rho motion magazine

The energy transition in the post pandemic era

In this issue:

- EV & ESS battery market update
- Battery chemistry & technology roadmaps
- EV motor & platform developments
- Decarbonising the mining sector

Introduction to the magazine

Adam Panayi
Managing Director, Rho Motion

Hello and welcome to the first edition of the Rho Motion Magazine. The magazine will be published quarterly and will feature news and analysis from our team as well as external contributors. I would like to thank the Advanced Propulsion Centre (APC), Platinum Group Metals (PGM) and EnPower for their fantastic contributions to this edition.

The purpose of the magazine is to draw attention to issues that we feel are important to the progress of the energy transition, with a focus on EV, ESS, charging and battery technology developments. This will draw on our ongoing research and analysis from our regular data and publications, as well as our bespoke consulting work. As such this issue will cover updates on EV chemistry and pack size developments, an analysis of EV production from my colleague Charles Lester, the latest developments in ESS from Iola Hughes, EV motor technology from Will Roberts, 800v EV platforms and their impact on EV charging from Mina Ha, an update on the latest battery capacity investments in China from Yu (Frank) Du, and electrification at the mine site from Terry Scarrott. I hope you enjoy the magazine.

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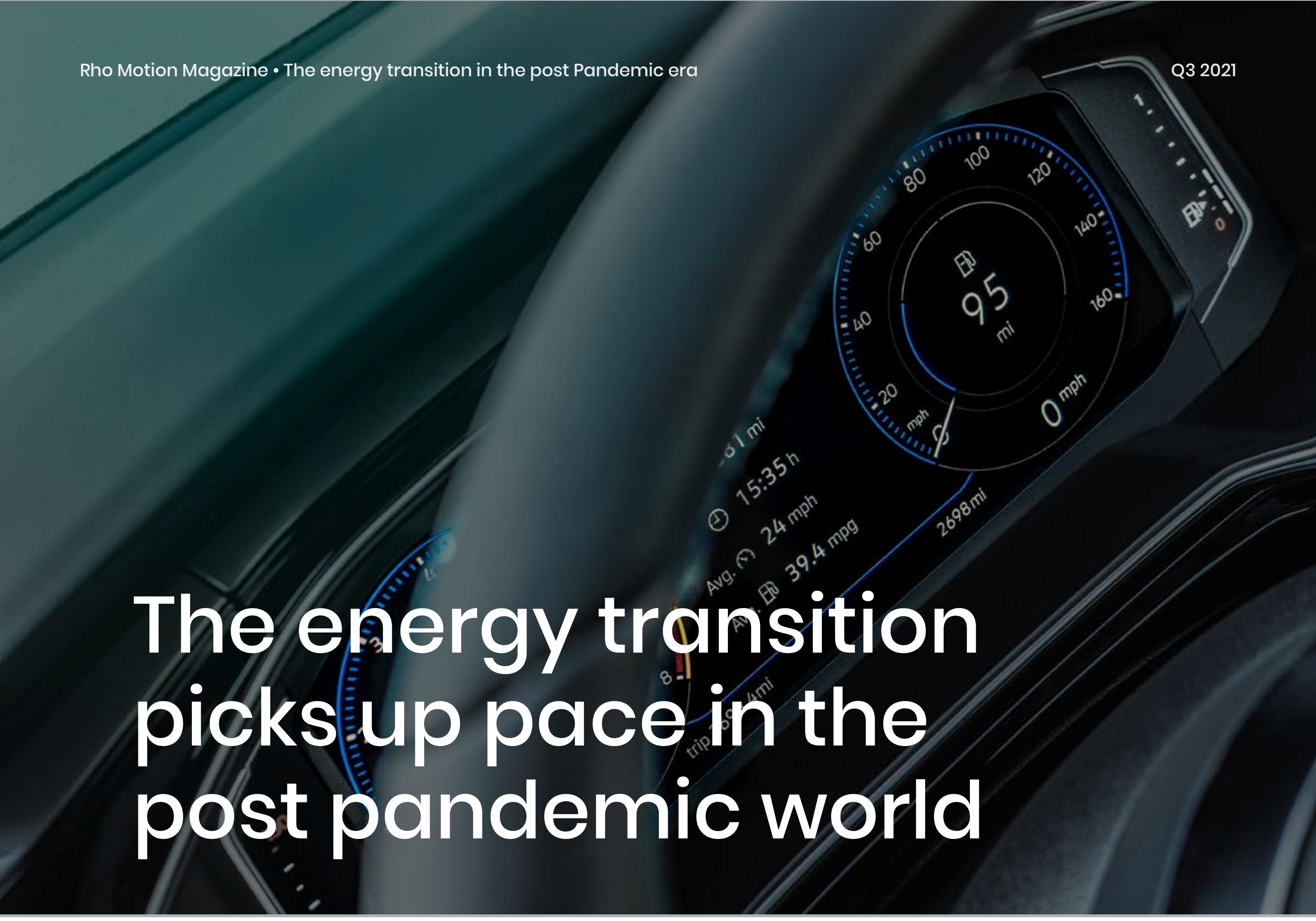


The energy transition picks up pace in the post pandemic world

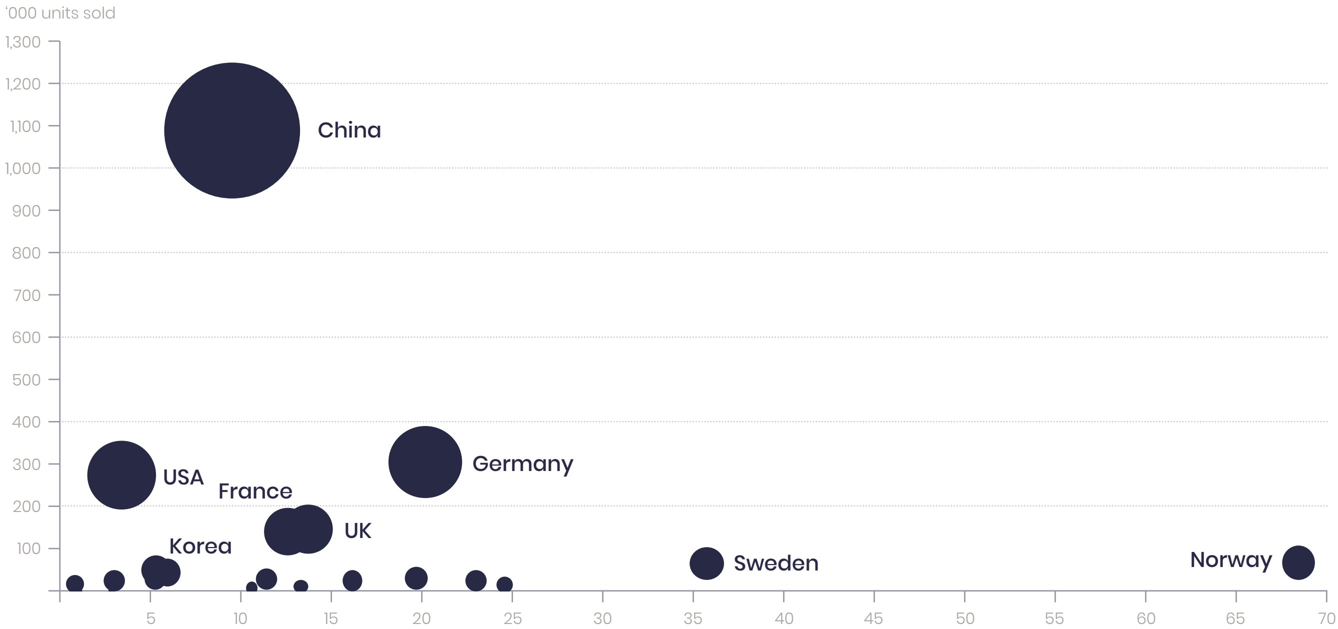
Adam Panayi
Managing Director, Rho Motion

As the world shut down to combat the coronavirus in the first and second quarters of 2020 so did the EV market, with sales dropping drastically, first in China, and then in the rest of the world. What followed, however, was a very strong recovery in EV sales as governments in many major markets introduced huge stimulus packages to protect economies from the worst of the downturn.

A key component of this for many countries was an emphasis on funding environmental technologies, and the EV market, particularly in Europe, benefited. In Germany, for example, the EV subsidy was increased to a maximum of €9,000 under its COVID-19 relief package, while in France the maximum subsidy was increased to €7,000 under its relief fund. What is significant is that both countries have large automotive sectors, which are transitioning to non-ICE technologies over this decade, and in our view governments acted to support these industries through this process. As a result, sales started to increase sharply in the second half of the year, with the European market growing very strongly.

In 2021, the stimulus packages that were drawn up last year are now being wound down and phased out, but we now point to several factors to support our assumptions on growth. In EU & EFTA & UK, there have been several announcements from OEMs targeting high levels of penetration rates in Europe, notably from Ford and Stellantis, and we have been providing briefings on these announcements as they happen to our Members at the rate of nearly 1 per week in recent months. A reduction in super credits, and the fact that 100% of all newly registered vehicles will be counted towards CO_2 emission targets, will continue to drive a strong push in EV sales throughout 2021. Further, as we expect a recovery in ICE sales in

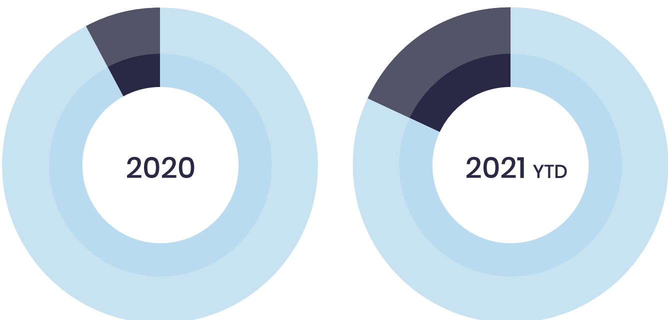
BEV & PHEV penetration rates and market size by country, YTD June 2021 *Source: Rho Motion*



2021, this will add upward pressure on fleet average CO2 emissions. It is noteworthy, therefore, that this year penetration rates for multiple major OEMs, such as Daimler and BMW, have increased in the European market.

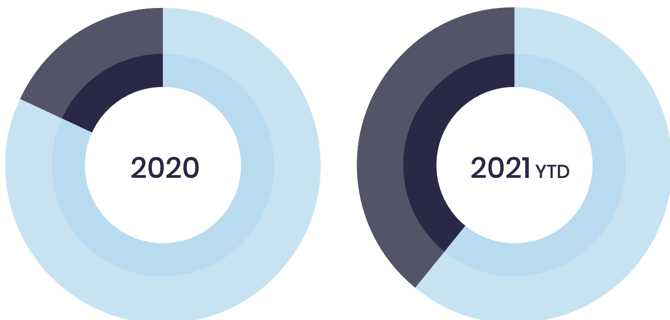
In the US, the timing of new incentives and legislation is expected to be the key demand driver. The core tenets of any policy are still something of a moving target, and a timeline has not been set, but we do not expect an introduction of new policies until Q4 2021 at the earliest. Once introduced, new national and state announcements will likely facilitate faster EV adoption. President Biden committed the US to halve greenhouse gas emissions by 2030, while the states of California and New York have committed to all zero-emission passenger cars sales by 2035, and all heavy-duty vehicles zero-emission by 2045. The State of Washington has committed to BEV only for all cars and LDV by 2030.

In China, there have been strong sales in the opening six months of the year, despite a 20% decline in the maximum EV subsidy in 2021 compared to 2020. It is likely there will be an increase in EV sales towards the end of the year before the subsidy is reduced by a further 30%. Consumer choice remains a key demand driver, with around 200 separate BEV and PHEV models sold in 2021 YTD alone. The small, low price, SAIC-GM-Wuling EV continues to lead sales with over 183,000 sold in the opening six months of the year. Tellingly, both second and third place models are Tesla's 'Made in China' Model 3 and Model Y respectively, followed by BYD's Han BEV. On the battery chemistry side, BYD is expected to use its LFP 'Blade Battery' in all its models going forward, with its NCM capacity to serve third party OEMs. Looking at the top four vehicles in China, all are available either exclusively with an LFP battery pack, or as an option. In the case of the Model 3 this accounts for roughly 80% of the model's sales in China. This has meant that 2021 has seen the LFP resurgence that was being pointed to in 2019 and 2020, with over a third of battery demand for BEV & PHEV passenger car and LDV sales now LFP. This trend will be coming to Europe from around 2024, although we do not expect at necessarily the same order of magnitude.



Global PC & LDV chemistry share, kWh

LFP Other chemistries



China PC & LDV chemistry share, kWh

LFP Other chemistries

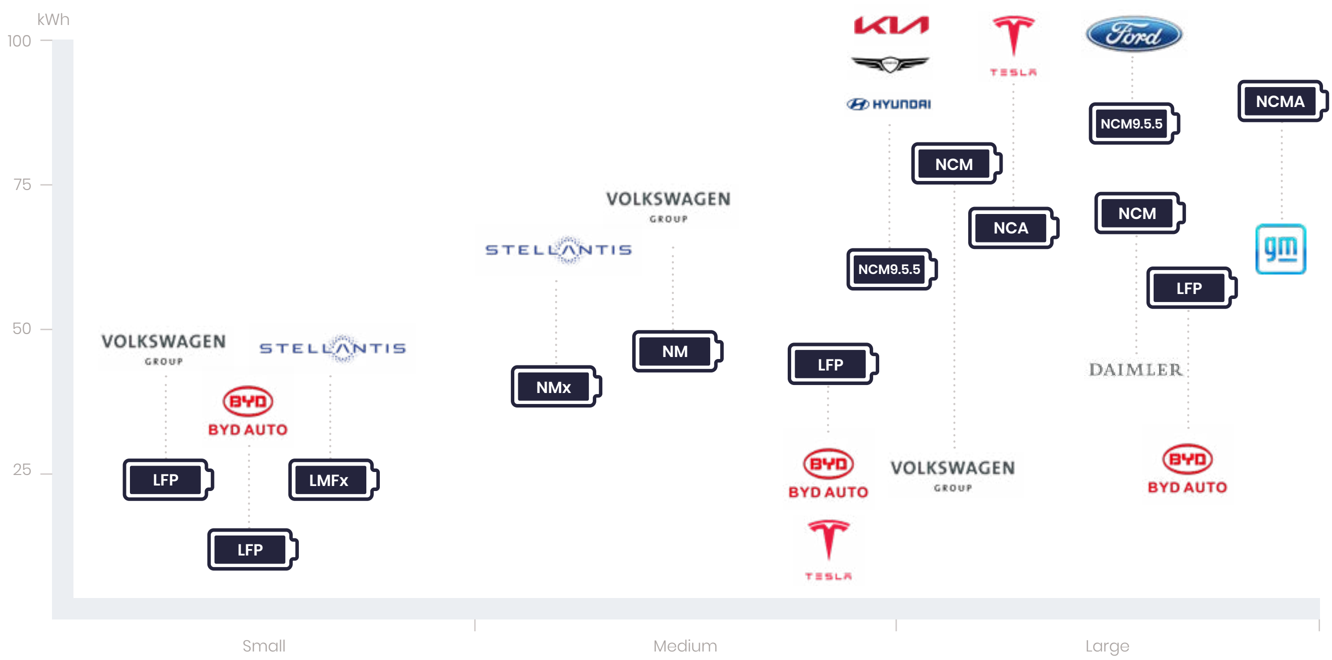
Source: Rho Motion

Photo: John Lockwood

For the outlook for battery chemistry developments both inside and outside of China, we look to vehicle use case, and market positioning for the range of vehicles that will be released over the coming decade. OEMs have been relatively clear in terms of their thinking for how they will deploy different battery chemistries for the range of vehicles in their portfolios. One key thing to remember from our point of view is that larger vehicles with larger pack sizes will, in most cases, skew towards high nickel chemistries to satisfy customer demands for performance and crucially range. This means that there will be something of a disconnect between the share of vehicles sold with different chemistries, and the relative battery demand coming from those sales. In short, this means that we believe that high nickel NCM chemistries will remain a highly significant part of the chemistry mix into the coming decade.

OEM battery strategy by segment

Source: Rho Motion



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EV & Battery

Our EV & Battery market analysis is based on bottom-up model-by-model analysis, combined with industry leading insights into the future direction of the sector

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EV & Battery Quarterly Outlook

Rho Motion is an industry leader in EV market analysis. Our forecast provides long-term outlooks for EV penetration, battery pack size and chemistry by vehicle class, based on robust and informed methodologies.

EV Battery Chemistry Monthly Assessment

The assessment provides monthly sales weighted average of battery pack sizes and battery demand by chemistry market share for the EV industry across vehicle classes.

EV & Battery Monthly Database

Our core EV & Battery database, tracking sales, vehicle and battery development on a by-model basis

EV Motors Monthly Assessment

The assessment provides monthly weighted averages of motor technology demand across vehicle classes, detailing the power and quantity deployed regionally and by vehicle segment.

