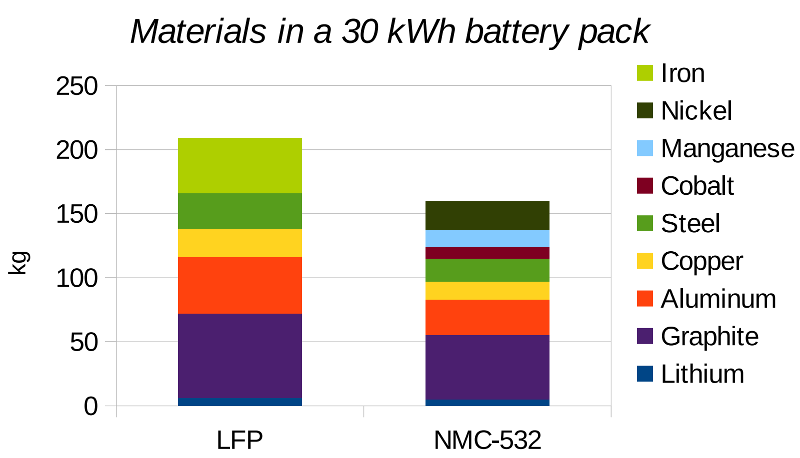
We enable LMFP to become the market-leading Li-ion battery technology

In the near future, the majority of batteries will be used for electric vehicles and grid/home energy storage. Recently, these major battery users are transitioning to LFP batteries, that comprise graphite and LFP ($LiFePO_4$) electrodes. The main reason is that LFP batteries have become cheaper than NMC batteries on a $/kWh basis. The recent cost of LFP battery materials is around $70/kWh, while the materials for NMC-532 batteries cost around $90/kWh[1].

The LFP battery advantage over NMC is even greater when the relevant comparison metric is $/kWh/cycle; LFP batteries' longevity is significantly beyond what NMC can achieve.

Automotive and grid storage companies are also motivated to use batteries made from abundant materials, whose manufacturing can be scaled more easily. The following chart shows the amount of various materials needed for the production of a 30 kWh battery pack, as well the abundance of these materials in the Earth's crust. The red font color highlights those materials whose supply is most restricted. Although lithium is the rarest on this list, the needed lithium quantity is only a small fraction of the overall cathode mass. Securing the supply of cobalt, nickel, and copper are becoming a greater challenge than securing the supply of lithium.



Abundance of relevant elements (mass fraction):

Li	2.0×10^{-5}
C	2.0×10^{-4}
Al	8.2×10^{-2}
Mn	9.50×10^{-4}
Fe	5.63×10^{-2}
Co	2.5×10^{-5}
Ni	8.4×10^{-5}
Cu	6.0×10^{-5}

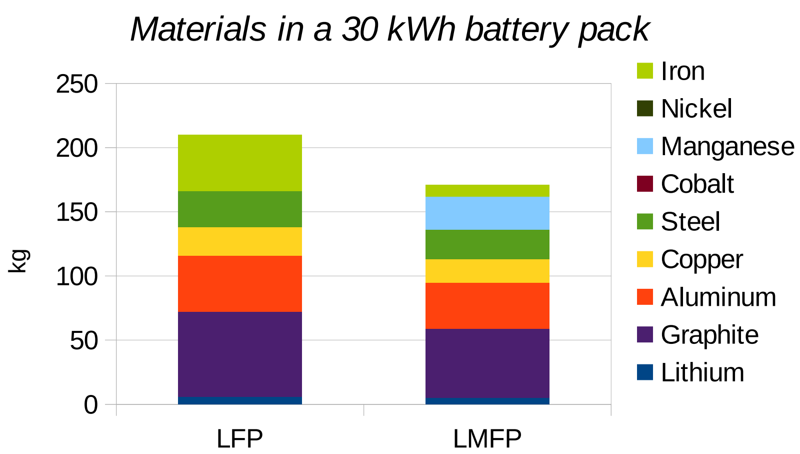
It is seen from the above data that LFP batteries are not only the cheaper, but also longer lasting and comprise more abundant materials. Under these circumstances, is there any better alternative to present-day LFP batteries?

