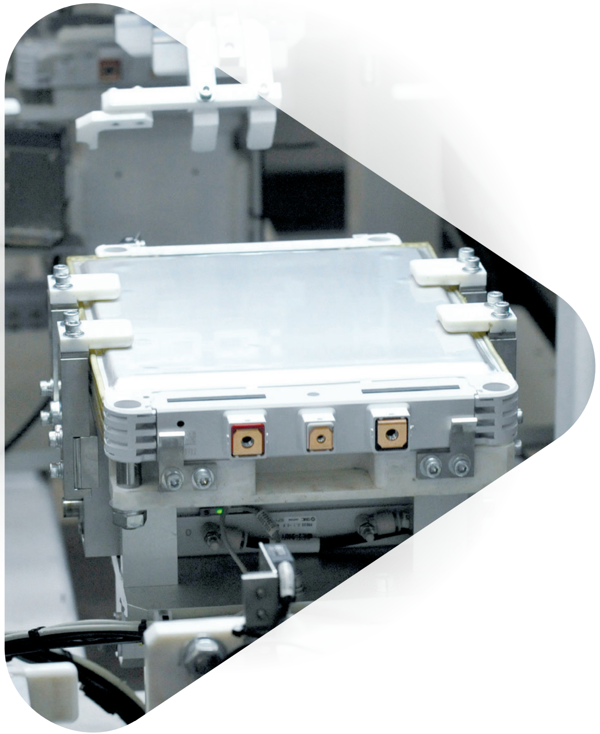
2025 and Beyond: Promising battery cell innovations for the UK automotive sector

October 2022

ADVANCED PROPULSION CENTRE UK

Accelerating Progress

This Insight Report is provided by the Technology Trends team at the APC



Contents

ADVANCED PROPULSION CENTRE UK

Accelerating Progress

Key trends in automotive batteries

The automotive sector will dominate future battery demand

The automotive sector will represent over 80% of lithium-ion battery demand by 2030.

Vehicle manufacturers need batteries that achieve the right balance of cost, energy density and life cycle impact while navigating volatile raw material prices.

A diverse range of future battery technologies will be developed to reduce reliance on one solution

The APC believes the automotive industry is coalescing around three broad clusters of batteries: entry level low cost, high volume performance and high performance specialist.

Within these three broad clusters, vehicle manufacturers are opting for different chemistry choices based on their cell suppliers, production numbers, and specific vehicle attributes.

Cross-cutting challenges will trigger further innovations

Irrespective of end application, automotive batteries will be subject to cross-cutting challenges that will trigger further innovations including cell safety, manufacturing improvements, recyclability and supply chain development.

Study method

The APC qualitatively assessed the relative market potential of next generation battery innovations versus how close they are to entering the automotive market.

A qualitative UK capability assessment was also conducted to understand where the UK has strategic advantages in terms of IP, supply chain and manufacturing capability.

Only the technologies that are the closest to entering the automotive market with a high market potential were analysed in this report. While earlier stage innovations are important for the UK, the APC tends to focus on commercialising late-stage technologies.

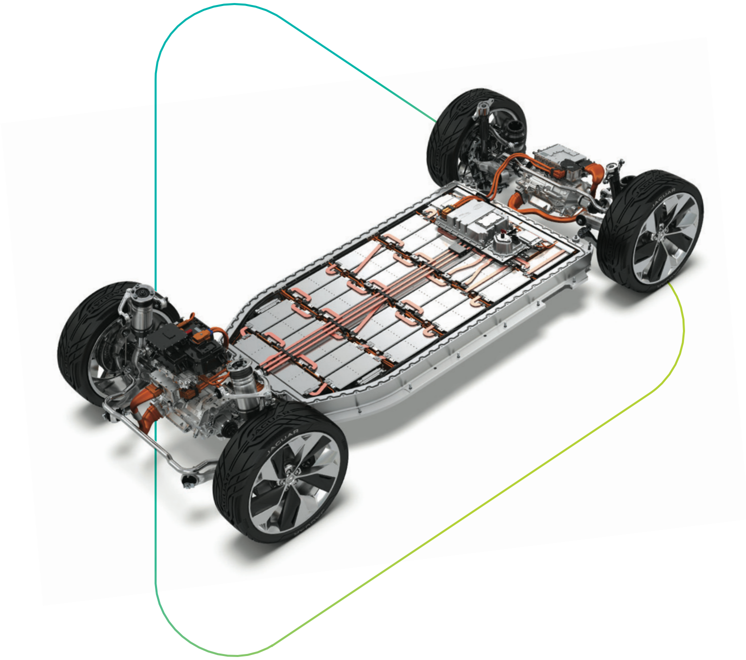
Key insights

Eight innovations emerged that are relatively close to market and could capture a significant portion of the automotive market.

- Silicon dominant anodes
- Manganese rich cathodes
- Industry scale battery materials recycling
- Solid state electrolytes
- Lithium metal anode
- Dry electrode manufacturing
- Lithiation techniques
- Sodium-ion

The UK has strategic advantages in sodium-ion and silicon anodes. There is a limited window of opportunity to capitalise on this advantage with targeted capital and late-stage R&D investments.

Areas such as battery materials recycling, solid state electrolytes and manganese rich cathodes are worth pursuing due to their high market potential and emerging UK capability.



Aim of the insight report

Key points

- This insight report aims to provide guidance on which technologies the UK should invest in based on the best information currently available.
- The UK's capability in next generation automotive battery technology is presented.

The aim of this insight report is to provide an automotive perspective on promising battery technologies. With the battery sector developing at such pace, it can be hard to keep track of what technologies are best suited to the automotive sector. Therefore, we have drawn on publicly available information, alongside our experience in the automotive sector, to assess the market.

