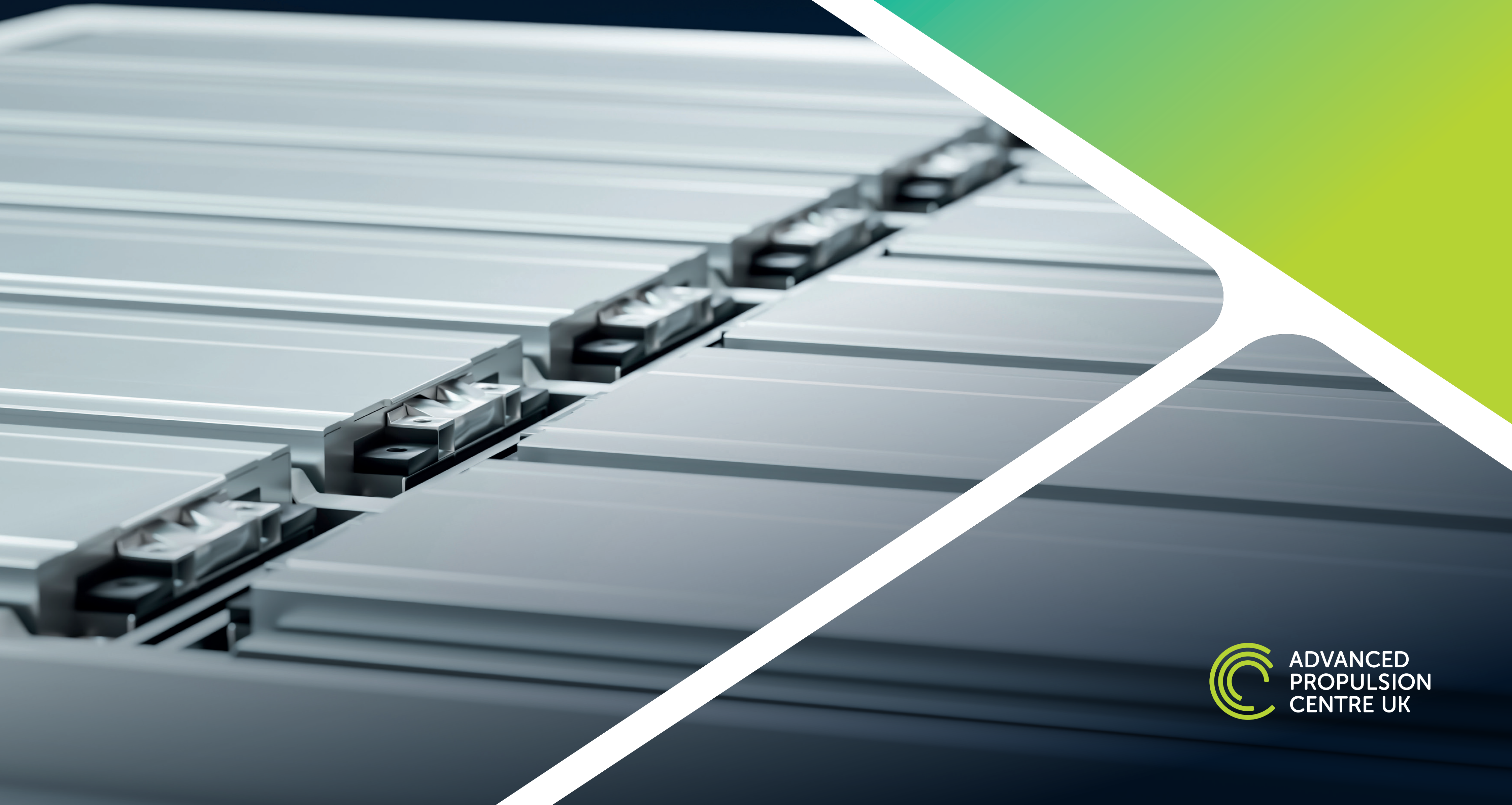
Insight report

L(M)FP batteries for EV adoption from a UK perspective



ADVANCED PROPULSION CENTRE UK

This document is aimed at supporting industry, academia, and government in the following ways:

Industry

- Identify strategic strengths within the UK battery industry for market growth opportunities
- Understand how each company's technology R&D fits in and its contribution to the battery supply chain
- Identify gaps within the local battery supply chain and opportunities for foreign direct investment or local scale-up

Academia

- Guide research and development (R&D) into next-generation technologies leveraging the case for lower cost battery chemistries to build a strong UK supply chain
- Develop up-skilling and re-skilling programmes to support UK industrial companies train their staff aligned with emerging trends in battery industry

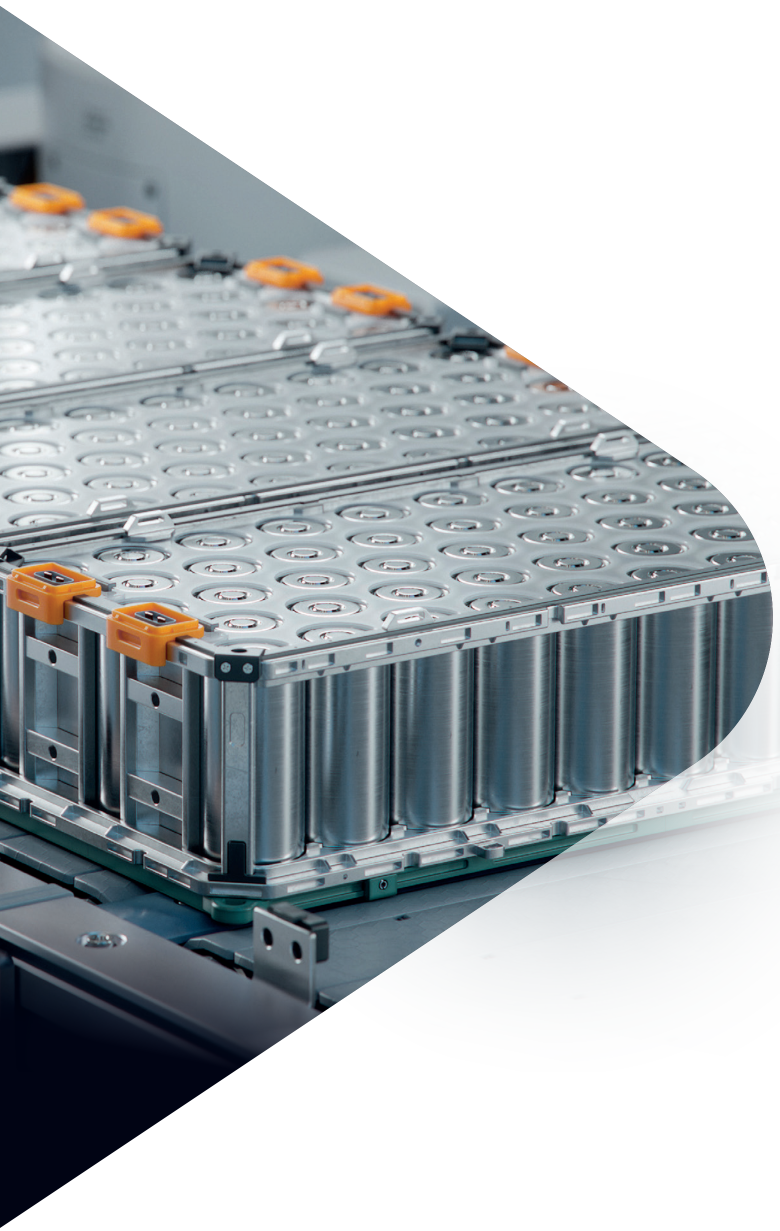
Government

- Understand where the UK's strengths and gaps lie in the automotive battery value chain
- Develop policy, strategy, and funding to accelerate scale-up in critical parts of the supply chain, specifically upstream materials supply chain as well as recycling of battery materials
- Support foreign direct investment decisions that complement UK strengths and incentivise local production of batteries

Contents

Department for
Business & Trade

The Advanced Propulsion Centre UK (APC) operational costs are funded by the UK Government's Department for Business and Trade (DBT) and industry contributions. DBT is the ministerial department for economic growth, supporting businesses to invest, grow, and export, creating jobs and opportunities across the country. Our combined mission is to accelerate the development of advanced propulsion technologies to reduce greenhouse gas emissions, minimise embedded carbon, and improve air quality.



