INSIGHT

Updated June 2021

Electric Vehicle Battery Supply Chain Analysis

How Battery Demand and Production Are Reshaping the Automotive Industry

AUTOMOTIVE
FROM ULTIMAMEDIA
Global. Business. Intelligence.

THIS REPORT IS IN PARTNERSHIP WITH

ABB is a leading global technology company that energizes the transformation of society and industry to achieve a more productive, sustainable future. By connecting software to its electrification, robotics, automation and motion portfolio, ABB pushes the boundaries of technology to drive performance to new levels. With a history of excellence stretching back more than 130 years, ABB's success is driven by about 105,000 talented employees in over 100 countries. www.abb.com

ABB Robotics & Discrete Automation is a pioneer in robotics, machine automation and digital services, providing innovative solutions for a diverse range of industries, from automotive to electronics to logistics. As one of the world's leading robotics and machine automation suppliers, we have shipped more than 500,000 robot solutions. We help our customers of all sizes to increase productivity, flexibility and simplicity and to improve output quality. We support their transition towards the connected and collaborative factory of the future. ABB Robotics & Discrete Automation employs more than 10,000 people at over 100 locations in more than 53 countries. www.abb.com/robotics

Having specialised in automotive logistics for nearly 70 years, GEFCO has a presence in 45 countries, with 13,000 employees and a turnover of €4.4 billion ($5 billion). GEFCO is number one in the European finished vehicle market and ranks among Europe's top ten leading transport and logistics groups. GEFCO has a presence in six continents and its operations cover a total of 150 countries. With a large workforce around the world, GEFCO thrives on the challenges of the global automotive industry.

Today GEFCO covers every aspect of automotive logistics for car manufacturers, parts suppliers and the two-wheeler industry, both inbound and outbound. The company's vision is to add value and generate savings for its automotive customers through multimodal supply chain engineering and optimisation. For more on GEFCO's supply chain solutions, including those supporting electric vehicle and battery supply chains, visit: gefco.net/en/industries/automotive

Electric Vehicle Battery Supply Chain Analysis

How Battery Demand and Production Are Reshaping the Automotive Industry

June 2021

Report author: Daniel Harrison, Automotive Analyst
Daniel.harrison@ultimamedia.com

Report editor: Christopher Ludwig, Editor-in-Chief
Christopher.ludwig@ultimamedia.com

This electric vehicle battery supply chain report and database is the independent work and research from Automotive from Ultima Media, the business intelligence unit of Ultima Media.

For more information and to read more reports and coverage of automotive manufacturing, register free to become a member of automotivemanufacturingsolutions.com.

For more reports and coverage of automotive supply chain and logistics, register free to become a member of automotivelogistics.media.

AUTOMOTIVE FROM ULTIMAMEDIA

Table of Contents

1. Executive Summary

1.1 Lithium-Ion Batteries Will Reshape Automotive Supply Chains

Lithium-ion batteries are central to the success of automotive OEMs' electrification strategies in terms of improving the driving range and price competitiveness of electric vehicles (EVs). Carmakers and battery manufacturers are aiming to improve battery quality and bring down prices to below $100 per kilowatt hour (KWh), a rate at which EVs can compete with traditional internal combustion engine (ICE) vehicles.

However, battery technology and prices are not the only factors at play. As EV demand rises, it is becoming especially critical for manufacturers to manage the procurement and production of batteries. And there are serious questions over whether supply will keep up with demand across the battery supply chain.

Even before the Covid-19 crisis, there were growing reports of OEMs facing production issues as a result of difficulties sourcing batteries and cells. In the aftermath of global shutdowns and subsequent restarts following the first wave of the pandemic, EV production again felt the squeeze in supply as demand ramped up, impacting output of key products like Tesla's Model 3, for example.

More recently, the wider shortage of electronic components, including semiconductors and microchips, has compounded these issues. There are further bottlenecks in the supply of lithium and certain materials and minerals in the battery supply chain, with the risk of price spikes.

Such supply issues could lead to potential lost sales, unnecessary costs and lower profits for manufacturers at a particularly critical time. Analysis of the fast-developing battery industry reveals why many of these teething problems arise. Not only are there a new set of companies compared to the supply chain for internal combustion engines (ICEs), but the EV battery chain introduces new technologies, regulations, safety and environmental concerns.

But growth of the sector is set to be exceptional, propelled by 20% compound annual growth rates (CAGR) for global EV sales over the next decade. Battery production capacity will likely need to outpace EV demand to meet the rising need for lithium-ion power in other sectors, along with mitigating supply and production constraints. There are already more than 100 gigafactories in the pipeline for construction globally. We estimate that global capacity for lithium-ion batteries will increase from 475 gigawatt hours (GWh) in 2020 to more than 2,850 GWh by 2030.

This supply chain will help to redefine the automotive industry, bringing strategic opportunities for many manufacturers and suppliers – but also considerable risks and disruptions.

This report tracks the rising scale and pace of the battery chain and maps out the detail of its fast-emerging supply chain. It will help OEMs, suppliers and service providers to better understand new requirements and evaluate the investments that the battery value chain will demand. One clear finding is that capitalising on the electric revolution will not just be about having the best technology or price – but also the need to build, secure and, where necessary, change battery capacity in different regions. This report will help stakeholders across the supply chain to anticipate and make these decisions.

1.2 The Future of Battery Supply Will Be Diversified

The battery supply chain is highly complex, made up of a number of critical minerals, materials and components, many sourced and produced from companies relatively new to the automotive sector. The locations for materials stretch across regions, including China, Africa, Australia and South America. The production of lithium-ion cells is also largely concentrated in Asia.

As the battery represents 30% or more of the value of a vehicle, established OEMs and tier suppliers – not to mention governments – want to take more control of the battery chain, rather than see profits and jobs shift to other players and locations. It has been estimated that a complete European battery supply chain, for example, from upstream materials to recycling, would be worth up to €250 billion ($303 billion) a year and could create 4m jobs across the EU.

OEMs such as the Volkswagen Group, Toyota, General Motors, BMW and most recently Ford are establishing new supply partnerships and joint ventures to increase lithium-ion battery and cell production, in some cases with a view to commercialise this capacity by selling batteries to other OEMs. Tesla, among others, is taking steps to gain more control and vertically integrate more aspects of battery production, including cell manufacturing but also the mining and processing of key materials. Other OEMs are considering the strategy that works best for them. But increasingly, carmakers are looking to a diversified battery strategy.

There are also emerging legislative and regulatory dimensions to this battery race. National governments in Europe and at the EU level, for example, are investing state money in supporting the development of a regional battery supply chain – as well as legislating for higher localisation rates. Trade agreements such as the EU-UK free trade deal, as well as the

US-Mexico-Canada Agreement (USMCA), include targets for increasing regional battery content. In February, Joe Biden, the new US president, also signed an executive order to undertake a strategic review of critical supply chains, including for large capacity batteries for electric vehicles, as well as for semiconductors. Increasingly, over dependence on a single region or set of suppliers is seen not only as a competitive issue but also one of potential national security concern. Some experts, such as Simon Moores, head of lithium-ion battery data firm Benchmark Minerals, have referred to the push for regional battery production and supply chains as an 'arms race'.

