White Paper 4

The future of **EV Technology**

Dr Euan McTurk
Plug Life Consulting
Vehicle Remarketing Association

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Introduction

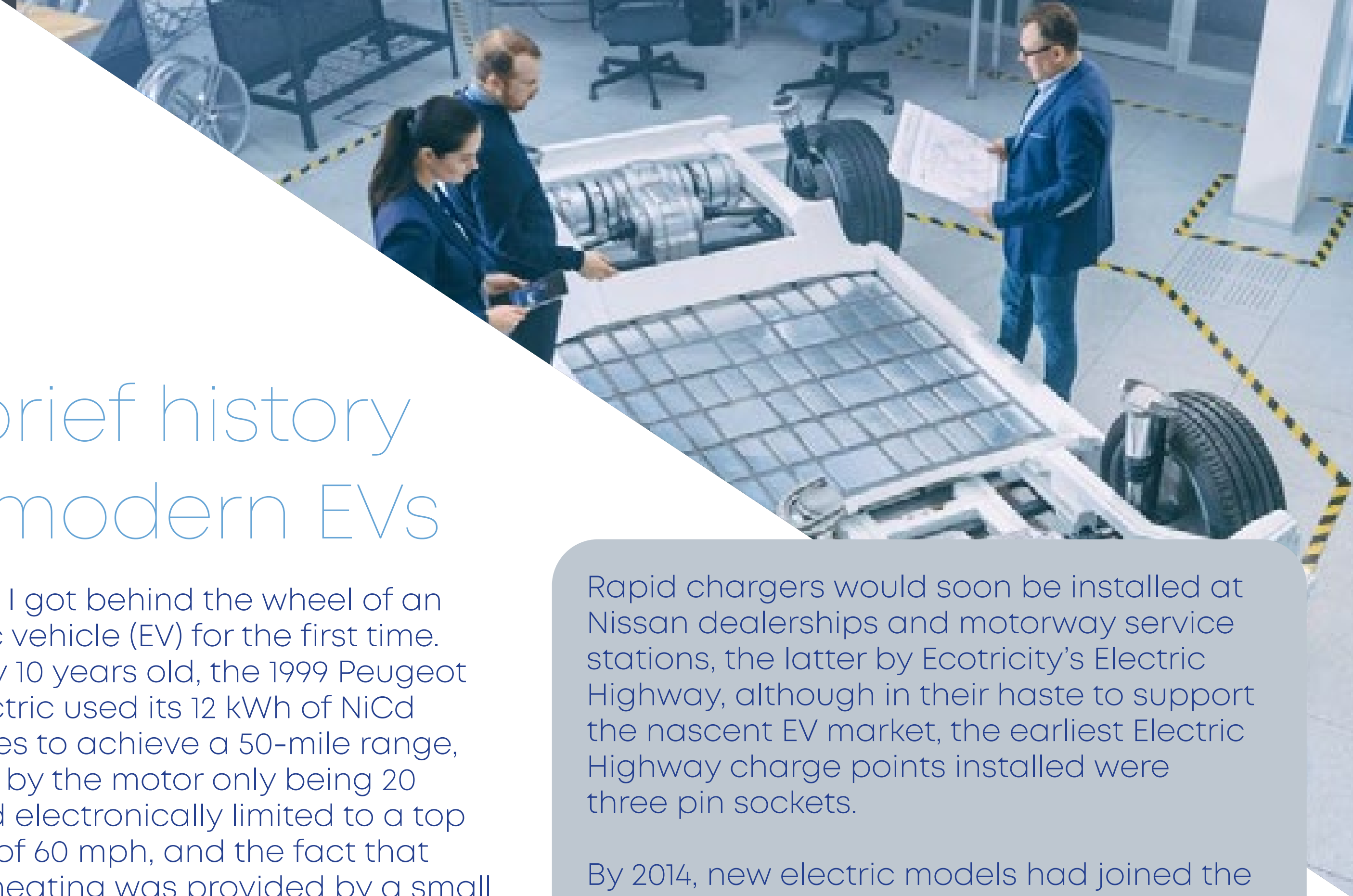
Welcome to our fourth white paper on electric vehicle (EV) remarketing. It looks in detail at forthcoming developments that will move EVs forward in all kinds of areas but especially battery range, charging speed, cost and durability.

These are subjects that everyone in remarketing needs to know about. You might not comprehend the hardcore chemistry – and I'm alongside you there – but having a knowledge of different battery types, and their characteristics, is becoming an essential part of understanding the EV landscape.

Advances are being made very regularly that mean this landscape is rapidly changing, and our document is designed to inform those involved in the used market about the advantages and weaknesses of the technology employed in vehicles they will be handling very soon. I found it very interesting and I am sure you will, too.

As ever, we'd love to hear your feedback on this white paper and others in the series, as well as your ideas for topics that you might like us to cover in the future.

Philip Nothard
Chair
VRA



A brief history of modern EVs

In 2009, I got behind the wheel of an electric vehicle (EV) for the first time. Already 10 years old, the 1999 Peugeot 106 Electric used its 12 kWh of NiCd batteries to achieve a 50-mile range, helped by the motor only being 20 kW and electronically limited to a top speed of 60 mph, and the fact that cabin heating was provided by a small petrol heater. The 106 Electric was responsible for the installation of the first on-street charge point in the UK - a three pin household socket which would give it a full charge in about six hours. My own 106 was charged on the three-pin socket in my garage, and periodically requested an electrolyte top-up with deionised water through a watering system under the bonnet.

Not long after I began my own electric adventure, the first wave of modern, lithium-ion equipped EVs was launched on the UK market - the Tesla Roadster, Mitsubishi i-MiEV and Nissan LEAF. The Roadster was an outlier based on its performance, range and charging requirements, while the i-MiEV and LEAF both achieved about 60-80 miles per charge. In addition to electric resistive cabin heating and maintenance-free batteries with capacities approaching double that of the 106 Electric, the i-MiEV and LEAF introduced the first widespread EV charging formats to the UK - Type 1 for about three times faster AC charging than a three-pin socket, and CHAdeMO for rapid charging within 30 minutes at up to 50 kW.