Introduction

2024 was a record year for the sales of electric vehicles (EVs) across the world with a total of 17 million vehicles sold. In the UK, EV sales grew to 20% of the overall car sales market. However, in the EU and EEA market it ended up down 3% compared to 2023.

As we journey through 2025, the environment remains a challenging time for the European and UK markets as more stringent EU emission standards and the UK's zero-emissions sales mandates are on the horizon. Global original equipment manufacturers (OEMs) are facing the sustained twin challenge of needing to invest in transitioning their fleets to electrified models and facing headwinds through slowing consumer demand, affecting their profit margins and cash flow.

To maintain a healthy cash flow and operating margin, OEMs must reduce the cost of EV production where battery packs account for a large part of the cost – up to 40%. The cost consists of manufacturing key cell components like the cathode and anode, as well as the assembly of the cell through packaging with separators and electrolytes. The cathode material determines the energy density, is a key factor in battery capacity, and can be up to one-third of the cell cost. The Cathode Active Material (CAM) could be made of lithium hydroxide / carbonate and be combined with energy-rich materials like nickel, manganese or cobalt. Managing the cost of CAM materials is important to keep control of the overall battery production cost.

There has been a proliferation of battery chemistries trialed and adopted across the world in automotive applications in response to consumer requirements. Battery chemistries that are low cost in CAM manufacturing are becoming more prevalent globally when compared to energy rich nickel and cobalt-based battery cells and this boosts overall efficiency for the scale-up needed for mass-EV production.

This report focuses on one such battery chemistry, LFP (Lithium Iron Phosphate) and provides an overview of its technology and supply chain competitiveness for increasing EV adoption in the region of the UK and Europe.

Executive summary

LFP (Lithium iron phosphate) battery chemistry can increase affordability, and compete with nickel-rich cathodes in the UK and European EV market.

1

LFP battery chemistry leverages EV adoption and penetration in the key global markets

- There is a global slowdown in EV adoption, and this is reflected by the announcements from global OEMs and battery manufacturers, detailing at least 600 GWh of planned battery manufacturing capacity in Europe is to be cancelled, delayed, or downsized.
- The EV adoption curve needs low-cost battery chemistries to make EVs affordable and increase penetration toward the mass-market segment.
- LFP (Lithium Iron Phosphate) battery chemistry is helping to accelerate EV penetration in key markets like China. 68% of EV batteries in China are LFP. In the HDV (heavy-duty vehicle) segment 99% of the battery capacity in new sales in China are LFP based.

2

LFP battery cells are competitive compared to NMC (Nickel Manganese Cobalt) batteries in cost, thermal stability and cycle life

- There are five levers which could impact the effectiveness of LFP battery chemistry: technology, cost, manufacturing, supply chain, and recycling.
- LFP cells are cheaper to produce compared to NMC-based batteries due to the lack of nickel and cobalt elements.
- LFP cells have better thermal runaway onset and heat rate discharge characteristics than NMC. LFP can leverage this overall thermal stability for higher pack-level efficiencies and larger cells, thus reducing the overall cost of the battery pack in the vehicle.

3

European capability on establishing LFP supply chain is influenced by policy, production cost and recycling implications

- Europe lacks capability within the upstream supply chain of L(M)FP chemistries such as lithium and manganese. Supply chain localisation will leverage this promising chemistry and support meeting the forthcoming EU-UK Rules of Origin (ROO) regulation in 2027 and LFP export controls from China.
- Recent APC research has analysed the cost competitiveness of producing LFP battery cells in both Europe and China, with findings highlighting that labour and CapEX cost are a major disadvantage for Europe.
- LFP recycling is typically less profitable compared to NMC batteries due to the lack of valuable metals like nickel and cobalt, however, it a better use as secondary battery storage systems due to extended cycle life.

Market dynamics impacting the choice of battery chemistry

There is a global slowdown in EV adoption which is reflected by the planned manufacturing reductions by global OEMs and battery manufacturers.

Global OEMs have pushed back their EV production and portfolio targets for the next 5 years due to slowing EV sales growth.

Figure 1: Announced delays in major OEM plans for EV production until 2030

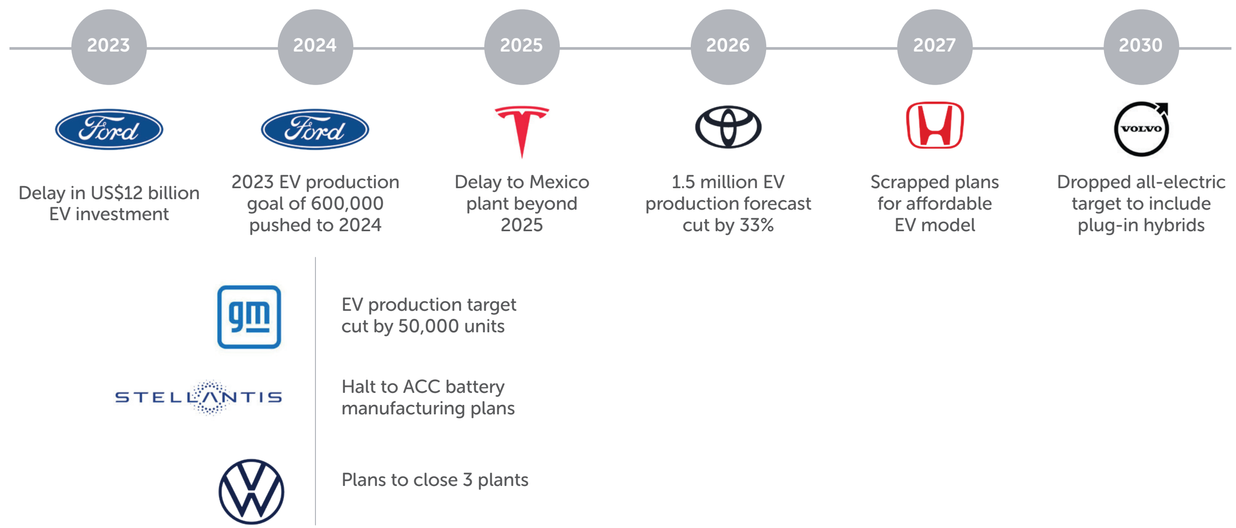
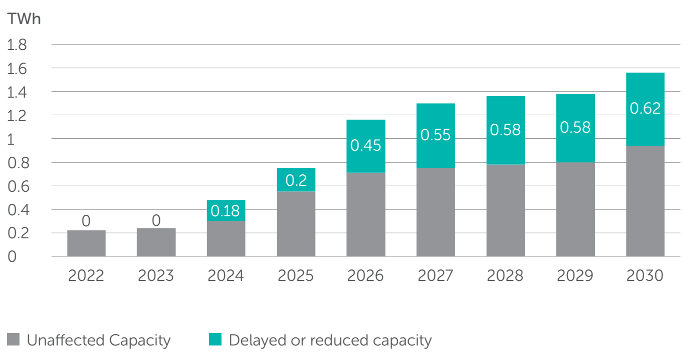


Figure 2: European lithium-ion cell manufacturing forecast illustrates the planned reduction in future capacity



Source: APC research, Woodmac and BNEF

Electric vehicle adoption curve needs affordable low-cost battery chemistries for increasing penetration towards the mass-market segment.