It is important to note this analysis represents a snapshot in time. But we feel the broad themes and technologies the APC have identified in this report are valid – even if the relative priorities change as the market matures. To help guide readers through the landscape, the report is structured into three parts:

Define automotive battery segments	Different light duty vehicles require certain attributes from batteries. Three broad types of automotive batteries were identified that have different cell cost and energy density requirements.
Cluster future battery innovations	The relative market size and commercial readiness of each battery cell opportunity was assessed. Four clusters were identified, showing the relative maturity and market opportunity size of different battery chemistries for the automotive market.
Assess the UK's relative strengths and opportunities	Merging the insights generated from the previous two sections, a qualitative assessment of the UK's capability in next generation automotive battery technology is presented. This section recommends which technologies the UK should pursue based on the best available information, the market, and the UK's competitive position.

Opportunities and challenges for automotive batteries

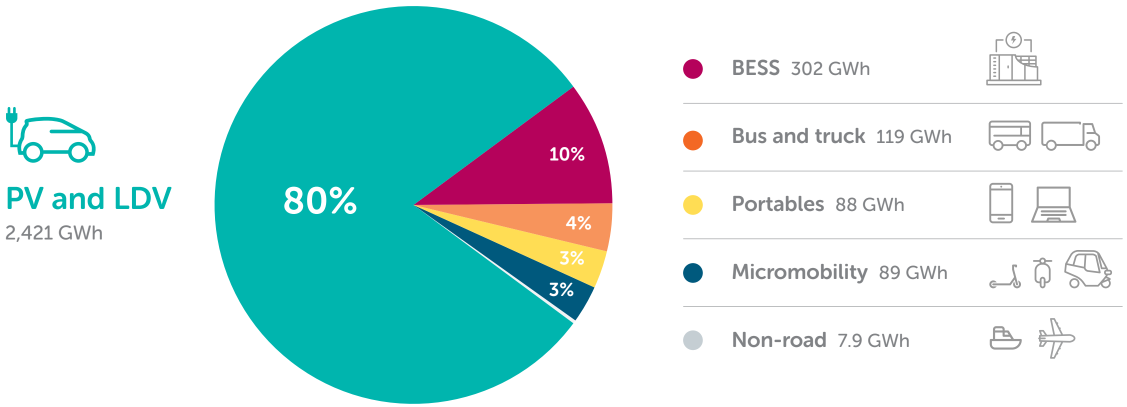
Key points

- Different cost and performance requirements will make batteries a differentiated product with a range of cell chemistries available.
- There is plenty of scope for innovation with differing price points.
- Volume passenger cars will require different batteries to sports cars, heavy goods vehicles, and the off-highway sector.
- By 2030, over 80% of battery demand will come from the automotive sector.

Batteries are a fundamental technology for a net zero economy and one of the fastest growing technology areas. Nations aiming to invigorate their native manufacturing bases are quickly establishing domestic battery industries to enable green growth. The automotive sector is predicted to be the dominant user of batteries in the future. By 2030, Rho Motion expect over 80% of the battery demand will come from the automotive sector, with adjacent sectors benefiting from the R&D and manufacturing advancements.

In fact, the sheer scale of automotive has been hugely beneficial to the battery industry. Battery pack prices have plummeted from an average of $1,100/kWh in 2010 to $132/kWh in 2021 according to Bloomberg New Energy Finance[1]. This has transformed electric vehicles from a niche product of the 2010s to one of the largest market opportunities of the 2020s. The improvements are not expected to stop – even in the face of short-term material price increases.

Figure 1: By 2030 approximately 80% of battery demand will come from the automotive sector



Source: Rho Motion

1. BNEF, 2021. Battery Pack Prices Fall to an Average of $132/kWh, But Rising Commodity Prices Start to Bite. Available from here.

By 2025, industry experts and OEMs are forecasting battery pack prices to hover around $100/kWh, falling further to around $80/kWh[2] by 2030. There are two routes to achieve $80/kWh at the pack level: reduce the cost of the input materials and maintain energy density, or increase the energy density at a greater rate than the cost of the new input materials.

While $80/kWh at the pack level by 2030 is in principle achievable, it can only be done if key materials like nickel, lithium, graphite and cobalt are low cost and secured in advance by OEMs and cell manufacturers.

APC analysis, shown in Figure 3, suggests that for nickel-rich chemistries such as NMC, future prices could vary a lot more than LFP. This is because NMC is extremely sensitive to the price of nickel, cobalt and lithium materials, whereas LFP is only sensitive to lithium.

This three-pronged challenge of reducing battery pack costs, improving energy density and avoiding material shortage disruptions is leading to a range of next generation technologies being considered by the industry.

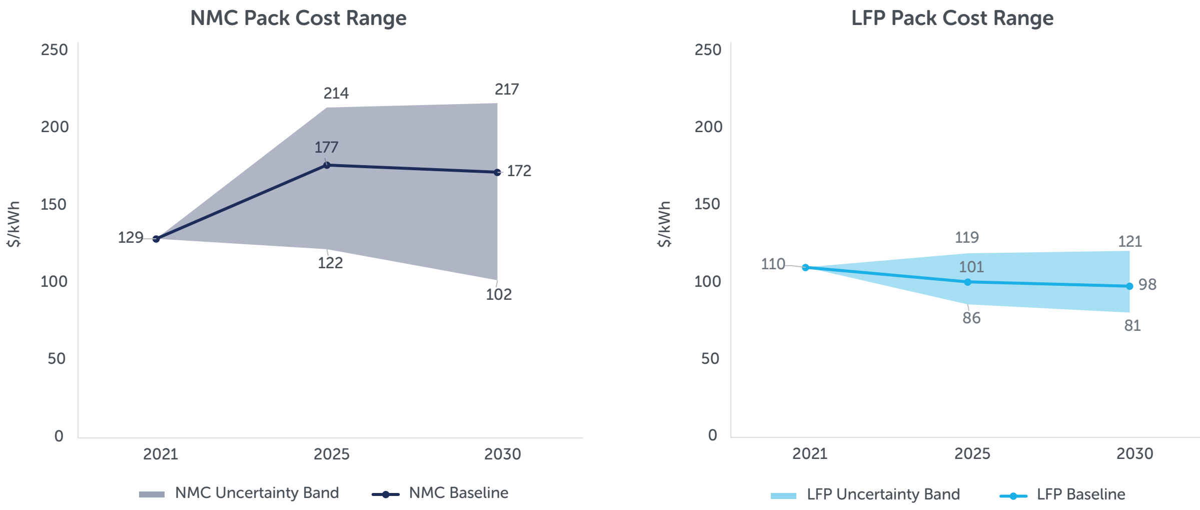
2. The lowest costs are only available to certain vehicle manufacturers who buy specific battery cells in high enough volumes. Specialist players, like many of the vehicle manufacturers in the UK, need higher performance chemistries at lower volumes. The key point is that batteries will be a differentiated product. This means there is plenty of scope for innovation with differing price points. Volume passenger cars will require different batteries to sports cars, heavy goods vehicles, and the off-highway sector. Moreover, batteries for aerospace and stationary storage will have their own performance and price points.