Rapid chargers would soon be installed at Nissan dealerships and motorway service stations, the latter by Ecotricity's Electric Highway, although in their haste to support the nascent EV market, the earliest Electric Highway charge points installed were three pin sockets.

By 2014, new electric models had joined the market, including the Renault Zoe, BMW i3 and Tesla Model S. While the former also had ranges of approximately 80 miles per charge, the Model S boasted a 200 mile-plus range, faster charging at over 120 kW through its proprietary supercharger network, and a futuristic, screen-heavy interior that changed vehicle design for almost all vehicle manufacturers. The i3 was notable for introducing CCS to the UK market - the Combined Charging System that integrates the Type 2 AC charging format with DC rapid charging. The LEAF still had a 24 kWh battery, but was now made in Sunderland, and featured a heat pump for more efficient cabin heating.

Fast forward a decade and we've had a format war (which Type 2 and CCS won), a boost of rapid charging power into triple kW figures for most new EVs, and such a rapid advance in battery chemistry and design that the Nissan LEAF's range per charge has trebled. The i3's range had doubled, using the same physical size of battery pack, by 2019.

My 106 Electric was placed in a transport museum in 2017.

Looking to the future

The EV has come a long way in a short time, with many of the latest entry-level models featuring ranges and charging speeds that would have been considered premium as recently as the late 2010s. Simultaneously, the charging network has grown exponentially. Zap-Map reported a 45% increase in the number of public charge points across the UK in 2023, and large charging hubs with double figures of 100 kW-plus high-power chargers have become the norm at motorway service stations and even some urban petrol stations.

However, what other improvements are we likely to see in the EV market in the near future?

Diversification of battery chemistries

Throughout the 2010s, EVs almost exclusively used NMC batteries (lithium nickel manganese cobalt oxide) or the similar NCA (lithium nickel cobalt aluminium oxide). These are both part of a broad church of lithium-ion chemistries and have different sub-variants depending on the ratio of materials used. Also included in that group is LFP (lithium iron phosphate), which is cheaper, safer (doesn't catch fire when damaged), more ethical (no cobalt, or indeed nickel or manganese, instead using cheaper and more abundant materials) and longer lasting, but has a lower energy density. That is, it can't provide as long a range as NMC or NCA.

The EV market is already starting to see a diversification in the chemistries used. In the early 2020s, tweaks to LFP's chemistry, and advances in battery pack design that allowed a higher capacity to be installed in the same space, resulted in Tesla launching the first modern LFP-equipped electric car, the Standard Range Tesla Model 3, with over 200 miles per charge. Other manufacturers were quick to take note, and now LFP is found in the MG4, BYD's electric vehicles, and some Maxus vans amongst others. Volkswagen, Ford and Mercedes are among the legacy vehicle manufacturers that have announced plans to offer LFP-equipped EVs in their line-up shortly. However, there are more battery diversifications coming soon.

"Tweaks to battery chemistry and the pack design has led to a higher capacity EV."

Longer-range batteries

Progress is being made towards chemistries that will result in a step change in the range per charge of electric vehicles. This includes swapping the graphite anode (carbon negative electrode) for silicon, which needs less space to do the same job of safely storing lithium, and can also charge quickly compared to today's leading battery packs, due to lithium's ability to enter and exit its structure quicker than graphite.

Another exciting cell variant under development is solid-state, which replaces the separator and liquid electrolyte with a single, solid design, allowing for further space-saving measures to be adopted. This means a pure lithium anode can be used, which allows 100% of the anode to store energy, rather than needing bulky graphite or silicon to store the lithium that holds the energy. Numerous car manufacturers have invested in silicon anode and solid-state start-ups, including Volvo, Volkswagen, Hyundai, Stellantis and Mercedes. The latter says it will use silicon anode batteries in its EQG, to be launched in 2024.

Progress is also being made on the cathode (positive electrode). LFP batteries don't have as much range as NMC or NCA batteries because their voltage is lower. However, some manufacturers are starting to add manganese or other metals to LFP (LMFP), which boosts the voltage and brings the energy contained in the pack closer to that of NMC or NCA, without using cobalt. Tesla is rumoured to be planning to use LMFP in the Standard Range Model 3 soon.

More efficient packaging

The 2020s have already seen an improvement in battery packaging with the introduction of cell-to-pack for many LFP-equipped EVs. A battery pack is traditionally made up of many modules connected together - individual boxes that contain several cells, which in turn are placed together in a bigger box which is the battery pack case. Cell-to-pack does away with individual modules and directly connects the cells together to form one big pack.