The competition is increasingly contentious. In the US, LG Energy Solution – the battery-focused division spun off by South Korean battery giant LG Chem – filed a trade-secret lawsuit against SK Innovation (SKI) that has resulted in a 10-year ban on SKI selling and importing batteries in the US (with an exception for supplying existing contracts with Volkswagen and Ford), raising serious questions over current supply and battery production plans.

Following political pressure, an out-of-court settlement was agreed in spring 2021 involving a $1.8 billion payment from SK Innovation to LG Energy Solution and ongoing royalty payments, which ultimately allows SK innovation to continue operating within the US. However, the dispute and subsequent political pressures on securing battery capacity has highlighted how important securing and diversifying battery supply will be for OEMs.

Despite these challenges, a firm outline of an expanding battery supply chain is clearly taking shape. Battery manufacturers and startups have announced construction of more than 80 new gigafactories across the globe to produce lithium-ion cells and batteries, and many more will be needed over the next decade. Europe, though still far behind China and Asia in battery and cell production, is set to emerge as a major player, with the most announcements for new gigafactories so far. The US and North America have lagged behind but are also set for growth. China is expanding its base even further and will likely play a major role in the global battery and finished electric vehicle supply chain.

There is no guarantee that the announced gigafactories will all become reality, nor that the ambitious battery capacity targets that many battery suppliers have set will be achievable. These factories, after all, require tremendous capital investment, and they are dependent on fast-changing technology. The profitability of such operations is also far from a certainty. And yet, the demand for this capacity is set to grow exponentially.

There are also questions over the strategic role that EV batteries will ultimately play for OEMs. Some experts suggest that batteries are becoming commodities and will eventually offer little difference in price or performance. Research for this report indicates the contrary: EV batteries are a long way from being truly commoditised, with considerable differences in price, quality, driving range and energy density across different chemistries and combinations.

That is partly why it has become even more important that OEMs develop multiple supply relationships and partnerships with battery specialists. Whereas OEMs previously tended to have exclusive battery supply agreements, they are increasingly pursuing the best quality and competitive technology available, including a mix of contracts with multiple players and even in-house production. We ultimately expect that OEMs will want such flexibility that they could even switch battery suppliers mid-product cycle, so as to take advantage of available supply and improvements in technology.

The race to electrification will inevitably bring pain and disruption to many parts of the supply chain. For OEMs, developing and producing ICE powertrains have been part of how brands differentiate themselves; phasing out petrol and diesel threatens many manufacturing and engineering jobs, too. As EV powertrains have fewer components, many existing suppliers may be threatened and even eliminated.

But electrification and especially the battery supply chain represent one of the most significant growth opportunities across the automotive industry. The new manufacturing networks, supply patterns and business relationships will play a large role in defining the next generation of the automotive value chain.

2. Market Definitions

2.1 Defining the Automotive Battery Supply Chain

- This report focuses only on batteries for tractive power or powertrain – as used in electric and hybrid electric vehicles. It does not cover the conventional, usually lead acid (Pb) batteries used for starting an engine and for ancillary functions such as lights, dashboard and other electrical systems.
- Batteries for vehicle powertrains are currently more than 99% of lithium-ion chemical composition. However, in some applications, such as the smaller batteries fitted to hybrids such as the Toyota Prius, the battery is the Nickel Metal Hydride type (NiMH). However, even that composition is changing with later model versions moving to lithium-ion.
- Both passenger vehicles and commercial vehicles are included in the definition because there is significant innovation and growth from vehicles such as buses and trucks.
- The report predominantly focuses upon conventional 4-wheel vehicles and does not specifically refer to 2-wheel electric motorcycles, e-bicycles or e-scooters. However, the battery supply chain detailed in this report may also supply those products.
- The report lists a wide range of lithium cell suppliers and manufacturers supplying the automotive industry. However, whilst many battery companies exclusively cater to automotive, some also supply a mixture of sectors such as energy storage, consumer electronics and others. We have also included some lithium battery cell manufacturers that currently only supply to non-automotive sectors, because they are still part of the wider lithium battery supply chain (albeit at lower volumes). As EV volumes rise, there is a possibility that these manufacturers will also get involved in supplying the automotive sector.
- The report does not focus on companies predominantly involved in the NiMh or Pb battery supply chains, although there is some overlap between those companies and the lithium-ion battery supply chain.

2.2 Note on Units

This report refers to various electrical power units. They refer to the following energy units:

KWh = 1,000 (or one thousand) watts for 1 hour
MWh = 1,000,000 (or one million) watts for 1 hour
GWh = 1,000,000,000 (or one billion) watts for 1 hour

A typical EV has a battery pack of 50 KWh (50,000 watts for 1 hour). A factory producing 1 GWh per year of battery cells can therefore supply around 20,000 vehicle battery packs per year.

2.3 Lithium-ion Battery Types

The term 'lithium-ion' battery is an umbrella term that refers to a broad group of battery chemistries that include lithium, but which are subtly different. Within this category there are significantly different chemistries with a range of different price and performance characteristics suitable for different applications. In development there are various other battery types such as lithium-sulphur (Li-S), lithium-air (Li-Air) and solid state but these are yet to be commercialised.

Table 2.1 summarises the key types of lithium-ion batteries that OEMs are using in electric and hybrid vehicles.

Table 2.1 Lithium-Ion Battery Types

Type	Description
LFP	**Lithium Iron Phosphate.** A type of cathode material containing LiFePO4. LFP is one of the safest li-ion battery cathodes, but with lower specific energy.
LCO	**Lithium Cobalt Oxide –** LCO has high specific energy and high cost due to high cobalt content. It is cathode material with a chemical formula of LiCoO2. Models that use this technology include the Tesla Roadster and Smart ForTwo EV.
LMO	**Lithium Manganese Oxide** – LMO has around 30% lower energy density than LCO, hence most blend with Lithium Nickel Manganese Cobalt Oxide.
NMC	**Lithium Nickel Manganese Cobalt Oxide.** This composition can provide high specific energy or power with high density and thermal stability. That proportion of N, M and C is denoted by the numbers NMC111 and varies by company having switched from NMC111 to NMC442 to NMC622, and now NMC811, with the exact blend remaining secret. The LMO-NMC combination has been used by multiple EV manufacturers in the past including Nissan Leaf, Chevy Volt and BMW i3.
NCA	**Lithium Nickel Cobalt Aluminium Oxide** offers high specific energy and power for specific applications. Tesla is the only OEM to use this chemistry including for the Model 3 and the first Model S in 2012.
NCM	**Lithium Nickel Cobalt Manganese** contain cathodes containing nickel, cobalt and manganese.
Solid State	**Solid state batteries** use a solid separator material such as ceramic instead of the liquid separator as used in conventional lithium-ion batteries. However, solid state batteries still use lithium in the battery chemistry and are a related, but not entirely separate battery technology.

Source: Automotive from Ultima Media

3. The Race to Build the Battery Supply Chain

3.1 Battle of The Value Chain

There are clear opportunities that arise across the supply chain in the transition to electrification, with many aspects likely to change OEM and supplier relationships.