Hybrid EV & Battery Quarterly Outlook

Our Global HEV forecast provides a long-term outlook for HEV penetration, battery pack size and chemistry by vehicle class. Alongside our EV & Battery Quarterly Outlook it sits as an essential tool for tracking the total vehicle markets battery demand.

Our EV and Battery market analysis is delivered in flexible, dynamic formats that can be customised for the user

Building a net-zero nation

ADVANCED PROPULSION CENTRE UK

Jon Regnart
Automotive Trend Specialist, APC

"Jon Regnart Automotive Trend Specialist from the Advanced Propulsion Centre discusses the roadmap for low-carbon propulsion technology and what the opportunities are over the coming decades."

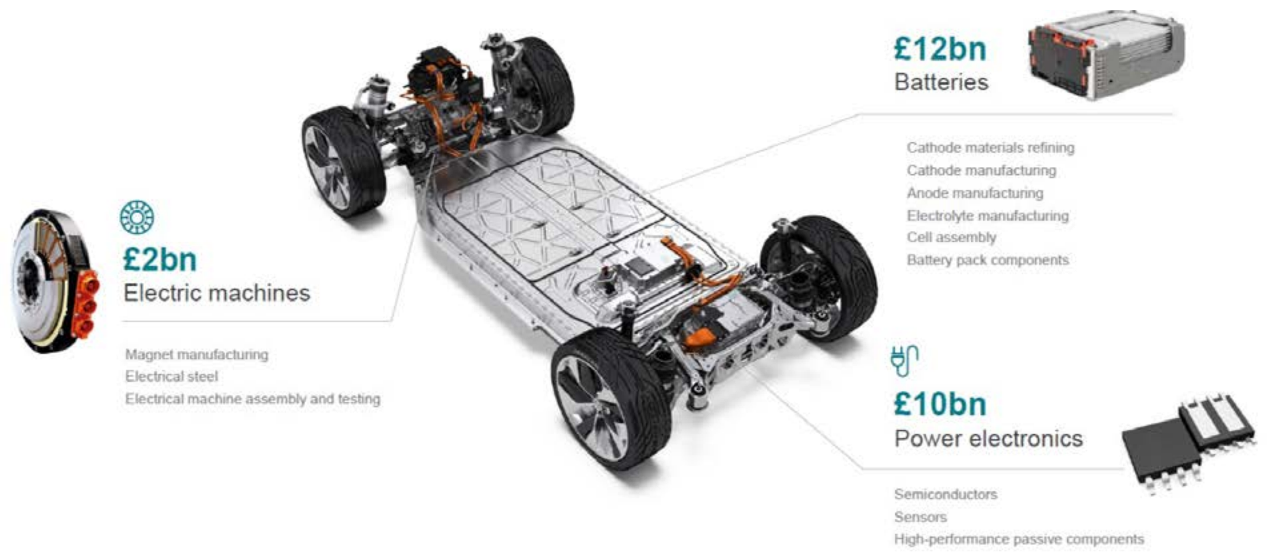
The world has changed dramatically since the UK Automotive Council released the first roadmaps in 2009. Back then the net-zero narrative was niche and the question was how much low-carbon propulsion would feature in future mobility.

Fast forward to today, and the shift in world views and government action is pronounced. In the past two months alone, we have seen more countries set ambitious decarbonisation targets, many following the UK's lead to phase out petrol and diesel engines before 2035. The decarbonisation of transport isn't even a question anymore, it's a given.

Every OEM and technology giant will have their own roadmaps detailing their projected focus. Where the APC's differ is that they present a global consensus view, built from engaging with over 147 different international organisations, to provide a comprehensive industry-wide view of developments in future powertrain technologies. We moved beyond analysing traditional vehicle segments and viewed vehicle development through the lens of mobility needs, offering a fresh perspective.

So what are the key things we can learn from the roadmaps and where are the opportunities?

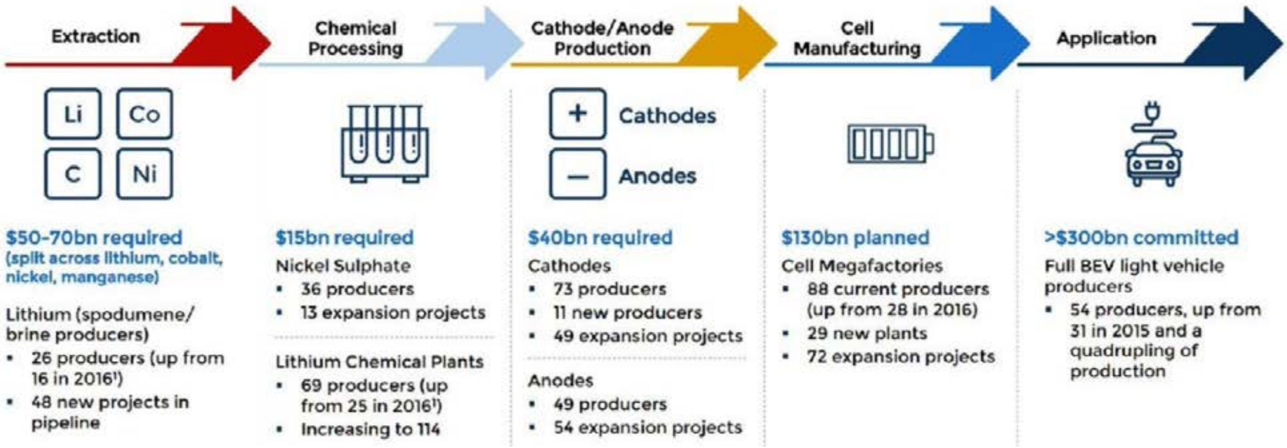
A roadmap gives you trajectory and sets a global vision. But how do you take that global landscape and build a strategy for where to invest? What's right for your business, country, portfolio? Our demand forecasts indicate that



Source: APC

EV supply chains are complicated and need billions in investing

Investment in clean tech can also include processing, components, R&D and new technologies.



1. Excludes some small-scale Chinese producers

Source: Benchmark Mineral Intelligence and Rho Motion

passenger car supply chain capacity will, in many cases, need to increase five to ten-fold over the next five years, representing a significant opportunity for suppliers to EU markets. Having conducted a thorough analysis of the entire value chain, it seems that the UK is particularly well positioned to address these opportunities within batteries, power electronics and electric machines. Our 'Strategic UK opportunities in passenger car electrification' report (June 2020) identified UK supply-chain opportunities worth at least £24bn.

Opportunities upstream

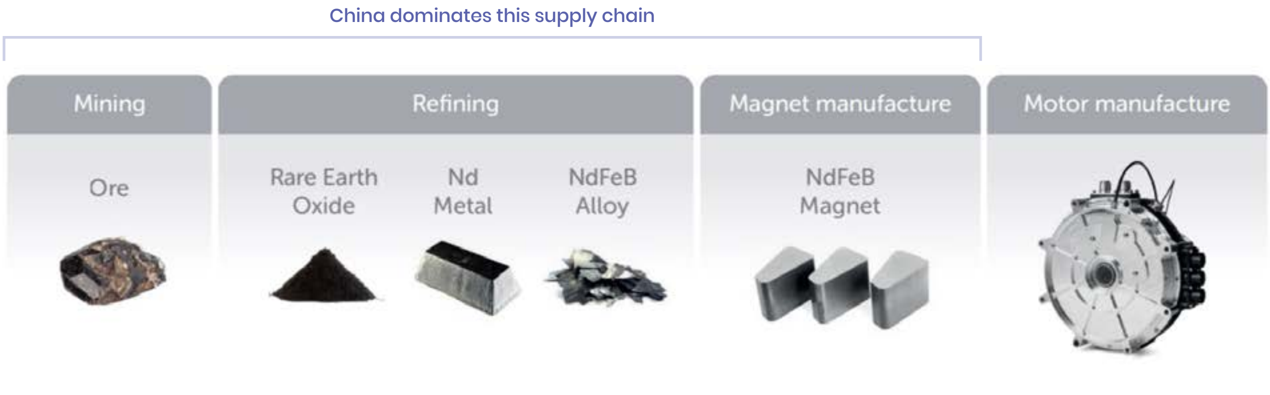
If I was to sum up the main point from this report, it's this: the value in the electrified supply chain is generated in the upstream processes. Refined battery grade materials, magnetic materials for motors and sophisticated compound semiconductors are where the margins lie. These technologies are typically IP intensive in terms of material composition and require significant manufacturing know-how.

The battery industry is a good case study for this. Significant investments have occurred in battery cell manufacturing to meet future battery electric vehicle (BEV) demand. Conventional wisdom states that attracting gigafactories to Europe secures the future of automotive hubs from Sunderland to Wolfsburg by cementing vehicle manufacturing, and this is true. But further up the supply chain, a lack of historic investment will likely result in material shortages in the next three-to-five years. This threatens the successful mass rollout of electrified vehicles. Therefore, immediate investments are needed in material extraction, chemical processing and cell components to meet the forecasted demand. With a few sage investments, the UK could be in a prime position to take advantage of the European need for battery-grade materials.

Cathodes are the most expensive element in a lithium ion cell, which is primarily driven by high purity nickel sulphates and lithium. One of Europe's largest nickel refineries is Vale's Clydach refinery. Located in South Wales, this facility has the capability to produce around 40kt of battery grade nickel, which could support around 60GWh of cell capacity. Add into the landscape manufacturers like Leverton-Lithium and Livent, who are large refiners of lithium-based chemicals, you start to have the building blocks needed for cathodes.
What's missing in the UK (and across Europe) are manufacturers that can take nickel, lithium, cobalt and manganese to produce cathode materials at high volume. Therefore, there's great investment opportunity for a cathode manufacturer to locate their next production facility in the UK next to a ready supply of precursor materials while leveraging our low carbon electricity grid.
It's a similar story with anodes. In Humberside, Phillips 66 is the only manufacturer in Europe capable of creating needle coke for synthetic graphite. The issue is that limited capability exists across Europe to take the feedstock and turn it into anode material that a cell manufacturer can use. The ecosystem in the North-East of England, with proximity to a large port and a ready supply of renewable energy, is well suited to refine anode materials.

There's more to the story than batteries....

Securing strategic materials also impacts electric motors. Rare earth magnets used to increase power density in electric motors represent anywhere between 25-50% of



Source: APC

the total motor cost. China enjoys a strong position across all areas of the rare earth supply chain: from mining right through to magnet manufacture.

To secure a stable supply of rare earths, free from price spikes, investment across the entire rare earth value chain must occur. Like the battery value chain, the UK has a rich ecosystem in the magnet supply chain. Less Common Metals are Europe's only rare earth metal and alloy producer. HyProMag are scaling up their unique processes that recycle rare earths from motors and hard disks drives to be re-used in electric motors. And in Teesside, companies like Peak Resources and Pensana are harnessing the surrounding chemical sector infrastructure to refine rare earths.

The other side of the argument is not to use rare earths at all – which the UK have covered as well. BMW and JLR have committed to jointly manufacturing electric drive units, using switched reluctance motors, with JLR manufacturing them in Wolverhampton. Innovative start up Advanced Electrical Machines are also commercialising switched reluctance motors for HGVs and Punch Powertrain have received APC funding to develop them for a plug-in hybrid Ford Transit vans.

The challenging requirements of the automotive sector is creating a demand for better semiconductors. The proliferation of wide band gap devices such as SiC and GaN has disrupted existing semiconductor supply chains. Companies who can grow high purity, silicon carbide ingots and conduct epitaxy processes are few and far between. While there are more companies fabricating SiC devices, the imminent demand means more players will need to enter the market. The UK is well placed via Newport Wafer Fab who have the capability to process devices. There's also significant capability in the GaN market, with IQE a world leader in GaN epitaxy processes and Nexperia conducting significant GaN R&D and Si MOSFET production from their Manchester facility.

Proactively building a UK supply chain for the world to enjoy

So, where does this leave the automotive sector? As it moves towards more sustainable mobility systems, a completely new set of products and services are needed to deliver net-zero. The immediate challenge is filling the gaps in the upstream supply chain for batteries, electric motors and power electronics. Through the Automotive Transformation Fund, a new £500m capital and R&D fund, the APC are supporting upstream suppliers to address these gaps. But with both the G7 Summit and COP26 this year having a strong focus on decarbonisation and the UK government wanting to 'build back greener' from the pandemic, I suspect building resilient, localised supply chains will be high on the agenda.

Jon Regnart is part of the Technology Trends team for the Advanced Propulsion Centre (APC). The APC's role is to accelerate the transition to automotive net-zero emission solutions by ensuring the UK remains competitive in the research, development and production of low carbon propulsion technologies. Tech Trends' evidence-based insight supports academia, industry and governments develop strategies to deliver clean transport solutions.

APC Roadmaps

APC's product roadmaps forecast out to 2050 and beyond for the different type and use of vehicles: light duty, heavy goods and off highway vehicles and bus and coach applications. Our technology roadmaps address technology trends and forecasts for automotive propulsion systems to 2040 and this time added fuel cell technology to the existing forecasts for electrical energy storage, electric machines, power electronics, thermal propulsion systems and lightweight vehicle and powertrain structures.

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Charging & Infrastructure

Our EV Charging and Infrastructure research provides flexible and dynamic analysis on both the current state of the market and the technological and commercial outlook for the sector

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Global EV Charging Outlook

Our Global EV Charging Outlook provides an electric vehicle market analysis of the current and planned technologies at both the vehicle and charger level, and profiles the major players in the market and their relative competitive position and plans for the future. The report can be customised to cover as many or as few countries or regions as needed.

EV Charging Monthly Assessment

The assessment provides an analysis of the maximum charging capacity of global and regional passenger car and light duty vehicle sales and fleets, as well as a fleet energy demand.

EV Charging Monthly Database

Our EV Charging database with model-by-model sales and analysis of vehicle charging capabilities and battery pack size and chemistry.

Our Charging & Infrastructure market analysis is delivered in flexible, dynamic formats that can be customised for the user

Electric Machines:

Dominance, alternatives, and what the future holds

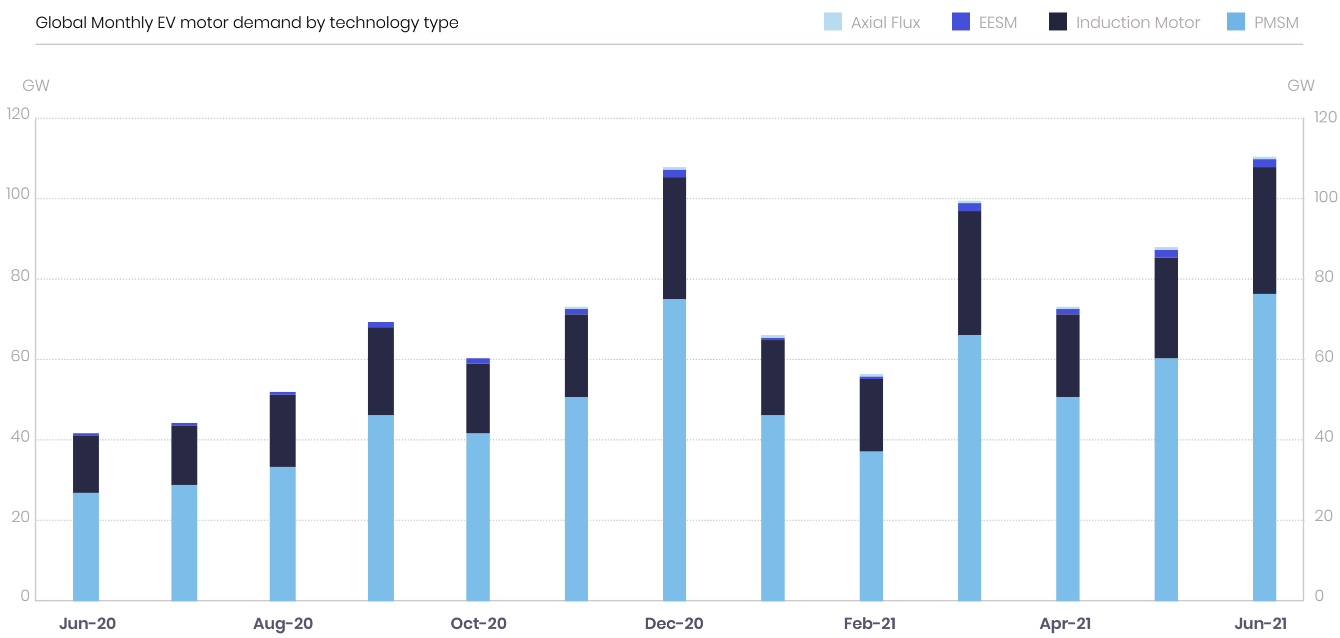
William Roberts
Research Analyst, Rho Motion

The first iterations of the electric motor have been around since the 18th century as scientists such as Michael Faraday experimented using electromagnetic fields for mechanical movement. Following the invention of the AC induction motor in the late 1880s by Nikola Tesla, electric machines have been used for automotive purposes – so where are we today with the technology which is now set to become the driving force of the global vehicle industry?