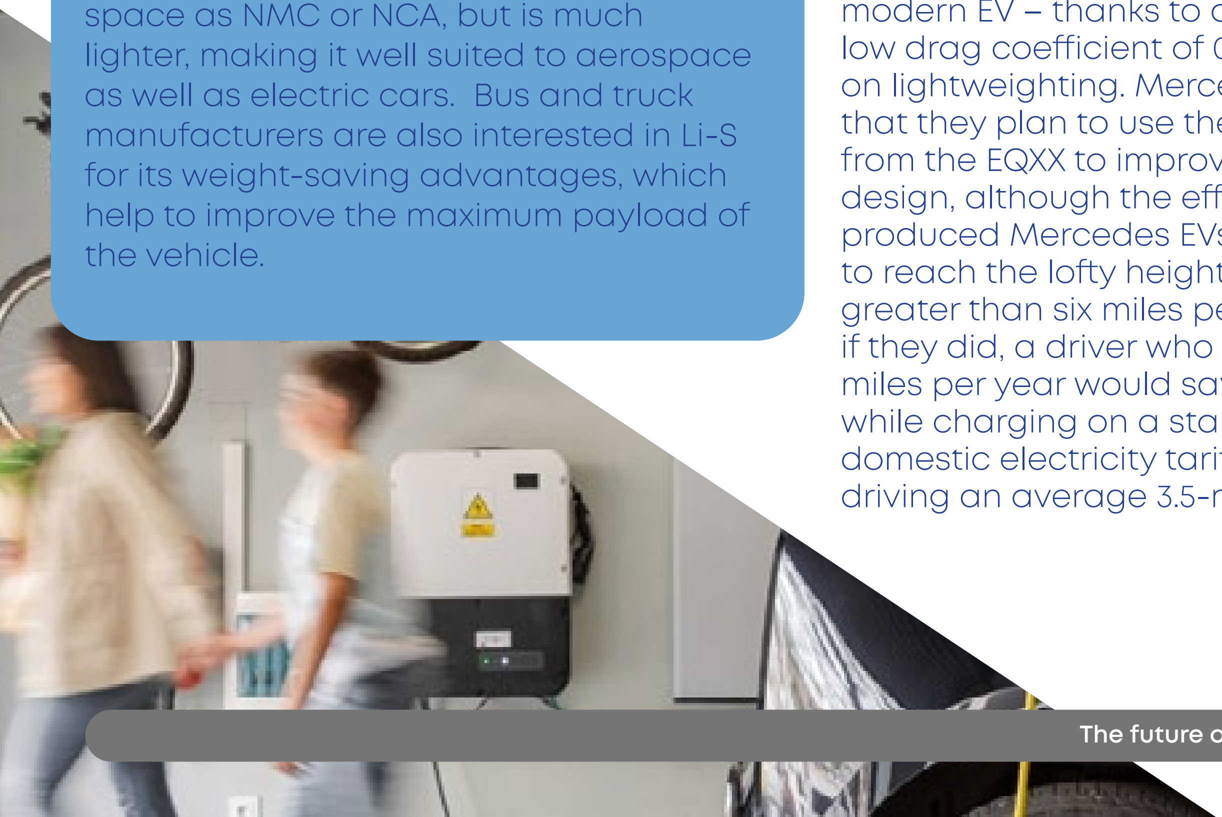
Some EV manufacturers plan to take this further by developing cell-to-chassis, where the cells become structural components, thus saving even more of the weight and bulk associated with the battery pack case. Cell manufacturers are also experimenting with electrode-to-pack, whereby the physical pouch or can of each cell, is done away with entirely.

All of these approaches mean more space used for storing energy and less dedicated to the bulk that makes up the components that store energy. An excellent analogy of this is the design of the fuel tank in the wings of jet planes: the wings don't contain a tank that contains the fuel; they are the tank that contains the fuel.

Lighter batteries

In 2023, tabloids went into overdrive with anti-EV stories and particularly latched onto battery weight as a negative point about EVs. However, the silicon anodes, solid-state chemistries and packaging efficiencies mentioned above offer two options - more range achieved within the same space for the battery pack, or the same range achieved with a smaller, lighter pack. In an era of 200–300-mile range EVs and increasingly plentiful high-power charging hubs nationwide, electric cars can already drive for longer than your average driver's bladder, and can rapid charge within the average dwell time at a UK motorway service station. So, while some ultra-long-range battery options may be introduced to the UK market, many buyers may opt for a smaller, cheaper – and yes, lighter – pack.

On top of this, there are exciting developments with lithium-sulphur (Li-S) cells. These replace the metal-based cathode with cheap and abundant sulphur, of which the UK has plentiful supply, ironically from petrol and diesel refining. Li-S takes up roughly the same space as NMC or NCA, but is much lighter, making it well suited to aerospace as well as electric cars. Bus and truck manufacturers are also interested in Li-S for its weight-saving advantages, which help to improve the maximum payload of the vehicle.