Figure 2: There is broad agreement in the direction of the cost of batteries, with $100/kWh achievable in 2025 and < $100/kWh achievable by 2030.

Battery Costs $/kWh	2020		2025		2030	
	Pack	Cell[1]	Pack	Cell[1]	Pack	Cell[1]
Bloomberg New Energy Finance	140	104[2]	85	63[2]	59[2]	39[2]
US Department of Energy	143	107	-	-	80	60[2]
Automotive Council UK	125	85[2]	97	70[2]	77	58[2]
Ford	165	123	100	75	80	60
Renault	150	113	100	75	80	60
GM	150	113	100	75	-	-
VW	133	100[2]	-	-	67[3] 93[3]	50 70
Tesla	129	97	73[4]	55[4]	-	-

1. Unless specified, cell costs are derived by multiplying the pack costs by 75%. 2. Cell $/kWh provided in the literature. 3. 50% cost reduction by 2030 for the 'Entry' Segment ; 30% for 'Volume' by 2030. 4. Based on Tesla's Battery Day Announcement Sept 2020 – 56% reduction before 2025

Figure 3: NMC is sensitive to the material costs of nickel and cobalt, materials absent in LFP batteries.



These sensitivities make it harder to forecast battery costs and suggest LFP is a safer bet where cost is key.
Where energy density is a key driver, e.g. for longer range or larger premium vehicles, NMC is still a good choice.

Clustering automotive battery types

Key points

The APC sees battery types broadly coalescing around three categories

- Entry level, low cost
- High volume performance
- High performance, specialist applications

Passenger car OEMs and their supply chains are gravitating towards three categories of batteries to suit their future EV portfolios:

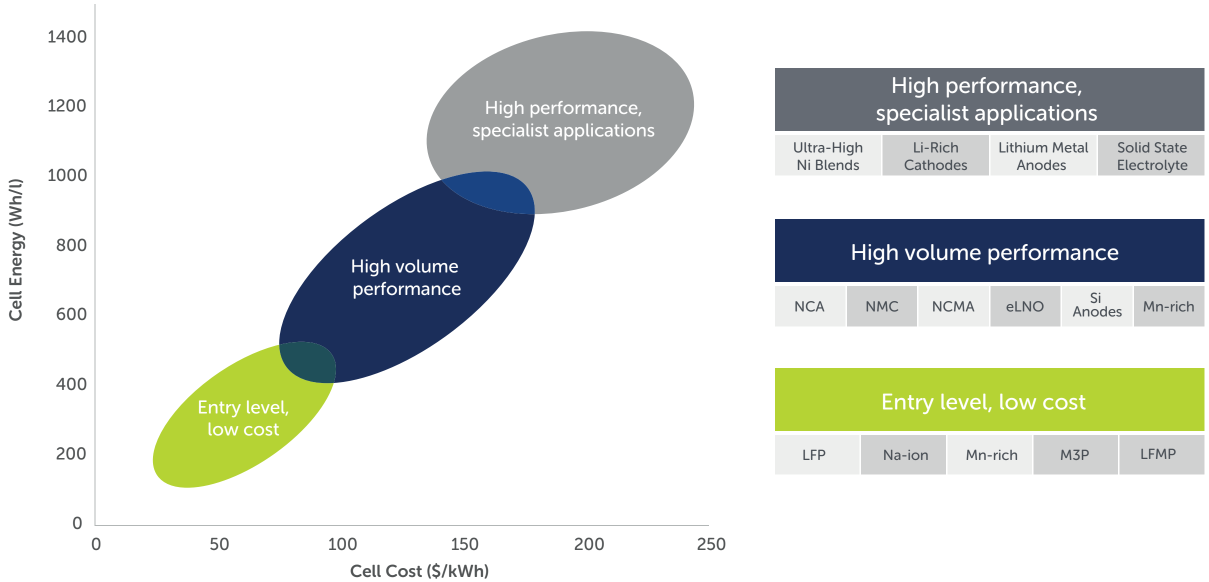
- Entry level, low cost
- High volume performance
- High performance, specialist applications

Vehicle manufactures communicate these categories differently but many are pursuing a multi-chemistry strategy based on their different products offerings.

Despite industry coalescing around three segments of batteries for light duty vehicles, significant divergence occurs surrounding the specific chemistry solutions. These differences occur for a number of reasons.

Some companies seem to be hedging against rising future raw material prices. Others are led by their cell manufacturers technology roadmaps. Some will prioritise specific vehicle attributes (say fast recharging) that require specific chemistries. Below is a brief discussion of the characteristics that define each category.

Figure 4: Cell cost and energy density needs for the three segments or clusters identified by the APC. RHS shows some example battery chemistries.



Entry level, low cost

Cost is king with acceptable energy density

For entry level, low cost solutions, a reduced energy density is acceptable if the $/kWh is low enough. Affordable vehicles that only do a modest daily mileage, such as city cars, are good candidates for these battery types.

