manganese (Mn)). (70 to 250 micron)

The mode of transporting lithium ions between electrodes during charging and discharging is the electrolyte; that's why it has to be a good ionic conductor and a good electronic insulator. The electrolytes are usually made up of a solution of lithium salt in an organic solvent; for example: lithium hexafluorophosphate ($LiPF_6$) with ethylene carbonate and methyl carbonate (EC-DMC).

The membrane that separates the anode and the cathode is called the separator and it is the host of the electrolyte. The separator prevents short circuits between anode and cathode but allows the Li ions to flow during charging and discharging. (20 to 25 micron)

Batteries can be classified by energy and power. This classification is marked by the composition and characteristics of the electrodes and their materials: Energy for long time discharge and power for high current discharge.

High Power cells – can discharge at rates 10 to 100C rate (from 6 min to <1 High Energy cells – can discharge at 2C rate (30 min) or less but energy content

High Energy cells – can discharge at 2C rate (30 min) or less but energy content exceeds 170 to 190 Wh/kg

Energy storage capacity of a battery: depends on the number of active components that the electrodes can store.

Power capacity: is a function of the surface area of the electrodes and the internal resistance of the battery.

These energy and power ratings depend on and are related to each other. The rate-C represents this energy / power ratio (it is the data that allows knowing how a battery is charged or discharged in relation to its maximum capacity). It should be added that the energy density depends on the chemistry of the battery, while the power density depends on the kinetics and the design of the cell. Thin electrodes can provide high power densities, and thick electrodes produce high energy densities. This is why batteries can be designed to supply high power or high energy depending on the needs.

3.1 POSITIVE CONTACT: CATHOTE OPTIONS

The positive electrode is called the cathode and typically defines the chemical type of the battery. It is built with an aluminium full coated in both sides with a lithium metal oxide compound and binder

Generally, research into lithium ion batteries is being carried out to find an economical material, with better cyclic performance, good thermal stability and conductive to high energy and power densities. In particular, thermal stability is a major concern when selecting cathode materials since heat generation at the cathode is three to four times greater than that of the anode.

3.1.1 Lithium cobalt oxide (LCO) ($LiCoO_2$)

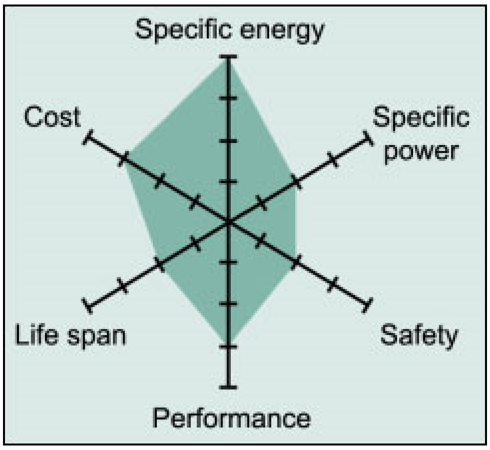
LCO has high energy density per unity mass, but is not well suited for use in off-grid products because of lower cycle life and poorer safety. Nonetheless, LCO batteries are ubiquitous and still frequently used for these applications.

Characteristic	$LiCoO_2$ (LCO)
Nominal voltage per cell	3,7 Vdc (4,2 Vdc 100% SOC)
Specific energy (Wh/kg)	175-200
Energy density (Wh/L)	400-640
Cycle life (to 80% original capacity at 100% DOD)	500
Calendar life (years)	>5
Ambient temperature during charge (°C)	0-45
Ambient temperature during discharge (°C)	-20-60
Self-discharge capacity loss per month	2-10%
Memory effect	No
Toxic metals	No
Battery management system required	Yes

Main disadvantages:

- Relatively short life span
- low thermal stability
- Limited load capabilities.

The Li-cobalt is losing favour to Li-manganese, but especially NMC and NCA because of the high cost of cobalt and improved performance by blending with other active cathode materials.