For example, OEMs have traditionally developed and produced ICE powertrains in house. But in the race to electrification, manufacturers are increasingly reliant on new suppliers across a complex and valuable supply chain. This shift in technology and production creates space for automotive suppliers – some traditional, others new to the industry – to capture (or re-capture) value.

For example, production of lithium-ion batteries, including key components such as cells, have been predominantly located in Asia. American and European OEMs are to this extent already on the backfoot in terms of competing with players in China, Japan and South Korea. The battery players who have emerged in the lead – including South Korea's LG Energy Solution, Japan's Panasonic and China's CATL – continue to establish major battery cell manufacturing bases in Europe and North America, along with a range of startups and even OEMs themselves.

Automotive manufacturers are pursing different business models to develop this regional value chain, including through joint ventures with cell suppliers, vertical integration and agreements to 'lock in' the supply of raw materials through large-scale purchasing agreements.

However, securing battery cells only addresses part of the overall manufacturing and supply chain challenge. There are many other dimensions to the total lifecycle of the battery value chain, including maintenance and recycling requirements.

Perhaps even more fundamentally, the automotive industry continues to struggle following the sharp fall in global vehicle sales in the wake of the Covid pandemic, leaving many OEMs and suppliers with shrinking margins. The transition to battery and EV supply chains puts a huge amount at stake for the automotive supply base. The entire industry needs to maximise its value proposition and cost base in the hopes of at least retaining its already tight operating margins.

3.2 Electric Vehicle Demand Forecast

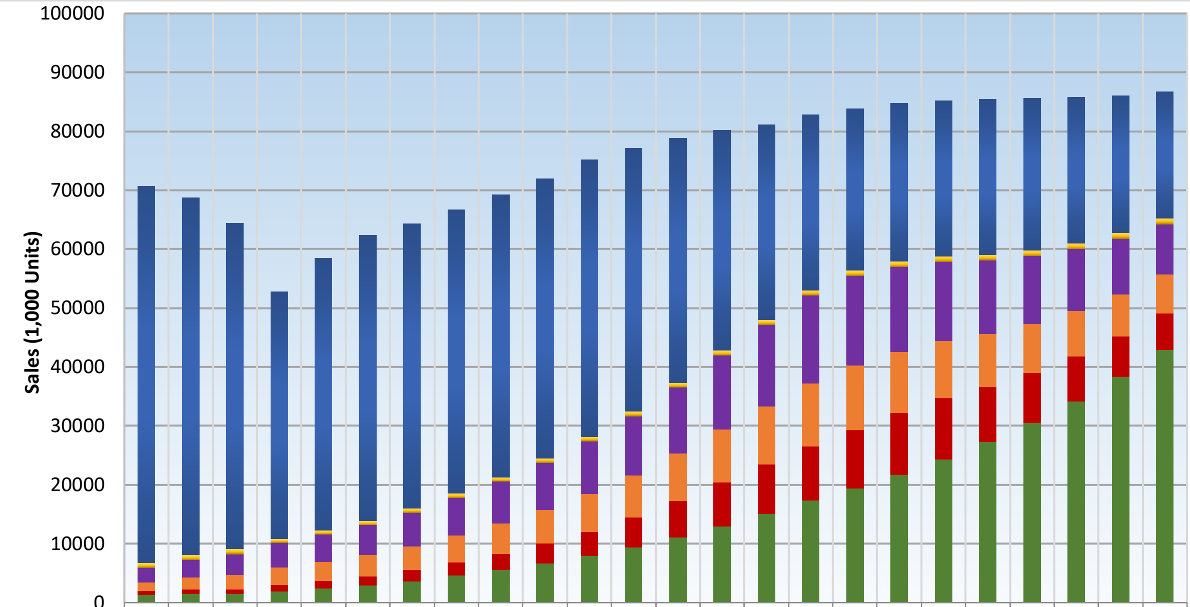
The battery supply chain is developing at a stunning pace even compared to expectations just a few years ago. The push to electrification is becoming increasingly central to the long-term prospects of many manufacturers.

Pre-Covid, a variety of factors were driving vehicle electrification, but the most significant was regulatory pressures, mainly in Europe and China and to a lesser extent in other regions, such as Japan. Post-Covid, consumer demand for battery and plug-in electric vehicles (PHEVs) has accelerated, spurred by a mix of improving technology, incentives from governments and OEMs.

According to our analysis, global electric passenger vehicle sales rose around 33% year-on-year in 2020 even as overall vehicle sales fell by around 20%. In Europe, sales of EV and PHEVs more than doubled in 2020. Globally, the share of EVs and PHEVs rose from 3.4% in 2019 to 5.6% (of which 3.7% were pure EVs), according to our analysis.

Combining EVs and all types of hybrids (including mild, full, and plug-in hybrids) accounted for 19.2% of the powertrain mix, meaning nearly one-fifth of all global passenger vehicle sales already have some sort of lithium-ion battery. By 2030, we forecast that 53% of global new vehicle sales will be fully electric or hybridised in some way.

Figure 3.1 Global Passenger New Vehicle Powertrain Forecast by Type 2021-2040 (Units)



	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Pure ICE	63950	60580	55200	41952	46147	48455	48309	48116	47875	47445	46970	44622	41498	37348	33128	29815	27430	26881	26344	26344	25817	24784	23297	21433
NGV + FCV	800	850	900	630	693	714	728	743	757	773	788	804	820	836	853	870	888	905	923	942	961	980	999	1019
MHEV	2500	3000	3500	4200	4620	5082	5692	6375	7140	7997	8956	10031	11235	12583	13841	14948	15247	14485	13471	12528	11526	10489	9440	8496
HEV	1500	2000	2500	3000	3300	3630	4066	4553	5100	5712	6397	7165	8025	8988	9887	10677	10891	10346	9622	8949	8322	7740	7198	6694
PHEV	650	750	750	1050	1260	1537	1875	2288	2791	3405	4155	5069	6184	7420	8385	9224	9962	10460	10460	9414	8472	7625	6863	6176
EV	1300	1500	1500	1950	2399	2926	3658	4572	5532	6639	7900	9401	11093	12979	15056	17314	19392	21719	24325	27244	30514	34175	38276	42869

Powertrain type: Internal Combustion Engine (ICE), Natural Gas Vehicle (NGV), Fuel Cell Vehicle (FCV), Mild Hybrid Electric Vehicle (MHEV), Hybrid Electric Vehicle (HEV, or 'Full' Hybrid), Plug-in Hybrid Electric Vehicle (PHEV), Electric Vehicle (EV, or 'Battery' Electric Vehicle)

Source for all tables and figures in this section unless noted otherwise: Automotive from Ultima Media