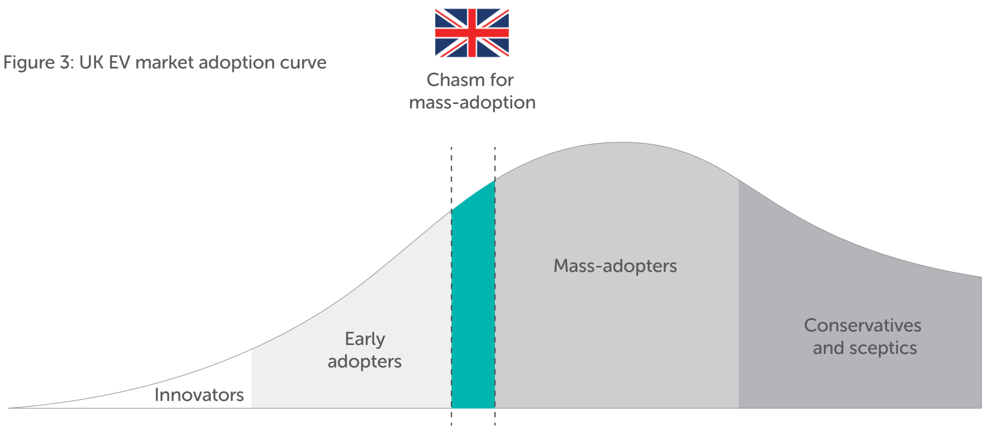
Despite a record 19.6% market share in 2024 for EV registrations in the UK (see Figure 3), it is still below the required ZEV mandate level of 22%. Vehicle affordability is a key barrier to unlocking mass EV adoption.

Affordability is a key issue for accelerating mass EV adoption

Although a changing picture with the OEMs in releasing cheaper models, the general lack of smaller, more cost-effective segment EV vehicles in the UK and Europe is impacting on the mass adoption of EVs (see Figure 4).

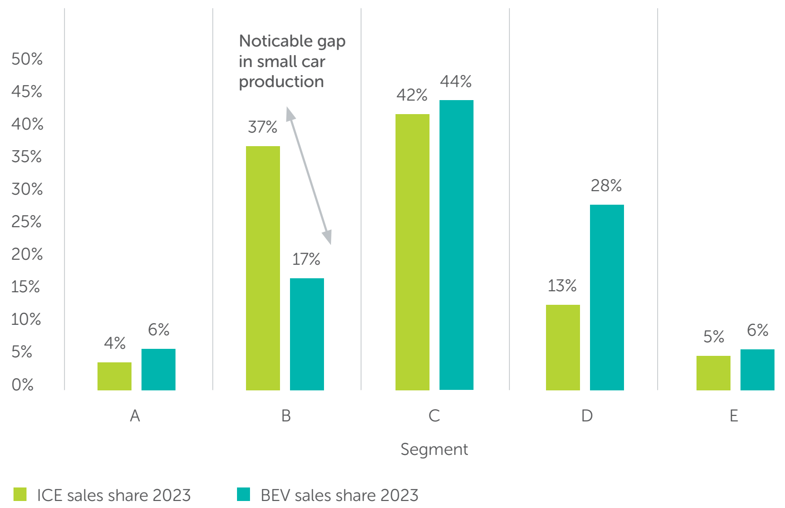
To increase the affordability of EVs, OEMs are focusing on reducing the cost of battery packs, which are a significant proportion of the overall vehicle cost.

Figure 3: UK EV market adoption curve



19.6% market-share* for the UK's Zero emission vehicles in passenger cars

Figure 4: EU+UK ICE and BEV sales share based on vehicle sales segment



Source: SMMT and APC Q4 2023 demand report

Lithium Iron Phosphate (LFP) battery chemistry is helping to accelerate EV penetration in key global market such as China.

China is leading the world in the sales penetration of EVs which account for more than 43% of the total sales (as of 2024 – see Figure 5). This is double the number of sales compared to Europe and North America in 2024. The adoption of mass-low-cost cathode chemistries is one of the key contributing factors to accelerating EV sales in China.

China's acceleration towards EV sales penetration could be attributed to LFP battery-based vehicles. In Q1 2024, 75% of EVs sold in China had a LFP battery, accounting for an overall market share of 68%.

Zero-emission HDV battery technologies in China

LFP remained the battery chemistry for the zero-emission HDV industry, representing 99.9% of the battery capacity for new sales in China. CATL was the dominant player in the market with 87% market share in 2023.

Figure 5: EV penetration by region from 2019-2024 (%)

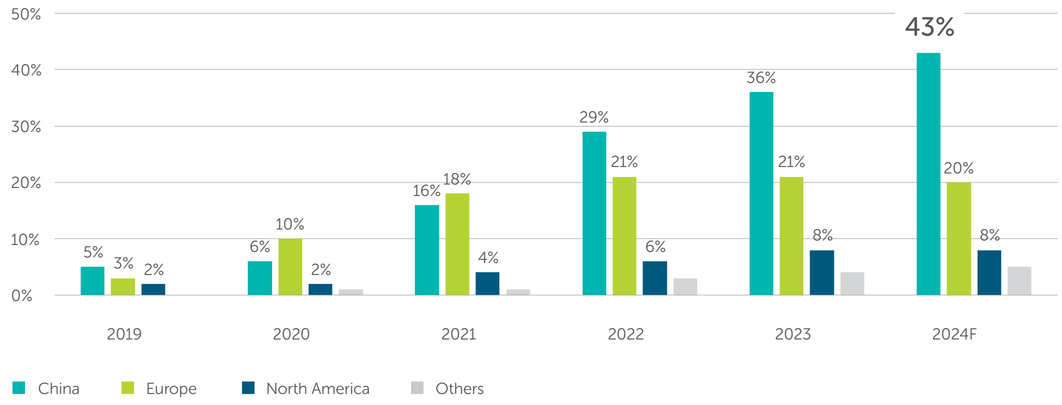
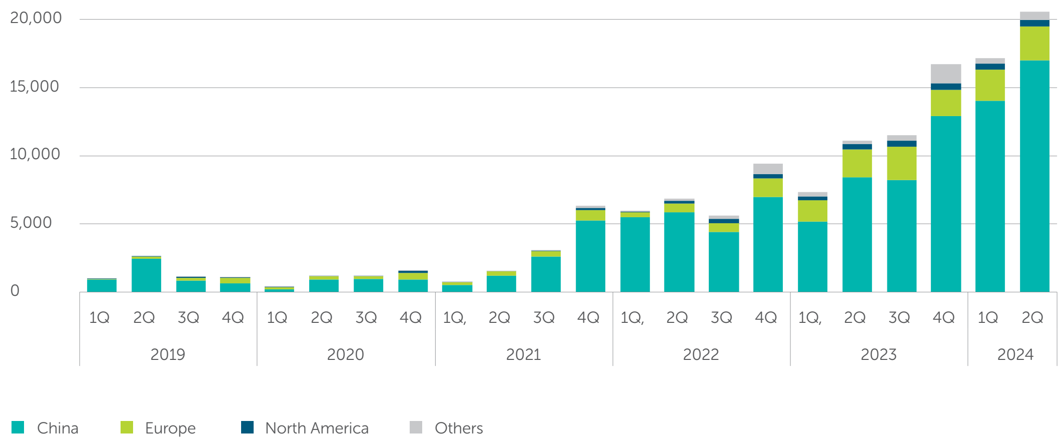


Figure 6: Global zero-emission truck sale by quarter



Source: Woodmac, BNEF and ICCT

LFP can compete on cost, thermal stability and cycle life compared to the NMC batteries.

