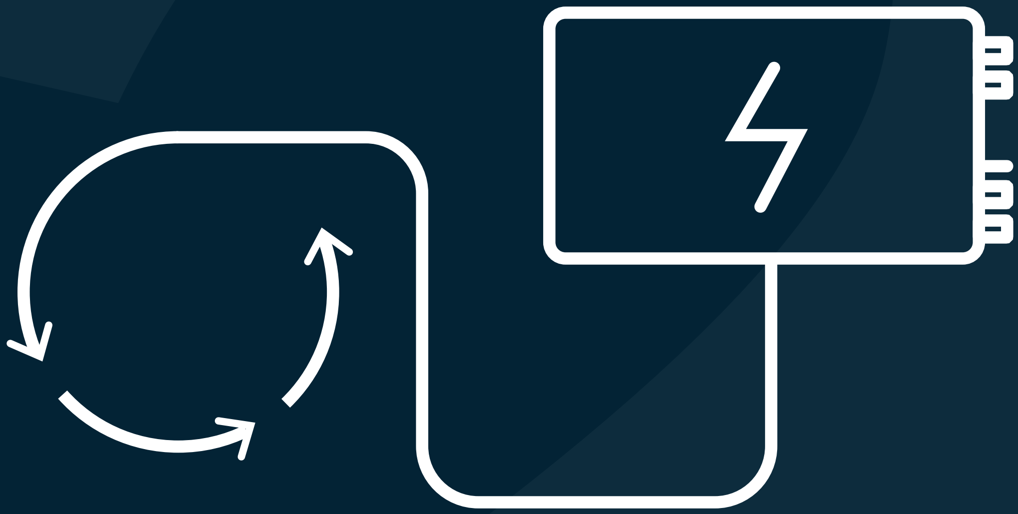

# Understanding how to choose the right battery cell chemistry

## #2

*Selecting the best battery cell chemistry for a particular application begins with a good understanding of both end user requirements and cell chemistries.*

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# How to select the best battery cells for a specific application

Selecting the best battery cell chemistry for a specific application begins with a good understanding of both end user requirements and cell chemistries. A balance of cost, energy, power, and safety requirements will determine the ideal chemistry for your specific application.

Industrial vehicles often operate with requirements of high uptime, which require frequent and often fast charging. For such applications, cells like LFP and LTO, or even moderate power to high power NMC and NCA cells, are good candidates as they provide longer lifetime and higher power compared to other types. Passenger cars on the contrary, need high energy cells like NMC or NCA, as they need long range but do not require daily charging and can thereby avoid fast charging which is in the favor of prolonging the battery life.

In this white paper, we will touch upon the cell and its chemistries – the part of the system that requires the most consideration from a cost, energy, power, and safety perspective. From a total system architecture point of view, there are of course more components to consider.

## Li ion battery cell chemistry introduction

Li ion batteries are energy storage devices where the cathode is a source of Lithium ions (Li ions). When the battery is charged the Li ions move from the cathode to the anode. The two electrodes are electrically separated by a polymer separator soaked with electrolyte and as the ions move to the anode, the cell voltage goes up. The energy is now stored in terms of electrochemical energy. When the battery is used to power a device or a vehicle, the Li ions will move back to the cathode and the cell voltage goes down. We refer to the battery as a Li ion battery because Li ions move back and forth between the anode and cathode.