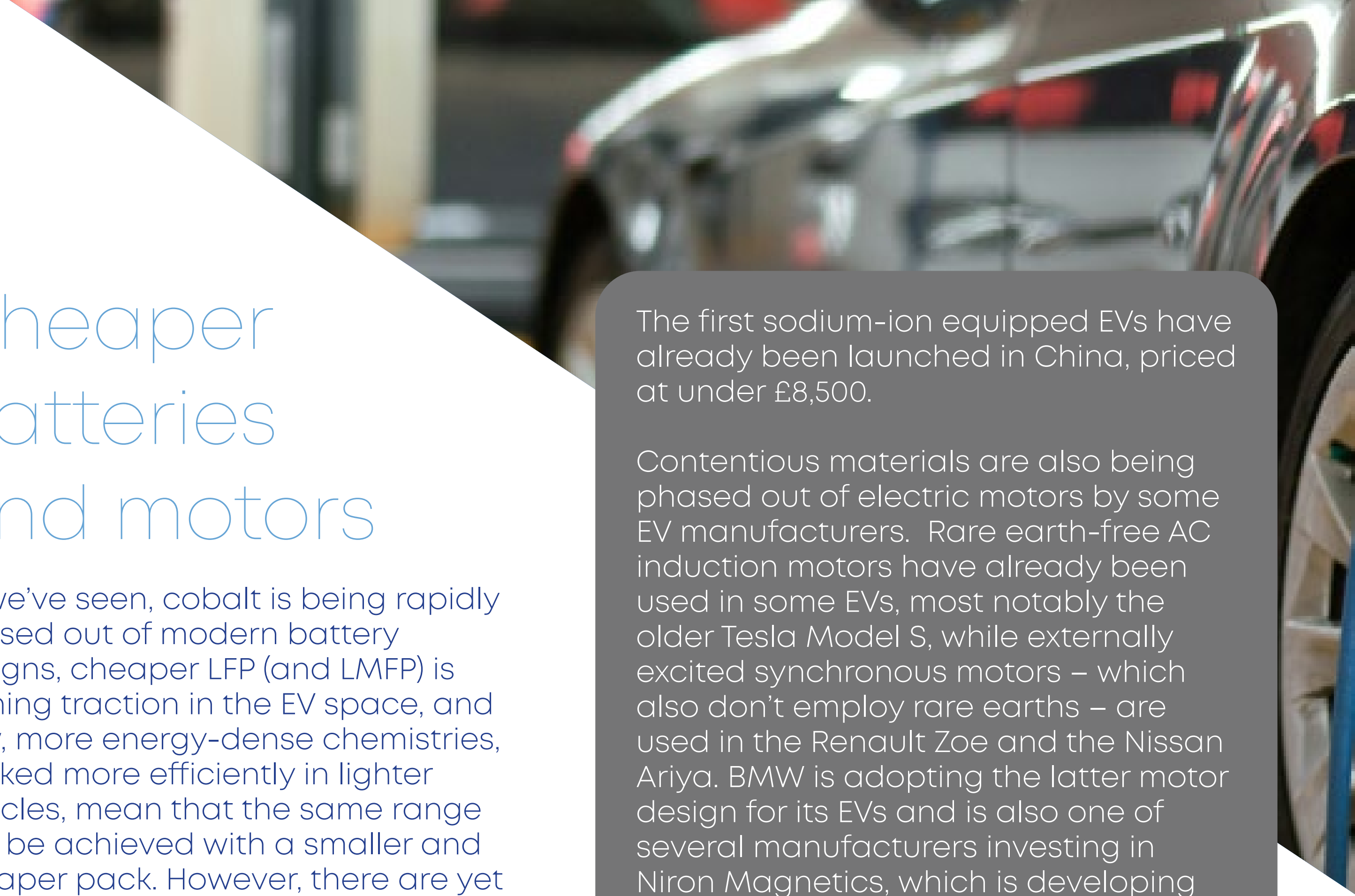


More emphasis on efficiency

Over the past five or so years, there has been a glut of electric SUVs on the market, which are often big, unwieldy and inefficient. Thankfully, some automotive manufacturers are paying close attention to efficiency, aerodynamics and lightweighting. Tesla has done a surprisingly good job at these, with their Model 3 being one of the most efficient EVs on the road, therefore resulting in one of the cheapest electricity bills for the driver.

One of the Model 3's few competitors from an efficiency perspective is the highly aerodynamic mark one Hyundai Ioniq EV, which was nicknamed the "windknife" by its owners on account of its seemingly physics-defying efficiency, achieving up to 140 miles per charge from a battery pack that had a slightly lower capacity than the 110-mile-per-charge 30 kWh Nissan LEAF, which itself is not an inefficient EV by any means.

The Mercedes Vision EQXX concept placed so much emphasis on efficiency that it achieved over 620 miles on a single charge from a 100 kWh battery – roughly double the miles that a battery of that size would achieve in a typical modern EV – thanks to an exceptionally low drag coefficient of 0.17 and a focus on lightweighting. Mercedes has said that they plan to use the lessons learnt from the EQXX to improve their EV design, although the efficiency of mass-produced Mercedes EVs would be unlikely to reach the lofty heights of the EQXX's greater than six miles per kWh. That said, if they did, a driver who covers 8,000 miles per year would save £286 annually while charging on a standard 30p/kWh domestic electricity tariff, compared to driving an average 3.5-miles-per-kWh EV.



Cheaper batteries and motors

As we've seen, cobalt is being rapidly phased out of modern battery designs, cheaper LFP (and LMFP) is gaining traction in the EV space, and new, more energy-dense chemistries, packed more efficiently in lighter vehicles, mean that the same range can be achieved with a smaller and cheaper pack. However, there are yet more chemistries coming that could reduce costs even further. Sodium-ion removes not only cobalt and nickel, but lithium too, replacing it with far more abundant and affordable materials. Additionally, copper isn't needed for the anode current collector (the foil onto which the anode is adhered, which connects it to the terminal on the outside of the cell), so this is replaced with much cheaper aluminium.

On top of this, unlike lithium-ion cells, sodium-ion cells can be fully flattenend to zero volts without damage, so can be fully discharged before being shipped, which mitigates the need for expensive packaging and safety measures. Therefore, not only are sodium-ion cells cheaper to make but they're cheaper to ship, resulting in a double saving compared to lithium-ion cells. The downside is that sodium-ion doesn't have as high an energy density as lithium-ion, but recent advances have brought it close to where LFP was a few years ago, which is good enough for city cars.

The first sodium-ion equipped EVs have already been launched in China, priced at under £8,500.

Contentious materials are also being phased out of electric motors by some EV manufacturers. Rare earth-free AC induction motors have already been used in some EVs, most notably the older Tesla Model S, while externally excited synchronous motors – which also don't employ rare earths – are used in the Renault Zoe and the Nissan Ariya. BMW is adopting the latter motor design for its EVs and is also one of several manufacturers investing in Niron Magnetics, which is developing permanent magnets for motors that don't require rare earth elements. The latter is particularly exciting because permanent magnet motors, which until now have used rare earths in the magnets, tend to be more efficient than rare earth-free induction motors, although progress is being made in closing this efficiency gap. This elimination of rare earths not only de-risks – and potentially shortens – the electric motor supply chain, but reduces costs to the manufacturer and to the customer.