There is one motor type which dominates the landscape at present, the permanent magnet synchronous motor (PMSM). YTD 75% of the motors deployed in electric passenger cars have contained permanent magnets in the rotor. The reason PMSMs have become dominant is down to efficiency and simplicity. No other technology has been able to replicate 95%+ efficiency at a reasonable cost and scale. The chart below is from our new EV Motors Monthly Assessment which tracks monthly deployment across vehicle classes by motor type.

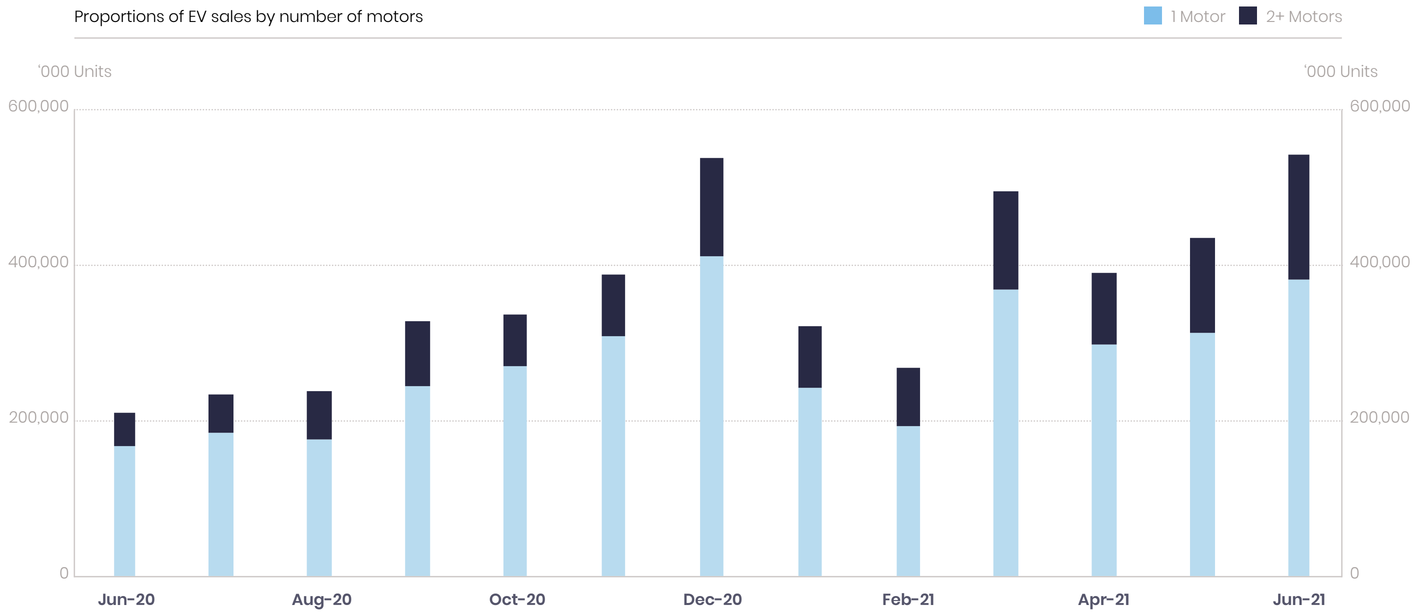
The future of the PMSM in EVs is by no means certain; material demand, environmental impact and supply chain security are all concerns. There has been a well-documented battery technology 'arms race' to date

Global Monthly EV motor demand by technology type



Source: Rho Motion

Proportions of EV sales by number of motors



Source: Rho Motion

however the unique requirements of an EV means the next race is only just beginning.

Permanent Magnets

As with electric vehicle batteries the materials demand for these crucial components must be examined. The outlook for EV sales will generate demand for vast quantities of magnets, it is important to look ahead and make sure the building blocks of the dominant technology will still be available when it is needed.

The materials involved are known as rare-earth elements (REE), specifically Neodymium, Dysprosium and Praseodymium. With the growth of the EV market as well as a high usage in wind turbine generators demand for NdFeB (Neodymium Iron Boron) magnets is of course set to rise, most likely doubling in the next decade. If the current proportion of EVs using PMSM stays consistent the situation may become unsustainable, especially as we see models with more motors arrive such as the Tesla Plaid models (three motors) and the Rivian R1T and R1S (four motors). Although to date, the proportion of vehicles with multiple motors has stayed consistent.

Fears also remain over the security of REE supply with 80-90% controlled by China. In 2011 a global price spike occurred as a trade dispute between China and Japan restricted supply to the rest of the world, although due to a growing number of new production locations outside China this is unlikely to happen again. This is not to rule out a more subtle management of the material and refinement process in order to remain a crucial part of the supply chain.

The environmental impacts of REEs also shouldn't be ignored. Despite the name these elements aren't particularly rare, just difficult to extract. The biproducts of the methods used are mildly radioactive waste and acidic sewage water as well as 20-40 tonnes of CO_2 per tonne of Neodymium Oxide. For an industry largely built on its green credentials, being able to eradicate this would be an achievement.

These issues present multiple reasons why OEMs will need to be well positioned to move away from PMSMs and adopt other approaches. Fortunately, alternative options for motor technology exist.

AC Induction Motors

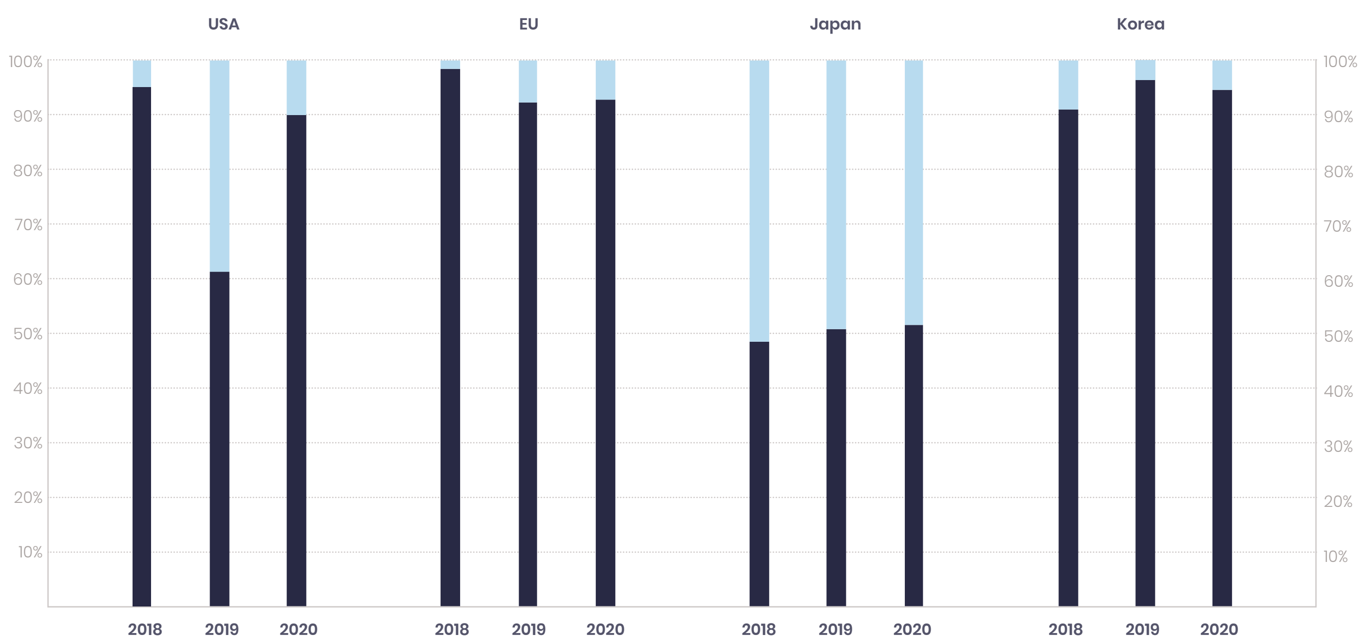
This motor design is very simple and uses no magnetic material in the rotor, however, it fall shorts compared to the permanent magnet design for efficiency. It is still the second most popular choice of motor design used in electric vehicles today. A large portion of this is the dual motor models from Tesla, both the Model 3 and S have the option to add an induction motor to the front axle, the Model X and Y come with one as standard. All Tesla models now use a PMSM on the rear wheels.

Other major OEMs also utilising this design include BYD, Mercedes-Benz, Hyundai-Kia, NIO and Audi. As in the Tesla it is often paired with a PMSM to utilise each technology's benefit at different speeds and torques. Being an established design in EVs, induction motors are well placed to take up market share from PMSMs.

Electrically Excited Synchronous Motor

Electrically Excited Synchronous Motors (EESM) operate on the exact same principle as the PMSM, the magnets are in this case replaced by an electromagnet in the rotor.

Percentage of Rare Earth Metals and Alloys Imports from China and ROW (Tonnes)



Source: Rho Motion

This technology has not often been utilised due to the added complexity of using an electric current to produce a magnetic field in the rotor when it can be achieved with permanent magnets. It also requires transferring power to a rotating rotor – traditionally done with brush contacts however this can lead to wear and tear in an otherwise maintenance free machine. Recently Mahle has designed an EESM using induction to get direct current to the rotor, removing the need for physical contacts and restoring the low maintenance design. The new 5th generation eDrive from BMW uses an EESM, it is already in place in the iX3 and will also be used in the iX and i4.

Reluctance Motors

Two core types of reluctance motor designs exist, Switched and Synchronous. Both use the principle of a magnetic material (usually steel) wanting to align itself with the magnetic field it is in – similar to how a nail would align if you placed a bar magnet on either side of it.

A downside to this technology is the requirement for more complicated motor control electronics, however this is becoming more achievable all the time. The complex motor controls are also necessary to reduce the design's other disadvantages: torque ripple, noise and vibration.

Some firms such as Advanced Electric Machines in Newcastle, England have produced a switched reluctance machine which reportedly matches the performance of a PMSM without the complex supply chain issues. A method whereby aluminium is used in place of copper in the stator windings has also been patented. This means the motor is made of only aluminium and steel, and therefore far easier to recycle at the end of life.

Going forward

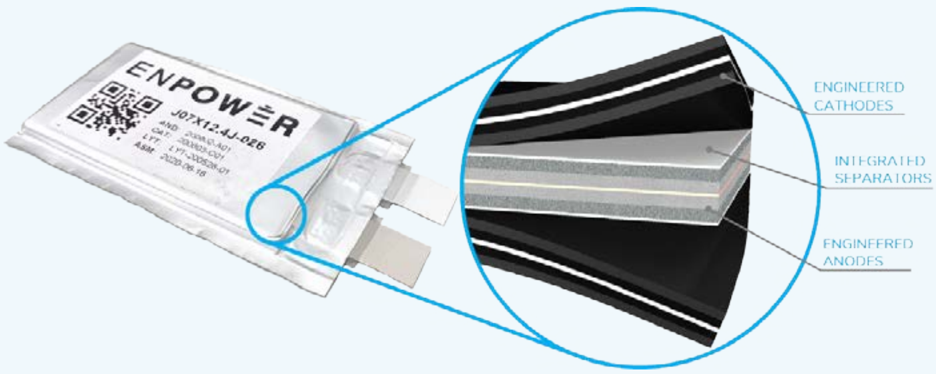
The permanent magnet synchronous motor will remain the dominant technology for some time in the electric vehicle space; however, OEMs will do well to diversify technical expertise into these other areas to protect against future issues.

The energy transition and EVs have provided more motivation to investigate alternative motor technologies than ever before. Now the race is on, it will not be long before the development of alternative drives matching PMSM performance arrive. From here the reasons to stick with permanent magnets and rare-earth elements becoming less convincing. Alternative options which are greener, cheaper, lighter, more efficient or all of the above will displace the incumbent dominant design.

Our new EV Motors Monthly Assessment from Rho Motion is the perfect place to keep up with all developments in this space. The report tracks monthly deployment across vehicle classes by motor type, it also keeps you up to date on the latest technology and market developments. The technology spotlight will also provide a deeper dive into the working and market-potential of game-changing components and designs.

ENPOWER

Re-Engineering the Lithium-Ion Battery



- Patented **Multilayer electrodes**
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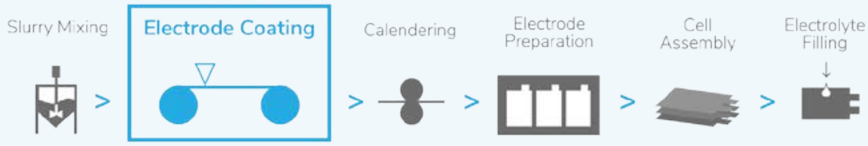
- BEV-class energy density
- Low cost, scalable solution

Drop-In Technology, Ready to Scale



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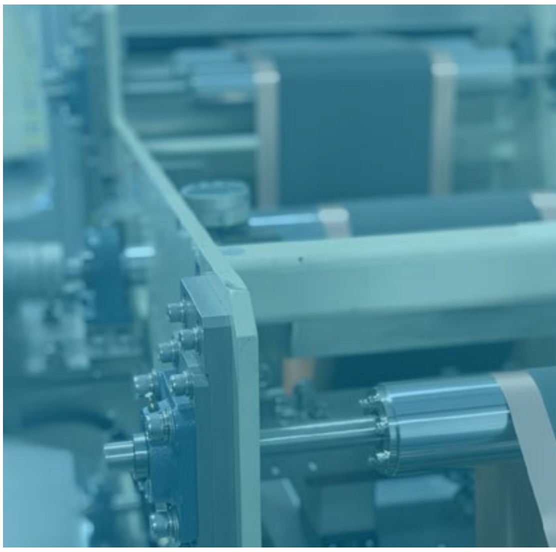


Breaking the Energy-Power Tradeoff

ENPOWER

All batteries suffer from the classic engineering tradeoff between energy and power, wherein cells designed to maximize energy content suffer from poor power performance and cells designed to rapidly charge and discharge suffer from lower energy densities.

While some applications can select either a power cell or an energy cell, the electrification of vehicles demands better batteries. The fundamental limitation is rooted in the underlying physics of mass transport within Li-ion electrodes. This is what prevents repeated fast charging or high C-rate discharging in high energy cells without experiencing harmful cell degradation.

EnPower's patented multilayer electrodes are designed specifically to address this tradeoff, enabling high energy density batteries to repeatedly fast charge without degradation to service life. EnPower's goal is to enable both 300+ mile range and 15-minute charging in the same system – a critical barrier to the mass adoption of electric vehicles.

EnPower's Multilayer Electrodes

To break away from the trade-off between energy and power, EnPower designs multilayer electrodes with strategic porosity, tortuosity, and other profiles to facilitate rapid ion transport through the thickness of electrodes. Multilayer electrodes can be designed to facilitate mass transport in both directions and on both electrodes (anode and cathode), thereby improving both charge and discharge rates without sacrificing energy density.

In collaboration with a global automaker, EnPower has demonstrated superior fast charge cycle life, reduced DC internal resistance (DCIR), and improved discharge performance of cells with multilayer electrodes when compared to the same cell designs with conventional electrode architectures. An excerpt from EnPower's white paper, "Multilayered Electrode Architectures for Lithium-ion Batteries," is included below, demonstrating a <20-minute charge time with 80% capacity retention over 500+ cycles with 50% fast charge duty cycle. You may download the complete white paper at www.enpowerinc.com/technology

Figure 1. Cross sections depicting conventional, homogeneous electrodes compared to EnPower's multilayer electrode designs.