1 Source: 2023 IDTechEx analysis

We introduce our LMFP (Li(Mn/Fe)PO_4) battery, comprising Aleees' LMFP cathode material and Broadbit Batteries' electrolyte. This battery chemistry has significant improvements over traditional LFP batteries, while retaining the above outlined LFP advantages. Specifically, the LFP and LMFP materials costs and production costs are practically the same. Our LMFP battery has the following advantages over present-day LFP batteries:

1. The average discharge voltage of LMFP is 20% higher than in the LFP case (3.8 V vs 3.2 V). Since the LFP and LMFP materials have the same density and gravimetric capacity, this elevated voltage means 20% higher energy density per cell.
2. With dry processed cathode production method, we obtained a high-performing cathode while using only 2.5% binder content. This means 5% lower cathode mass in comparison to traditional slurry-based cathode production methods.

The above factors mean **20% higher gravimetric energy density for conventionally produced LMFP batteries**, and **22% higher gravimetric energy density for dry-processed LMFP batteries**, in comparison to the LFP baseline. Regarding the overall battery pack, the following chart shows the amount of various materials needed to construct a 30 kWh LMFP battery pack.



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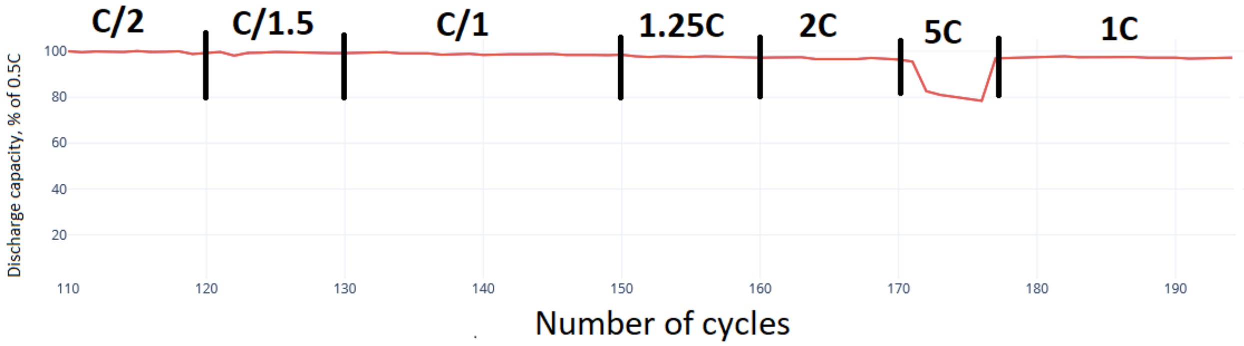
The anticipated replacement of LFP batteries with LMFP batteries is starting to be recognized by battery manufacturers. CATL and Gotion - two major battery manufacturers - recently started the production of LMFP batteries, intended for eventual LFP replacement.