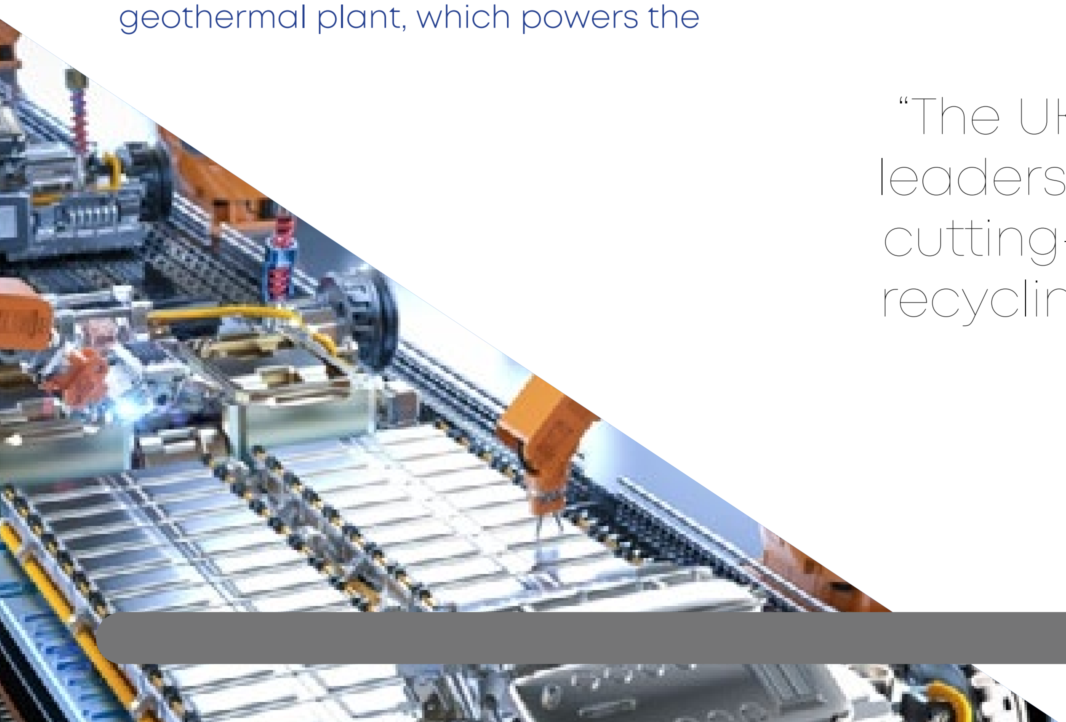
"There are yet more battery chemistries coming that could reduce costs even further."

More ethical batteries

The elimination of cobalt, nickel and even lithium have already been discussed above. However, where these continue to be used - and they will be needed for long-range EVs - new batteries using these materials shall soon be mandated by the EU to contain an increasing percentage of recycled content. This will inevitably have positive implications not just for EV battery recycling, which is already a rapidly growing sector worldwide, but for the recycled content of new EV batteries in the UK too. The latest recycling techniques can recover close to 100% of the materials from EV batteries, at a fraction of the energy and cost of older, less efficient techniques, and the UK is one of the leaders in developing cutting-edge battery recycling techniques.

There will, of course, be a continuing need for more raw materials to be extracted. Again, the UK is a leader here, with Cornish Lithium developing an ultra-efficient Direct Lithium Extraction technique that extracts lithium from geothermal waters in old mines, using a fraction of the fresh water of conventional techniques and yielding three times as much useable material – as well as using the heat of the geothermal waters to power a geothermal plant, which powers the entire process.

Cobalt is typically a by-product of copper and nickel mining, and its ongoing elimination from EV batteries means that there is a surplus of cobalt supply forecast by 2030. The Fair Cobalt Alliance has been established to tackle human rights concerns in the Democratic Republic of Congo, ensuring that wages are reasonable, working conditions in artisanal mines are safe (note that these make up a small proportion of DRC's output, which mostly comes from large mines operated by global mining giants that have to play by the rules), and that children are in schools, not mines. Battery and EV manufacturers are amongst the Fair Cobalt Alliance's members, but oil and gas companies – which use cobalt to refine petrol and diesel – are conspicuous in their absence.



"The UK is one of the leaders in developing cutting-edge battery recycling techniques."

"EVs are between 20-60 times less likely to catch fire than a petrol or diesel car."

Safer batteries

The latest statistics show that EVs are already between 20-60 times less likely to catch fire than a petrol or diesel car – and that figure is based on a fleet that mostly uses NMC and NCA batteries, which may catch fire if severely damaged. However, LFP is already improving battery safety. Even when severely damaged, LFP may vent hot gas but doesn't catch fire. New battery designs are further improving safety, not least BYD's Blade LFP cells, which if drilled through when fully charged don't even vent gas and only get slightly warm, reaching around 60°C.

EVs with lithium-ion batteries are still a relatively new technology, and new firefighting techniques will be developed that improve the response to EV battery fires that do take place. Some of the latest developments can extinguish EV battery fires in a matter of minutes with vastly reduced water use compared to existing strategies.

Plug and play charging

Previously the reserve of Teslas at superchargers, AutoCharge is starting to be rolled out across several charging networks, including Fastned and Ionity. This allows an EV to be simply plugged into a charger, without needing an app or card, and the EV and charger automatically sort out billing and initiate the charging session. Charger manufacturer Tritium recently announced support for AutoCharge on its latest chargers, and key charging industry stakeholders like Hubject support plug and charge across multiple networks, and makes and models of EV and charger.

AutoCharge is unfortunately difficult to universalise, since it involves so many different manufacturers, rather than Tesla's vertical integration that allowed them to enable plug and charge on their supercharger network from day one. However, strong progress is being made that should allow drivers of modern EVs to have a seamless, card- and app-free public charging experience in the near future.

Faster charging

Some of the leading battery developments described above support faster charging times than today's EV battery packs. For example, StoreDot's silicon anode-based cells can rapid charge to an 80% state of charge within 10 minutes, and UK-based Nyobolt has developed an ultra-fast charging chemistry that, when installed in an electric sports car, rapid charged on a real-world high-power charger in six minutes. However, there is an important caveat - Nyobolt's EV had a comparatively small 35 kWh battery pack, and today's fastest high-power chargers are typically 350 kW, with some pushing the CCS standard up to 400 kW. So, the Nyobolt EV was already maxing out the capability of the 350 kW charger that it used (35 kWh divided by 350 kW = 0.1 hours = 6 minutes). Therefore, a higher capacity battery pack would require a higher power charger to achieve the same six-minute charging time.