The renewed interest in LFP batteries from VW, Ford and Stellantis underscores the demand for these types of chemistries from high volume automotive players. A recent development has been Tesla's and Mercedes' commitment to LFP chemistries outside of China. This suggests that the entry level, low cost chemistries could satisfy the needs of some high volume performance vehicles. This is due to novel LFP cell-to-pack concepts[3], more energy dense LFMP cells, as well as raw material price increases in other chemistries.

In the medium-term, CATL's commitment to manufacture sodium-ion cells by 2023 is a promising, albeit uncertain development. With a potentially lower cost floor than LFP, Na-ion could offer a viable alternative to lithium-ion. Other options include zero-cobalt chemistries like NMC370 from players like BASF or high voltage LNMO offered by companies like Haldor Topsoe.

3. LFP chemistries are less likely to experience thermal runaway events compared to NMC. Therefore, larger format cells can be safely packaged closer together within a battery pack. This reduces the need for elaborate thermal management systems and reduces the inactive volume and weight that comes with smaller format cells. This enables a higher 'cell-to-pack' ratio – the BYD Blade battery is a good example of this.


Tesla Model Y
Courtesy of Tesla, Inc.

High volume performance

Good energy density at a reasonable cost

Offering high energy densities at a modest cost, OEMs in Europe and North America tend to gravitate towards NMC and NCA batteries. These chemistries currently dominate in Western markets as they offer the highest range and are best suited to vehicles that travel long distances, experience high utilisation or are heavier.

A series of incremental innovations are occurring in these high volume performance cells that simultaneously improve the energy density and reduce the $/kWh. Nickel-rich NMCs such as NMC9.5.5[4] and NCA95 cathodes will enter the market in the next 2-3 years. On the anode side, increasing amounts of silicon will be added alongside graphite, rising from 5% silicon content today to as high as 20% in the next few years.

Another flavour of high volume performance includes the NCMA cells offered by LG Energy Solutions which are being used in the Tesla Model Y in China and General Motor's Hummer EV. Other innovations include NMx chemistries being commercialised by SVolt which eliminate cobalt but claim to maintain the performance of NMC811.

4. NMC chemistries tend to have numbers after them which refer to the relative mass fractions of each element. For example, NMC111 means approximately equal amounts of nickel, manganese and cobalt. NMC9.5.5 means 90% nickel and 5% each of cobalt and manganese.

Mercedes Benz will incorporate Sila's silicon anode chemistry for the first time in the electric G-Class

High performance, specialist applications

New chemistries are needed to enhance energy or power density

High performance, specialist batteries will offer a step change in energy and power density, but will initially command a price premium. Therefore, high performance vehicles are likely to be the first customers. However if these technologies can be manufactured at scale effectively, they could also trickle down into the high volume performance segment, displacing some existing technologies in the long-term.

The last decade of lithium-ion development in the automotive sector has focused on enhancing cathodes. The next decade is expected to herald new developments in anode technology and the electrolytes that can enable them. The two most promising anode choices that can achieve a step change in performance are lithium metal anodes and silicon dominant anodes.

New anodes and electrolytes have not been validated at the pack level for automotive applications. Therefore, one route to prove the viability of new chemistries before graduating to the automotive sector is to focus first on smaller applications like consumer electronics or medical devices. Sila Nanotechnologies are using their Si anode technology in watches, Ilika have developed solid state batteries for medical devices and StoreDot initially introduced their rapid charge anode concept for consumer electronics.

Cross-cutting themes that drive innovation

In addition to battery innovations being developed to suit certain vehicle categories, all automotive batteries have additional criteria to meet which is generating cross-cutting innovations:

LCA considerations

Battery recycling	Water-based solvents	Design for disassembly

Emission targets, recycling mandates and eliminating harmful chemicals are incentivising companies to improve the environmental impact of batteries. This has driven extensive research into water-based solvents for high-nickel cathodes, industrial scale battery recycling facilities and designing cells / packs for disassembly.

Manufacturing improvements

Dry electrodes	Lithiation techniques	Metal-to-electrode

Li-ion manufacturing has focused on scaling up to reduce costs over the last few years. The next phase will feature innovations that optimise existing manufacturing processes to reduce cost and improve performance. Examples include pre-lithiation techniques, combining electrode manufacturing process steps, and dry electrode manufacturing.

Safety improvements

HV liquid electrolytes	New current collectors	Next-gen separators

As more EV battery cells are placed on the market, enhancing safety has become a high priority. Despite ever improving manufacturing processes, the risk of on-board cell failure increases as EV volumes rise. Therefore to avoid costly recalls, some OEMs may pay a premium for safer cells. Enhanced current collectors, next generation separators and more stable liquid electrolytes for high voltage cathodes are being explored to reduce the likelihood of thermal runaway events.

Supply chain vulnerability

LFP	Na-ion	Li-S	Mn-rich

Increased demand for nickel, cobalt and lithium are driving up prices in the short to medium term. Alternative chemistries that are made from more abundant and cheaper materials like LFP, sodium-ion and manganese-rich are expected to increase in market share. Depending on the duration and severity of the raw materials price spike, these lower cost chemistries could replace a significant portion of high-nickel chemistries.

Commercial readiness versus size of opportunity for next generation chemistries

Key points

- The APC has assessed the commercial opportunity and readiness for numerous battery cell related technologies.
- Eight innovations stand out as promising developments that could be introduced into the automotive market by 2025 or just after.

The APC considered numerous cell-level innovations and ranked them using a qualitative 2x2 graph[5]. The horizontal axis assesses the commercial readiness while the vertical axis ranks the size of the opportunity. The metrics used to assess the commercial readiness and size of opportunity are listed below and were qualitatively scored from 1-5. From the analysis, four broad categories emerged. These were created to help structure battery chemistry innovations and should not be viewed as rigid categories. A more detailed explanation of each category is defined below.