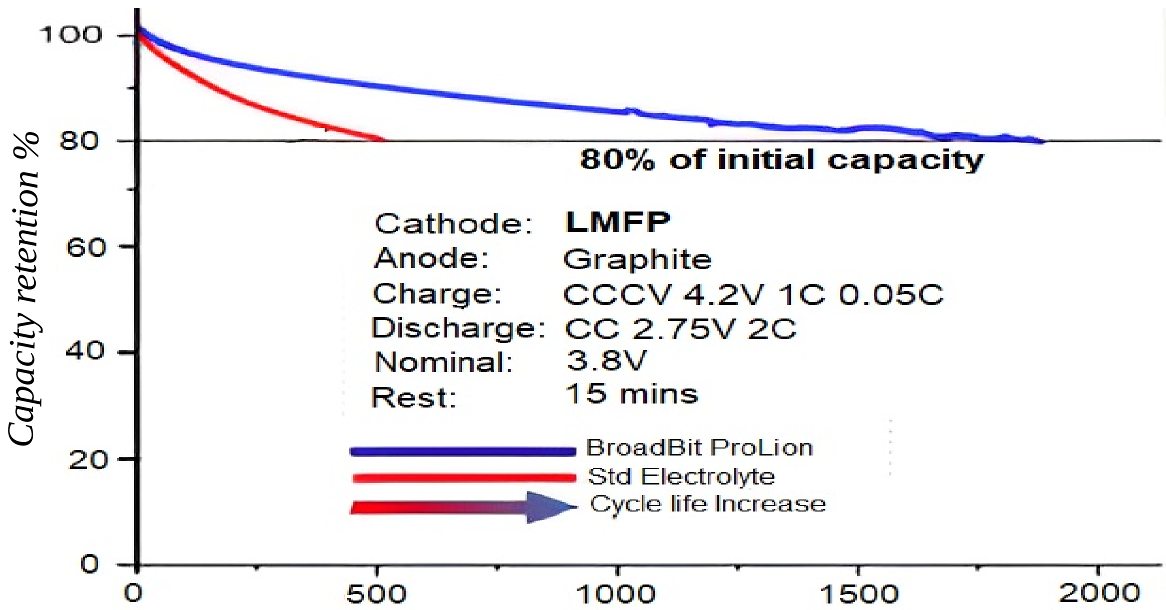
Our technology enables other battery manufacturers to successfully compete with the above-mentioned companies. In the following, we present the performance data of our LMFP technology, which is ready for both automotive and grid-storage use.

We firstly tested LMFP cathodes against lithium counter-electrode, with the cathodes comprising 85% Aleees LMFP, and using BroadBit Batteries' ProLion™ electrolyte. The theoretical capacity of LMFP material is 160 mAh/g. We obtained 158 mAh/g discharge capacity at the slow discharge rate of 13 hours. The following chart shows the retention of discharge capacity at faster discharge rates:



As can be seen from the above data, our battery utilizes close-to-theoretic capacity of LMFP when discharge discharge rate is 1 hour or slower. In most use cases, including electric vehicles, a full battery discharge takes at least a few hours. Therefore, for most practical applications, our LMFP cathode works close to its theoretic limit. Upon increasing the discharge speed to 12 minutes, we still retain 80% of theoretic capacity. We attribute this superior performance to the high conductivity of LMFP material and to the low binder content of our cathode.

In the past, the commercial use of LMFP batteries has been hindered by their limited cycle life, which has been attributed to the dissolution of manganese from the cathode. BroadBit Batteries' ProLion™ electrolyte resolves this problem: as shown in the following chart, the **LMFP battery retains 80% of initial capacity after 1800 full discharge cycles with ProLion™ electrolyte**. This cycling performance data has been measured on 18650 format cylindrical battery cells.