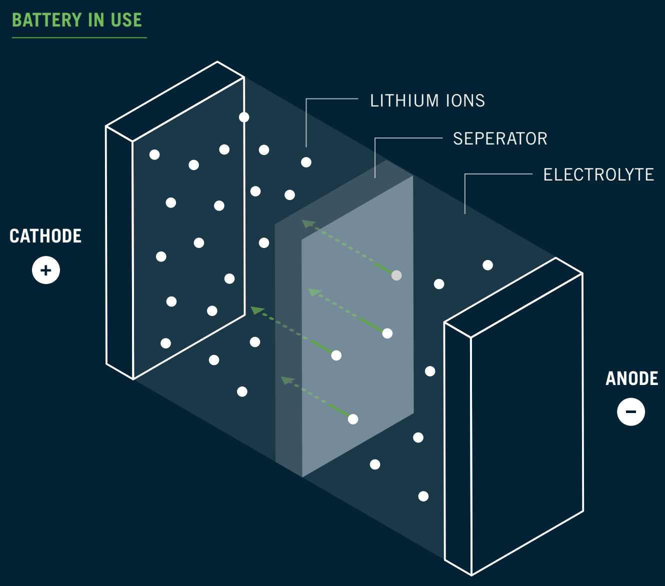
## Cell chemistries in the Li ion battery family

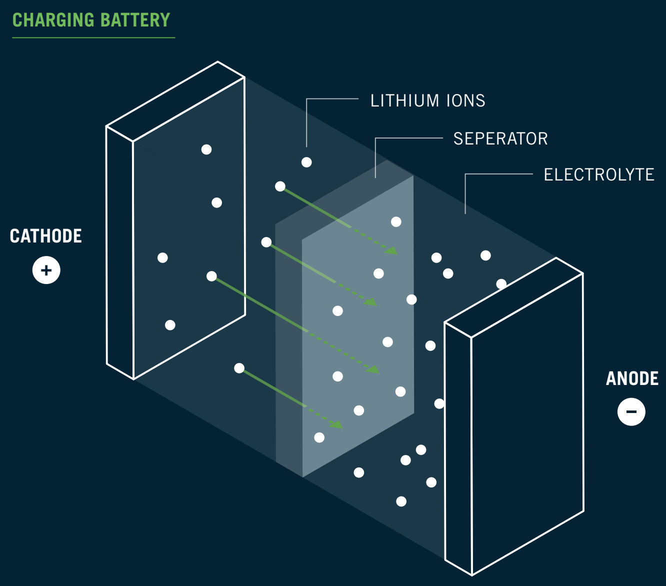
Today's most well-known Li ion battery chemistries are NMC, NCA, LFP, and LTO. The abbreviations are of the electrode materials:

- **NMC:** Lithium Nickel Manganese Cobalt oxide
- **NCA:** Lithium Nickel Cobalt Aluminum oxide
- **LFP:** Lithium Iron Phosphate
- **LTO:** Lithium titanate

NMC, NCA, and LFP are all examples of cathode materials. They are best paired with graphite as the anode.

LTO is an anode material which is usually paired with NMC or NCA and not as often paired with LFP since the nominal cell voltage and capacity of this pairing is too low to be beneficial.





## *Optimizing the capacity and power of Li ion batteries through cell design and electrode chemistry*

The battery cell's capacity in Ah or energy in Wh is how much current we can store. Power in W, is how fast we can get the current in or out (fig. 1). These can be tailored by cell design and/or chemistry of the electrodes.

### Electrode chemistry

To optimize the capacity and power of Li ion batteries it is also possible to play with the composition of the transition metals in certain types of cathode materials such as NMC and NCA to achieve specific properties.

As per today the most used chemistry for BEV* cells, i.e high energy cells, is NMC811 (80% Nickel, 10% Manganese, 10% Cobalt). For HEV* high-power cells, and PHEV* moderate power-energy cells, the most common chemistries are NMC333 and NMC532. In some cases, a small amount of Silicon is mixed in with graphite to improve the capacity of the anode. Unfortunately, every choice we make involves a trade-off. When we boost one property, we lessen others as no cell can work against the laws of physics. A good example of such a trade-off is high-energy NMC and NCA battery cells: they can provide high energy, but power and lifetime are compromised.

### Cell design

One way to obtain the properties that we seek is to tailor the electrode coating and particle sizes of the electrode material. A thin electrode coating in combination with small particles will allow higher cell power due to faster kinetics, but lower capacity due to lower amount of active material. The analogy is the small bottle with the big opening (fig. 1). The opposite is achieved with a thick electrode coating and larger particle sizes.