The table in Figure 7 provides an overview of different battery chemistries typically used in light duty vehicles and their effectiveness on cost, energy density, and cycle life. It illustrates that LFP can compete well with nickel-based chemistries.

Figure 7: Performance characteristics comparison of key battery chemistry materials

Material	Cost	Energy density	Thermal stability	Cycle life	Charging cycle life
Lithium Cobalt Oxide (LCO)	High	Moderate	Poor	Moderate	500-1000
Lithium Iron Phosphate (LFP)	Low	Low	Good	Good	2000-4000
Lithium-ion Manganese Oxide (LMO)	Low	Moderate	Good	Poor	500-1000
Nickel manganese cobalt oxide (NMC 622)	High	High	Moderate	Good	~1500
Nickel manganese cobalt oxide (NMC 811)	High	High	Poor	Moderate	~2000
Nickel Cobalt Aluminium oxides (NCA)	High	High	Poor	Moderate	300-500
Lithium and manganese rich NMC material (LMR-NMC)	Moderate	High	Moderate	Poor	~500

Though LFPs have poor energy density, it can be improved by doping with other elements like manganese to improve operating voltage. L(M)FP can potentially improve 15% to 20% of the energy density compared to standard LFP batteries.

Source: APC research and Faraday Institution

Why L(M)FP chemistry?

Here we explore the following themes and market dynamics that showcase where LFP battery chemistry can make an impact on the UK battery manufacturing industry.

Cost

LFP battery chemistries are proven to be cost-effective compared to the nickel-rich cathodes. This is due to lack of price sensitive critical materials like nickel, cobalt etc.

Technology and thermal safety

Though LFPs trail behind NMC-related chemistries in energy density, there have been technology developments to enrich and increase the gravimetric energy of the cells (Wh/kg) like LMFP.

Manufacturing

Cell-to-pack (CTP) efficiencies and larger cells make LFP batteries competitive to NMCs at a battery system level. Additionally, thermal stability is better in LFP batteries.

Supply chain and regulation

China is currently dominating the supply chain for LFP chemistries, however, incoming regulations like ROO and recently drafted China's export controls on LFP technology can lead to localisation in the UK and Europe.

Recycling

The recycling profitability of LFP is less than nickel-rich cathode chemistries, but the extended charging life cycle means LFP batteries have the potential for end-of-life secondary usage.

LFPs are cheaper to produce when compared to NMC based batteries due to lack of critical materials like nickel and cobalt.

The table on the right provides the high-level manufacturing cost for battery cells in the UK. It compares the cost with LFP, LMFP, and NMC 811 cells. NMC cells cost more to produce per kWh due to the presence of energy-rich nickel, manganese and cobalt sulphates.

Battery production scale and lithium material price have the highest impact on cost sensitivity for the production of LFP and LMFP batteries. Though there is an additional process step of doping manganese in LMFP CAM material, the higher energy density results in cheaper LMFP cells when compared to LFP batteries.

Figure 8: Battery cell cost comparison of LFP, LMFP and NMC 811 cell

	LFP	LMFP	NMC 811
Cell cost €/kWh Production in the UK with components supplied from the EU	65.5	61.6	73.0
Cost share – OPEX share	33%	32%	25%
Cost share – Other component share	50%	46%	38%
Cost share – CAM share	17%	21%	37%

Source: APC, FBC and Porsche Consulting LFP cost study

LFP batteries have less of a need for lithium carbonate equivalent (LCE) to produce the cathode materials.

In subterranean lithium extraction, lithium salts are extracted from brine reservoirs and processed to produce lithium carbonate which is further treated to obtain lithium hydroxide

Figure 9: Lithium extraction value chain from Q3 2023 report

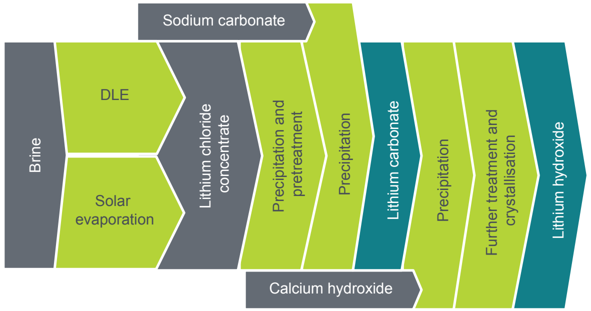
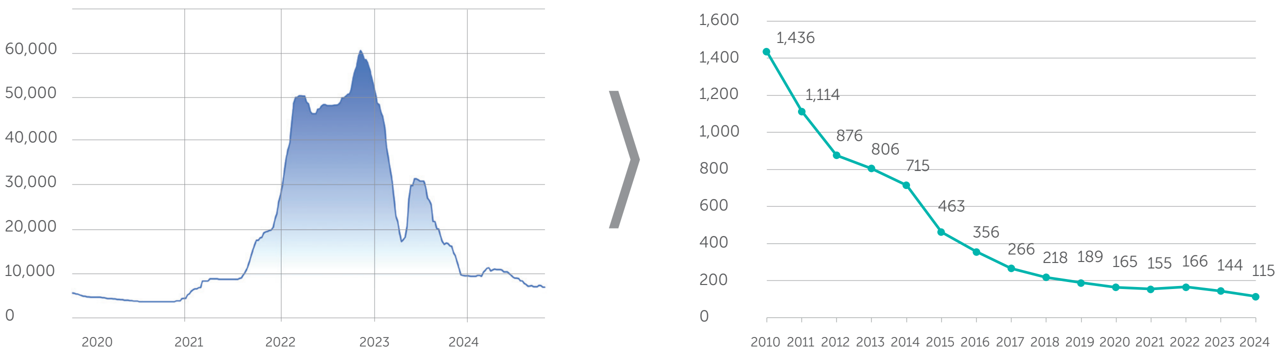


Figure 10: LFP has reduced lithium carbonate equivalent need compared to high-nickel and lithium metal batteries

Lithium Extract	Usage	LCE equivalent
Lithium Hydroxide	High-nickel batteries	1.544
Lithium Carbonate	LFP batteries	1
Lithium Metal	Li Metal batteries	5.323

Figure 11: Lithium carbonate prices have reduced from the 2022-2023 peaks, unlocking a reduction in battery pack prices



Source: APC, Volta foundation battery report and BNEF

LFP technology advantages, issues and recent cathode developments.

Greater stability

LFP's key property is its stability. This is due to the strong bonding of iron and phosphate within the compound, creating a highly stable structure. This, in turn, makes the compound thermally stable and safe from thermal runaway incidents.

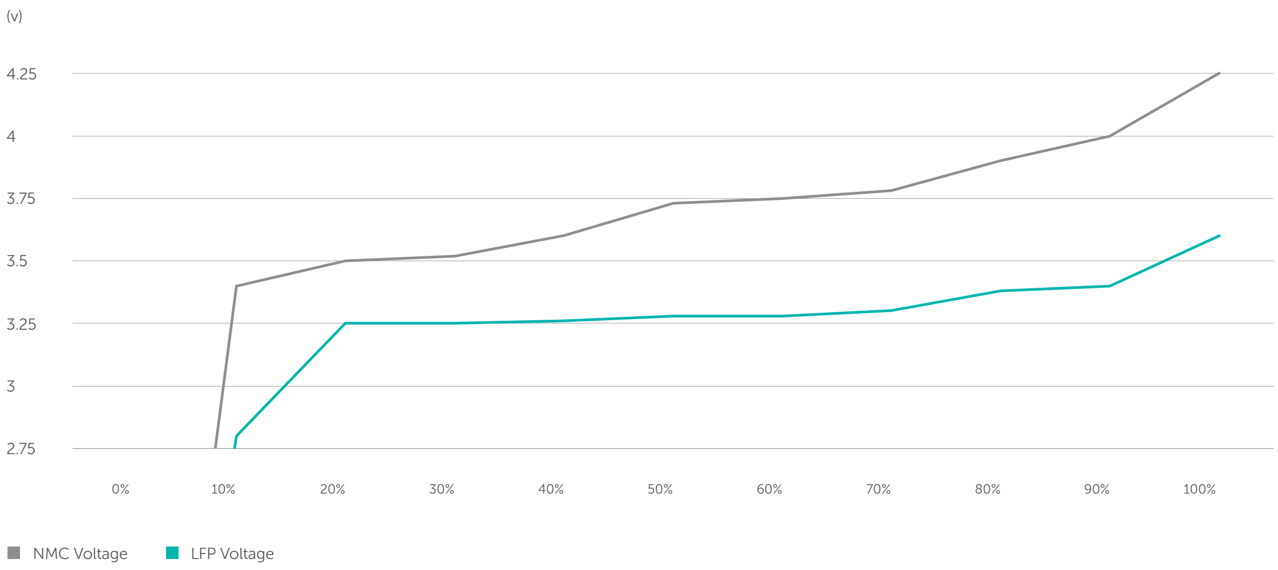
Increasing voltage through doping:

Iron has lower electrochemical potential, decreasing the nominal voltage compared to NMCs and, in turn, the energy density (see Figure 12). To increase the voltage of LFP, manganese could be doped to the cathode material, resulting in higher voltage for the battery cells, and can result in higher energy density (Wh/kg) of up to 30%. However, LMFP has challenges which include poor conductivity and a shorter life-cycle because of manganese. To overcome this shortage, hybrids are being created by blending LMFP with other cathode materials like NMC. Chinese manufacturers such as CATL and Ronbay New Energy have created blended LMFP with NMCs.

Challenges in cold temperature

With lower temperatures there is the potential for reduced charging speeds and a lower state-of-charge because of the decreased lithium diffusion within the battery cell.

Figure 12: State-of-charge voltage relationship for NMC and LFP batteries

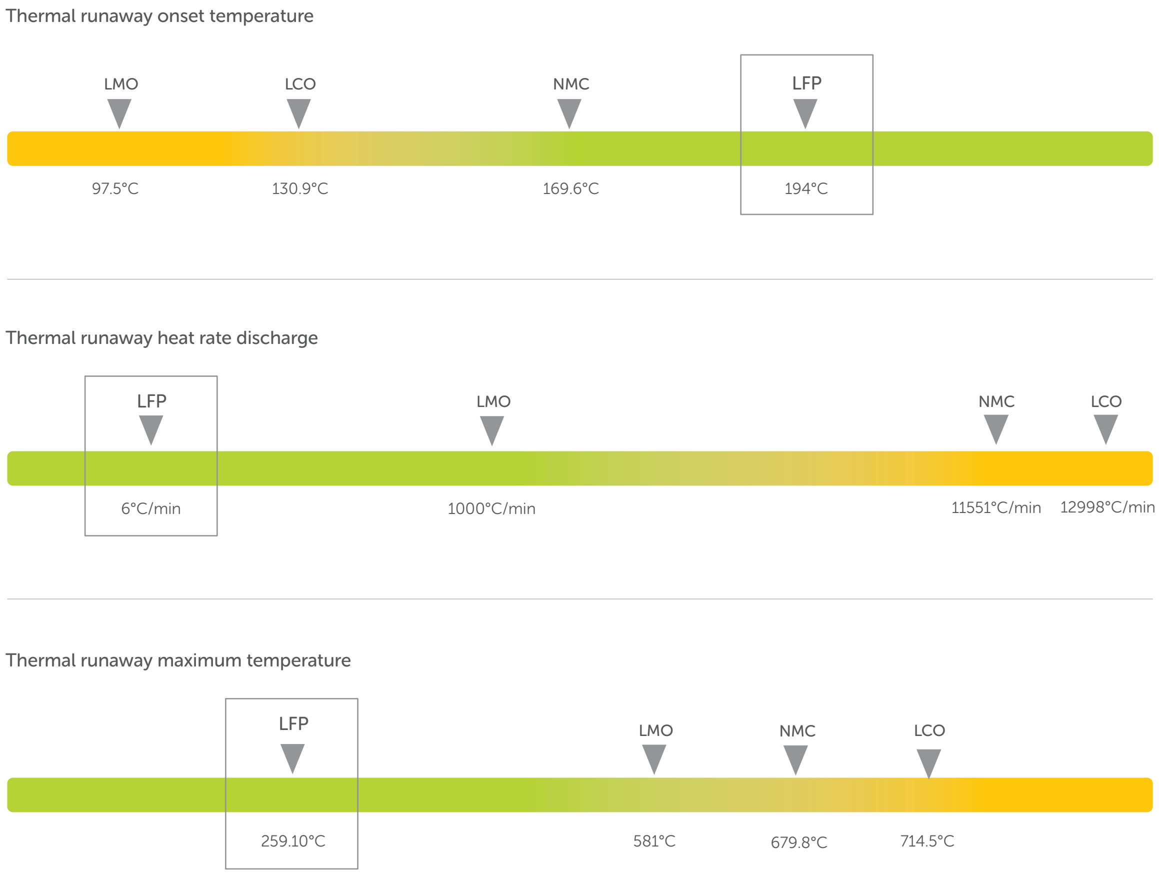


Source: Rho motion and PowerUp technology

LFP has a better thermal runaway onset and heat rate discharge characteristics compared to NMC.

Due to the strong bonding of iron and phosphate in the cathode, LFP creates a highly stable structure resulting in greater thermal stability. This reduces the incidence of thermal runaway. Thermal runaway is when the lithium-ion cell enters an uncontrollable, self-heating state.

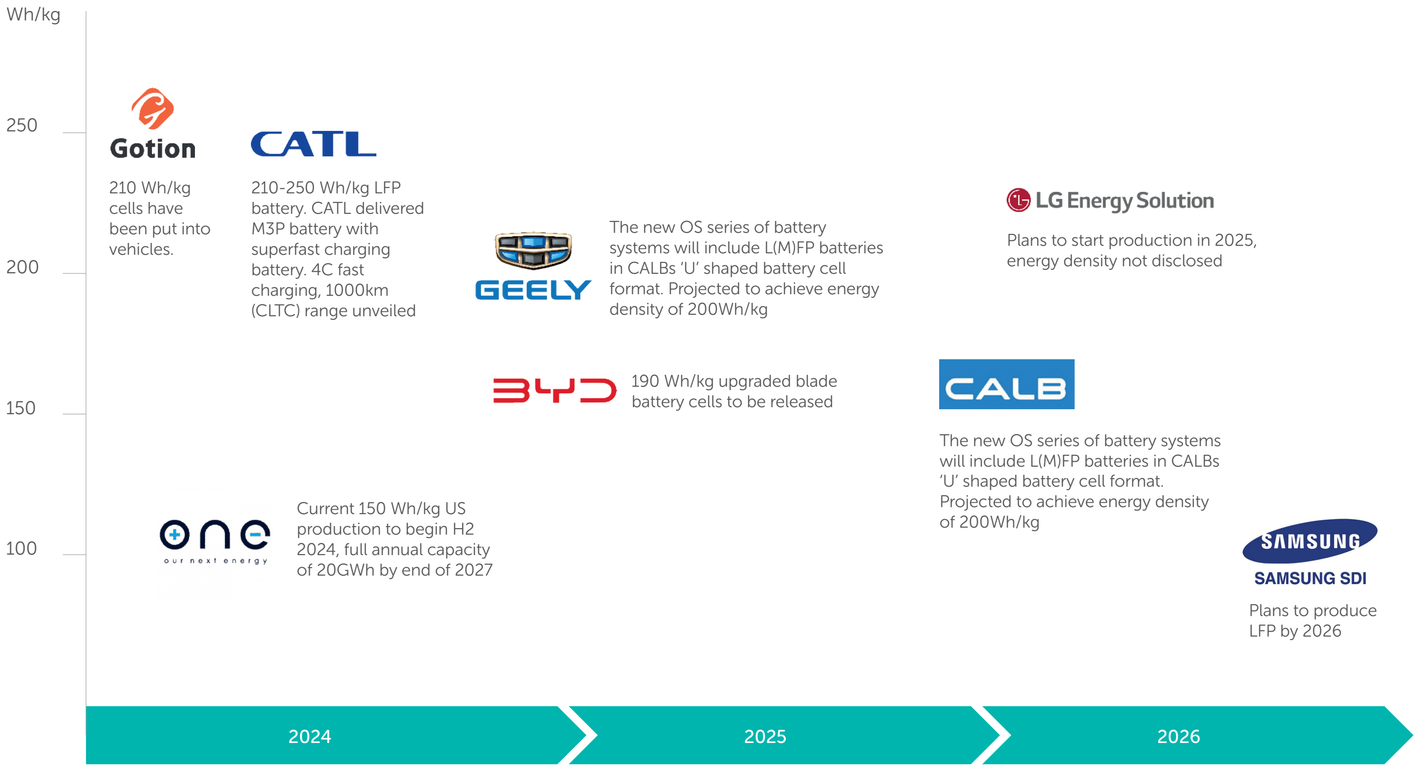
Figure 13: Thermal runaway characteristics for LFP and other key battery chemistries