Figure 3.2 Global New Vehicle Powertrain Forecast Marketshare by Type 2020

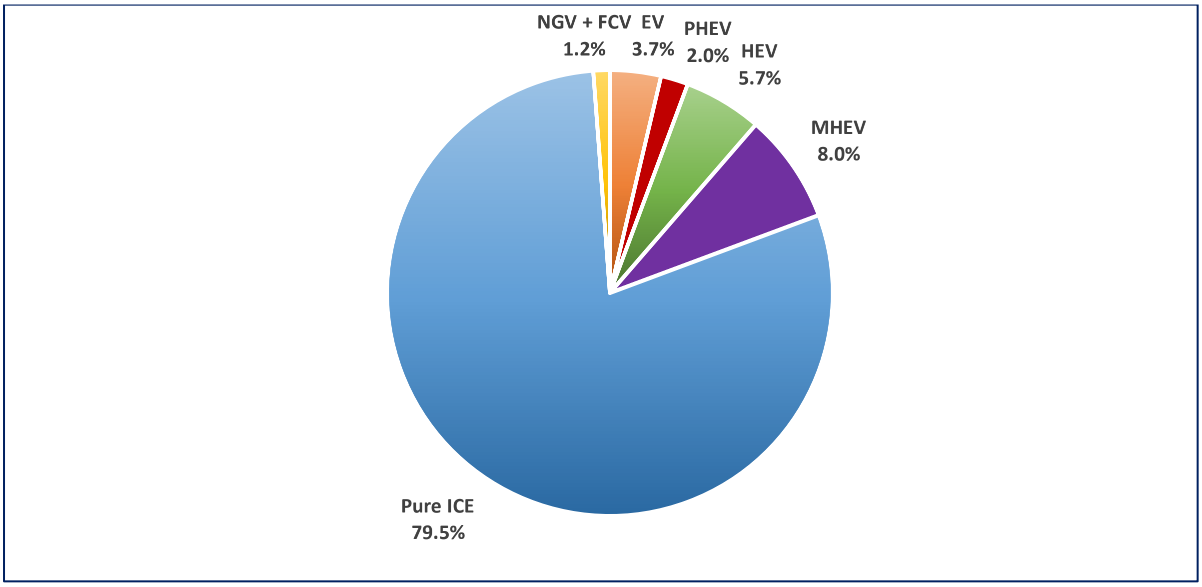


Figure 3.3 Global New Vehicle Powertrain Forecast Marketshare by Type 2030

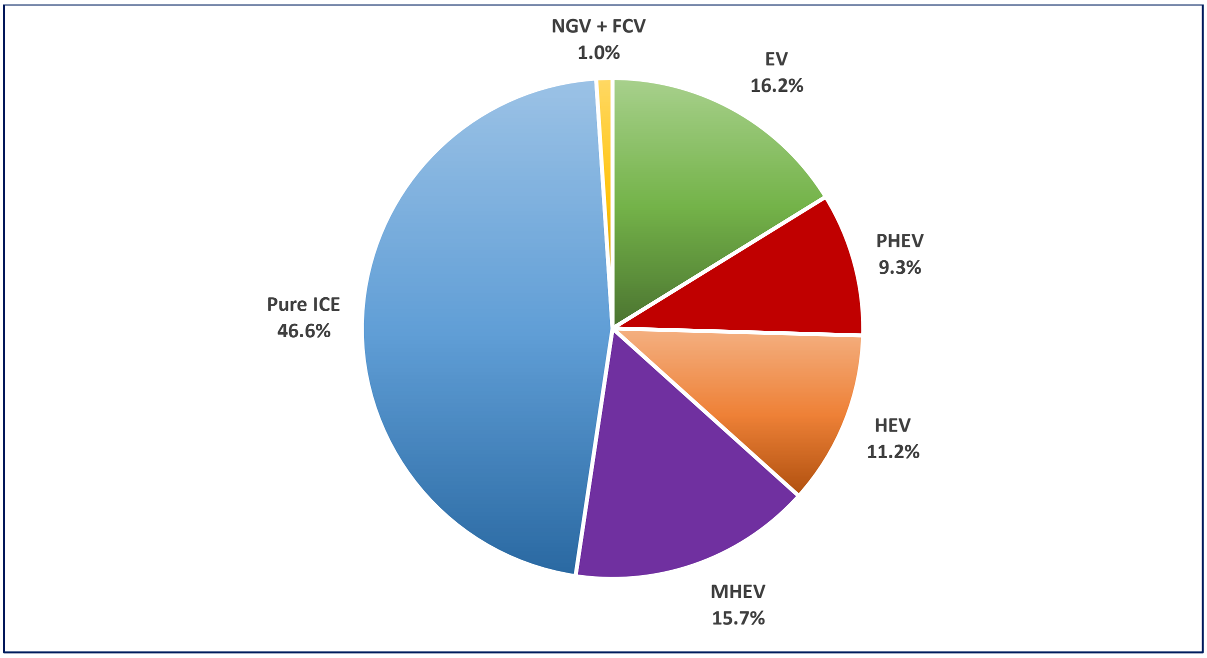
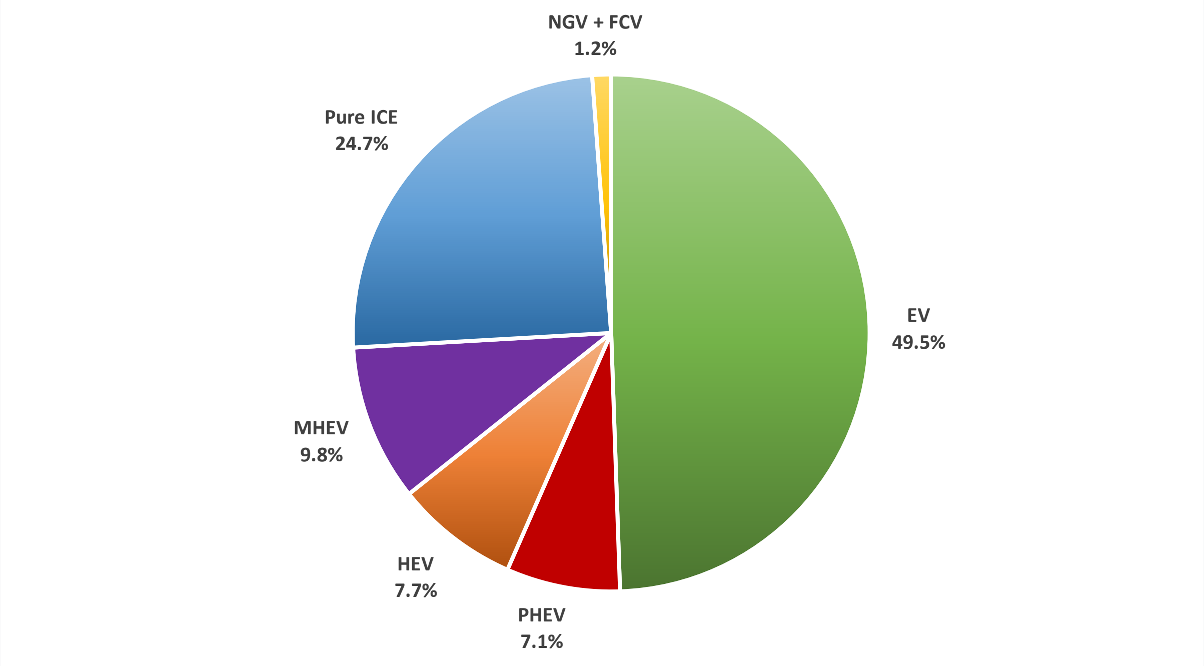