Source: EnPower

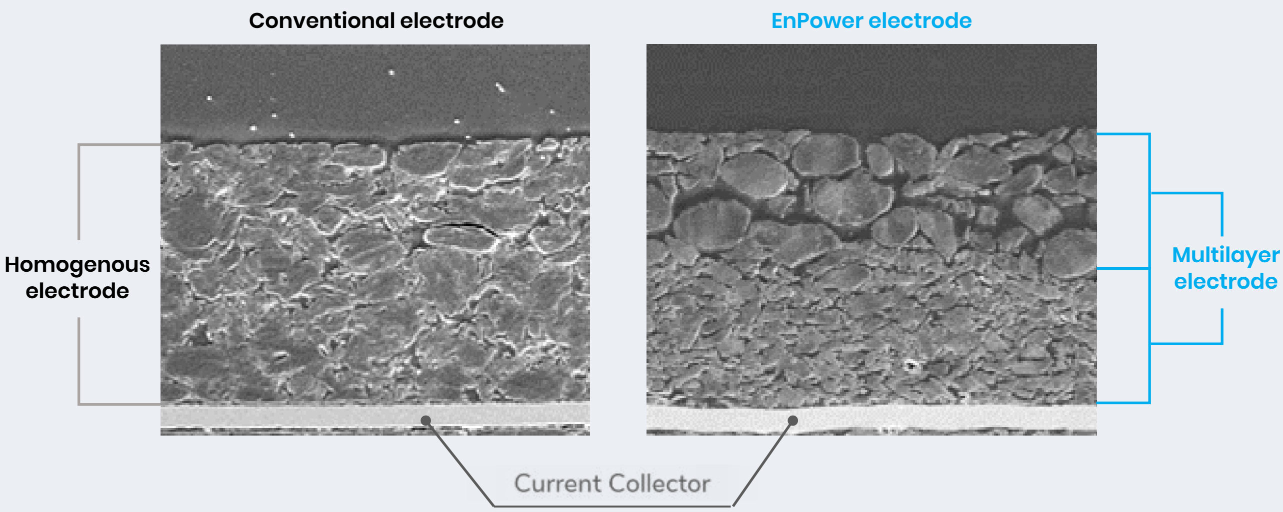
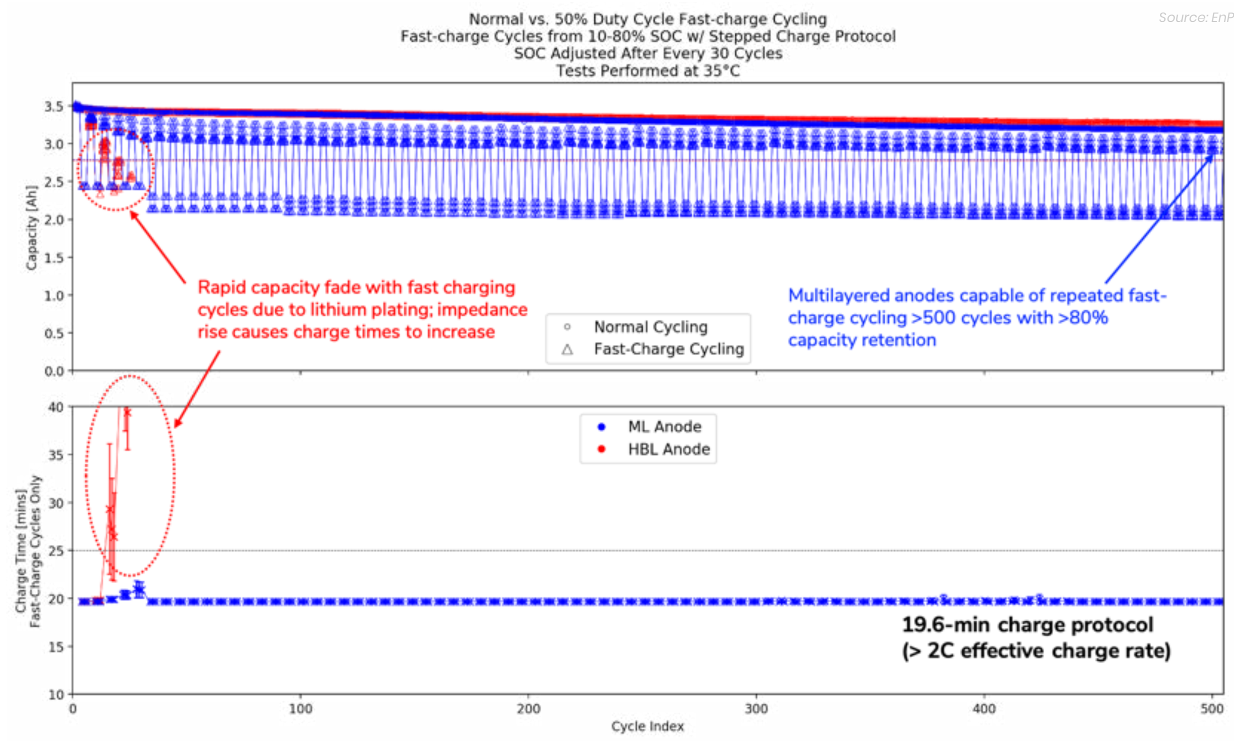


Figure 2: Normal vs. Fast Charge cycling performance between cells assembled with multilayered anodes and their homogeneous baselines. Top graph plots Capacity vs. Cycle Index; Bottom graph plots charge times of fast charge cycles only.



Fast Charge Cycling

The ability to mitigate lithium plating on anode electrodes is the first step towards enabling faster charging in high energy density cells. Various multilayer anode design strategies can be employed to improve ion mass transport, reducing oversaturation of lithium at the electrode-separator interface, and preventing the deposition of lithium metal. To demonstrate improved fast charge cycling performance, EnPower compared cells with graphite-based multilayer anodes to cells with homogeneous baseline anodes (i.e. conventionally-coated anodes without the multilayer structure but comprising identical active materials at the same overall mass fractions). The anodes were paired with NMC622 cathodes (~4.5 mAh/cm2 loading, conventional homogeneous design), and assembled into 3.5 Ah pouch cells. The electrolyte remained a standard "un-engineered" formulation.

Under normal cycling (C/3 CCCV charging and C/2 discharging), both electrode designs retained >90% capacity over 500 cycles, as expected. However, upon fast charge cycling, the performance of multilayer and conventional anodes diverge significantly. To test fast charge cycling, cells were cycled in a "3N3F" protocol at

Figure 3: Post-mortem disassembly of anode electrodes after fast charge cycling (10 anode electrodes/cell).

Homogeneous anodes after 30x fast-charge cycles @50% duty cycle

Multilayered anodes after 500+ fast-charge cycles @50% duty cycle

Source: EnPower

35°C which alternated between three "Normal" cycles (C/3 CCCV charging and C/2 discharging) and three "Fast charge" cycles (10-80% SOC in under 20-minutes using a multi-phase stepped charging protocol and discharged at C/2). Results showed that EnPower's multilayer anodes far outperform their homogeneous baselines under fast charge cycling, retaining >80% capacity over 500 cycles, whereas conventional anodes reached end-of-life in only 30 cycles due to severe lithium plating.

This was confirmed upon post-mortem, where the homogeneous anodes were extensively covered with the silvery appearance of metallic lithium. Presence of lithium plating represents permanent loss to usable "lithium inventory", which corresponds to the rapid capacity fade observed in the fast charge cycling data. In contrast, the multilayer anodes appear to have only experienced mild aging.

Improved Discharge Performance

While improving fast charge capability is critical to the mass adoption of electric vehicles, many segments of electric mobility demand far greater power performance without sacrificing energy density. For example, electric air taxis require a combination of discharge power for take-off/landing and energy density for range. EnPower has demonstrated 30-40% increase in capacity retention at elevated discharge rates for multilayer anodes versus their homogeneous baselines. This discharge performance benefit of multilayer anodes persists across three different electrode design regimes spanning a large range of areal capacities (mAh/cm2) and therefore thicknesses and energy densities—labeled as the Power, Balanced, and Energy regimes.

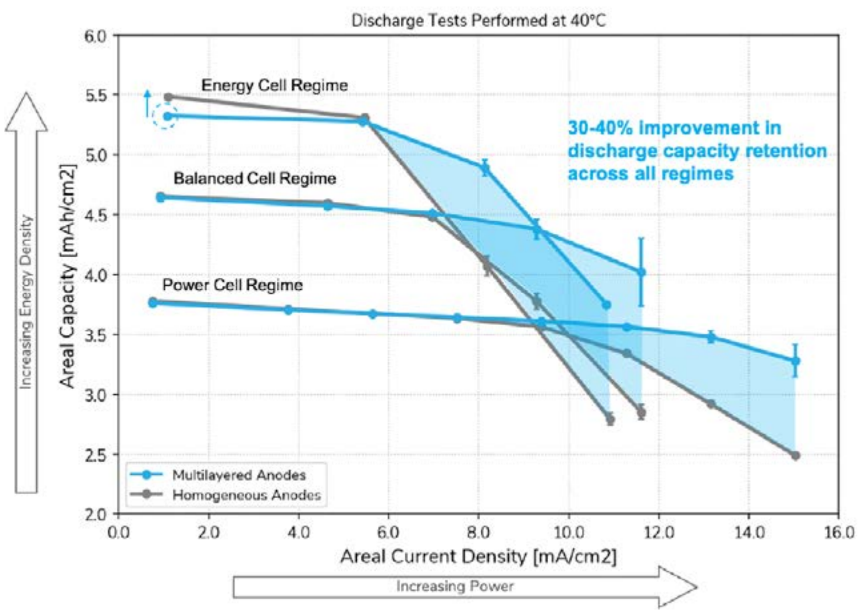
The results are shown in the Peukert-style plot below with areal discharge current density on the x-axis and areal capacity retention on the y-axis. Two pouch cell replicates of each group were tested, and three cycles were performed at each rate.

As expected, increased areal capacity loadings (y-axis) result in reduced capacity retention at elevated discharge rates (x-axis). This is particularly pronounced in the cells assembled with homogeneous baseline anodes (gray) which represent state-of-art Li-ion cells. It is interesting to observe that the three Peukert plots for the homogeneous baseline anodes across the Power, Balanced, and Energy regimes appear to share an upper limit in power delivery—a seemingly invisible "wall" that illustrates the notorious energy-power tradeoff. In contrast, cells assembled with EnPower's multilayer anodes clearly break away from this limitation, demonstrating the ability to "lift" performance curves up. By breaking away from the energy-power trade-off, EnPower's multilayer electrodes unlock a wide range of electric mobility applications.

No Novel Materials, No Novel Equipment

While much of the industry searches for magic molecules to disrupt current Lithium-ion technology, EnPower is focused on engineering-based innovations that can be readily scaled to meet the window of opportunity. The company is already demonstrating the technology in ~7Ah pouch cells and aims to scale up to >50 Ah cells for commercialization in automotive-relevant cells by 2023. To ensure scalability of the technology, the mantra at EnPower since 2018 has been, "No novel materials, no novel equipment."

Figure 4: Power performance benefit demonstrated by EnPower's multilayer anodes versus their homogeneous baselines. *Source: EnPower*



EnPower's multilayer electrode architectures significantly improve the performance of commercially available materials. While much of the development has been completed using graphite-based anodes and NMC 622 or NMC 811 cathodes, the platform technology is chemistry agnostic, having the potential to improve any anode or cathode material by strategically designing the electrode architecture. This allows EnPower to work with materials defined by their customers, streamlining the development and qualification process.

What makes EnPower's technology truly market-ready, though, is the drop-in compatibility to traditional Lithium-ion manufacturing lines. From slurry mixing to cell assembly and formation, the only change in a Lithium-ion manufacturing plant that EnPower's technology requires is an advanced slot-die head on an otherwise standard roll-to-roll coater. The company's patents and trade secrets protect the processing know-how required to simultaneously deposit up to three layers of material onto the metal foil in a roll-to-roll fashion. Simultaneous deposition is critical, because it allows multilayer electrodes to be manufactured with the same throughput as traditional coating lines.

Using industry-standard materials and equipment ensures that EnPower's multilayer electrodes can be made at cost-parity to today's state-of-art and at the volumes required for the electric vehicle market. It also gives EnPower the flexibility to license the technology in addition to scaling its own manufacturing.

Commercialization

EnPower owns and operates an engineering development and pilot facility in Phoenix, AZ where it designs, builds, and tests 3.5-7.0Ah stacked pouch cells. Development from powders-to-test can be completed in under three weeks, enabling EnPower to rapidly prototype and iterate electrode and cell designs. The pilot line is a small-scale production facility with industry-standard equipment, including planetary vacuum mixers, a 300 mm slot-die coater with 8m of drying oven, roll-to-roll calendering and continuously fed electrode blanking capabilities, automatic Z-fold stacking, and 500+ climate-controlled channels for cell testing.

The current facility enables EnPower to produce cells for sampling and third-party validation, as well as work with customers to optimize electrode and cell designs for specific applications. EnPower is currently working on a Technology Assessment Program with the United States Advanced Battery Consortium (USABC) and previously completed two technical evaluations with an automaker. EnPower continues to seek joint development partners and commence automotive cell sampling.

Given the tremendous demand for Lithium-ion batteries, especially those manufactured domestically, EnPower is breaking ground on a manufacturing and customer qualification plant this year, with start-of-production planned in 2023. This 300-500 MWh/y facility will enable automotive-scale cell sampling and low volume production in various form factors.

Work with EnPower

EnPower is actively seeking strategic partners to jointly develop high energy, high power Lithium-ion batteries. The team has extensive knowledge of lithium-ion chemistries, design strategies, and development expertise. Bring your most challenging battery specifications to EnPower and see how multilayer designs can maximize performance! [Contact EnPower today.]

800-volt EV platforms on the rise

Mina Ha
Research Analyst, Rho Motion

An increasing number of OEMs are responding to the requirement for faster-charging capabilities for battery electric vehicles (BEVs) by upgrading power systems from 400-volt to 800-volt.

800-volt systems allow a reduced charging time and a higher power output on account of lower energy losses to heat and give the potential for the use of smaller and lighter motors with less usage of copper. 800-volt systems typically require a charging time of about 20-25 minutes for charging up to 80% at up to 350kW.

In parallel, the development of new semiconductor materials for use in high voltage inverters is seeing Silicon Carbide (SiC) enter the frame. SiC is being employed in MOSFET devices, a type of switch the inverter uses to transform direct current (DC) from the battery, to the alternating current (AC) required for the electric motor. These MOSFET devices are replacing Silicon based IGBTs, thanks to the properties of the silicon carbide, including a wide band gap and higher thermal conductivity, these devices have a number of advantages: higher switching frequency, far lower internal resistance (R_(DS(on))) and cooler operating temperatures.

These can have a number of positive impacts, most importantly is an increase in efficiency of the motor-inverter system, studies have found this improvement to be between one and six percentage points. The greatest gains coming at lower speed (rpm) and high torque – in the range which a motor spends most of its operational life. Lower operating temperatures also allow OEMs to reduce and simplify the cooling requirements for the inverter saving weight and space, both crucial aspects of successful EV design. These performance improvements are true in both 400 and 800-volt architectures. However, they are far more pronounced in 800-volt systems meaning as OEMs make this transition, SiC will likely become a more common choice.

Deployment of high-voltage systems is expected to be on an upward trajectory in the coming years, with OEMs launching new or upgraded EV platforms. The 800-volt systems are expected to be first seen in electric sports cars, premium EVs, and commercial EVs: the Porsche Taycan has been the only series-production model to use an 800-volt system when it was released in 2020. OEMs

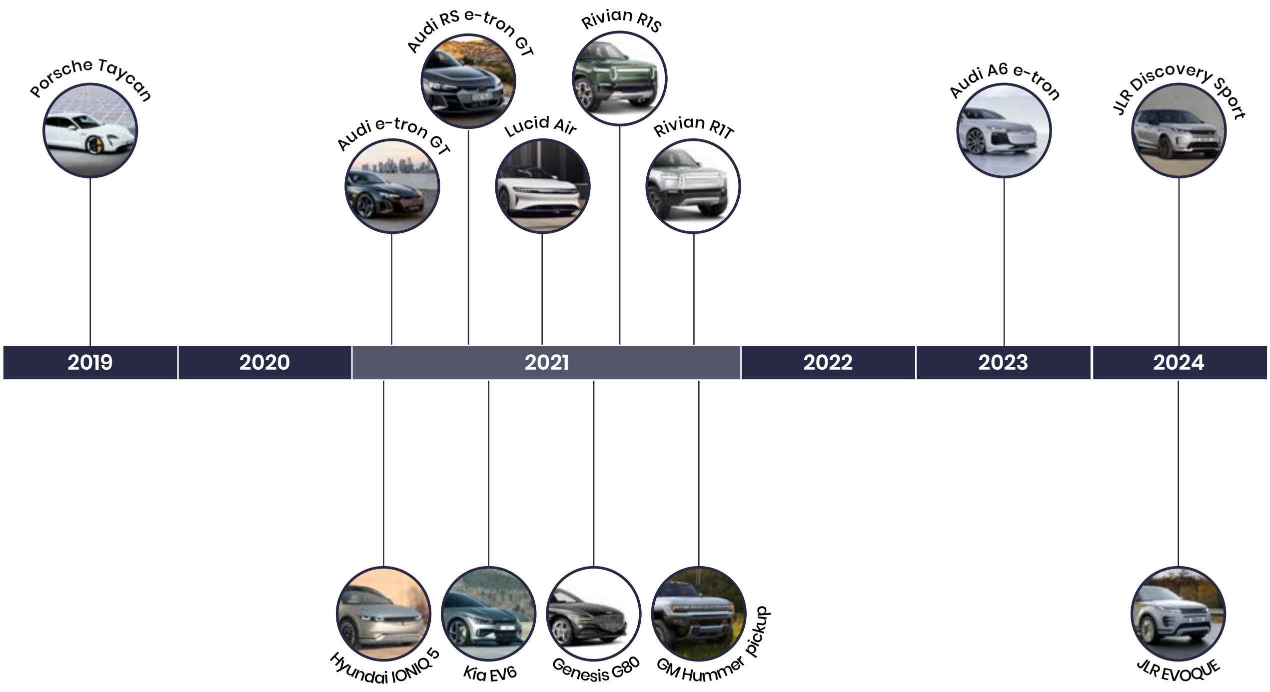
OEMs and 800-volt inverter suppliers

OEMs	Platform	EV model	Charging Power	800V inverter supplier
Porsche	J1	Taycan	270kW	Hitachi
Audi	J1	E-Tron GT, RS E-Tron GT	270kW	Hitachi
Hyundai	E-GMP	Ioniq5	350kW	Vitesco Technologies
Kia	E-GMP	EV6	350kW	Vitesco Technologies
Genesis Motors	E-GMP	G80, GV60	350kW	Vitesco Technologies
General Motors	Ultium	Hummer pickup truck	350kW	LG Magna e-Powertrain
Lucid Motors	LEAP	Air	300kW	Lucid Motors
Rivian	Skateboard	R1T pickup truck, R1S SUV	300kW	Unspecified
Jaguar Land Rover	MEA	Discovery Sport, Evoque	Unspecified	LG Magna e-Powertrain

Source: Rho Motion

Chart: OEM taking up 800V systems in 2019 - 2024

Source: Rho Motion



such as Hyundai Kia Group, General Motors, and Rivian are expected to deliver new EV models with 800-volt systems installed in 2021.