While one megawatt chargers are being rolled out for electric heavy goods vehicles, it is unlikely that new chargers for cars and vans will routinely exceed 350 kW. This is because higher power chargers require more expensive hardware and grid connections, alongside other cost implications such as capacity charges, which would inevitably be passed onto the driver in a higher tariff per kWh. It remains to be seen if drivers will be willing to wait a few extra minutes to charge their EV at a lower cost, rather than take the financial hit and charge faster especially given that, as mentioned earlier, a modern EV can already rapid charge within the average dwell time at a UK motorway service station. If your car is ready to leave the service station at roughly the same time that you are, do you need it to charge faster?

That said, batteries that can be repeatedly charged faster will likely generate less heat when charging at conventional rapid charging speeds, increasing longevity.

Wireless charging

Wireless charging is regularly suggested as an exciting future technology. To date, there have been several different approaches trialled, all of which required an expensive retrofit to the vehicle. Really, a standard needs to be agreed – like CCS – that will be adopted by all EV and charger manufacturers. Such a standard was recently announced by SAE International, which may be adopted by some EV and charger manufacturers, depending on cost and customer demand. However, the most likely outcome is that wireless charging will find specific uses such as taxi charging in taxi ranks, and Motability customers who have limited mobility and find a wireless home charger much easier to use than a conventional cable.

"It is unlikely that new chargers for cars and vans will routinely exceed 350 kW."

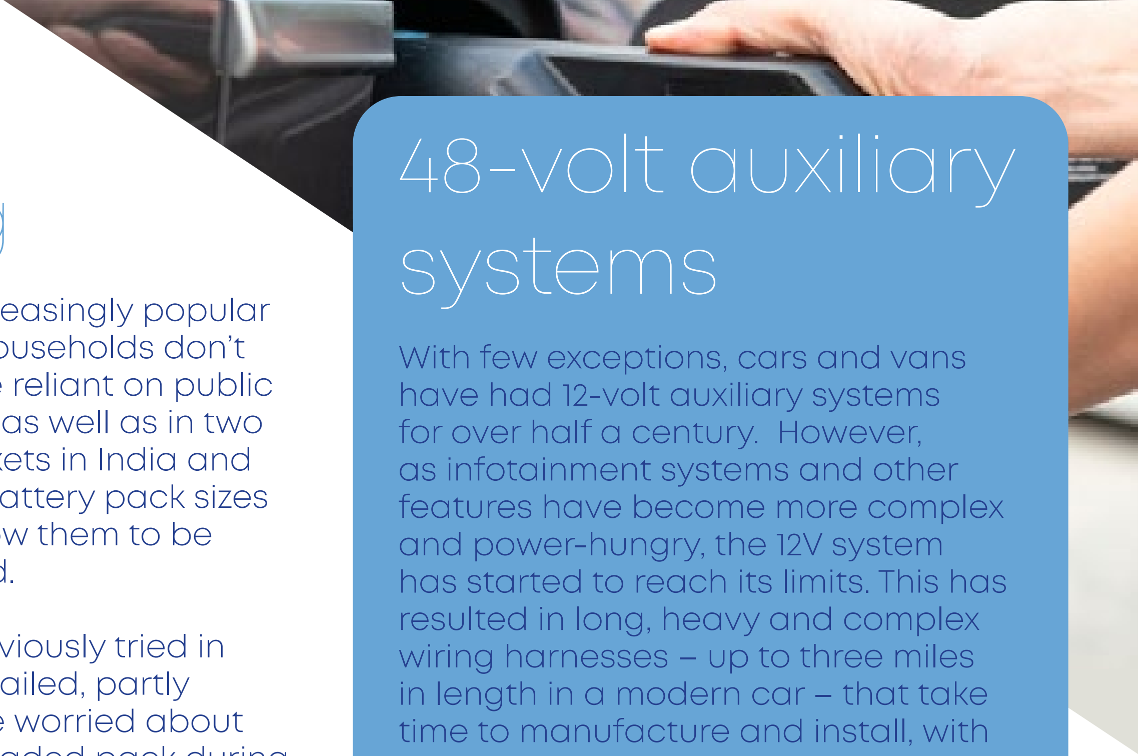
Battery swapping

Battery swapping is increasingly popular in China, where many households don't have driveways and are reliant on public charging infrastructure, as well as in two and three-wheeler markets in India and Southeast Asia, where battery pack sizes are small enough to allow them to be easily swapped by hand.

The technology was previously tried in Europe by Renault and failed, partly because EV drivers were worried about receiving a heavily degraded pack during the swap. Now that worries over battery longevity are largely allayed, the main objection to battery swapping is that it entails a monthly lease for a pack, which has also fallen out of fashion with UK and European customers. Indeed, it may transpire that a battery swapping EV with a separate battery lease element is more difficult to sell second hand.

Furthermore, EV batteries come in different shapes, sizes and chemistries, so swapping stations would have to hold stock of battery packs for many different makes and models of EV. Chinese EV manufacturer Nio is building battery swap stations in continental Europe, but recently put most of its UK plans on hold.