Figure 3.4 Global New Vehicle Powertrain Forecast Marketshare by Type 2040



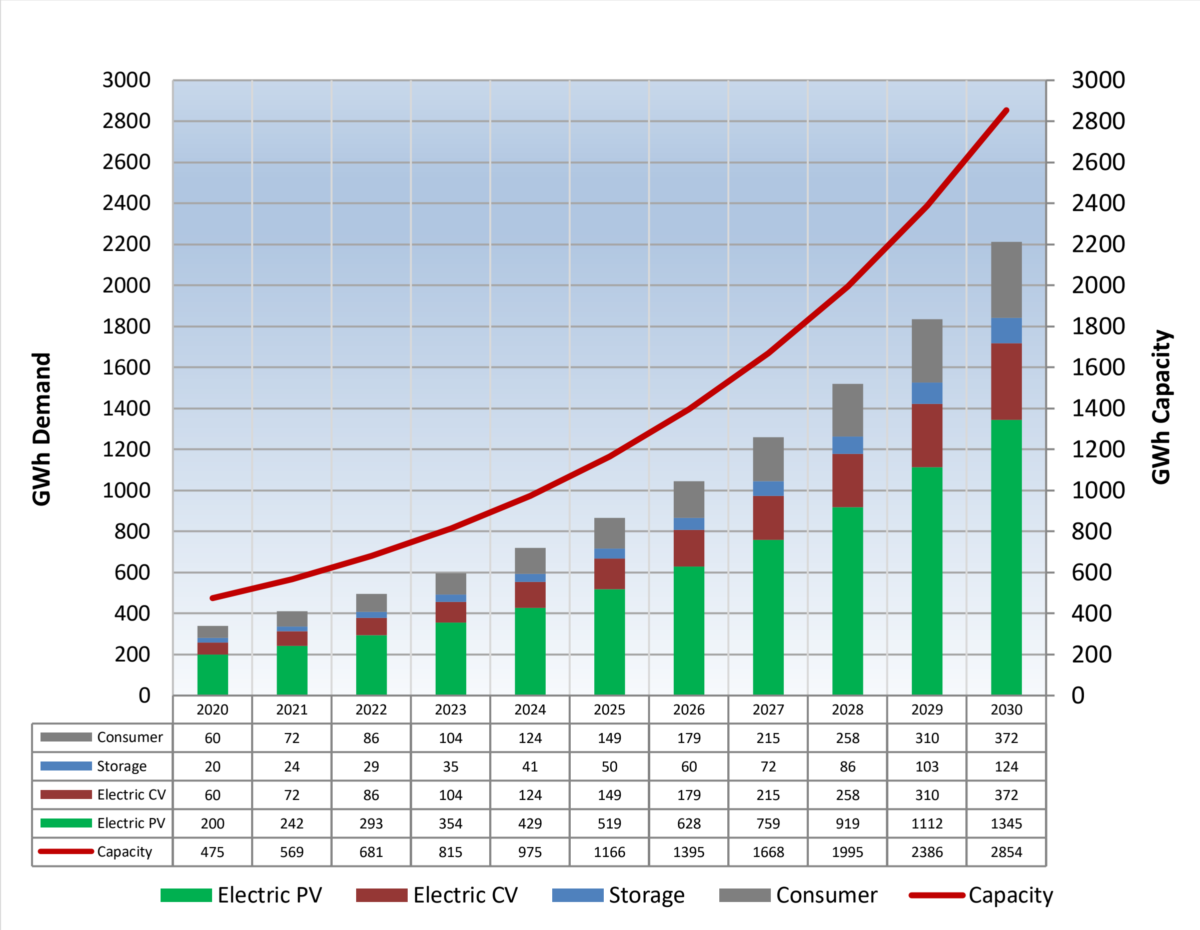
While we forecast global EV sales to grow by a remarkable 21% CAGR over the next decade, the increase in battery production and capacity will be even higher. That is because the kilowatt hour (KWh) battery capacity required per vehicle is likely to rise as well. We estimate the average vehicle battery capacity will increase by 3% per year over the next decade as battery prices fall, allowing OEMs to fit larger capacity batteries to improve driving range. Thus far, fully electric variants have also tended to be of the smaller to mid-size models in an OEMs range, which were easier to electrify to meet emissions targets. But OEMs will increasingly be compelled to electrify most if not all of their fleets. The increase in the e-SUV globally and electric pickup truck segment in North America, for example, will likely increase battery sizes and thus battery demand.

Demand for other home, consumer and energy storage products will also increase the need for gigawatt hour capacity.

Battery production will thus need to increase faster than EV sales volumes would suggest. Furthermore, battery capacity needs to exceed demand significantly because the theoretical maximum capacity of battery plants is rarely achieved as a result of technical and logistical issues. For example, there may be a slowdown due to a shortage of cobalt, cathodes or quality control issues, which could mean that not all cells produced will be viable. A rule of thumb is that a realistic production output is around 70% of the stated maximum capacity.

We forecast that while battery demand will rise from 330 GWh in 2020 to 2,180 GWh in 2030, battery production capacity will rise in the same period from 475 GWh to 2,854 GWh.

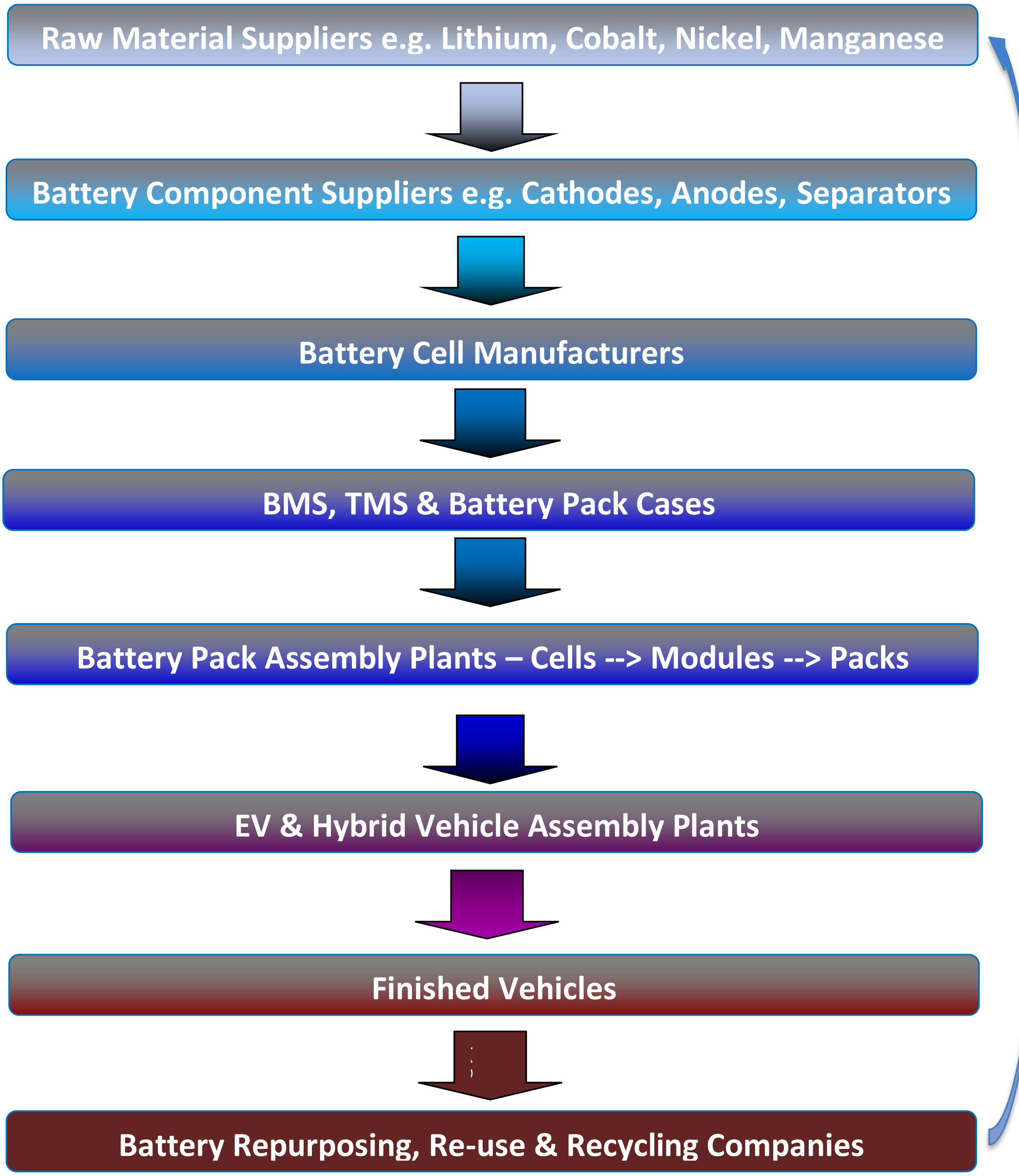
Figure 3.5 Global Lithium Battery Demand & Capacity Forecast by Sector 2020-2030