Li-cobalt excels on high specific energy but offers only moderate performance specific power, safety and life span.

LCO technology LiCoO2 available here, please check:

https://www.norwatt.es/products/batteries-and-accessories-lithium-ion-batteries-saft-rechargeable-lithium-ion-battery-en.html

https://www.norwatt.es/products/batteries-and-accessories-lithium-ion-batteries-saft-sally-en.html

3.1.2 Lithium manganese oxide (LMO) (LiMn2O4)

Pure LMO batteries have good thermal stability and safety but lower cycle life; they have been replaced by blending the manganese oxide with nickel and cobalt (NMC).

Characteristic	LiMn2O4 (LMO)
Nominal voltage per cell	3.70V (3.80V) nominal; typical operating range 3.0–4.2V/cell
Specific energy (Wh/kg)	100-150
Energy density (Wh/L)	150-300
Cycle life (to 80% original capacity at 100% DOD)	300-700
Calendar life (years)	>5
Ambient temperature during charge (°C)	5-45
Ambient temperature during discharge (°C)	5-45
Self-discharge capacity loss per month	---
Memory effect	No
Toxic metals	No
Battery management system required	Yes

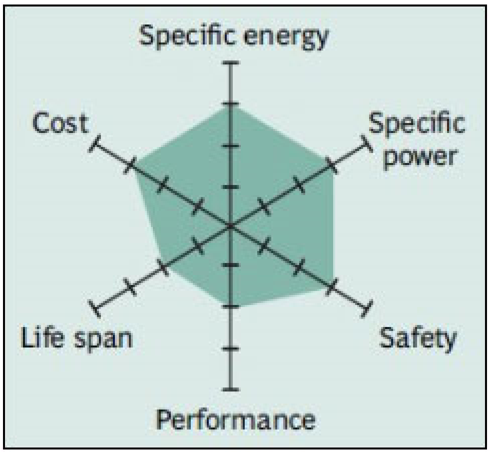
Main advantages:

- Improved current handling
- Lower internal resistance
- High thermal stability
- Enhanced safety

Main disadvantages:

- The cycle and calendar life are limited.

Li-manganese has a capacity that is roughly one-third lower than Li-cobalt. Design flexibility allows engineers to maximize the battery for either optimal longevity (life span), maximum load current (specific power) or high capacity (specific energy).



Although moderate in overall performance, newer designs of Li-manganese offer improvements in specific power, safety and life span.

3.1.3 Nickel cobalt aluminium (NCA) LiNiCoAlO2

NCA has the highest energy density per unity mass. Like LCO and NCA batteries, it has lower thermal stability than competing technologies. It shares similarities with NMC by offering high specific energy, reasonably good specific power and a long-life span.

Characteristic	LiNiCoAlO2 (NCA)
Nominal voltage per cell	3.60V nominal; typical operating range 3.0–4.2V/cell
Specific energy (Wh/kg)	200-260
Energy density (Wh/L)	200-250
Cycle life (to 80% original capacity at 100% DOD)	500
Calendar life (years)	>5
Ambient temperature during charge (°C)	0-40
Ambient temperature during discharge (°C)	0-40
Self-discharge capacity loss per month	--
Memory effect	No
Toxic metals	Yes
Battery management system required	Yes

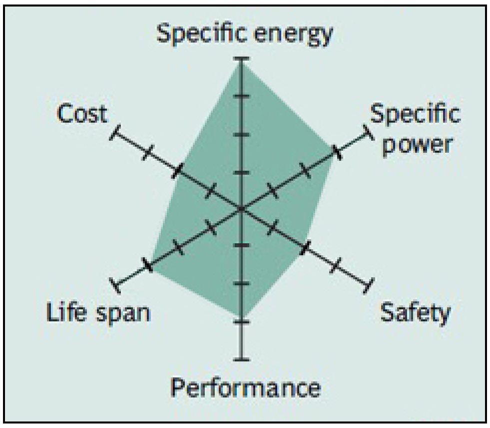
Main advantages

- High specific energy
- Reasonably good specific power

- Long life span
- NCA cathodes contain the most energy amount by weight and volume (as NMC).