800-volt inverter producers are expanding their capacities to meet the increasing demand for the high-voltage inverters, and consequently raising capital to fund the expansions through various investment activities such as equity financing, an IPO, and M&A. Below further elaborates on OEMs adopting 800-volt systems on their latest EV models and their inverter suppliers.

OEMs taking up 800-volt systems and their suppliers

Porsche launched its first electric sports vehicle with an 800-volt system, Taycan, in 2019. The high-voltage system allowed DC fast charging of its 93kWh battery from 5 to 80% in 22.5 minutes at up to 270kW. This is reported to be twice as fast as a vehicle with 400-volt architecture. Audi E-Tron GT and RS E-Tron GT, developed on the Porsche Taycan's J1 platform, also run on the 800-volt system. Audi's A6 e-tron, which is scheduled to arrive in 2023, will be based on its new Premium Platform Electric (PPE) architecture with an 800-volt system. Audi stated that the 800-volt system enables DC fast charging from 5 to 80% in less than 25 minutes at up to 270kW. Hitachi Automotive Systems supplies 800-volt inverters to Porsche and Audi.

Hyundai introduced its first EV model built on the new Electric-Global Modular Platform (E-GMP), the Ioniq 5, in February 2021. The Hyundai Ioniq 5 runs on an 800-volt architecture, with a charging capacity of up to 350kW.

Kia and Genesis use the Hyundai E-GMP on their new EV models arriving in 2021: the Kia EV6 is expected to run on an 800-volt DC fast-charging system which takes about 18 minutes to charge from 10 to 80%. The Genesis G80 and GV60 are expected to provide similar charging capabilities.

Vitesco Technologies supplies its 800-volt silicon-carbide (SiC) inverters to the Hyundai Ioniq 5, Kia EV6, and Genesis G80 and GV60. Vitesco Technologies is expected to supply its 800-volt SiC inverters to all the future EV models built on the Hyundai E-GMP. In April 2021, Vitesco Technologies, Continental AG's powertrain division, was approved for a spin-off and an IPO to accelerate its expansion. Its IPO is reported to take place after Its spin-off in the second half of 2021.

Jaguar Land Rover (JLR) announced its 'Reimagine' strategy in early 2021, which includes its electrification plan with a new 800-volt platform: JLR is currently developing its new EV platforms, the Modular Longitudinal Architecture (MLA) and the Electrified Modular Architecture (EMA). The latter is expected to use an 800-volt system, and JLR's next-generation Discovery Sport and Evoque are likely to be built on the EMA, arriving in 2024. General Motors (GM) is expected to use 800-volt battery packs with 350kW DC fast-charging capacity on the Ultium-based Hummer EV trucks in 2021.

GM and JLR source theirs 800-volt inverters from the LG Magna e-Powertrain, a joint venture between LG Electronics and Magna International. The LG Magna e-Powertrain is a spin-off of LG electronics' EV component business, with 49% of its shares acquired by Magna International.

Lucid Motors (LM) plans to produce its first EV model, the Lucid Air, built on the Lucid Electric Advanced Platform (LEAP), by the second half of 2021. LM's in-house developed 900V+ architecture will be deployed on the Air, allowing DC fast charging at up to 300kW.

Rivian's R1T pickup truck and R1S SUV, arriving in mid-2021, are expected to use 800-volt systems enabling DC fast charging at up to 300kW.

The Case for PGMs in Batteries A Little Bit of Catalyst Goes a Long Way

Dr. Bilal El-Zahab - Associate Professor, Florida International University
R. Michael Jones - President and CEO, Platinum Group Metals Ltd.

Platinum and palladium (PGMs), in small amounts, can deliver a positive difference in the energy to weight ratio of lithium batteries and the value proposition is better than you might think. Lion Battery Technologies Inc. was formed in 2019 to investigate and further develop a patented technology that uses the unique catalytic properties of PGMs to build better batteries. Research and commercialization efforts are being advanced under a partnership between Platinum Group Metals Ltd. (PLG-NYSE), Anglo American Platinum and Florida International University.

When we first started discussing the concept of a battery containing some of the world's rarest and most precious metals, we were met with a great deal of skepticism. Chemical companies, automakers, OEM's and other experts all reacted the same way; PGMs are just too expensive. Three points were missing in the immediate reaction. First, PGMs are well known catalysts and a small amount makes a big difference. Second, the elimination of other common battery materials can cut both weight and cost. What you thrift out of the battery is important and this can allow for the addition of a small amount of PGMs. Thirdly, PGMs can facilitate in the transition to new lithium battery chemistries leading to potentially higher specific energy and improved performance.

Lithium-sulphur and lithium-air have been recognized in battery circles as "next generation" chemistries with a theoretical stair-step up in specific energy from 300 Whr/kg to 750 Whr/kg or higher. The main technical issue is how can Li-S and Li-Air be made to cycle? Since these chemistries are essentially a "chemical reaction in a box" PGMs are a logical addition given their conventional role as a catalyst.

PGM Background -Life Beyond the Catalytic Converter

Given that both Platinum Group and Anglo Platinum are focused on mining, holding millions of ounces of PGMs in reserves,we approach PGMs in batteries differently than most. We ask what can these metals do first and then think about the cost. We own the metals. Since the 1970's the catalytic converter has been the mainstay pollution control device for the automobile industry. The growing market share of EVs may reduce the demandfor PGMs and catalytic converters. This change potentially "frees up" PGMs for consideration in other applications. PGMs being used in a battery is a natural pivot for these metals.

Why PGMs in Batteries?

Today's typical lithium-ion batteries use intercalation electrodes that can be reversibly intercalated or deintercalated with lithium ions while undergoing minor structural change. These electrodes often have low lithium content, even when fully lithiated. To increase their energy densities, their formula weights, excluding lithium, have to be reduced. This constraint has accelerated the research into lighter and Li-richer electrode materials. In other words, non-lithium metals have to be cut, e.g. nickel and cobalt.

As intercalation-based lithium-ion batteries approach their energy storage limit, emerging technologies such lithium-sulphur and lithium-air batteries are increasingly garnering attention. Owing to their high theoretical volumetric and gravimetric energy densities, these batteries can afford longer driving ranges in EVs in addition to a much-needed reduction in demand for conventional battery metals. Furthermore, this switch from intercalation chemistry to reaction chemistry opens up the door for a group of materials new to the battery field, i.e., PGMs as catalysts to the battery's charge and discharge reactions. In doing so, PGMs would allow faster (higher C-rate), more reproducible (more cycles), and higher efficiency of operation in the batteries (higher Coulombic efficiency).

An analogy to explain difference between Li-ion and Li-S is to compare the cathode to a movie theatre. In this

Table 1. Theoretical capacity for different battery chemistries.[1]

Battery Chemistry	Cell Voltage (V)	Theoretical Wh/kg	Theoretical Wh/L
Li-ion	3.8	387	1015
Li-S	2.2	2567	2199
Li-Air	3.0	3505	3436

[1] N. Choi, Angew. Chem. Int. Ed. 2012, 51, 9994 – 10024

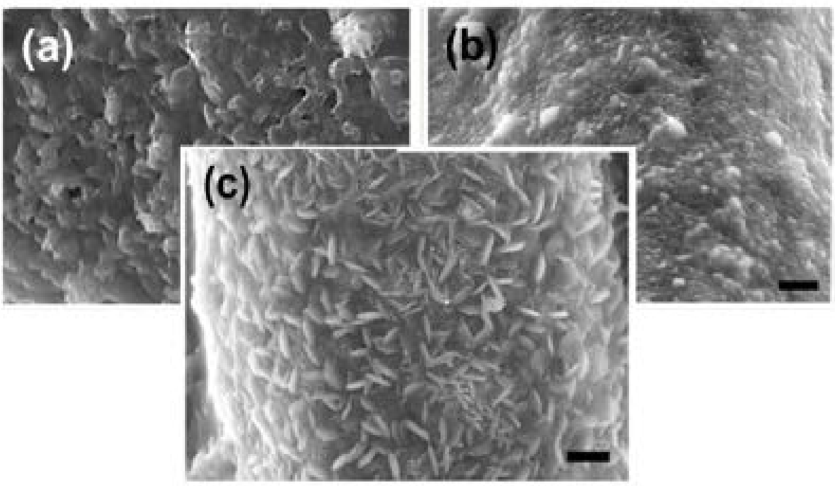
case the theatre seats represent the cathode metals such as nickel, cobalt, and others. During the discharge, lithium ions waiting in the lobby seated on the benches of graphite rush into the theatre to find an empty seat. This reaction is often well-organized and efficient at relatively low C-rates. In Li-S, these seats are largely eliminated and replaced with designated spots where Li+ can find sulphur to couple with mainly as a free-to-move (soluble) species regulated by a tiny amount of PGM catalysts. The net result is more lithium filling up the theatre, which in battery terms translates to higher specific energy in Wh/kg.

Lithium-air and lithium-sulphur batteries have some of the most impressive theoretical specific energy and energy density known to date (Table 1). These batteries use lithium metal for anode instead of graphite, and their cathode is based on an electron conductive matrix on which the discharge species, Li2O2 (non-aqueous) or LiOH (aqueous) in the case of Li-air and Li2S in the case of Li-sulphur deposit. However, they often suffer from sluggish reaction rates, poor reversibility, and high charge and discharge over potentials. The use of PGM catalysts offers a simple solution to these shortcomings as it can provide higher kinetics during the discharge operations, which in turn can allow higher C-rate operations. In addition, they provide improved reverse reaction efficiency, which can lead to improved Coulombic efficiency.

PGMs in Li-Air Batteries

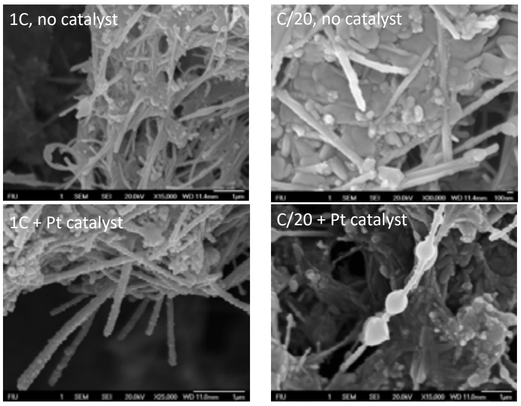
First reported by Abraham in 1996[2], Li-air batteries are composed of lithium metal anodes and often porous carbon cathodes. For non-aqueous electrolytes, during the discharge, the lithium ions oxidize at the anode and diffuse through the electrolyte to combine with $O2^{2-}$ reduced from oxygen in the air inside the pores of the cathode. These pores are filled with electrolytes to allow the lithium ion to reach the reaction sites. The final discharge species is lithium peroxide, Li_2O_2 that can be readily converted back to lithium ion and O2 during the charge operation. The overall reaction of the charge and discharge reactions is: $2\ Li+ + O2^{2-} + 2e <-> Li_2O_2$ with a theoretical open circuit voltage of 2.96 V. The discharge species however will often include other lithium species other than Li_2O_2 such as Li_2O, LiOH, and Li_2CO_3, and various lithium alkyl carbonates. Electrolyte stability has been considered a major factor in carbonates formation in both the anode and the cathode. The introduction of PGMs such as Pd, Pt, or Ru has been previously studied for use as catalysts for the oxygen reduction reaction (ORR) and oxygen evolution reaction (OER). While they do bring considerable improvement when used to decorate the carbon matrix in the cathode, they also exacerbate the electrolyte decomposition problem. Our team proposed using these catalysts in the carbon matrix,

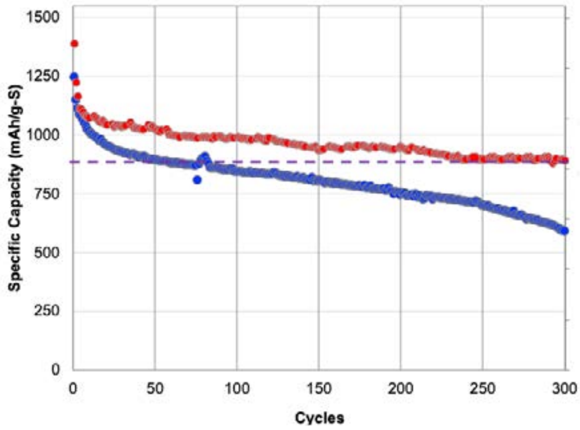
Figure 1. Scanning electron micrograph of discharge species on a carbon strand coated with (a) pristine CNTs, (b) Pd-coated CNTs, (c) Pd-filled CNTs. [3]



[2] K. M. Abraham and Z. Jiang, J. Electrochem. Soc. 1996, 143,1–5.
[3] N. Chawla et al 2017 J. Electrochem. Soc. 164 A6303

Figure 2. (a) Scanning electron micrographs of Pt-containing versus no catalyst containing CNT cathode after a full discharge cycle at C/20 and 1C rates. (b) Specific capacity of Pt-containing Li-S battery (red) compared to a control battery with no Pt (blue).





[4] J. U. D. Herbert, US Patent 3043896, 1962

however not as surface nanoparticles, instead from behind the graphene sheets of carbon nanotubes. Due to their large electron cloud, PGMs provide the catalytic improvement performance of the ORR and OER reactions while minimizing the electrolyte decomposition. Batteries containing Pd shielded behind the graphene sheets of multiwall carbon nanotubes increased the cycle capacity by up to 7-fold and nearly tripled the number of the cycles of such batteries compared to no Pd controls. Since then, these results were further built upon to achieve Li-O_2 batteries with more than 400 cycles of 500 mAh/g-CNT and more than 200 cycles of 1000 mAh/g-CNT partial discharge cycles. In addition, the Pd catalysts altered the morphology of the discharge species to yield smaller and uniform shaped deposits coating the carbon nanotubes, compared to conformal nonporous layers when cathodes did not contain Pd (Figure 1).

PGMs in Li-Sulphur Batteries

The earliest report on using sulphur as cathode was reported in 1962 in a patent by Herbert[4]. Since then, sulphur has found uses in different battery systems, including Na-S and Li-S. In Li-S batteries, sulphur is often used as S_8 with a puckered ring eight sulphur atoms arrangement. During discharge, lithium-ions oxidized in the anode reach the cathode to combine with sulphur to produce various polysulphide species, Sn^{2-}. The solubility of these polysulphide species is attributed to various phenomena of capacity fade due to sulphur loss in the electrolyte and at the anode. The diffusion of polysulphide to the anode causes the formation of passivating species in addition to the consumption of lithium. The repetitive diffusion of long chain polysulphides to the anode where they react to form shorter polysulphide chains which return back to the cathode to get oxidized back to longer chain polysulphide is known the shuttle phenomenon. The shuttle phenomenon contributes to higher capacity during the charge than during the discharge, referred to as a reduction in Coulombic efficiency. Another undesirable phenomenon is the formation of larger agglomerates of the insoluble Li_2S_2 and Li_2S species. This agglomeration leads to resistance growth, sulphur loss caused by poor accessibility, and leads to continuous capacity fade. PGMs, such as Pt, can help remedy the agglomeration problem by providing "growth sites" that can guide the precipitation of the insoluble species. In batteries in which Pt was used in CNTs the insoluble discharge species can be seen forming nodular structures around the CNT strands (Figure 2a), a phenomenon that allows them to redissolve easier and thus contribute to higher capacity retention and higher Coulombic efficiency. This behavior was also observed in batteries cycling for 300 cycles with > 70% capacity retention relative to the first cycle at C/2 rate (Figure 2b).