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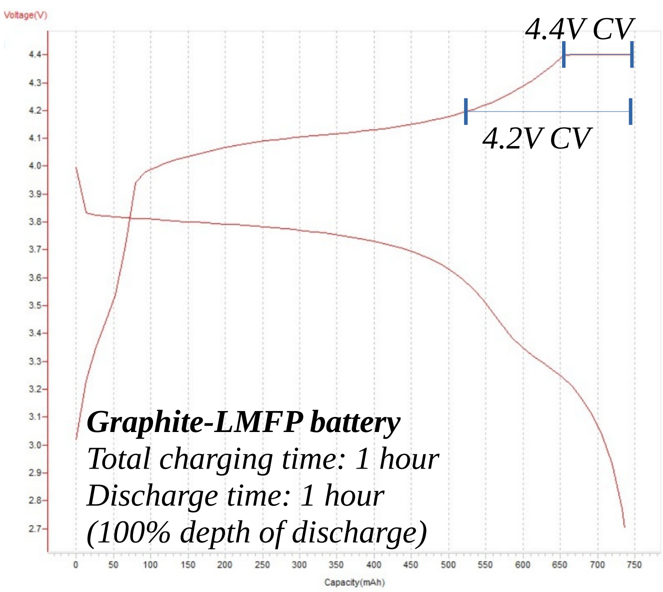
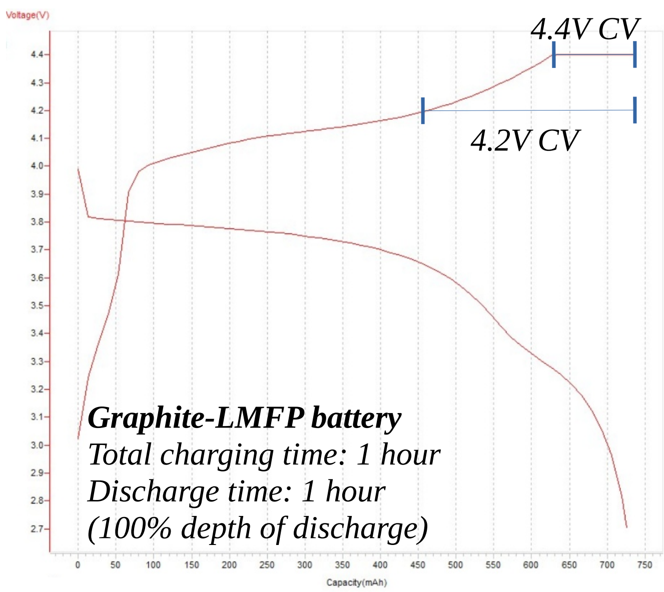
In the context of LMFP cathodes, another concern of automotive customers has been the gradual slowing of battery charging speed. Since the main charging plateau of LMFP is close to the 4.2 V stability limit of conventional electrolytes, fully charging an LMFP cell takes a significant fraction of charging time in the slow-charging 4.2 V CV regime. Moreover, as shown in the following figure, this 4.2 V CV regime duration grows with the number of cycles, causing a gradual increase of the time it takes to fully charge the battery.