Main disadvantages:

- Less safety than other Li-ion battery types (they require extra safety features and circuits for use in electric cars for example)
- Higher cost in comparison to other Li-ion battery types



High energy and power densities, as well as good life span, make NCA a candidate for EV powertrains. High cost and marginal safety are negatives.

NCA technology LiNiCoAlO2 available here, please check:

https://www.norwatt.es/products/batteries-and-accessories-lithium-ion-batteries-saft-evolion-en.html

3.1.4 Lithium nickel manganese cobalt oxide LiNiMnCoO2 (NMC)

One of the most successful Li-ion systems is a cathode combination of nickel-manganese-cobalt (NMC). The secret of NMC lies in combining nickel and manganese.

NMC blends offer combinations of good cycle life, safety, and high energy density. The ratios of elements can be tailored to emphasize qualities that target specific applications including off-grid products.

Battery manufacturers move away from cobalt systems toward nickel cathodes because of the high cost of cobalt. Nickel-based systems have higher energy density, lower cost, and longer cycle life than the cobalt-based cells but they have a slightly lower voltage.

NMC batteries are widely used for power tools, energy storage systems (EES) which need frequent cycling and electrical power-trains like automotives. The cathode combination typically used is 1-1-1 which means one third nickel, one third manganese and one third cobalt. This reduces the raw material cost due to lowered content of cobalt. Other combinations are also possible.

Characteristic	LiNiMnCoO2 (NMC)
Nominal voltage per cell	3.60V, 3.70V nominal; typical operating range 3.0–4.2V/cell, or higher
Specific energy (Wh/kg)	150-220
Energy density (Wh/L)	205-300
Cycle life (to 80% original capacity at 100% DOD)	1000-2000
Calendar life (years)	>10
Ambient temperature during charge (°C)	-10 + 45
Ambient temperature during discharge (°C)	-10 +45
Self-discharge capacity loss per month	0,35 – 2,5
Memory effect	No
Toxic metals	Yes
Battery management system required	Yes

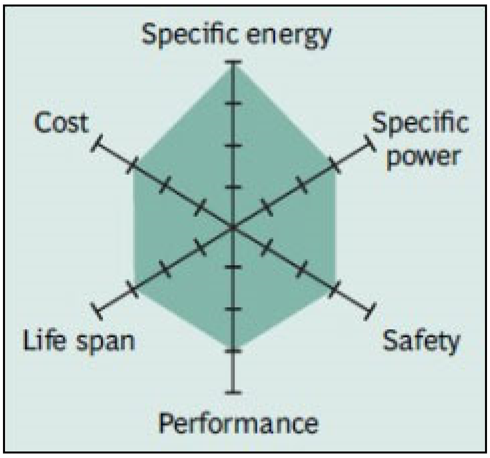
Main advantages:

- NMC cells provide longer life cycle
- Lower cost
- Higher energy density

- NMC cathodes contain the most energy amount by weight and volume.

Main disadvantages:

- Adding silicon to graphite has the downside of making the anode grow and shrink through charging and discharging, leading to mechanical instability of the cell.
- Slightly lower voltage than cobalt systems



NMC has good overall performance and excels on specific energy. This battery is the preferred candidate for the electric vehicle and has the lowest self-heating rate.

NMC technology LiNiMnCoO2 available here, please check:

https://www.norwatt.es/products/batteries-and-accessories-lithium-ion-batteries-saft-intensium-max-20-high-energy-en.html

https://www.norwatt.es/products/batteries-and-accessories-lithium-ion-batteries-saft-intensium-max-en.html

https://www.norwatt.es/products/batteries-and-accessories-lithium-ion-batteries-saft-intensium-flex-en.html

3.1.5 Lithium Iron Phosphate (SLFP, LFP) LiFePO4

LiFePO4 batteries exhibit qualities that make them ideally suited for off-grid products where cost, safety, stability, and cycle life are primary requirements. It does not release oxygen, which makes it a safe material to use with better thermal stability.