	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Consumer	60	72	86	104	124	149	179	215	258	310	372
Storage	20	24	29	35	41	50	60	72	86	103	124
Electric CV	60	72	86	104	124	149	179	215	258	310	372
Electric PV	200	242	293	354	429	519	628	759	919	1112	1345
Capacity	475	569	681	815	975	1166	1395	1668	1995	2386	2854

Figure 3.6 Battery Supply Chain Schematic Diagram

To understand and analyse the automotive battery supply chain, we have broken down the value chain into eight key stages. As volumes ramp up, the 'closed-loop' nature of the supply chain is becoming more important, including where batteries are recycled, and the raw materials fed back into the start of the supply chain to mitigate potential shortages of raw materials.



3.3 Localisation of the Battery Supply Chain

Not only is there an arms race for the battery supply chain, but the impetus to localise production grows as EV volumes accelerate. Logistics and supply costs play a key role here, as batteries are heavy, costly and complicated to move because of varying regulations around transporting hazardous goods. Carmakers such as BMW are organising supply chains around local lithium-ion battery manufacturing in all regions where it is feasible, in part to keep logistics costs to a minimum.

Although batteries are generally cheaper to manufacture in low-wage regions in Asia and specifically China, supply and transport costs are likely to eliminate that cost advantage when shipping to Europe or North America, for example. The localisation of battery production is also increasingly preferred because it helps to ensure visibility and security of supply. Increasingly, OEMs and regulators are focusing more on the sustainability of the EV and battery supply chain.

The Covid-19 crisis has further exposed weaknesses in single-sourced purchasing, lean inventory strategies and over-reliance on limited supply bases. The ongoing shortages of semiconductors and microchips highlight a potential problem for battery supply chains. Currently, China, South Korea and Japan dominate battery cell manufacturing, while raw minerals are sourced from several primary locations including Chile, China, Africa, as well as the US, Canada and Australia for some materials.

Even as battery cell manufacturing increases in North America and Europe, regional plants will still be reliant upon imports of cell components and raw materials from far afield, including politically sensitive areas such as cobalt mining from the Democratic Republic of Congo (DRC).

As hybrid and EV penetration increases, this reliance on particular regions and a narrow range of specialist companies will remain an inherent and growing vulnerability – not least when the supply chain is hit by shocks and shortages.

Put simply, manufacturers will need to build up commensurate raw material and cell component capacity alongside cell manufacturing plants. Otherwise, the full battery value chain is at risk not only of disruption but of considerable value being lost to Asia.

This risk is not lost on major OEMs or on governments keen to gain the investments and jobs expected to accompany it. But higher labour costs and environmental standards, along with lower economies of scale for now, will make it harder to suppliers and manufacturers to compete with countries in Asia.

That is partly why governments are targeting the battery value chain through legislation, including environmental standards and minimum sourcing levels, which are clearly aimed at discouraging imports and ramping up regional battery sectors. The European Commission, for example, has set a list of green criteria that imported batteries will need to meet, ranging from sustainability of raw material production to energy used during manufacture.

In December 2020, the EU announced the roadmap for the environmental criteria for the production of lithium batteries, with a view towards increasing localisation.

Table 3.1 EU Roadmap For Rules Of Origin For European Lithium Battery Production

Date	Level of Localisation
Now until Dec 2023	No change
2024 to 2027	Key parts such as cathodes, anodes and chemicals must be sourced in the EU
2027 onwards	The target is for 100% sourcing from Europe, resilient and independent of foreign supply

European Commission Vice-President Maroš Šefčovič has also indicated that batteries that do not meet green standards could be banned from the European market, and that EU state aid would be steered under the Battery Alliance to European battery projects that do meet those standards. France and Germany in particular are pushing the idea of 'green batteries'.

The EU-UK free trade agreement also includes provisions for rising battery localisation in electric vehicles with a six-year phase-in period for EVs and batteries. Until the end of 2023, complete EVs, including hybrid, plug-in hybrid and battery electric vehicles, have a minimum origin threshold of 40% parts coming from the EU or UK, compared to 55% required for combustion engine vehicles. During this period, batteries must have at least 30% of parts sourced in the EU or UK. From 2024 to end of 2026, the origin threshold for finished EVs rises to 45%, while batteries must have at least 50% regional content. From 2027, the rules are expected to tighten further as part of wider EU and UK objectives to develop a regional battery supply chain.

A number of OEMs and experts have greeted the high localisation proposals with scepticism, voicing doubts about the viability of producing so much of the battery supply chain in such a short time frame.

State support is likely to continue. The EU and UK have been investing government money in developing the battery value chain. In January of 2021, the European Commission approved €2.9 billion in subsidies as part of the Important Project of Common European

Interest (IPCEI) to support an EU battery industry, which came on top of €3.2 billion in 2019. The funds are part of an objective for the EU to power at least 6m electric cars by 2025 and are adjoined to the latest 'European Battery Innovation' scheme set to go to 42 companies across 12 EU member states. The companies include European firms including BMW, French chemical firm Arkema and Swedish battery manufacturer Northvolt, but also foreign firms such as Tesla, which is building an EV and battery plant in Germany.

The French and German government have also given backing to the Automotive Cell Company (ACC), joint venture between SAFT and Stellantis, which plans significant battery cell production across two plants In Hauts-de-France in northern France and Kaiserslautern, Germany. The Germany government has also allocated €300m to German battery manufacturer Varta as part of a €1.5 billion in R&D. Varta intends to develop lithium-ion technology further with the aim of increasing the energy density of cells, as well as to put silicon-dominated anodes into mass production.