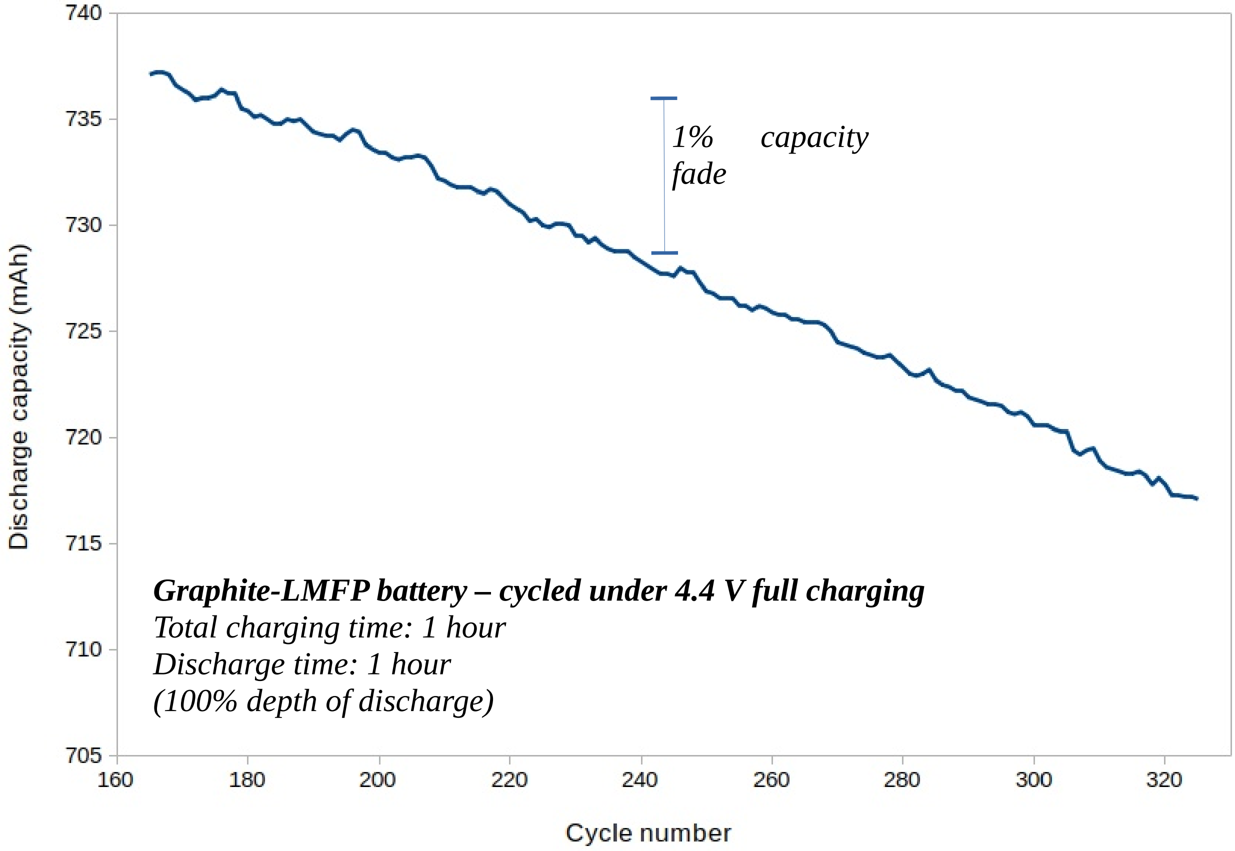
150th cycle voltage curves at 4.4V limit



250th cycle voltage curves at 4.4V limit

This slow charging problem is resolved by the wider voltage range of BroadBit Batteries' ProLion™ electrolyte, which withstands 4.4 V charging voltage without degradation. The above charts show the corresponding charge and discharge voltage curves, evaluated on 18650 cylindrical cells. It takes 2.5 hours under 4.2 V CCCV regime to charge our cell to 740 mAh capacity, and it takes only 1 hour under 4.4 V CCCV regime to charge it to the same 740 mAh capacity. Most importantly, the duration of the slow-charging 4.4 V CV regime remains practically the same with the growing number of cycles: full charging took 1:07 hours after switching to 4.4 V charging, and took 1:08 after 160 more cycles. This data shows that **our LMFP battery maintains its ability to be fully charged in 1 hour**. Using the same current rate, the usual automotive requirement of **30% to 80% charging in 25 minutes** is also fulfilled.

We switched to 4.4 V CCCV regime after 100-120 initial cycles, that had the usual 4.2 V charging limit. This procedure ensures a formation of strong passivation layer on the electrode surfaces, before switching to 4.4 V charging limit. The following chart shows the battery capacity retention under the 4.4 V CCCV regime. This fading rate means that, **under 4.4 V voltage limit, the LMFP battery retains 80% of initial capacity after 1200 full discharge cycles with ProLion™ electrolyte**.



Battery safety is another important requirement for both grid-storage and automotive applications. Because of its similar chemistry, an LMFP battery has the same safety profile as an LFP battery. We performed short-circuit testing of a fully charged 18650 format LMFP battery; it passed the short circuit test without any incidents[2].

The combination of Aleees' cathode material and BroadBit Batteries' electrolyte enables fast, safe, durable, and mass-producible Li-ion batteries. After completing the planned production up-scaling, this battery type will represent the lowest cost per kWh: an inherent cost reduction of 20%-22% on a per-kWh basis with respect to LFP batteries.

Aleees and BroadBit Batteries welcome field trial enquiries.

2 Short-circuit testing video: https://youtu.be/cuEAWSNhI1o