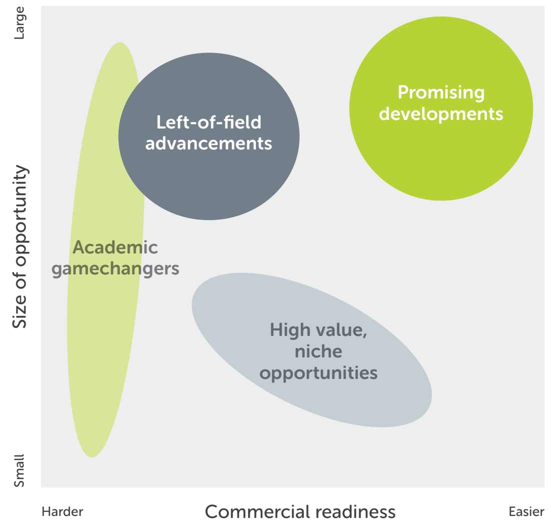
Figure 5: Battery technologies were characterised into four categories based on opportunity size and commercial readiness. The technologies are listed in each category. This report focussed on the promising developments.

Left-of-field advancements
~7-10 years from the first automotive product

- Advanced liquid electrolytes for Li-metal
- Conversion reaction cathodes
- Novel current collectors
- Metal to electrode technologies
- Disordered rocksalt cathodes
- Semi-solid / hybrid solid state

Academic gamechangers
~10-15+ years from the first automotive product

- Lithium-air
- Metal-ion
- Multi-valent chemistries
- Structural batteries



Promising developments
~3-5 years from the first automotive product

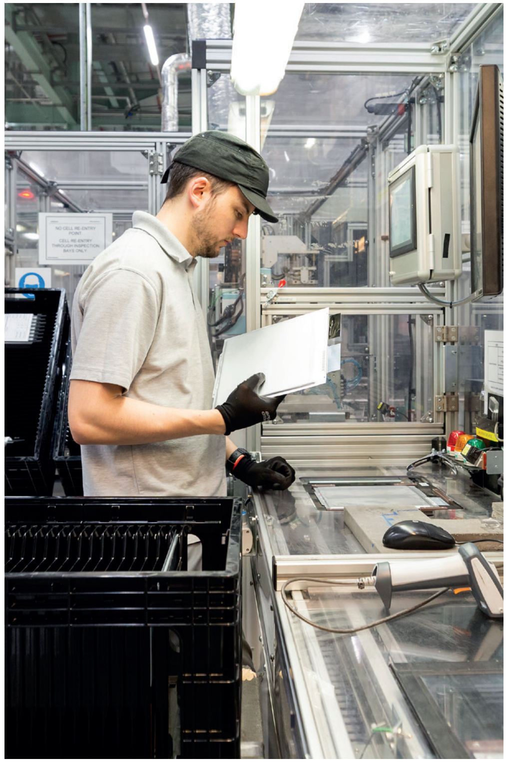
- Silicon dominant anodes
- Manganese rich cathodes
- Battery recycling
- Li-Metal anode
- Solid State Electrolytes
- Dry electrode manufacturing
- Lithiation Techniques
- Sodium-ion

High value, niche opportunities
~5-7 years from the first automotive product

- Li-S
- Hybrid ultra-capacitors
- Zinc-ion
- Advanced sodium-nickel chloride
- Rapid charge anodes (i.e., Nb)

Size of opportunity metrics (score 1-5)	Commercial readiness metrics (score 1-5)
Potential global market size	OEM / cell manufacturer interest
Cross-sector spillover	TRL / MRL level for automotive
How widespread it could be for automotive	Future supply chain / technology challenges
	Potential of existing lithium-ion eroding USP

5. It is important to stress that this 2x2 is a snapshot at a point in time from an automotive perspective. Individual technologies could move from one bucket to another based on the sector you are looking at. The APC maintains a watching brief on all the clusters and continuously reviews assumptions based on the latest industry insights



Promising developments

Investments in these technologies appear lucrative based on the current trajectory of the automotive industry. There is a broad consensus that, despite some technical challenges, these technologies could be 3-5 years away from being commercialised. Numerous OEMs and cell manufacturers have these technologies on their roadmaps and have invested significant sums of money to get to market first. The challenge for the UK is that large, global companies are working on these innovations. Therefore, the UK's offering must be highly competitive.

A UK case study: Promising developments

Solid state electrolytes

The UK is nurturing a solid electrolyte ecosystem with some encouraging recent investments. In academia, the Faraday Institution's £15.3m SOLBAT programme is conducting fundamental research on anodes, cathodes as well as viable manufacturing processes for solid state batteries.

Other later stage R&D activity includes the LiMHiT project. Involving Nissan, this project is exploring how thin, thermally evaporated lithium metal anodes interact with sulfide based electrolytes. The Automotive Transformation Fund's SOLSTICE project investigated potential manufacturing routes and production equipment for Ilika's oxide based material.

Left-of-field advancements

This category is higher risk with the innovations still predominately in academia, but, with some pioneering companies accelerating their development. The technology challenges are greater than in the 'promising developments' category and attract less automotive sector investment. However, if the technical challenges are overcome in this category, a large market size is possible.

A UK case study: Left-of-field advancements

Advanced Li-ion cathodes

NMC, NCA and LFP currently dominate the automotive sector. Despite the huge interest in Ni-rich and Mn-rich cathodes as the next innovations for the automotive sector, there is research also being conducted in other advanced lithium-ion cathodes.

The FutureCat (£9.9m) and CATMAT (£11m) projects, funded by the Faraday Institution, are assessing the viability of lithium rich and disordered rock salt cathodes (DRX). These could offer very high theoretical energy densities and potentially lower costs. Moving away from just chemistry, NEXTRODE (£12m) are looking at new approaches to slurry casting and particle alignment to enhance the performance of both new and existing cathode materials.

High value, niche opportunities

These are innovations which are unlikely to feature in traditional high volume automotive segments. However, given their unique performance characteristics, they may carve out profitable niches if the remaining few technical barriers are overcome. Other sectors such as aerospace, energy storage or consumer electronics could benefit more from these innovations.