Developing a lithium-ion battery base is also a strategic issue in North America. Although the US has neither the same level of EV penetration nor growth trajectory for EVs as Europe or China, the Biden administration is set to drive a more ambitious climate policy, which is likely to include tightening fuel economy standards, providing purchase incentives and investment in charging infrastructure. Already, the administration has committed to purchasing American-made electric vehicles for government fleets.

And recently in February, President Biden announced a 100-day review in the US to address critical supply chain items such as the sourcing of rare earth metals, lithium batteries and semiconductors – all items inextricably associated with the growth in electric vehicles.

The localisation of a North American battery supply chain will also be driven in part by the new rules of origin under the USMCA, which came into effect in July 2020. From a 62.5% localisation rate across the region to quality for tariff-free trade under NAFTA, the rate is rising in a phase manner to 70-75% over the next three years, including for core parts like batteries. As EV batteries represent around 40% of the value of a vehicles, OEMs will need to localise these components.

But as the dispute between LG Energy Solution and SK Innovation in the US demonstrated, developing the battery chain is highly strategic and competitive. The original decision by the US International Trade Commission to ban SK Innovation from the US for ten years put into stark contrast the importance and complexities for OEMs when it comes to securing long-term battery cell supply. That the ban was lifted does not mean the competitive pressures will ease with it.

3.4 Diversifying the Supply Base

Until recently, OEMs have mainly established exclusive supply agreements with battery suppliers, or even exclusive joint venture partnerships. With relatively low volumes of electrification, it made sense for carmakers to commit to purchasing from a specific supplier as a means to mitigate risk and share potential gains together.

However, that approach is changing. With rising EV demand, there have already been bottlenecks in supply, meanwhile OEMs want to ensure they have flexible access to supply and new technology.

A good example of the changing approach to battery supply is with Tesla, which previously had an exclusive arrangement for cells with Panasonic, with which it jointly built the Gigafactory 1 near Reno, Nevada. However, Tesla CEO Elon Musk has criticised Panasonic for not meeting necessary levels of production. Tesla is temporarily using LG Chem batteries at its Gigafactory 3 in Shanghai and has agreed a supply arrangement with CATL for EVs built in Asia. Tesla is also planning to develop its own in-house cells to diversify its supply base even further.

Nissan also had an exclusive relationship for battery supply through AESC, a joint venture with Japan’s NEC. Although a good relationship when Nissan launched the Leaf EV in 2008, less than a decade later AESC was no longer the cheapest or best battery supplier. Arguably, the battery manufacturer became uncompetitive precisely because of this exclusive agreement. In 2016, Nissan announced plans to sell the unit and use a wider variety of suppliers, and it along with NEC eventually sold their majority stake to China’s Envision in 2019 (Nissan retains a 25% share).

Volkswagen, meanwhile, exclusively used Samsung SDI batteries for its previous generations of EVs, such as the e-Golf. For its hugely ambitious EV plans, including its MEB platform and the ID range, the group has diversified its procurement of batteries, forging supply agreements with LG Chem, Samsung SDI and SKI for production in Europe, CATL for China and SKI for North America from 2022. VW has also signed an agreement with Sweden’s Northvolt, recently taking a 20% stake in the battery cell supplier; the OEM has also taken over Northvolt’s share in a planned joint venture battery plant in Salzgitter, Germany. Volkswagen Group plans to go even further expanding production of cells: at its recent ‘Power Day’ on its battery strategy, it announced plans for 240 GWh of battery capacity in Europe by 2030, which would encompass six plants of 40 GWh each.

Other OEMs, including BMW, have also signed multiple agreements with battery suppliers, including CATL, Samsung SDI and Northvolt. Toyota has established a joint venture with Panasonic, while also signing agreements with CATL.

This trend demonstrates that flexibility of battery supply is increasingly important. As battery technology evolves, OEMs want to make sure they can keep up, and so it is important to be able to either switch or to have additional access to new suppliers according to changing local requirements, price or performance parameters.

3.5 Vertical Integration in the Battery Supply Chain

Flexibility and control of supply will, however, continue to shape different strategies and relationships in the battery supply chain. While Nissan has moved away from vertical integration in battery supply, others are investing in precisely such capability and capacity, including new joint ventures with established battery players.

The transition to electrification already disrupts the control that OEMs have held over internal combustion engines. Most OEMs take an in-house approach to develop and build powertrains – comprising the engine, gearbox and transmission – as these modules help to differentiate brands in terms of quality, performance, reliability and even the exhaust sound. As batteries represent 30-40% of the cost of the manufactured vehicle, giving over this element to suppliers is a risk.

Joint ventures between OEMs and battery manufacturers bring clear benefits. They help to convince suppliers to invest as they will have a guaranteed customer, while sharing investment reduces the risk and upfront capital expenditure required on both sides. OEMs also gain insight into the battery manufacturing process, not only in terms of factory design and layout, but in producing cells and battery packs. The complete visibility and understanding of the battery supply chain ultimately allows the OEM to optimise battery performance and factory output.

Table 3.2 Vertical Integration and Level of Control in EV Batteries Compared by OEM

Low Control	Moderate Control	High Control	Total Control
Cell, module and pack outsourced to 3rd party supplier	Cell production outsourced. In-house module, pack design and manufacturing	Cell production through joint ventures/partnerships. In-house pack design and manufacturing	In-house manufacturing of cell, module and pack design
Many EV start-ups -	BMW	Nissan	BYD
Nio, Lucid, Fisker	Renault	Mitsubishi	

	Daimler	Tesla →	Tesla from 2021/22
	VW →	GM →	
	Ford→	PSA (Stellantis)	
		Toyota	

One of the best-known examples of a joint venture is the Tesla and Panasonic joint venture in Nevada, which is possibly the most successful partnerships between an OEM and battery supplier. Panasonic bring its battery manufacturing expertise to supplying the cells and then Tesla performs the module and pack assembly.

Other OEMs have also established major joint ventures for battery cell production, including Volkswagen Group with Northvolt and GM's Ultium joint venture with LG Chem. Ford has recently announced a joint venture with South Korea's SK Innovation in North America.

OEMs are not just integrating battery cell production to save costs, but also to gain more flexibility, technological innovation and differentiation compared to other OEMs. Unlike other components, lithium-ion batteries are not commoditised and there is considerable competitive advantage to be had by developing and commercialising a specific battery technology.

This is an advantage that some OEMs may even look to commercialise further by supplying other manufacturers. GM's Ultium is also expected to sell to other brands. China's BYD, which builds its own batteries, is already a supplier to other OEMs. Another Chinese OEM, Great Wall, has spun out its own battery division to create SVOLT, which is investing in new capacity in Asia and Europe. Ford's joint venture with SKI intends to have battery capacity levels by 2030 that could also suggest it will supply other OEMs.

BYD is in fact a rare example of an OEM that also has fully in-house battery cell, module and pack production for its own vehicles. Its growth as a battery supplier was further supported by the Chinese government's previous policy up to 2019, which required foreign OEMs selling EVs in China to fit a Chinese-made battery from its 'white list' to quality for subsidies – which benefitted BYD and CATL. The government has since removed this requirement, further opening up the Chinese battery market.