PGMs in Current Lithium-Ion Batteries

Further application of PGMs in conventional lithium-ion batteries are currently being explored as remedies to various phenomena such as dendrite shorting. We also see a significant role PGMs can play at the anode to facilitate the transition from graphite to lithium metal anode. The replacement of graphite or silicon with lithium metal can achieve as high as 35% higher specific energy. Improving the cyclability and safety of the lithium anode batteries remains the main challenge. We see an opportunity for PGMs to play a role in this transition with our newly developed patent-pending technology is this area.

About Lion Battery Technologies Inc.

Lion Battery Technologies Inc. is a subsidiary of Platinum Group Metals Ltd. (PLG-NYSE, PTM-TSX). Lion was formed in 2019 as a partnership between Platinum Group, Anglo American Platinum and Florida International University to research and commercialize the use of platinum and palladium in existing and emerging battery chemistries. www.platinumgroupmetals.net

Decarbonisation and the shift to longer duration battery energy stationary storage

Iola Hughes
Senior Research Analyst, Rho Motion

As the world looks to decarbonize its electricity grid and countries step up their climate actions, the use of battery energy stationary storage (BESS) is set to play an increasingly important role in the energy transition.

Reaching Net-Zero

In May 2021 the International Energy Agency released its report on the actions required to meet net-zero globally by 2050. In the report it set out the countries that have made commitments to net-zero, with some 137 countries having made some level of commitment to carbon neutrality so far. The following graphs show the trends of net-zero pledges from 2015 to 2021. A surprisingly low figure of just 10 countries have net-zero pledges set in law, whilst a further 34 countries have pledges in policy or proposed, with the remaining countries net-zero targets under discussion. Overall, the countries that have made pledges account for more than 70% of global CO2 emissions.

Chart: Number of National Net Zero Pledges

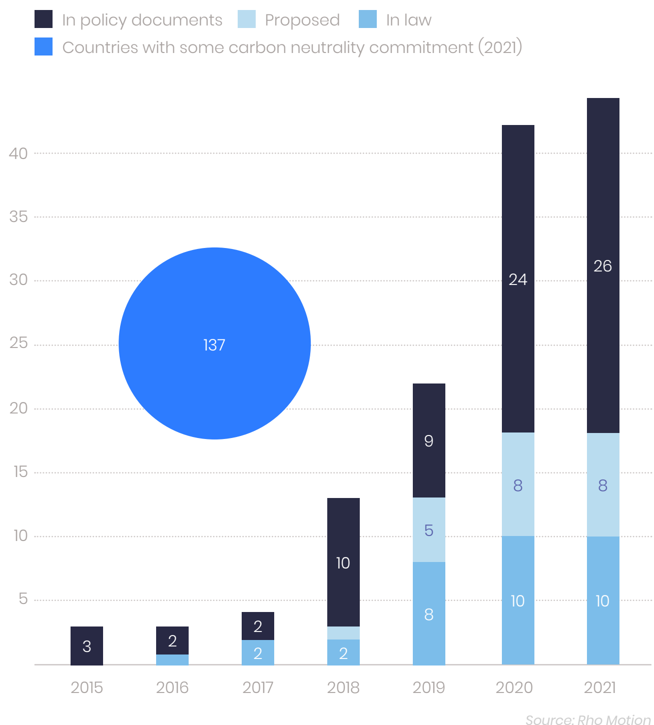


Chart: Global CO2 emissions covered by Net-Zero Pledges

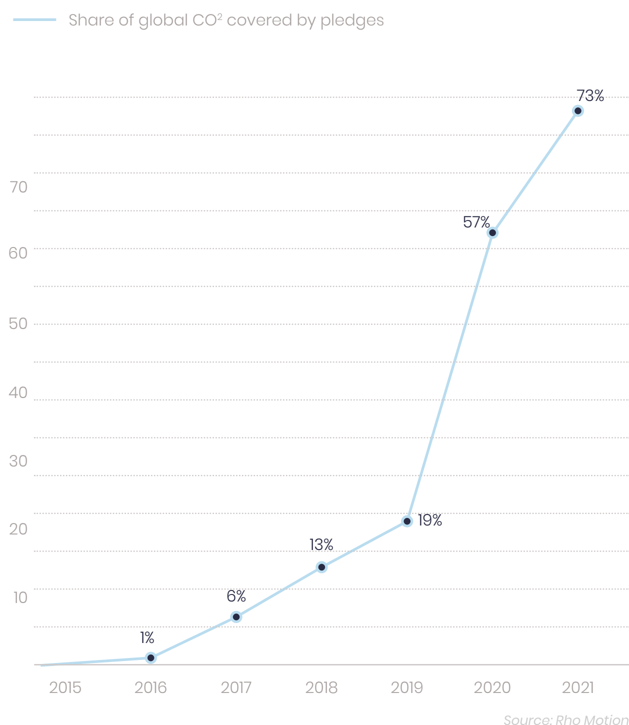
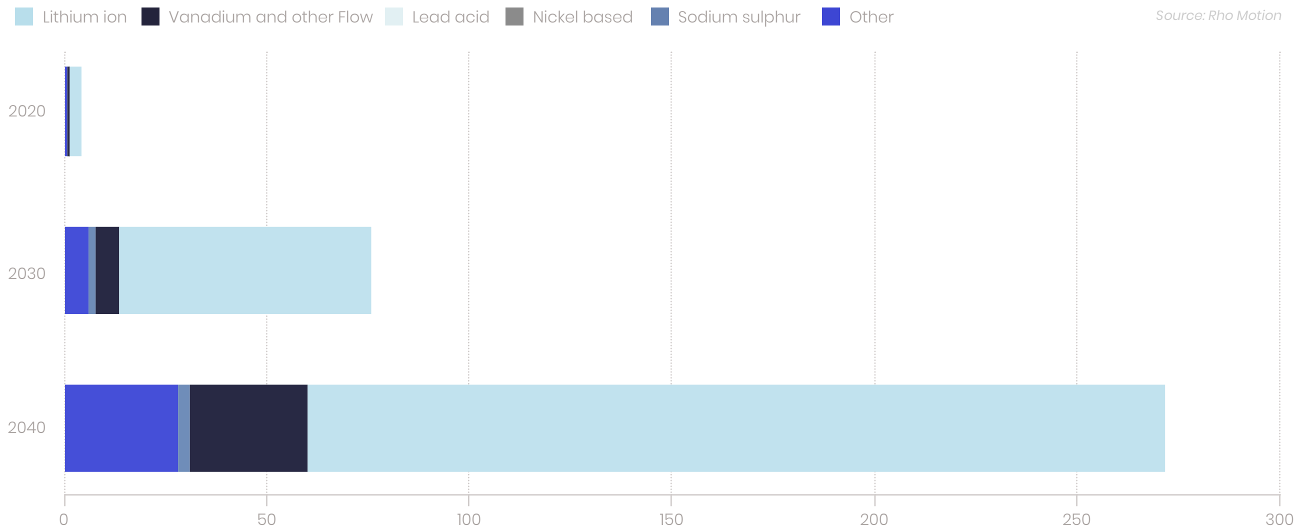


Chart: Annual installed battery ESS Grid capacity GWh



Reaching net zero requires a regeneration of the electricity grid, a full transition to renewables and significant investment into the battery energy stationary storage required to support this. Countries are already recognising a variety of benefits from renewable energy investments, including greater energy independence, improved grid reliability, lower costs, new jobs, and more investment capital.

> *The need for longer duration storage is expanding*

The Growth of Grid Scale Storage

The change in electricity generation and supply is having a knock-on effect on the structure and future of the electricity grid, driving the need for energy stationary storage. Grid scale storage covers batteries with capacity ranging from tens to thousands of megawatt-hours, from small scale commercial and industrial,to large scale batteries that support the grid by balancing renewables, mitigating grid congestion and preventing blackouts. Annual installed capacity for grid scale battery energy stationary storage installation is set to increase from 4GWhin 2020 to 271GWh in 2040, with lithium ion batteries dominating the market. The forecast below is taken from our Battery Energy Stationary Quarterly Outlook.

An increasing number of large-scale projects with durations up to and exceeding four hours are being announced. This year in the US & Canada the weighted average duration of lithium ion battery projects entering operation is just below three hours,by tracking projects in the pipeline we expect this to increase to close to four hours by 2023. Californian infrastructure operator CAISO reported that it expects the majority of new batteries deployed to the grid in the next few years to be four hours duration, before expanding into longer duration with other technologies. CAISO identifies four hours as the upper limit for cost effectively using lithium ion batteries at large scale. The primary use for long duration storage is energy supply shift, with increased renewables and the removal of base load generation such as coal and gas, the need for longer duration storage is expanding.

ESS Project Spotlight

Here, we examine the dynamics of some recently announced BESS project as we take a closer look at three large scale projects that are in the pipeline from our Battery Energy Stationary Storage Monthly Assessment.

The projects discussed fall under two categories, replacement of coal or gas plants (Yallourn) and hybrid solar and storage projects (Crimson and Geermu). In the coming years we expect these two sectors to represent a large share of the growth in the energy storage space.

Coal and Gas Replacement

The amount of energy produced by renewables worldwide is increasing, meanwhile an increasing number of coal and gas power plants are being decommissioned. At the UK-hosted meeting of the G7 in June, the leaders failed to

agree on a 2030 group wide commitment to the phase out of coal. At COP26 to take place in the UK later this year, we expect this coal ban to be revisited along with wider climate ambitions and commitments to be brought forwards by attending UN members. Decommissioning of coal and gas provides an opportunity for energy storage. As coal is removed from the grid and an increasing share of variable renewables are added, energy storage assets can play an increasingly important role in meeting peak demand. Similarly, as wholesale energy prices become more volatile –due to the variable nature of renewable generation –the opportunity for storage to participate in wholesale arbitrage and balancing will also grow.

The growth of paired hybrid-solar

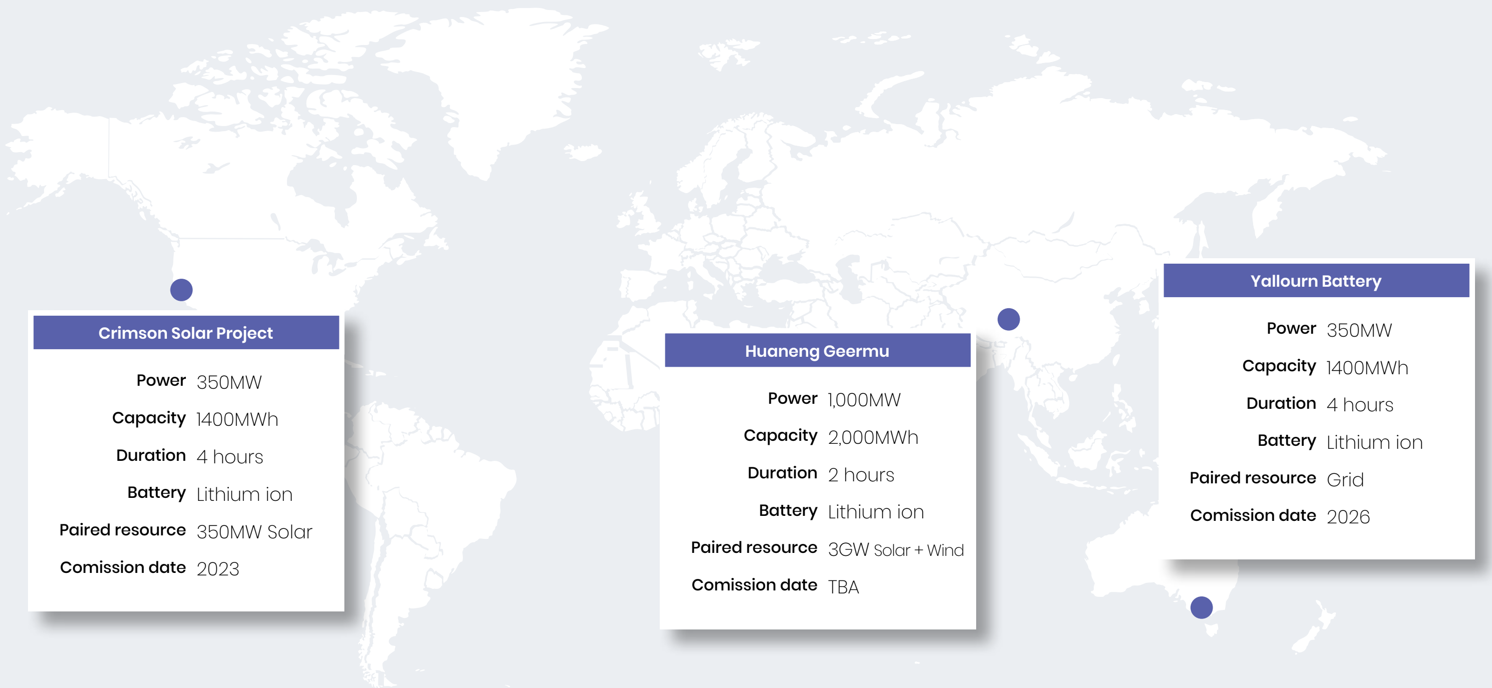
The growth of the hybrid solar and storage project is the result of two trends, the rapid deployment of solar paired with the falling costs of energy storage. An increasing number of co-located, large scale solar and storage projects are being regularly announced around the world, as the expansion and economic viability of solar and storage grows. Solar deployments are expected to grow at a rate of 125GW of capacity per year over the next five years, meanwhile energy storage prices are expected to continue to fall by over 6% per year. As a paired resource, solar and storage is highly cost competitive. On a levelized cost of energy basis it is cost competitive against gas generators with a capacity factor up to 40-50%, meaning utilities will increasingly favour this hybrid model.

> *Legislation will provide the basis for market growth*

Legislation continues to be a key driver

As the market continues to develop, legislation will provide the basis for market growth. Net zero emission targets and renewable mandates drive the need for storage. Similarly, an increasing number of countries and regions are recognising the importance of stationary storage and adopting storage mandates in themselves. In the last month Connecticut and Maine have become the 8th and 9th US states to adopt a storage mandate, targeting 1,000MW and 500MW of storage by 2030 respectively.

The role of battery energy stationary storage in global markets is set to explode in the coming decade. The decommissioning of fossil fuels, paired with the rapid roll out of renewables and strict emission legislation provides a growing opportunity for the battery energy stationary storage space to both support and benefit from the energy transition.



PROJECT SPOTLIGHT

The Crimson Solar Project

in California, US

In May 2021, final approval was granted by the US Department of the Interior (DOI) for the construction of Crimson Solarand Storage Project in California. The 350MW battery storage system will support a 350MW solar array and generate power through the Southern California Edison Colorado River Substation. The project will be owned and operated by Sonoran West Solar Holdings, a subsidiary of Recurrent Energy and Canadian Solar. Upon completion, set for 2023, the project will be amongst the largest by capacity in the US, and is reported by the DOI to have the ability to power 87,500 homes

PROJECT SPOTLIGHT

Huaneng Geermu Solar, Wind & storage Project

in Qinghai, China

Another particularly large storage project is the Huaneng Geermu Solar, Wind &Storage Project at a massive 2000MWh/1000MW, located in Qinghai Province, China. In June 2021 China Electric Power Planning & Engineering Institute was awarded the project and will provide a design within 100 days from 16/06/21. At present this project has no expected date for commission, however we expect construction of this large project to begin in Q4-2021.The battery will support a combination of solar PV and wind, as well as peak shaving resources to maximise the transmission capacity of the AC section of the Haixi Power Grid.