Source: WMG and Yih shing Duh et al 2023

Chinese battery companies who are major players in the supply chain are pushing gravimetric density of LFP batteries above 200 Wh/Kg.

Figure 14: LFP energy density technology development timeline



Source: Rho motion

LFP batteries can leverage the overall thermal stability for higher pack-level efficiencies compared to NMC battery packs.

While NMC battery cells have a higher theoretical energy density, the thermal efficiencies of LFP batteries compete well at a pack level with NMC batteries.

Cell-to-pack (CTP) opportunity

In a traditional battery pack, the number of inactive components increases to prevent thermal runaway incidents. However, due to higher thermal stability, there is less need for LFP batteries at a pack level to have inactive components packaged within the vehicle. This results in overall system-level efficiency savings for LFP to compete successfully with NMC-based chemistries.

Larger cells

Thermal stability of LFP batteries can contribute to the direct integration of CTP without a need for modules, and can benefit from larger format cells, contributing to higher pack energy density.

Case in Point: CATL batteries

In April 2024, CATL unveiled Shenxing PLUS- a LFP battery that will reach 1,000 kilometers with superfast charging. The battery has proprietary anode material that boosts energy density and has innovative CTP topological structure that enhances the overall system efficiency.

Figure 15: Energy density comparison between LFP & NMC at cell to pack-level

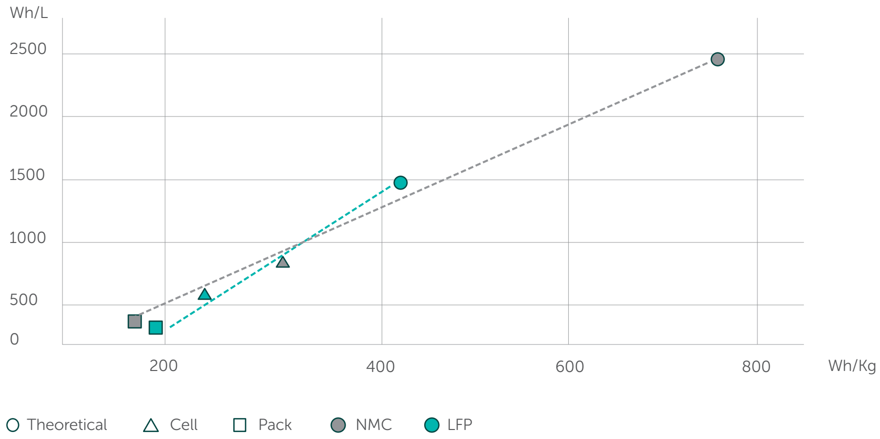
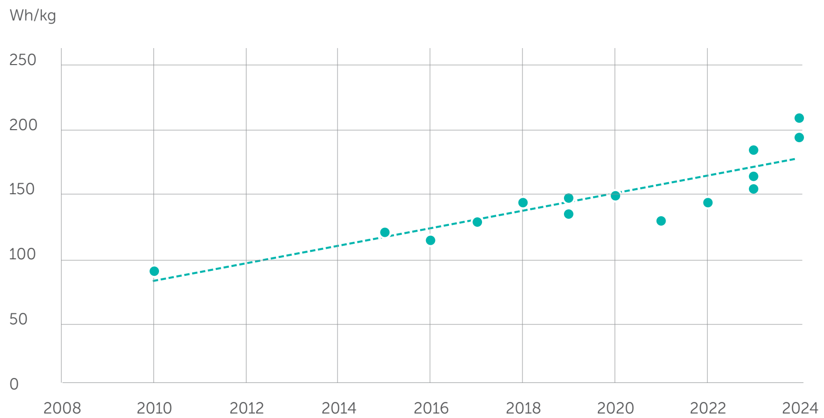


Figure 16: LFP pack density has been evolving to higher energy density in recent years



Source: Woodmac, Rho motion, BNEF

Supply chain and recycling implications of using L(M)FP chemistries

Currently, Europe lacks capability within the supply chain of L(M)FP chemistries such as lithium and manganese.

China dominates the supply chain for critical materials needed to make LFP batteries such as lithium and manganese. Though the mines for lithium are concentrated in South America, the lithium chemicals production that are needed to produce battery-grade lithium carbonate and hydroxide are dominated by China.

Right to play in Europe and the UK for LFP

Iron phosphate is a key material in the development of LFP battery cells. They contain purified phosphoric acid (PPA), made using mined phosphorus feedstock and high-purity iron. The biggest ores are present in China, the USA, and Morocco. However, the EU has identified phosphate rocks as a key critical raw material and vulnerable to supply risk issues. In 2023, a substantial phosphate rock deposit was discovered in Norway that has since been pitched as the world's largest.

Figure 17: Lithium chemical production 2024: China vs Rest of the World (RoW)

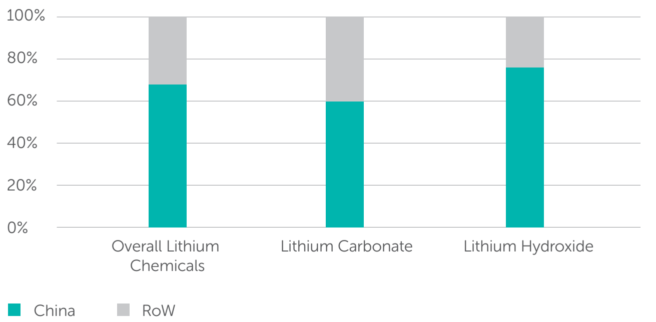


Figure 18: Manganese refinement capacity

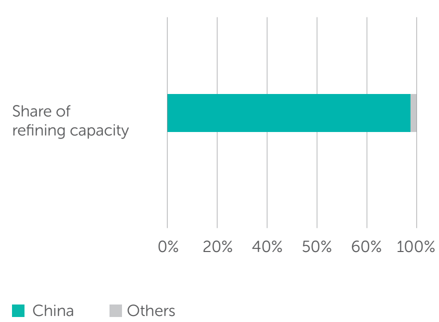
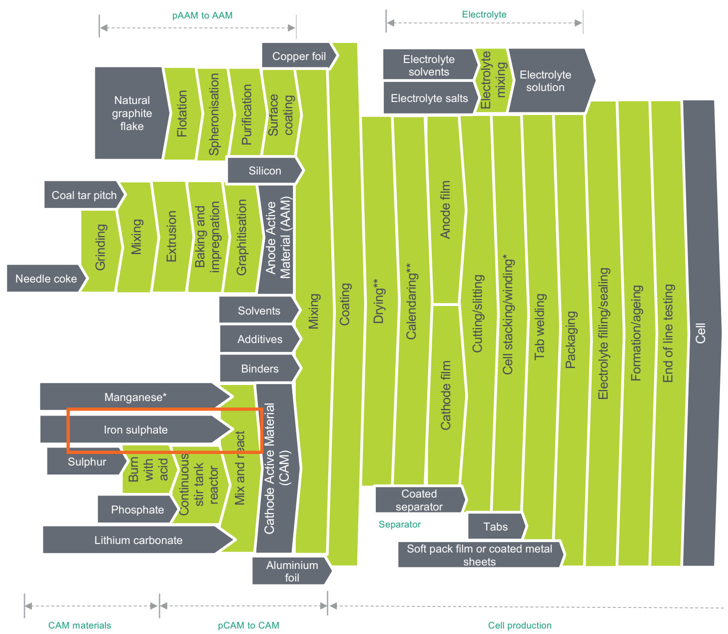