LFP 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. As a trade-off, its lower nominal voltage of 3.2V/cell reduces the specific energy below that of cobalt-blended lithium-ion. With most batteries, cold temperature reduces performance and elevated storage temperature shortens the service life, and Li-phosphate is no exception. Li-phosphate has a higher self-discharge than other Li-ion batteries, which can cause balancing issues with aging.

The LiFePO4 batteries can improve electrochemical performance is to nano-structure LiFePO4 particles or coating the cathode with Sn.

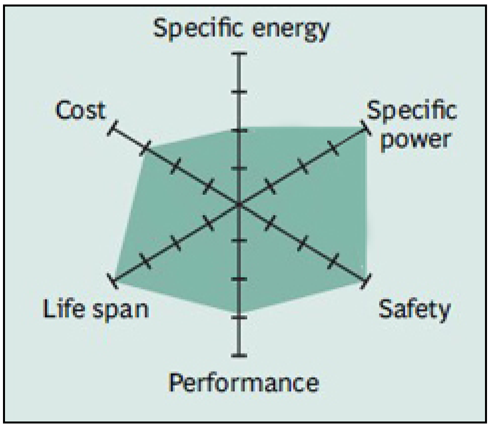
Characteristic	LiFePO4 (LFP)
Nominal voltage per cell	3.20, 3.30V nominal; typical operating range 2.5–3.65V/cell
Specific energy (Wh/kg)	90-120
Energy density (Wh/L)	125-250
Cycle life (to 80% original capacity at 100% DOD)	1000 – 2000 (can retain 95% capacity after 1000 cycles)
Calendar life (years)	>5
Ambient temperature during charge (°C)	0-45
Ambient temperature during discharge (°C)	-30-60
Self-discharge capacity loss per month	2-10
Memory effect	No
Toxic metals	No
Battery management system required	Yes

Main advantages:

- Improves power and energy
- Allows for floating at less than 100% SOC
- Enables accepting REGEN
- Improves electronics performance
- Improves overcharge tolerance
- Excellent safety

Main disadvantages:

- More tolerant to conditions of full charge and is less stressed at higher voltage for a long time.
- lower nominal voltage which reduces the specific energy
- Higher self-discharge than other types Li-ion batteries, which causes balancing issues with aging.



Li-phosphate has excellent safety and long life span but moderate specific energy and elevated self-discharge.

SLFP technology LiFePO4 available here, please check:

https://www.norwatt.es/products/batteries-and-accessories-lithium-ion-batteries-saft-flexion-en.html

3.2 NEGATIVE CONTACT: ANODE OPTIONS

Anode composition and electrochemical properties are very important to the performance of a battery. For the anode material to be effective, high electronic conductivity, low working potential, high cycle stability and low volume change are required during lithium insertion and extraction.

In order to be suitable for lithium-ion battery manufacturing, anode materials should meet the following requirements:

- Excellent porosity and conductivity.
- Good durability and light weight.
- Low Cost.
- Voltage match with preferred cathode.

During initial Lithium ion battery operation, the SEI (solid electrolyte interphase) layer forms on the graphite surfaces, the most common anode material. The SEI is essential to the long-term performance of LIBs, and it also has an impact on its initial capacity loss, self-discharge characteristics, rate capability, and safety. While the presence of the anode SEI is vital, it is difficult to control its formation and growth, as they depend on several factors. These factors include the type of graphite, electrolyte composition, electrochemical conditions, and temperature.

3.2.1 Carbon based anodes

Graphite formulations (A cooper foil coated with natural graphite, synthetic graphite or amorphous carbon) are used for the negative electrode in the majority of Li-ion commercial cells.

Graphite and carbon-based anode materials have been used in commercial Li-ion cells since 1991 because of the good electrochemical properties, low cost, and nontoxicity of graphite.