PROJECT SPOTLIGHT

Yallourn Battery Storage

in Victoria, Australia

In April 2021, Energy Australia announced the construction of a 350MW BESS project to replace the Yallourn coal-fired power plant, which is due for shutdown in 2028.The four-hour duration, 1,400MWh grid scale battery will ensure reliable electricity supply continues and enable an increased share of renewables to be deployed. This is by far the largest project announced to date by Energy Australia, with Ballarat Substation BESS (30MWh) and Ganawarra Solar BESS (50MWh) completed in 2018and 2019, respectively. Energy Australia have set the goal to be carbon neutral by 2050, the retirement of the Yallourn Coal Plant will reduce the company's emission profile by 60%, a significant step in helping the company reach its ambition

*Rho Motion's **BESS Quarterly Outlook** and **BESS Monthly Assessment** provide up to date insight with all developments in this space. The assessment provides analysis of project announcements, updates, and commissions, tracking the development of key battery stationary storage metrics over time, as well as monthly news and market updates. Our outlook provides long-term outlooks for battery demand and battery chemistry, by application and region, based on robust and informed methodologies.*

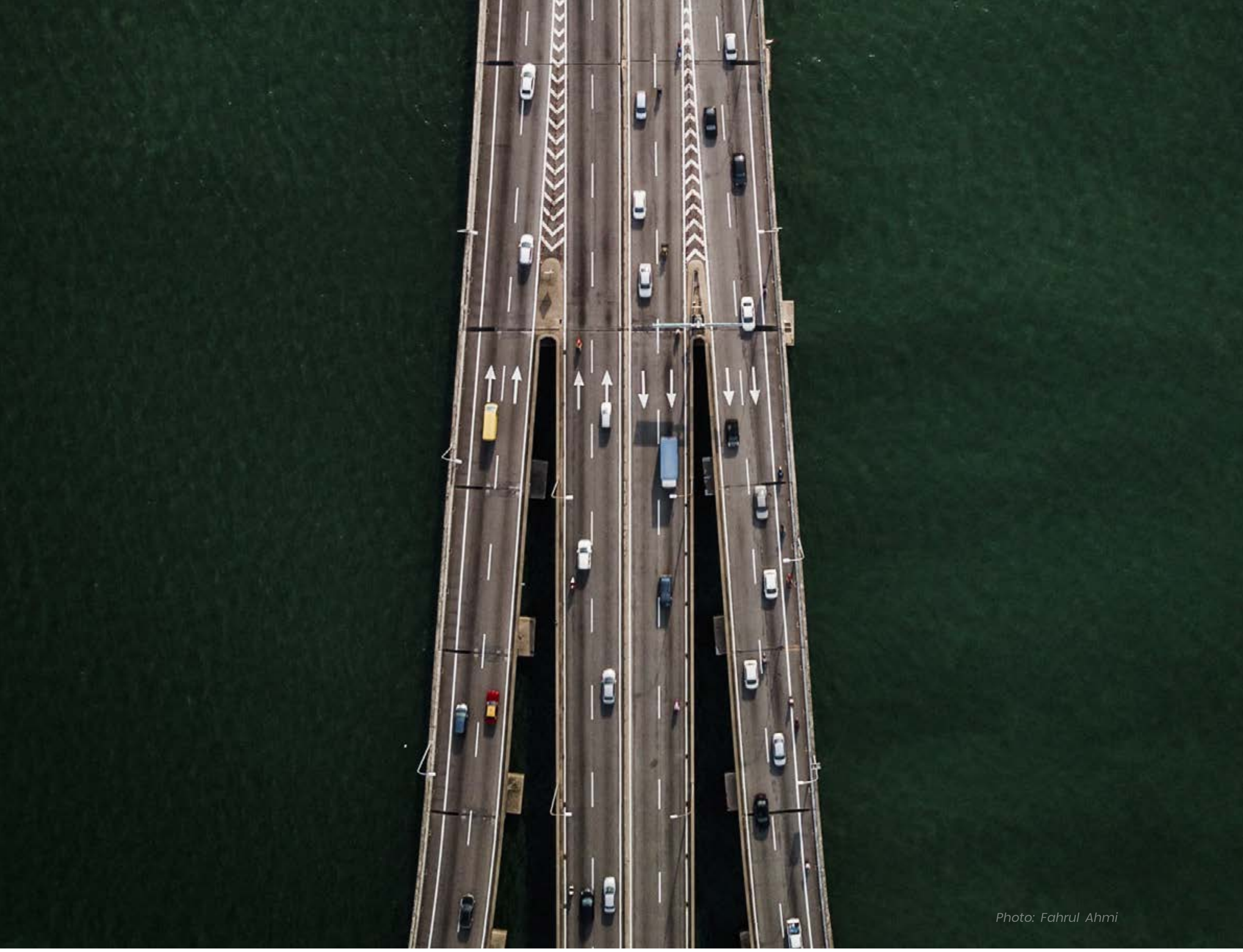


Photo: Fahrul Ahmi

EV production dynamics

Charles Lester
Senior Research Analyst, Rho Motion

The dynamics of global electric vehicle sales are widely discussed and analysed, but production facilities are often overlooked for consideration. Here, we take a deep dive in the dynamics of EV production, draw a comparison with ICE production, and examine the current market of EV exports.

We track country EV sales in our EV & Battery Database and collect different variables including EV Production facility. The map below highlights where EVs have been produced ytd to June 2021 in the major regions. As expected, China produces the most EVs, with around 1.2 million vehicles benefiting from local supply chains and a more established EV market. The majority of EVs produced in China stay within China. We will focus more on the current dynamics of exports later in this article.

In Europe, around 792,000 vehicles were produced in ytd June 2021. The top producer is Germany, where over one-third of these vehicles were produced by major OEMs such as Volkswagen, Daimler, and BMW. The second and third are Spain and France, respectively, where Renault-Nissan and Stellantis play a large role. EV production is also growing in eastern European countries, such as the Czech Republic, Slovakia, and Hungary, and the region is also seeing a rise in lithium ion battery capacity. For example, LG Chem's Poland plant is rising to 67GWh capacity by 2025 and SK Innovation is also expanding its capacity in Hungary. In the UK, production capacity will increase following the recent announcement from Stellantis to build an electric van and passenger car production facility, costing around USD 100 million.

In North America, two-thirds of the production is from Tesla's facilities in the US. Traditional OEMs such as Ford with the Mach-e have gained some EV production market share from Tesla in 2021. However, with the Austin plant expected to come online in late 2021, Tesla will likely maintain it's dominance for many years to come.

In the Rest of Asia outside of China, over 95% of EV production is in Korea and Japan, this is primarily Hyundai Kia in Korea and, Toyota and Mitsubishi in Japan. There are also smaller EV manufacturing facilities in India, Malaysia, and Thailand.

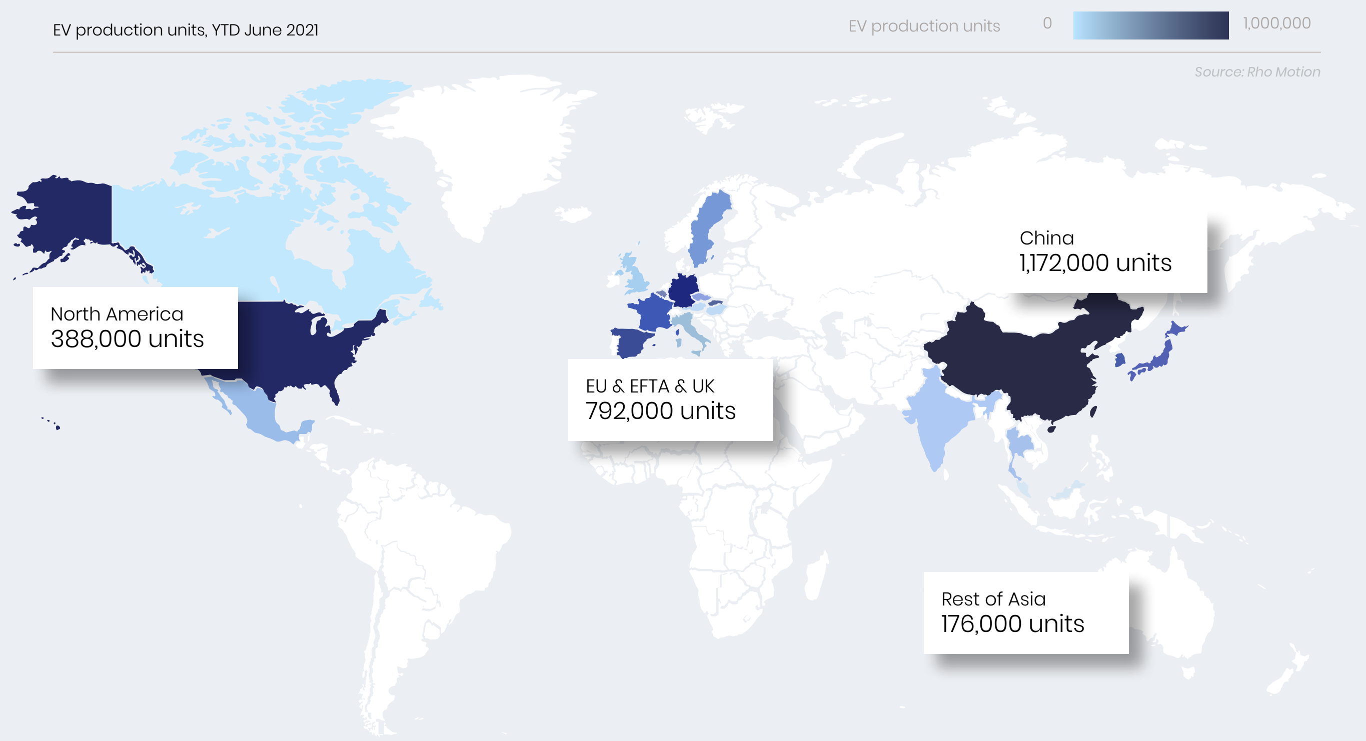
How does it compare to the ICE market?

We look at the production ratios of each region, calculated by dividing production by sales, and display the findings below for the opening six months of 2021 in the table below. If the ratio is above 1, then there are more vehicles produced than sold, and ultimately exported. China will typically have a ratio close to 1 for both the EV and ICE market, as most OEMs produce for the domestic market. The current EV production ratio in China is 1.23, this is mostly due to exports from the Tesla Shanghai facility to several regions such as Europe, Central Asia, and Australasia, which we track through trade data.

Another interesting comparison is in Europe, where more EVs are sold than being produced, with an EV production ratio of 0.78. This is mostly driven by Tesla imports from the US and China. The dynamics will likely shift once Giga Berlin is up and running at a reasonable production rate. Interestingly, more ICE PC & LDV vehicles are produced than sold in Europe, with an ICE production ratio of 1.06.

The production ratios in North America are currently the reverse of the European market. More EVs are currently produced than sold in North America, mostly driven by Tesla. However, in the ICE market, North America has a

EV production units, YTD June 2021



Production ratio, YTD June 2021

	EV production	EV sales	EV production ratio	ICE production ratio
North America	388,000	315,000	1.23	0.70
EU & EFTA & UK	792,000	1,016,000	0.78	1.06
China	1,172,000	1,092,000	1.07	0.98
Rest of Asia	176,000	92,000	1.92	1.46

*A ratio above 1 indicates the region produces more than is sold, the rest is exported to other regions.

Source: Rho Motion

production ratio of 0.70, driven by imports from Japan, Korea, and Europe.

At the other end of the spectrum, for both ICE and EV, Asian countries produce significantly more than is sold domestically. For EV sales, this is mostly in Japan and Korea. The current uptake in EV sales in countries such as Japan has been limited to date, lending itself to exports.

Where are electric vehicle exports going?

Continuing with the Rest of Asia category, of the 176,000 EVs produced ytd June 2021, around half of these were exported to Europe and one-quarter to North America. Likewise, only half of the vehicles sold in the Rest of Asia are domestically produced, with most of the rest coming from Europe or North America. This is shown in the graph below.

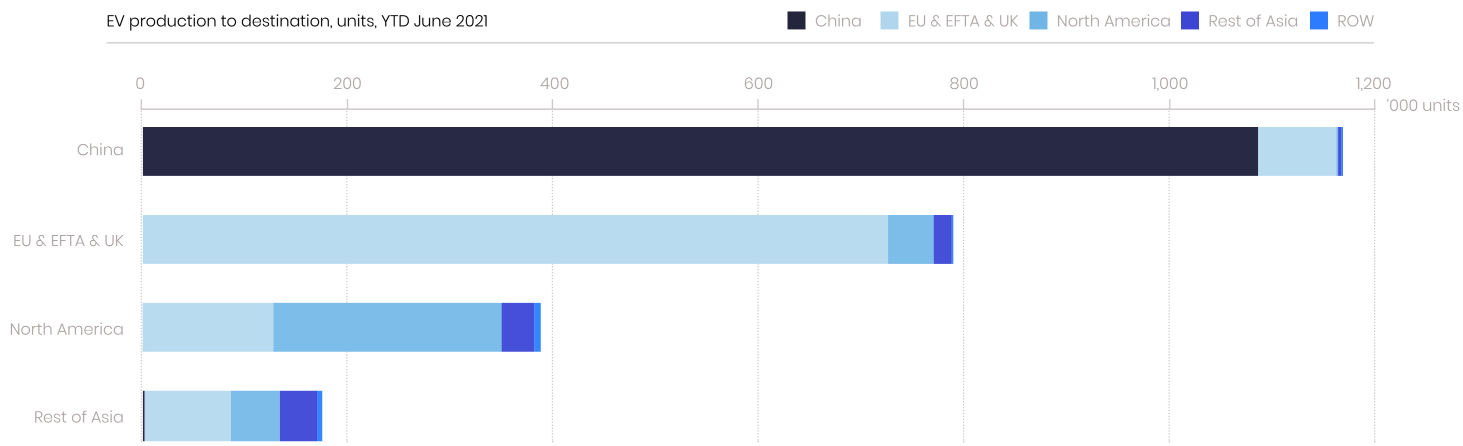
In Europe, there is currently an EV production ratio of 0.78. Of the 792,000 EVs produced in the region, around 90% are sold domestically. Exports out of Europe mostly go to North America and the Rest of Asia.

In China, the majority of EVs are produced and sold domestically. However, we are also seeing an increased number of exports from China into Europe. This is mostly from SAIC and Tesla. Tesla began exporting its Standard Range Model 3, with an LFP battery, late last year. We have now tracked several more shipments in the first half of 2021 from China to Europe.

Finally, the North American market is currently dominated by Tesla production and sales. Around 70% of vehicles produced in North America are sold domestically, with most of the rest exported to Europe.

Overall, the current production ratios vary from ICE to EV and from region to region. As OEMs increase commitments to electrification, and governments push to reach targets, the location of production facilities will be a key factor to watch out for, as well as the role exports play in the global EV market.

EV production to destination, units, YTD June 2021



Source: Rho Motion

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The case for transitional technologies to facilitate the move towards decarbonisation at mining sites

Terry Scarrott
Principal Consultant, Rho Motion


Source: ABB

Following the Paris Agreement (COP 21) in 2015, the world's leading powers have sought to address their concerns around carbon emissions, and to that end, have intensified efforts to step-up climate actions. To meet decarbonisation targets, mining operators have come under the spotlight as they seek alternative methods to carbon-friendly processes, namely in transportation, which is by far the largest net emitter of carbon at mine sites.

There is no one-size fits all approach when it comes to solving the biggest decarbonisation challenges at mining sites. Geographical location, topographic setting, geology, technical and operational factors all determine site design and planning, and as such, each mining site should be treated as a discrete case with a unique set of outcomes.

Electrification at mining sites is one solution that can solve this issue, however, mine operators must overcome sizable trade-offs to balance cost with a net reduction in emissions: i) Legislation – associated with CO2 reduction environmental penalties; ii) cost reduction – used as a measure of an operator's health; ii) reliability – in terms of grid connection, quality and performance, unfettered access to electricity, efficient transport and better diagnostics; iv) safety – to cope with power transfer, high mechanical loads, capacity increases, and; v) flexibility – of a system to cope with harsh terrain, scalability and changing mine requirements in remote locations.

Underground mines have moved, or are moving, towards full electrification; where there is a compelling argument for improved overall air quality for workers, and where the performance characteristics of the machinery and transport are suited to current lithium-ion battery technology and charging infrastructure. For open-pit mines, the challenges are far greater because current lithium-ion battery technology is unable satisfy the power requirements of the biggest (and heaviest) mining dump trucks. Catenary technology, in the form of Trolley Assist, provides a short to medium-term solution to address this issue, and is becoming more widely accepted by mine operators. These are compatible with hybrid diesel-electric drive trucks.

What is Trolley Assist?

Also known as simple catenary, trolley assist comprises a single overhead wire that transmits electrical energy to the truck's drive motors via a pantograph. Electricity is sourced from a substation and is normally used with low voltage DC (i.e. less than 1.5 kV). When connected to the overhead catenary, the diesel engine idles as the full power capacity switches to the electric wheel motors.

Trolley assist has been around since the 1880s; primarily used for traditional tram systems in metropolitan areas, and at mining sites for haul trucks since the 1960s.

The basic premise for the use of trolley assist is that hybrid diesel-electric-drive trucks use conventional diesel to power the vehicles on flat terrain (e.g. in the pits and on level segments) and connect to the overhead catenary on the grade, where greater power and overall performance is needed.

The case for trolley assist

Single trolley is appropriate for low running speed and current requirements and complex track layouts. While trolley assist technology has remained largely unchanged since the late 19th Century, big advancements in lithium-ion battery technology and digital monitoring have made this a more convincing business case as electric-drive haul trucks can transport greater payload capacity over longer distances and at optimal performance. This is demonstrated by successful pilots across the globe, including Boliden's Aitik open-pit copper mine in Sweden.