A UK case study: High value, niche opportunites

Niobium anodes

As EV adoption increases, the requirement for rapid charging batteries could emerge as more people rely on public charging. There are many approaches to improving charging speeds, both from a materials and cell level, right through to the BMS, pack level and thermal management strategies.

From the research labs of Cambridge University, the UK has established two promising start ups: Nyobolt and Echion Technologies. Both companies have developed niobium based anodes that exhibit better fast charging capability than silicon or graphite based anodes and offer better energy density than LTO.

Academic-led game changers

These chemistries are being researched by academic institutions and are long-term technologies. This makes their market potential difficult to assess. However, if they deliver on their lab-based claims, they could present a huge market opportunity.

A UK case study: Academic-led game changers

Seeding future opportunities[6]

In June 2022, The Faraday Institution awarded £2 million to 16 small, focused projects in areas not covered within the existing UK battery research portfolios. The projects covered a range of different technologies spanning anodes, cathodes, electrolytes and novel battery concepts.

For example, the Universities of Nottingham and Oxford are investigating novel gas diffusion polymers to enhance the capacity and rate of lithium-air batteries. Another project involving the Universities of Strathclyde and Nottingham is exploring the use of magnesium-based batteries, focusing on suitable electrolytes that offer acceptable cycle life. Fundamental research projects like this are crucial in challenging the status quo of battery research and give the UK a competitive advantage.

6. Faraday Institution, 2022. Seed project details. Available from here.

Promising battery cell innovations for the UK automotive sector

This section of the report individually assesses the technologies identified in the 'promising developments' cluster. The following analysis only focuses on the promising developments as these are most likely to be mass-market in the next 3-5 years. The metrics used to assess the size of opportunity and UK capability are listed below.

Key points

- The eight promising developments identified by the APC are ranked against UK capability.
- Silicon Dominant Anodes, Battery Materials Recycling and Sodium-Ion emerge as large opportunities with significant UK capability.

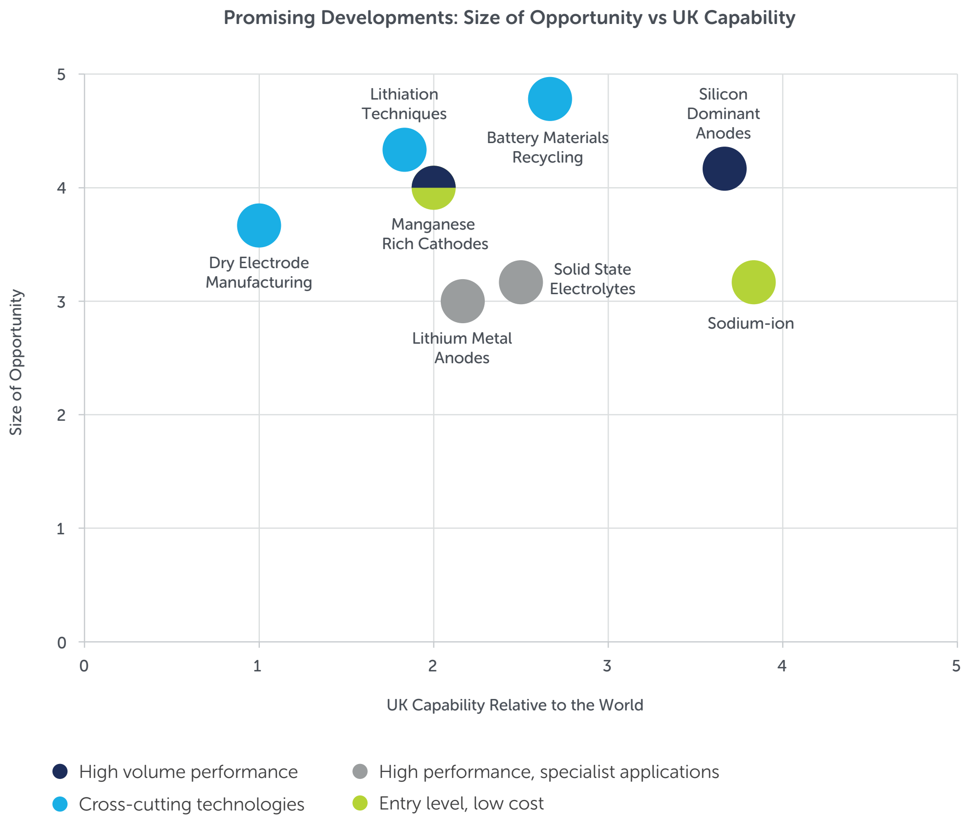
UK capability relative to the world (score 1-5)

The UK's relative R&D capability
The UK's relative manufacturing capacity
The UK's relative supply chain capability

Size of opportunity metrics (score 1-5)

Potential global market size
Cross-sector spillover
How widespread it could be for automotive

Figure 6: Promising developments: Size of opportunity vs UK capability – the promising developments are plotted against opportunity size and UK capability to exploit the opportunity. Opportunities are colour-coded according to the cluster they belong to. Multiple colours are used to indicate technologies suited to more than one category.