Cell form factor will also influence the cell performances in terms of electrical, thermal and mechanical. There are 3 major types of cell form factors (fig. 2):

- Pouch
- Cylindrical
- Prismatic

Each of them has its own pros and cons. The answer to which form factor is the best will depend on the requirements of the application.

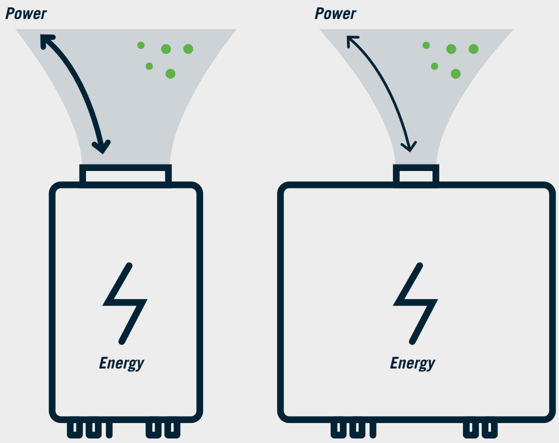


Fig. 1

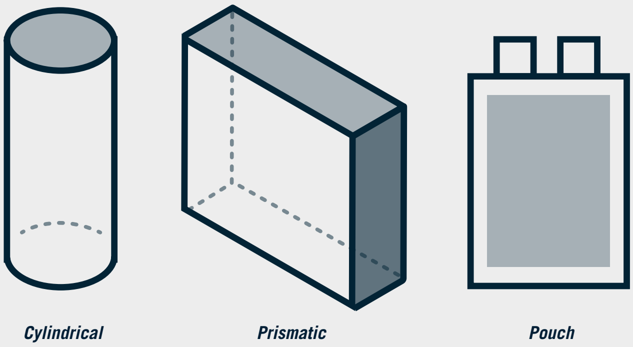


Fig. 2

## *Optimizing battery systems for industrial applications*

Industrial applications such as terminal tractors, forklifts, mining vehicles, and passenger ferries often require high uptime, meaning that vehicles are in operation most of the time, some of them almost constantly. This inevitably leads to fast charging requirements as previously mentioned.

The high up time requirement is not desired to be solved by oversizing the battery system or installing a greater number of batteries than needed in these vehicles. Over-dimensioning of the battery system drives cost from an investment point of view and also throughout the cost chain including maintenance, in addition to the environmental cost. Instead, the batteries that are selected for these applications need to be capable of fast charging to maximize short windows of downtime. This could be lunch hours or shift changes. This way the batteries will be charging several times a day to manage the task the application is meant to carry out.

Choosing the right battery chemistry is essential for optimizing the battery system including aspects such as weight, volume, power, energy, lifetime, and TCO – total cost of ownership.

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* BEV: battery electric vehicle, high energy, HEV: hybrid electric vehicle, high power, PHEV: plug-in hybrid electric vehicle, medium power-energy.