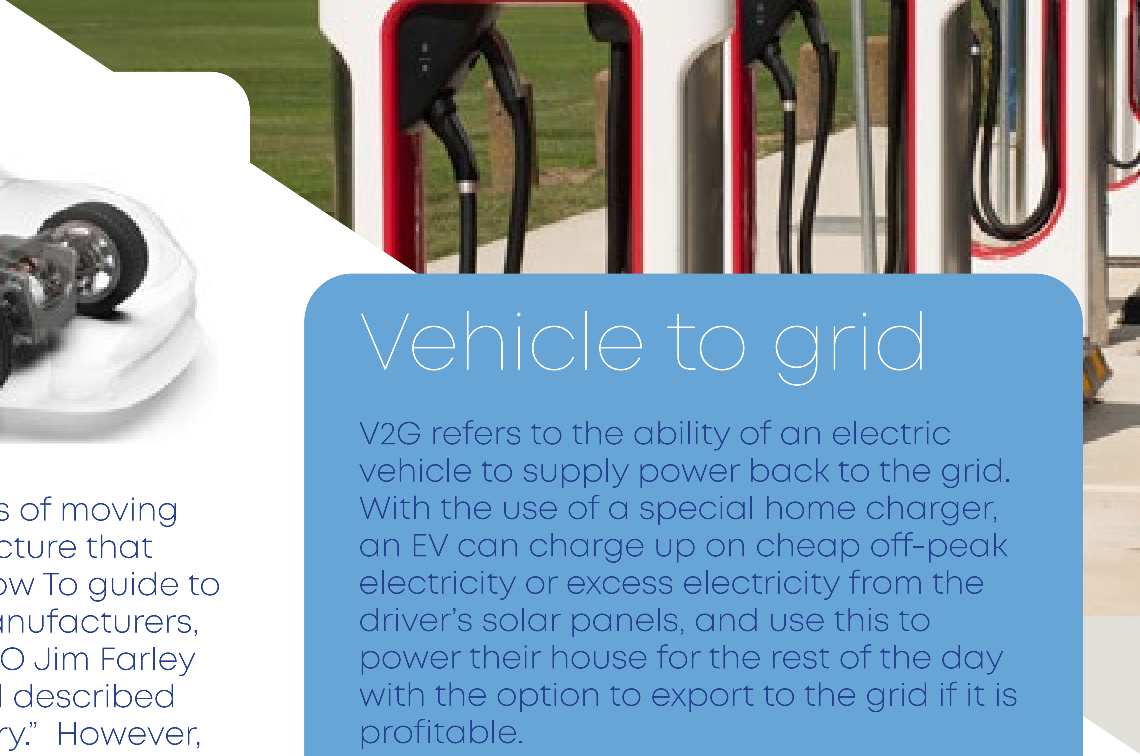
It remains to be seen if battery swapping will take off in the UK or Europe, but it is likely to be the reserve of niche applications, such as fleets of identical makes and models of EV. For example, battery swapping for fully electric road train HGVs in Australia is a prime example of where the technology works well.



48-volt auxiliary systems

With few exceptions, cars and vans have had 12-volt auxiliary systems for over half a century. However, as infotainment systems and other features have become more complex and power-hungry, the 12V system has started to reach its limits. This has resulted in long, heavy and complex wiring harnesses – up to three miles in length in a modern car – that take time to manufacture and install, with considerable material and labour costs.

Tesla has taken the decision to adopt a 48V auxiliary system in its new Cybertruck. Since power is equal to current multiplied by voltage, a quadrupling of voltage means that the same power demand can be met with a quarter of the current, which means that smaller-diameter, lighter, cheaper cables can be used. High-voltage, low-current systems are also more efficient than a low-voltage, high-current approach, translating more of the energy stored in the battery into useful work, such as running the air conditioning unit, with less heat loss in the wires (note that this is also explains why some EV manufacturers are moving from 400V traction batteries to 800V systems, such as the Porsche Taycan and Hyundai IONIQ 5). Furthermore, the higher voltage system allows the CAN bus to be replaced with a more efficient, ethernet-esque data bus that allows components to be daisy chained in a much shorter, cheaper network, rather than needing separate data cable runs to every single component in the vehicle. All of this has resulted in the Cybertruck's wiring harness allegedly being reduced from several miles to just 100 metres in length.



Such are the advantages of moving to a 48V auxiliary architecture that Elon Musk even sent a How To guide to the CEOs of other car manufacturers, including Ford, whose CEO Jim Farley gratefully received it and described it as "great for the industry." However, this wasn't an entirely philanthropic move from Elon - the more EV manufacturers that start to move to 48V systems, the more that component manufacturers will start to offer 48V components such as lights and wiper motors, creating more choice and a cheaper bill of materials.

AI becomes an electrochemist

In an interesting recent use of Artificial Intelligence, academics at Pacific Northwest National Laboratory teamed up with Microsoft to use AI to find a promising new battery material out of 32 million possible structures. Within a fortnight, Microsoft's AI had identified a material that reduced lithium content by up to 70% by utilising sodium in an otherwise lithium-ion cell. This would have taken academics years to research using conventional methods. PNNL is currently testing the material to assess its suitability for mass production. This use of AI opens up the possibility of massively accelerated battery research with the simultaneous optimisation of ethics, cost, safety, charging speed, extreme temperature tolerance and lifespan.

Vehicle to grid

V2G refers to the ability of an electric vehicle to supply power back to the grid. With the use of a special home charger, an EV can charge up on cheap off-peak electricity or excess electricity from the driver's solar panels, and use this to power their house for the rest of the day with the option to export to the grid if it is profitable.

CHAdeMO was capable of V2G from day one, and CCS is having its V2G capability finalised now. No doubt there will be CCS V2G-capable EVs on the market eventually – and EVs with bidirectional onboard chargers that allow V2G to be performed using a standard Type 2 home charge point – but for now, V2G is the reserve of Sunderland-built (2014 onwards) Nissan LEAFs and e-NV200s.

For anyone who's worried about battery life being shortened by being charged and discharged more often for V2G duties, WMG at the University of Warwick undertook a comprehensive lab study on how V2G could impact battery health and found that, if done properly, V2G can actually extend battery life by 10%.

"AI opens up the possibility of massively accelerated battery research."

What about older EVs?

Despite all of the advances covered in this white paper, older EVs appear to be avoiding obsolescence. Lithium-ion batteries are comfortably outlasting expectations, even on the oldest BMW i3s and Renault Zoes from the early 2010s. Meanwhile, the average UK annual mileage is around 8,000 miles per annum and the average commute is 26 miles – comfortably within the range of these EVs, even once their range starts to noticeably degrade.