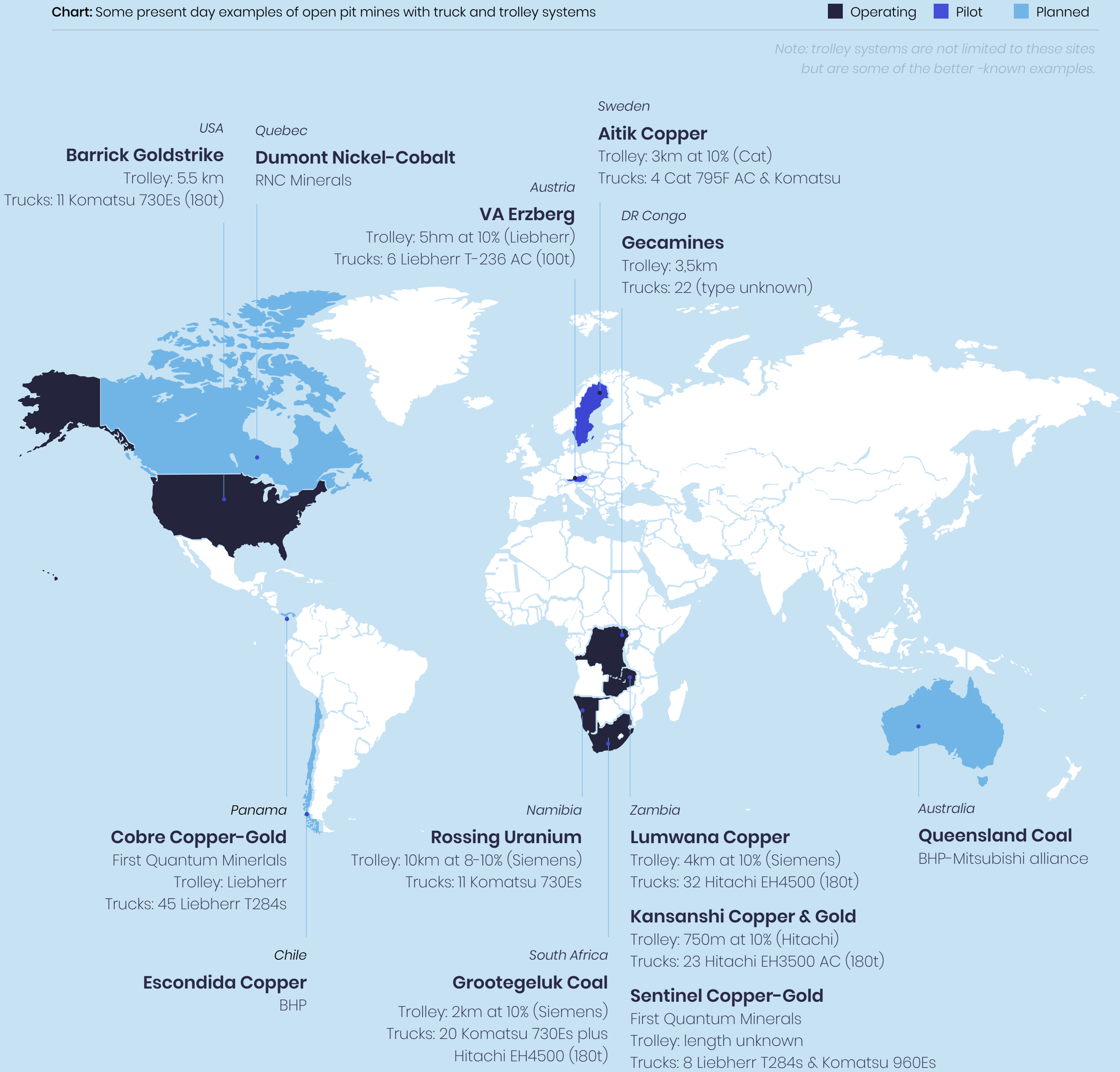
Based on different use cases, trolley assist could provide several benefits for mine operators, including:

- Environmental improvements such as reduced emissions
- Increased productivity while connected to the trolley line on the grade
- Reduced costs including maintenance and fuel savings

In some reported use cases, maintenance costs have been significantly reduced due to minimised use of diesel engines and maximised potential of wheel motors through regenerative braking, leading to less wear and tear and increased engine life (by up to 25%). This has also resulted in significant fuel savings (up to 90%) per truck per cycle, which has translated to improved operator health.

Nevertheless, there are several barriers to achieve success with trolley assist, most notably high capital expenditure associated with the trolley system and upgrades to existing fleets.

Chart: Some present day examples of open pit mines with truck and trolley systems



Source: Rho Motion

The 'electrification' challenge for mine operators

Mine operators are being presented with difficult decisions regarding their transport electrification strategy. Do they become an early adopter of battery electric or hydrogen fuel cell vehicles, where current pilot technology (e.g. from Williams, Belaz and Weichai-Ballard) shows potential but is relatively unproven at a commercial level? Do they seek a transitional technology, such as overhead catenary, that will help them to achieve decarbonisation targets but present economic trade-offs? Or do they maintain the status quo and continue with current diesel-powered heavy haul trucks until they are forced to change or presented with more convincing business cases?

When faced with these questions, mine operators will have specific design prerequisites and decision criteria that will determine the applicability of different power trains and enabling technologies onsite. One of the critical components for mine operators to consider is what charging infrastructure is most suitable? For example, whether to implement opportunity charging, overnight charging or battery swapping? What transport innovations are compatible with the site grid infrastructure? And what is an appropriate business case for smart power applications, such as microgrids, to electrify these power-hungry behemoths?

In 2021, major OEMs associated with the manufacture, installation and maintenance of trolley assist are leveraging their decades of experience in the rail and tram sector to produce optimised trolley assist solutions for mining operators. These OEMs are forming alliances with the major truck OEMs to create a compatible ecosystem that provides packaged solutions rather than discrete equipment offerings. However, while some mining operators are phasing in transitional electrification technologies to address their transportation challenges, no single operator has dealt with this comprehensively.

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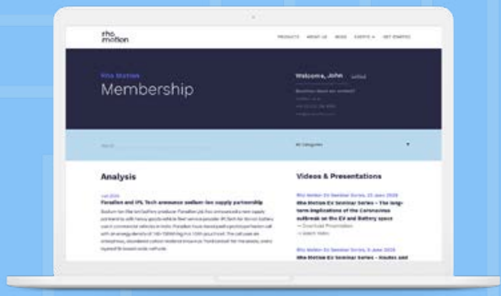

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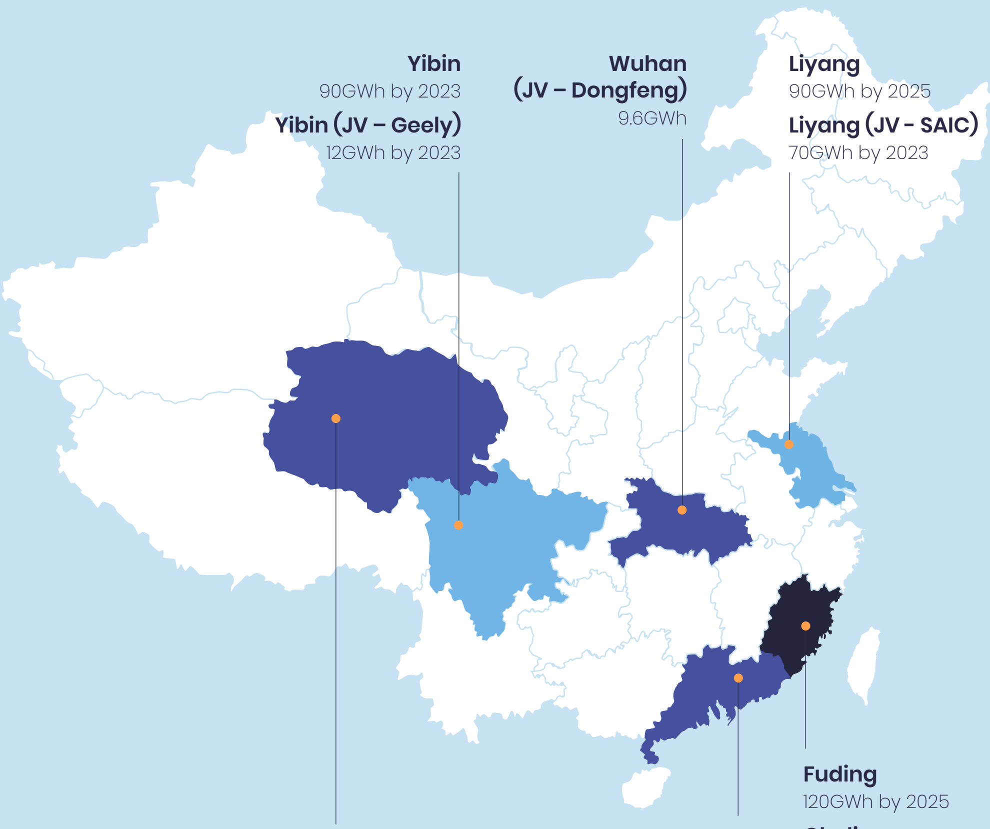
China planning for its own EV future, as well as rest of the world

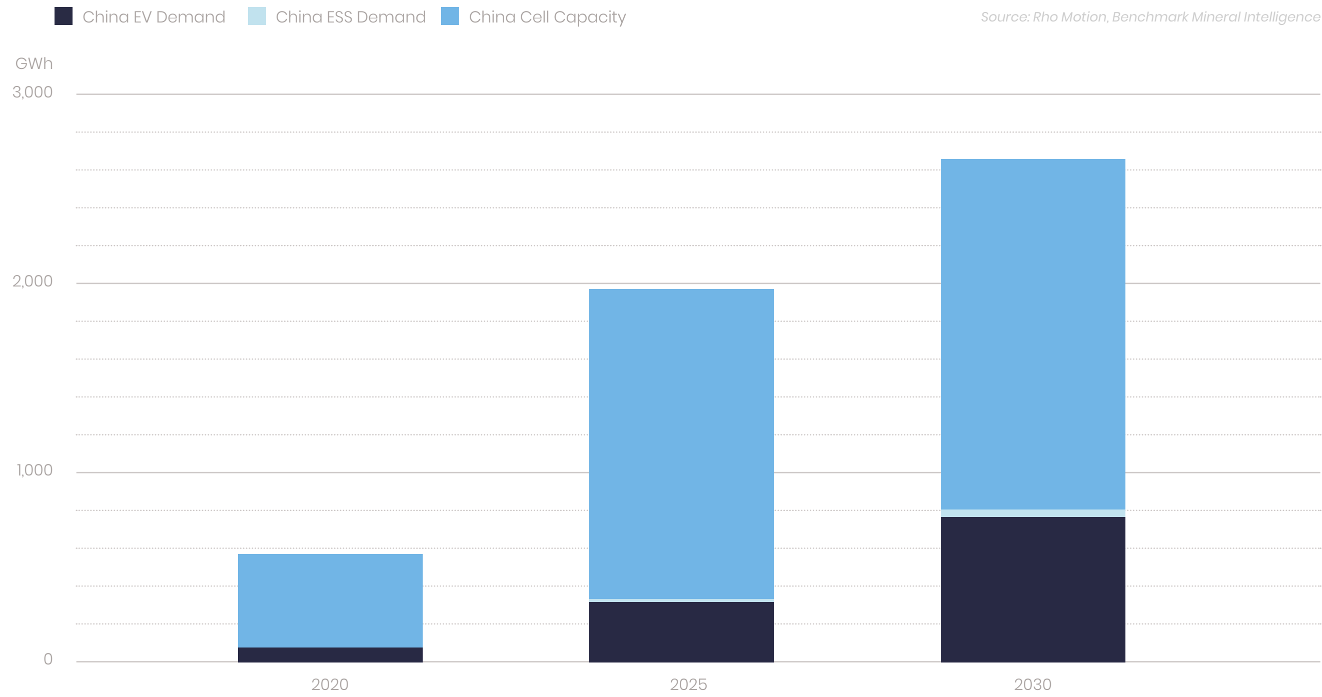
Yu (Frank) Du
Research Analyst, Rho Motion

In Europe and North America governments and investors are increasingly aware of the need to invest in the battery supply chain and have started to make tangible moves to develop capacity and capabilities to support the growth of the EV and renewable energy markets.

Chart: Some present day examples of open pit mines with truck and trolley systems



China Lithium Ion Cell Capacity versus domestic demand



It remains the case, however, that China remains many years ahead of the rest of world in terms of current capacity and investments being made for the future. In this article we examine the current situation for cell manufacturers in China and how their capacity investments are likely to evolve in the coming years.

In June, CATL's Yibin battery project phase 1 went into production. This project is the first piece of a RMB 30 billion (~USD 4.5 billion) 7-phase megaproject in Yibin, Sichuan. Currently, CATL has 8 wholly owned manufacturing bases in production or in plan. It also has formed 5 joint ventures with top OEM partners across China. After consolidating all projects for CATL, we estimate that CATL's total annual capacity will be around 554.5GWh with additional 138.6GWh capacity from JV by 2025.

CATL is not the only operator that is trying to speed up in the capacity competition. Top EV battery providers, such as BYD, EVE, CALB and Gotion, are all in a phase of rapid expansion. BYD owns 6 battery manufacturing bases in production or in plan with over 75GWh total planned capacity by 2023. SVOLT, a Great Wall Auto subsidiary, plans to increase its production capacity from current less than 10GWh per year to 110GWh, including an overseas facility of 24GWh per year in Saarland, Germany. In June, EVE Energy made 3 announcements in a row and its revealed expansion plans. In three years, EVE Energy's battery production capacity will increase to over 104.5GWh per year from the current 11GWh per year capacity. CALB also plans to expand its capacity and aims to achieve 200GWh per year by 2025. This will include its Xiamen base (20+30GWh), Luoyang (10GWh), Changzhou (70GWh), and Chengdu (70GWh).

The main driver for these investments is of course the growth in EV demand, however the scale of the investment in China makes it clear that suppliers expect to be exporting to overseas markets as well as serving domestic OEMs. As the chart below shows, Rho Motion expects that EV sales (excluding HEV) in China region will reach 5.6 million units by 2025 and 12.2 million units by 2030. Accordingly, we expect that battery demand for these vehicles will reach 305.7GWh in 2025 and 767GWh in 2030, battery cell capacity in the country is likely to reach nearly 2,000 GWh and 2,700 GWh over the same period.

With the expected rapid expansion in battery production in the next few years we are also seeing large scale investments in battery materials in order to secure supply for the development of the industry. In the table below we show the announcements from June 2021 alone as tracked by Rho Motion's regular China briefing, which is provided to our Members via our online platform.

Battery Material Project Highlights

2021

- Nuode will raise RMB 2.3 billion to finance its new electrodeposited copper projects in Qinghai and Huizhou.
- Gelong's new silicon carbon composite anode is fully commercialised with 3000 tons/year capacity at the moment. Annual capacity is expected to be 10,000 tons/year by the end of 2021.
- Tinci Materials announced RMB 1.049 billion new project - 150,000 tons/year LiPF6 and 2,000 tons/year LiPO2F2
- Fulin P.M. plans to issue public offering to raise no more than RMB 1.5 billion. RMB 0.86 billion of the raised capital will be used to fund a EV electronic control system project. RMB 0.272 billion will be used to finance a RMB 0.8 billion LFP cathode material project in Sheyang, Sichuan.

2022

- Kelong Energy IPO application has been accepted. According to the plan, Kelong will raise RMB 613 million to build factory with 12,000 ton/year high performance ternary precursor and 4,000 tons/year cathode material.
- Sunwoda invests RMB 750 million in battery material production in Zhejiang to secure its battery supply chain. Commission date July 2022. This is the second phase of a RMB 5.2 billion 3-phase project. Upon completion of all 3 phases, the overall capacity will go up to 240 million battery module unit per year.

2023

- Huayou Cobalt disclose public offering plan to raise RMB 7.6 billion for 2 projects: RMB 6.3 billion for 50,000 tons NCM cathode material/ 100,000 tons ternary precursors annual capacity and RMB 1.4 billion for 50,000 tons ternary precursors annual capacity. Both projects are expected to be in production in 2 years.
- Shanshan Technology held ground-breaking ceremony in Wulanchabu, Inner Mongolia. Upon completion, the first phase will provide 50,000 tons anode material annual capacity.
- Hi-Tech Spring's IPO application has been accepted. Hi-Tech Spring will raise RMB 1.512 billion to finance its three expansion projects, Including the construction of a 40,000 tons/year battery-grade vinyl carbonate plant, a 60,000 tons/year battery-grade methyl/diethyl carbonate plant and 2 sets of 70,000 tons/year dimethyl carbonate plants.
- Putailai spent RMB 430 million to acquire factory in Jiangsu to expand its battery separator capacity. As CATL's key supplier of anode materials and separators, Putailai has followed CATL's expansion plan closely. Last month, Putailai just announced projects in Zhaoqing, Guangzhou and Yibin, Sichuan.

2024

- Yongtai Tech announced RMB 790 million project - 20,000 tons/year LiPF6 and 50,000 tons/year Hydrofluoric Acid
- Ronbay Tech's 100,000 tons/year cathode material factory has started construction. This is the second phase and is expected to be completed in 2021. The full 3-phase project will be completed by 2024 and the main products will be NCM811 and NCA materials.
- Xiangfenghua will invest RMB 1.2 billion in synthetic graphite anode material project in Suining (annual capacity 60,000 tons)

Source: Rho Motion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