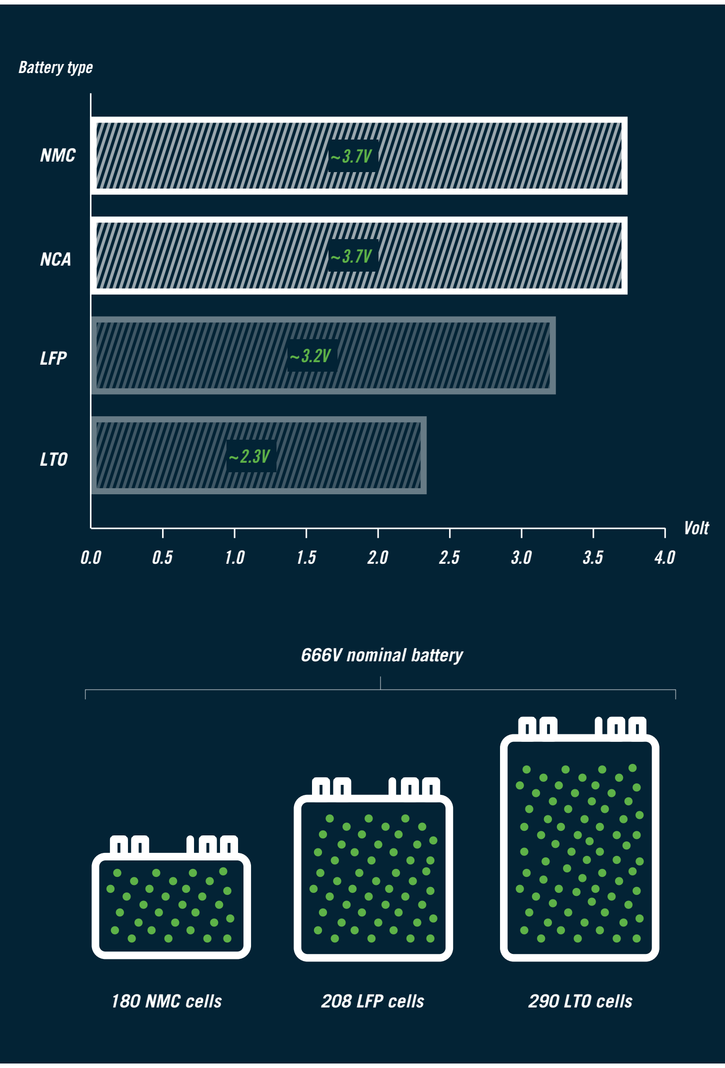
## *Power-optimized NMC or NCA, LFP and LTO provide high power and long lifetime*

The ideal chemistry comes down to the vehicles' specific battery requirements. To date, power optimized NMC or NCA, LFP, and LTO are good candidates for industrial applications since they are capable of both high power and a long lifetime. Power optimized NMC and NCA are also capable of fast charging and could reach 3000 cycles with some usage limitations, such as maximum 80% depth of discharge e.g. 10-90% SOC. LFP and LTO are well known for higher power allowing fast charging and longer lifetime – possibly up to 4000 and 10 000 cycles respectively.

### Pros and cons

The first drawback of LFP and LTO is that they have lower specific energy (Wh/kg) and energy density (Wh/L) compared to NMC and NCA. This is due to the intrinsic properties of the materials themselves.

The second drawback of LFP and LTO is that their cell voltages are lower than NMC and NCA. This implies that LFP and LTO battery systems will consequently be bigger and heavier compared to those of NMC and NCA.



### Safety perspective

LFP and LTO chemistries have some advantages over NMC and NCA chemistries. Since LFP and LTO are both considered safer chemistries compared to NMC and NCA, they are good candidates for applications with stringent safety requirements such as mining, forestry, and marine. This is thanks to the high stability of LFP and LTO's structure which enhances the safety. They are also less likely to contribute to the exothermic chain reaction during thermal runaway. Even though LFP and LTO are considered safer by comparison, thermal runaway events can still happen since they still contain the same family of flammable organic electrolytes used in NMC and NCA.

However, to address the safety perspective, risk mitigation should be applied by the quality of the system architecture. Safety measures in the cell, the battery hardware, and the BMS – the battery management system – the brain of the system, are all important parts of the architecture.

### Which battery cell chemistry is most cost-effective?

It bears repeating that the best way to control cost is to design battery systems that are optimized for the specific requirements of the application.

> *Safety measures in the cell, the battery hardware, and the BMS – the battery management system – the brain of the system, are all important parts of the architecture.*

From a chemistry perspective, LFP usually has a lower cell cost compared to the others due to the absence of expensive metals like cobalt which tend to be scarce and unethically mined, in addition to being toxic.