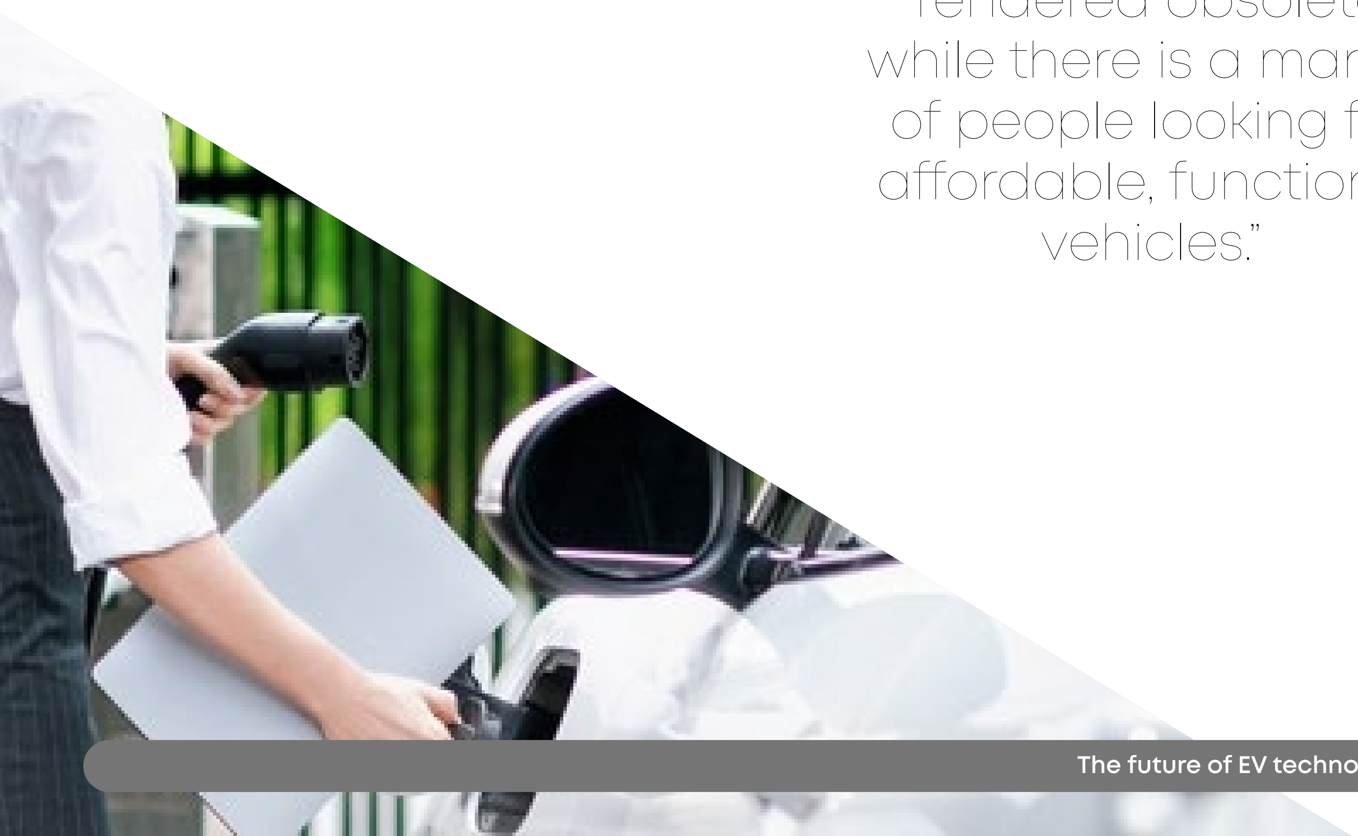
The EV market appears to have something of a floor below which the value of the oldest, shortest-range EVs have not dropped. For example, at the time of writing, a 10-year-old Nissan LEAF or Renault Zoe is typically worth over 50% more than a 10-year-old Vauxhall Astra. This is in part because many buyers want an affordable box on wheels that gets them from A to B cheaply, reliably and ideally cleanly, which arguably includes many climate-conscious, young, first-time car buyers. There is also interest from those who want to dip their toes into the water regarding EVs and buy one as a second vehicle for local journeys.

So, although electric vehicle technology has an increasingly exciting future, it is worth reiterating that older EVs will not be rendered obsolete while there is a market of people looking for affordable, functional vehicles that do the job that they require.

Any modern EV can charge at a Type 2 public charge point, and even although CHAdeMO has lost the format war, the majority of rapid charging locations still offer CHAdeMO today, which is good news for prospective buyers of Nissan LEAFs in particular. Indeed, I'm aware of the enduring versatility of even the oldest EVs courtesy of my electric road trip from Edinburgh to Skye in my "short range" Nissan LEAF (https://youtu.be/8DBGN1ReT_s).

Incidentally, that LEAF is powering my house as I write this article, justifying my decision to hold onto it after buying a high mileage 2015 Tesla Model S. In fact, such is the reliability and versatility of older EVs that my 106 Electric will soon emerge from its transport museum home and return to the road, 25 years after it was made.

"Older EVs will not be rendered obsolete while there is a market of people looking for affordable, functional vehicles."



Vehicle Remarketing Association

The Vehicle Remarketing Association exists to promote networking and provide essential briefings for companies who work in the handling, selling, inspection, transportation and management of used vehicles.

We aim to help our members – who together process more than 1.5 million cars, vans and trucks every year – to forge new and productive links as well as share good practices to help them prosper in a rapidly changing and challenging environment.

The VRA creates a crucial environment where industry issues are addressed by the sector's leading experts in a collegiate and constructive manner. As a result of this successful approach, the Association has expanded by 25% since 2020.

The key objectives of the VRA are:

- To create better awareness of the activities of professional remarketing
- To raise standards and generate an accepted best practice across the industry for key disciplines like vehicle inspection
- To provide a much needed voice to represent the sector in the trade and consumer media on issues which affect remarketing suppliers and customers
- To provide an effective focal point through which major matters concerning those involved in remarketing can be addressed
- To raise the profile and professionalism of the industry to ensure recruiting good quality people becomes much easier
- To generate views and opinions of the industry for use in lobbying for the greater good of the remarketing sector
- To create a forum where members can network, exchange views, debate key topics and share best practice

For more information contact:

info@thevra.co.uk

www.thevra.co.uk