Figure 19: L(M)FP battery value chain from APC



Source: APC, BNEF and Benchmark Intelligence

APC research predicts that while Europe can produce LFP and LMFP Cathode Active Material (CAM) there is a cost disadvantage of between 0.7- 1.2 €/kg when compared to China. This is driven by higher labour and CAPEX cost.

The APC analysed and evaluated battery production cost in Europe and China based on LFP and LMFP materials.

Figure 20: CAM Production cost comparison between Europe and China

Based on annual plant capacity of 50 kt and no tariffs or transport cost considered
Source: APC research in collaboration with Porsche Consulting and FBC

China produces and ships LFP and LMFP battery cells with a cost advantage of a minimum of 10-12 €/kWh, with the main difference is in lower production cost compared to Europe.

Four different scenarios were evaluated in the APC's research on production cost analysis of LFP battery cells in Europe and China

1. European material and production (precursor CAM sourced from China)
2. ROO-compliant production in Europe, CAM produced in China using a selection of Chinese components
3. ROO-compliant production in Europe, CAM produced in EU, using further Chinese components
4. Chinese materials and production sent to Europe

- The major cost disadvantage for the production of LFP and LMFP cells in Europe compared to China would be the production cost, dominated by the cost of labour and CAPEX depreciation.
- Industrial energy cost, in the UK is one of the highest in Europe, is another major contributor to the high battery manufacturing cost.
- One of the major reasons for China to produce LFP cells at a competitive price is due to the advantage of producing titanium dioxide and having to generate large volume of sulphuric acid and ferrous sulphate as a waste by-product. Both sulphuric acid and ferrous sulphate can be utilised to produce iron phosphate, which are central for LFP cathodes.

Figure 21: LFP Cell cost €/kWh

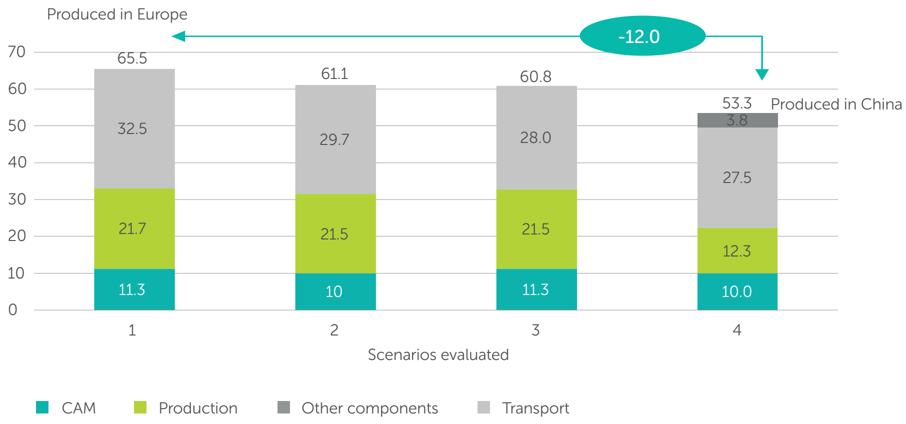


Figure 22: LMFP cell cost €/kWh

Europe includes the United Kingdom
Source: APC research in collaboration with Porsche Consulting and FBC

Establishing LFP supply chain in Europe is influenced by incoming ROO regulations and export controls.

Though the LFP supply chain is currently dominated by China, there are good reasons for establishing a localised supply chain in Europe due to incoming regulations as part of the EU-UK ROO and the recently drafted export controls from China.

Rules of Origin regulations

EU-UK ROO regulation states that, by 2027, no less than 65% of battery cell content should originate from within the EU or UK to ensure products are eligible for zero tariffs. This has potential implications for the global battery supply chain and for the direction European OEMs will take on their sourcing strategy.

What does it mean for LFP supply chain?

LFP battery cells are more resilient to incoming ROO regulations, and they have a higher tolerance to lithium carbonate prices. LFPs could breach ROO regulations only if the lithium carbonate (Li2CO3) prices hit 51 €/kg (currently around 9 €/kg). This is due to the relatively lower value composition of CAM materials in LFP than NMC batteries.

What does China's export controls mean for the industry?

If the proposed curbs come into effect, affected technologies would need approval from the Chinese government to be exported, based on a case-by-case review. Licensing agreements between Chinese suppliers and foreign OEMs will be affected.

Figure 23: China LFP export controls

China LFP export controls	
Technology to be restricted (draft stage)	**Key control points**
LFP material production technology	Equipment and Intellectual property (IP) for making LFP battery cathode materials that are to be used in the next two years
LMFP material production technology	Equipment and IP for making LMFP cathode materials for high energy density battery applications
Phosphate-based cathode precursor production technology	Equipment and IP for making precursor materials used to produce LFP and LMFP battery cathode materials
Metallic lithium and lithium alloy production technology	Equipment and IP for making anode materials used in lithium metal batteries used in lithium metal batteries and solid-state batteries

Europe includes the United Kingdom
Source: APC research in collaboration with Porsche Consulting and FBC, BNEF and BMI

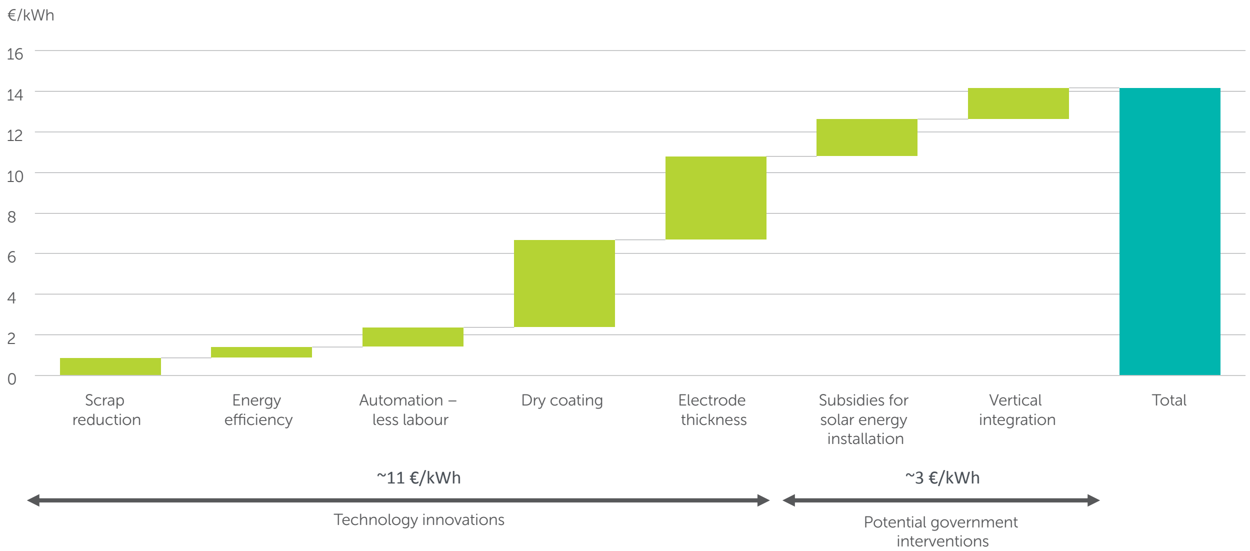
A range of technology and government interventions could reduce the production cost of LFP cells in Europe by up to 14 €/kWh.