Innovation	Technology description	Rationale for being in 'promising developments'	Relevant UK activity
Silicon dominant anodes	Anode formulations and structures where silicon is the dominant material. It excludes business as usual silicon blended with graphite.	Scored as a high market opportunity as it is easier to integrate into existing Li-ion manufacturing lines than Li-metal with only slightly lower performance capability.	Companies like Nexeon and Talga Technologies are conducting R&D in high Si content anodes. EV Metals Group also acquired Johnson Matthey's Si anode patents. Alkegen also manufacture silicon fibres in the UK. FBC projects such as SABRE & SPICE are further anchoring Si anode capability across the UK supply chain[7].
Manganese rich cathodes	Cathode formulations that contain a high proportion of manganese. These include layered oxides (NMC730), olivines (LFMP, LMP) and spinels (LMO, LNMO).	Mn-rich is an alternative option that could be attractive for European companies who are behind China in the LFP race but want a low cost, decent performing chemistry. Its market share potential is high given the broad range of applications it could apply to.	UK capability is relatively low as only Johnson Matthey had IP in LFMP / LNMO which has now been acquired by EV Metals Group. Vale could process battery grade manganese but currently does not in the UK.
Industry scale battery materials recycling	Manufacturing techniques that enable the mechanical disassembly and cost-effective separation of black mass for automotive battery packs to ensure a circular economy.	All automotive batteries will need to be recycled at some point, even if some do go into second-life applications. Battery recycling is a very significant market opportunity in light of the proposed EU Battery Directive and expected raw material shortages.	The UK has several shredders and metal recyclers but only has a couple of companies with emerging capability in hydrometallurgical or direct separation processes. The UK currently lacks battery recycling at industrial scale. It also lacks an anchoring cathode manufacturer to use the recycled materials and achieve a circular economy. The Faraday Institution ReLIB project is looking at novel ways to efficiently separate the materials in battery cells.
Solid state electrolytes	A term that captures oxide, sulfide and polymer-based materials for electrolytes. It does not include hybrid or semi-solid approaches.	Many OEMs such as VW, Toyota, Renault, Nissan and BMW are committed to solid state batteries as an end point in their battery development. Given the continuous improvements of liquid based NMC and LFP, there are some question marks around whether it could enter the highest volume segments.	The UK's capability is fair due to Ilika's capabilities in oxide-based materials. The UK does seem to lack capability in sulfide and polymer-based electrolytes. Since it is currently unknown which technology can effectively be scaled up to service automotive, the UK lacks a balanced portfolio of options.

● High volume performance ● Cross-cutting technologies ● High performance, specialist applications ● Entry level, low cost

7. Faraday Battery Challenge, 2021. Faraday Battery Challenge: funded projects to date. Available from here.

Innovation	Technology description	Rationale for being in 'promising developments'	Relevant UK activity
Lithium metal anode	Using lithium metal via a thin foil, vapour deposited or 'anodeless' format to replace graphite in the anode.	Lithium metal offers excellent energy density, but big questions remain over how to manufacture lithium metal at high volumes and integrate it into Gigafactories.	The UK has some lithium chemical companies, like Livent and Leverton Lithium, who could manufacture precursors for lithium metal anodes. The UK currently lacks companies with the process capability to turn this into a Li-metal anode.
Dry electrode manufacturing	Processes that eliminate the need for harmful solvents such as NMP in the manufacture of battery cells.	This is a battery cell-agnostic innovation so has a large market potential for a range of different cathode and anodes that use liquid-based slurries. Dry electrode manufacturing is being pioneered by the likes of Tesla, LG and Fraunhofer with first introduction likely to occur in the mid 2020s.	There is little evidence of any UK activity in this area. Building capability would require a UK-based cell manufacturer acquiring the right IP and processes.
Lithiation techniques	Approaches that optimise the use of lithium in the cell formation and aging process.	Advanced pre-lithiation techniques will likely be integrated into existing cell manufacturers plans over the next 2-3 years. It is also an enabler for a more effective adoption of silicon dominant anodes so are a big market opportunity.	No UK company is actively looking at pre-lithiation techniques so this would have to be adopted by a large cell manufacturer.
Sodium-ion	A secondary battery (i.e., same intercalation principles as lithium-ion) which uses sodium instead of lithium in the cathode or anode.	Significant industry activity has occurred over the last year. This includes CATL announcing Na-ion cells for 2023 and other Chinese manufacturers such as HiNa. There is also ramp-up activity in the supply chain from cathode manufacturers (Altris, Natrium) and anode players (Phillips 66). The acquisition of Faradion by Reliance Industries has also bolstered the credibility of Na-ion as a potential automotive solution. However, no major vehicle manufacturer has publicly committed to using Na-ion yet.	The UK is well-placed with sodium carbonate producer Tata Chemicals and hard carbon producer Phillips 66 manufacturing products in the UK. There is also strong R&D presence in Na-ion through the likes of Faradion, Deregallera and AMTE Power hence the UK's capability is ranked very high. Faraday Battery Challenge projects, such as NEXGENNA and HIPERCARB, have been key to enhancing UK research capabilities across the sodium-ion value chain.

● High volume performance ● Cross-cutting technologies ● High performance, specialist applications ● Entry level, low cost

What does this mean for the UK?

Key points

- The UK needs to attract cathode and anode manufacturers to build an ecosystem around new electrode concepts and recycling.
- Manufacturing and process R&D should be conducted to investigate cost effective manufacturing methods for Si dominant anodes.
- The UK should double down on its strength in Na-ion and aim for cells that reach >200Wh/kg. The establishment of a Na-ion industry also benefits the UK's growing energy storage market.

Below is a summary table of the UK players and prominent international players in each area to give an indication on the competition the UK faces. Some thoughts on the implications for the UK in each of the automotive categories of batteries is offered below.

Across all these technology segments the UK is currently a fast follower compared to China, the US and some European nations. The UK has some exceptional R&D activity, a few big companies and some good start-ups in most of the areas identified as crucial for UK automotive batteries. However, to excel in these technology areas the UK should adopt a parallel approach of quickly growing domestic capabilities while encouraging FDI to augment these. The UK Battery Industrialisation Centre (UKBIC) plays a crucial role in attracting next generation battery cell chemistries, with UK academia key in providing a steady flow of high-quality R&D and skilled talent.