At the other end of the spectrum, LTO is the most expensive of the chemistries as it contains titanium. However, thanks to LTO's superiorly long lifetime, the total cost of ownership is not necessarily higher for LTO than for LFP, NMC and NCA. NMC and NCA are in middle of the scale.

# Alelion Insight

***Since we are nearly tapping out the full potential of Li ion batteries and the energy increase will likely be less and less over the coming years, substantial efforts on research and development for the next generation batteries and cells are currently made.***

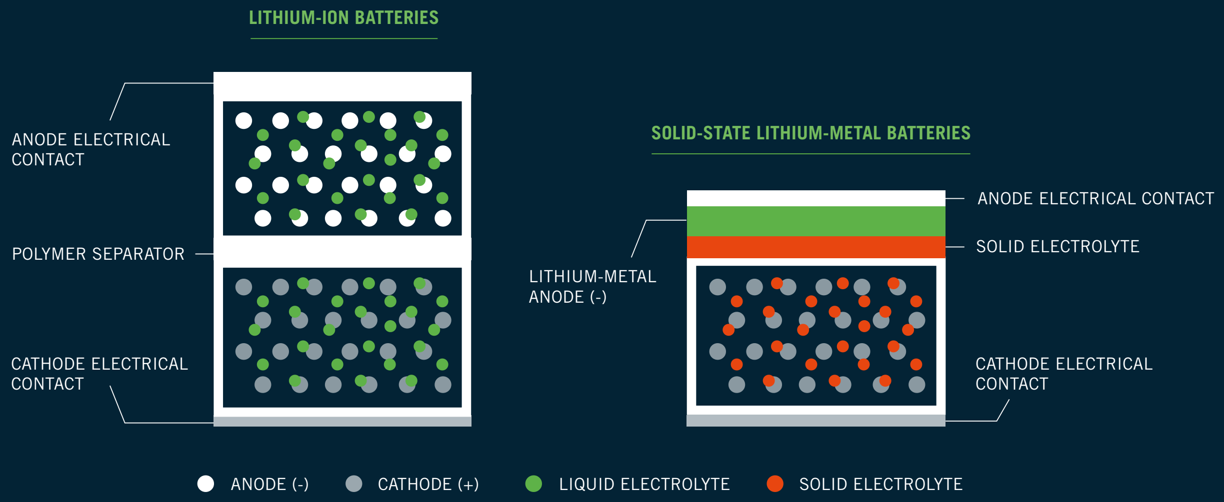
Many battery startups are racing to make solid-state batteries from research scale to full commercialization. Looking ahead, we believe that solid-state batteries could largely replace Li ion batteries by 2030.

Solid state batteries can come in various chemistries with different cathode materials, using a solid electrolyte that also functions as a separator, and with anodes made of Li metal or Si. In so-called anode-free cells, there is no anode material when the cell is first assembled. However, Li metal will deposit on the anode side after the first charge, and then striping back to the cathode during the discharge.

Solid state battery offers many benefits though. The major benefit is the absence of flammable liquid electrolyte. This makes for a safer cell and simplifies the safety design in the battery pack and battery management system. The second benefit is that the specific energy (Wh/kg) and energy density (Wh/L) could possibly be increased by 30% compared to Li ion batteries.

Even though solid electrolytes with comparable ionic conductivity* compared to liquid electrolyte has been discovered, there is still obstacles for the realization of the commercialized solid-state batteries. Establishing a good contact between solid electrolyte and solid electrode interface is the main hinder for high power and long lifetime. In the liquid electrolyte of today, we do not have this problem as liquid can penetrate through pores and voids of the electrodes. We wait with excitement to see what is coming in the area, even if it is expected to take some time still.

* How fast lithium ions move



LITHIUM-ION BATTERIES

SOLID-STATE LITHIUM-METAL BATTERIES

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## *Alelion – Sharing knowledge and experiences*

Alelion is an established developer, manufacturer, and supplier of advanced battery systems for off-highway vehicles in a number of different segments. With more than 15 years of experience, we now share our key learnings in a series of white papers.

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