To enable cost competitiveness in the European / UK manufacturing of LFP cells, the following interventions detailed in the chart on the right could be considered. The key innovations are around electrode technology manufacturing and the need to reduce energy usage in the cell manufacturing process.

In the conventional lithium-ion cell process, a slurry mix is created with cathode / anode active material with binders, wet solvents, and additives to make the active electrodes within the battery cell.

Dry coating technology could potentially remove the energy-intensive wet process of making electrodes by removing the need for a solvent like NMP (n-methyl-2-oyrrolidone), which is toxic and considered to be a pollutant. Dry coating technology could eliminate the need for solvents and reduce energy consumption by not having a drying process for solvent evaporation. There are currently technology challenges in adopting dry electrode technology, and this could be an active R&D technology area in Europe to improve innovations in battery cell manufacturing.

Figure 24: Saving potential of different cost levers to reduce the production of LFP cells in the Europe (in €/kWh)



Source: APC research in collaboration with Porsche Consulting and FBC

LFP recycling is less profitable compared to NMC batteries due to lack of critical materials like cobalt and nickel, however, has better use as a secondary battery storage system.

- There are recycling challenges for the automotive supply chain, if it is to transition between NMC and LFP battery cells.
- The LFP battery cells are less profitable for recycling compared to NMC batteries, as they lack valuable critical materials like cobalt and nickel.
- Lithium is the only metal that could be extracted from the LFP batteries and there are new techniques being adopted to increase the recovery rate of the metal to maximise recycling profitability.
- There could be a potential opportunity to investigate and explore the feasibility of a circular business model proposition, by deploying the end-of-life LFP batteries as stationary energy storage systems for micro grid applications. This would exploit the strengths of LFP batteries from their durability and extended battery life.
- Pack design for ease of disassembly will be pivotal in unlocking second life use.

Figure 25: LFP recycling process

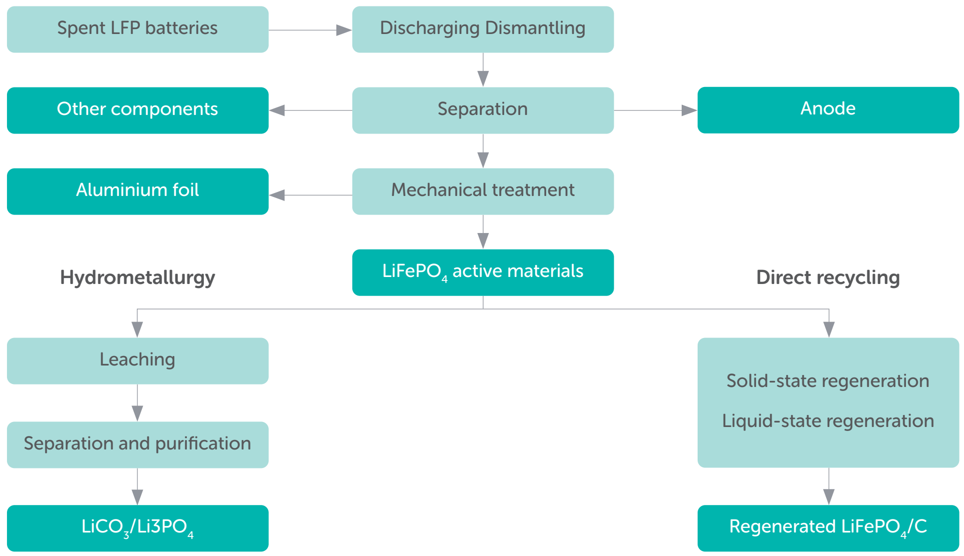
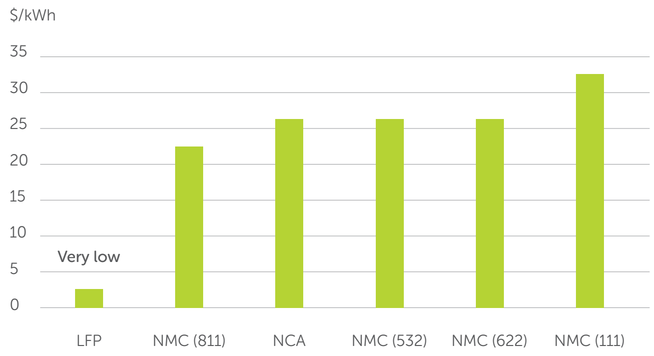


Figure 26: Battery recycling profitability by battery chemistry



Source: Faraday Institution, Rho motion and CRU analysis

Summary and recommendations

Summary and recommendations for the UK market

- LFP battery chemistry is helping to penetrate and accelerate EV adoption in the key global markets like China.
- LFP battery cells are competitive compared to NMC batteries in cost, thermal stability and cycle life, performing very well at a pack level. LMFP cells are being explored to improve the low energy density challenges.
- There is a need to localise LFP battery cell supply chain in the UK and Europe to protect local automotive companies from incoming export controls and ROO regulations coming into effect across the globe.

How can the UK battery industry take advantage of the LFP battery chemistry in the EV market?

Invest

Investment in R&D activities for the UK and European competitiveness in battery cell manufacturing, such as dry coating technology, will enable reducing energy consumption when compared to conventional process, reducing the overall cost of manufacturing.

Incentivise

Incentivise the development of renewable energy infrastructure adjacent to LFP battery manufacturing plants, e.g., solar to reduce battery manufacturing production costs.

Incentivise establishing a vertical supply chain within the UK to avoid future export controls on key critical technologies and facilitate the infrastructure for international talent to develop their battery technology Intellectual properties (IPs) in the UK.

Investigate

Investigate the feasibility of a sustainable circular business model for potential adjacency between OEM production of LFP batteries and application of LFP stationary battery storage systems as a secondary life.

Appendix

Glossary

BEV	Battery Electric Vehicle
CALB	China Aviation Lithium Battery
CAM	Cathode Active Material
CaPEX	Capital expenditures
CATL	Contemporary Amperex Technology Co., Limited
CTP	Cell-to-pack
EV	Electric Vehicle
HDV	Heavy-duty vehicle
LFP	Lithium iron phosphate
LCO	Lithium cobalt oxide
LMO	Lithium-ion manganese oxide
NMC	Nickel manganese cobalt oxide
LCE	Lithium Carbonate Equivalent
LMR-NMC	Lithium and manganese rich NMC material
L(M)FP	Lithium manganese iron phosphate or Lithium iron phosphate
LMFP	Lithium manganese iron phosphate
LFxP	Lithium iron phosphate (LFP) lithium-ion cathode which can include manganese (LFMP)
NCA	Nickel Cobalt and Aluminium lithium-ion cathode
OEM	Original Equipment Manufacturer
ROO	Rules of Origin
xEV	Electrified vehicle including BEV, PHEV, HEV, FCEV
ZEV	Zero Emission Vehicle

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Further information

If you have any questions or would like more detail on any of the graphs or data, email info@apcuk.co.uk

Sharing this document

This report is provided by the Technology Trends team at the APC. When sharing the contents of this document, please reference the APC to help others connect with our research and support.

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