Figure 7: Summary of promising technologies with colour coding to categories showing the UK and international players

Category	Technology	Potential UK Players*	Examples of Leading Players Abroad*
Cross cutting technologies	Battery Recycling	RS Bruce, uRecycle, Johnson Matthey, UKBIC, EMR, Fenix	Umicore, BASF, Gangfeng Lithium, Li-Cycle, Redwood Materials, CATL
	Dry Electrodes	PPG, UKBIC	Tesla, VW, AM Batteries, LG
	Lithiation Techniques	N/A	Varta, LG, Nanoscale Components
High performance, specialist applications	Solid State Electrolytes	Ilika, Britishvolt, Emerson & Renwick, UKBIC, Morgan Advanced Materials	Solid Power, Quantumscape, Prologium, Factorial Energy, SES, Blue Solutions
	Lithium Metal Anodes	Livent, Leverton Lithium, Sigma Lithium	Abermale, Gangfeng Lithium, Hydro-Quebec, Li-Metal
High volume performance	Silicon Dominant Anodes	Nexeon, Talga Technologies, EV Metals Group**, Alkegen	StoreDot, Enevate, Enovix, Sila Nanotechnologies
	Manganese Rich	EV Metals Group**, Vale, iCoNiChem	BASF, Haldor Topsoe, NanoOne, Umicore
Entry level, low cost	Sodium-ion	Faradion, Deregallera, AMTE Power, Phillips 66	CATL, HiNa Energy, Haldor Topsoe, Natron, Tiamat, Altris AB

*Non-exhaustive
**Assumed to have acquired Johnson Matthey's battery material IP

Cross-cutting technologies

These technologies appear attractive to the UK but are reliant on large companies deciding to pursue them. Both dry electrode manufacturing and lithiation strategies require the cell manufacturer to integrate them in their Gigafactories. This means that companies such as Envision-AESC, Britishvolt or AMTE Power must develop the IP in-house or acquire it from a smaller research company.

With regards to battery recycling, new methods to cost effectively and sustainably process black mass should be explored, especially methods that can successfully extract and lithiate cathodes which could make recycling LFP profitable. A UK-based cathode manufacturer is needed to anchor black mass processing in the UK.

High performance, specialist applications

Given the UK's vehicle production base, high performance specialist application technologies seem attractive to the UK's automotive sector future R&D pathway. With regards to lithium metal and solid state electrolytes, some fundamental questions remain around how appropriate existing lithium-ion processes are to manufacture them.

Given this uncertainty, UK R&D should explore approaches that investigate the high volume manufacturing routes for solid state and lithium metal. This is to ascertain whether existing manufacturing assets can be utilised without compromising the performance or low cost potential of a solid state battery. Alternatively, new approaches may be needed to maximise the performance and achieve the ambitious $/kWh and energy density targets set by proponents of solid state batteries.

FDI is also needed in solid state electrolytes to encourage a balanced portfolio between oxides, sulfides and polymers. At the moment, the UK has good capability in oxides but no polymer or sulfide capability.

High volume performance

This category will likely be characterised by incremental innovations in existing high-end cell chemistries such as NMC9.5.5 and 20% Si anodes. Innovation and manufacturing will likely be carried out by established cell manufacturers so the UK should be aiming to attract these companies and their respective cathode and anode suppliers into the UK. Silicon dominant anodes will likely enter this market shortly after first entering high performance, specialist applications. Therefore, advanced manufacturing and process R&D should be conducted to investigate cost-effective manufacturing methods for Si dominant anodes.

Newer cathode chemistries are more likely to be adopted if they can reduce reliance on critical materials. Therefore, some forms of zero-cobalt / Mn-rich chemistries could be adopted in this segment as they offer good performance at an acceptable cost. In the mid-2030s, innovations like lithium metal and solid state electrolytes are forecast to reach a cost point where they are viable in the high volume performance segment of the market.

Entry level, low cost

Given the already low costs LFP can achieve, it is understandable that there are not many low-cost innovation routes that are open for the UK: only Mn-rich and Na-ion. The rising interest in LFMP is a commercialisation risk to these technologies, potentially making them uncompetitive before they are introduced. However, diversifying away from a chemistry that China holds such dominance in makes strategic sense.

In the case of Na-ion, there are also benefits in moving away from lithium as it experiences supply shortages in the short to medium term. The UK should double down on its strength in Na-ion and aim for cells that reach >200Wh/kg. In the meantime, the establishment of a Na-ion industry could also benefit the UK's rapidly growing energy storage market. First generation Na-ion technology is suitable for this market so could help de-risk the initial investment for the automotive sector.

Get in touch

Contact

Funding for
Battery projects

Dan Bunting
Head of Business Development
dan.bunting@apcuk.co.uk

Discuss
Battery technology

Dr Hadi Moztarzadeh
Head of Technology Trends
hadi.moztarzadeh@apcuk.co.uk

Contributors

APC Technology Trends Team
Luke Bates
Dr Chris Jones
Dr Hadi Moztarzadeh
Jon Regnart

Organisations
Faraday Battery Challenge
Faraday Institution
UK Battery Industrialisation Centre
Rho Motion

Glossary

APC	Advanced Propulsion Centre
BESS	Battery Energy Stationary Storage
Li-S	Lithium Sulfur
LFP	Lithium Iron Phosphate
LFMP	Lithium Iron Manganese Phosphate
LMO	Lithium Manganese Oxide
LNMO	Lithium Nickel Manganese Oxide
Na-ion	Sodium-ion
Nb	Niobium
NCA	Nickel Cobalt Aluminium
NCA95	NCA that has 95% nickel with 5% cobalt and aluminium
NCMA	Nickel Cobalt Manganese Aluminium
NMC	Nickel Manganese Cobalt
NMC370	NMC that has 30% nickel, 70% manganese and 0% cobalt
NMC 811	NMC that has 80% nickel, 10% manganese and 10% cobalt
NMx	Generic term for a mid / high manganese cathode with nickel in
OEM	Original Equipment Manufacturer (vehicle manufacturer)

Advanced Propulsion Centre
University Road
Coventry CV4 7AL
+44 (0) 2476 528 700

www.apcuk.co.uk

@theapcuk
Advanced Propulsion Centre UK

ADVANCED PROPULSION CENTRE UK

Accelerating Progress