During the first charge cycle a solid electrolyte interphase layer (SEI) forms in the graphite surface that helps to stabilize the molecular structure and prevent it from reaching with the liquid electrolyte.

The SEI layer stabilizes the anode by preventing reactions between the graphite and the electrolyte. SEI layer integrity plays an important role in cell performance. The SEI can therefore be described as a protective layer.

The secondary SEI mainly consists of $Li2CO3$ and LiF. It has been suggested that besides the formation of the secondary SEI, a new organic SEI is formed by solvent reduction. These complex processes of SEI formation and change occur up to a temperature of approx. 200°C.

3.2.2 LTO cells

The LTO ($Li_4Ti_5O_{12}$) is bringing a new dimension of possibilities for the energy storage with a number of economical as well as ecological aspects.

With applications in many sectors, with a primary focus on high speed charging and energy storage, LTO technology is the future of battery-powered technology.

LTO cells offers very high cycle life, excellent thermal stability, excellent safety, and good low temperature operation. LTO can be used with NMC or LMO cathodes.

LTO does not react with organic electrolytes, therefore SEI is not formed which makes it highly thermal stable and an excellent choice for large scale battery anode material.

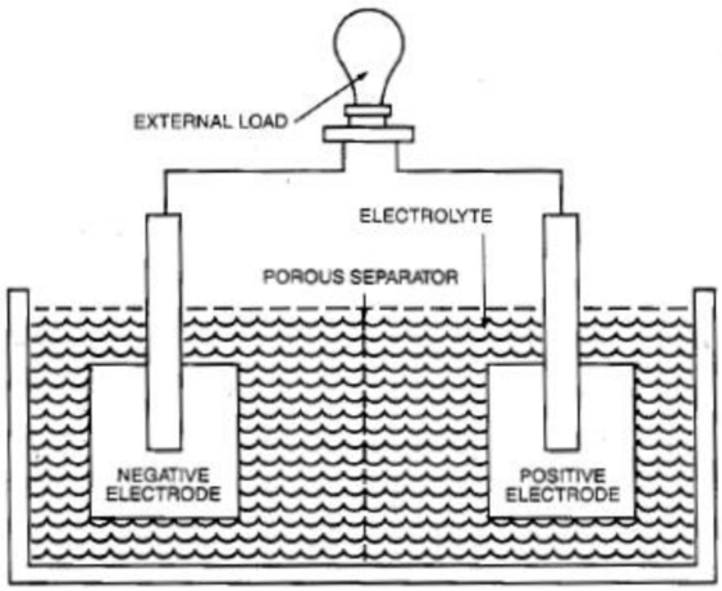
Main advantages:

- More than 7000 charge discharge cycles
- Excellent hight and low temperature performance
- Extremely long lifetime
- Rapid battery charging and discharging
- Enhanced safety
- Low-temperature performance
- Integration with energy storage

Main disadvantages:

- Lower inherent voltage (2.4 V) than other Li-ion technologies
- Lower specific energy than other Li-ion technologies

3.3 ELECTROLYTE AND SEPARATOR



The battery separator is an essential component of batteries that strongly affects their performance. The control of their properties being particularly important for obtaining lithium-ion batteries with high cycling performance. Separators are placed between both electrodes, should show high ionic conductivity, excellent mechanical and thermal stability.

Electrochemical performance of the batteries is highly dependent on the material, structure, and separators used. Most common separators are polypropylene (PP) monolayer and polypropylene/polyethylene/polypropylene (PP/PE/PP) trilayer.

The electrolyte is a lithium salt dissolved in an organic solvent. A liquid electrolyte acts as a conductive pathway for the movement of cations passing from the negative to the positive electrodes during discharge.

Recent advances in battery technology involve using a solid as the electrolyte material. The most promising of these are ceramics. The main benefit of solid electrolytes is that there is no risk of leaks, which is a serious safety issue for batteries with liquid electrolytes.

Coming soon… *Chapter 4 - Lithium ion cells construction*