Some OEMs are considering moves to achieve even more supply chain integration further upstream. This can be witnessed by the links being forged with the cathode manufacturers and mining companies who extract and process the raw lithium, cobalt, nickel and manganese elements used within lithium-ion batteries.

BMW Group has formed a joint technology consortium with Northvolt and Umicore, a Belgian developer of cathode materials for battery cells, but also in the development of a more holistic and sustainable supply chain including recycling – which is particularly important given the finite availability of some of the raw elements. In November 2018, BYD signed a contract to buy lithium-ion battery cathode materials from China's Beijing Easpring Materials Technology.

It has been reported that Tesla is in negotiations to purchase cobalt from Glencore specifically for Tesla's Shanghai plant. Furthermore, Tesla announced the acquisition of Maxwell Technologies in 2019, and Elon Musk suggested at the time that the company could enter the mining business to ensure it scales fast enough. On Tesla's 'battery day' in September 2020, the company confirmed that it intended to get involved in mining lithium in North America.

3.6 Ethical Supply Chains

Gaining more control of the battery supply chain is not just about securing supplies – it is also about securing the reputations of OEMs. The supply chain for lithium-ion batteries is increasingly under the scrutiny of environmentalists, regulators and consumers, with serious questions about the emissions and pollution created in the process, as well as the ethics and working practices in mining and mineral extraction, for example of cobalt from DRC. The fear is that brands could be tarnished with regulators, shareholders and customers if they are associated with poor practices and labour conditions in the supply chain.

As a result, corporate social responsibility (CSR) for electric vehicles is moving well beyond a tick-box exercise to become a business-critical issue to protect huge capital investment into electrification. OEMs are thus forging alliances with raw material suppliers partly to secure supply – but also to improve visibility of working conditions under which raw materials such as lithium, cobalt, nickel and manganese are mined and refined.

For example, BMW has announced a €540m contract with Ganfeng Lithium to 'lock-in' 100% of its supply of lithium hydroxide until 2025. But BMW is also concerned about the human rights and environmental impact of mining raw materials, and how it could tarnish its brand image. By being more involved in the value chain, BMW believes it can better control the conditions under which raw materials are procured.

In October 2019, BMW launched the 'Cobalt for Development' pilot project jointly with BASF SE, Samsung SDI and Samsung Electronics to promote responsible artisanal cobalt mining in the DRC. Since 2020, the carmaker began sourcing both lithium and cobalt directly before the materials are supplied to its battery cell suppliers, CATL and Samsung SDI. From

2021, it plans to manufacture its fifth generation EV powertrains without using any rare earth metals.

In September 2020, VW Group partnered with RCS Global, a specialist in analysing supply chains, with the aim of auditing its extensive supplier base to ensure that it conforms with human rights, safe working conditions and environmental protection. This strongly relates to the battery supply chain and issues around mines, raw materials, child labour, and health and safety.

Mercedes-Benz has said that it will only source battery cells in future with cobalt and lithium from certified mining sites, while the company also aims to significantly reduce cobalt levels.

Companies including China's SVOLT and CATL, as well as Tesla, have said that they are in the advanced stages of developing batteries that do not require any cobalt. Although this can reduce battery power density, engineers are developing ways around this. The elimination of cobalt would reduce the price of the battery as well as making companies less reliant on erratic supply from the DRC.

3.7 Changing Strategies for Battery Pack Integration

As the battery supply chain develops, the lines are increasingly blurring between supply and production roles of battery cells and complete pack manufacturing. The 'battery integration' process, for example, includes turning the basic individual cells into modules and then combining these to form the pack – effectively the hardware – which includes key software, namely the battery management system (BMS) and a thermal management system (TMS).

Battery performance is not just down to the individual cell, but how the battery modules and pack are combined into a single entity, processes which offer OEMs and suppliers more opportunities to add value. Larger OEMs are often more involved in the module and battery pack integration, while smaller OEMs and start-ups usually rely on battery cell suppliers to manage the production stages of cell, module and battery pack, and then deliver a complete, ready-to-install pack to vehicles.

These relationships vary based on OEMs and model programmes but demonstrate the fluid relationships between manufacturers and suppliers, as well as the room for new manufacturing and supply chain services. For example, there have been recent moves towards a combined 'cell-to-pack' process.

Tesla has made a patent application for a new approach to battery cells and pack assembly. Although not yet implemented, the process would see the cell manufacturing plant produce small-cell modules, which can then be combined like building blocks into complete battery packs. In September 2019, CATL introduced a similar process called 'cell to pack', which claims a higher energy density than usual batteries thanks to a tighter packing of the cells. Like much around battery technology, these processes remain shrouded in secrecy, but they are aimed at simplifying the manufacturing and assembly process, pursuing efficiency and lower costs to deliver on the holy grail of reducing battery prices to $100 per KWh or below.

3.8 Potential Disruptors to Battery Capacity Demand

The expansion of the battery supply chain is contingent upon two things: the growth in EV market share and an expanding requirement for battery capacity in each vehicle. The first is almost guaranteed given the heavy regulatory push and massive OEM investment in EV development. However, the growth in battery capacity is not quite as clear cut.

Installing large, heavy and expensive batteries in vehicles is done to increase driving distances between charges and reduce 'range anxiety.' However, the vast majority of car journeys are within short distances and well within 50-60km rather than the 400km or more range that most new EV models promise. If vehicle batteries were more geared around this reality, than EVs would require neither the expense, capacity nor the long-charging times common today.

Proposing vehicles with shorter ranges would however require a significant change in mindset for consumers, and likely different business model for OEMs – such as battery swap or vehicle subscriptions, for example. But several OEMs and startups are pursing just these types of offers.

There also other technologies that may play a bigger role in the overall electrification and diversification of propulsion. Several OEMs, notably in Japan and South Korea, are investing in hydrogen fuel cell technology, for example. However, we don't forecast fuel cell propulsion to play a major role in the overall powertrain mix for a variety of reasons, including a lack of fuelling infrastructure.

Many companies are also developing solid-state battery technology that they claim can reduce charging times to around 10 minutes. Toyota has revealed such a battery will be close to commercialisation in 2021 and will be fitted to vehicles for sale by 2025. Whilst we don't anticipate solid state playing a significant role in the overall powertrain mix over the next decade, technology is developing fast and there is room for disruption.

3.9 Battery Supply Chain is a Competitive Advantage

The rapid acceleration of electric vehicle demand and the commensurate ramping up of the battery supply chain creates multiple challenges. Bottlenecks in supply could ultimately stifle production, sales and consumer uptake, and put billions of dollars of investment at risk.

With other supply chain shortages, OEMs are already prioritising the production of vehicles with customer orders and those that deliver higher margins. It is notable that OEMs already tend to manufacture electric vehicles on a more 'built-to-order' basis, rather than for stock at compounds and dealerships. The result has been longer average waiting times for EVs in hot-selling markets. The longer customers have to wait, the more of a risk it is to sales.

These supply issues underline how important the battery supply chain is as EV production and sales ramp up. OEMs able to provide the best batteries will have advantages on range and price. But important, too, will be having a flexible, resilient and multi-sourced battery supply chain that can respond to fluctuating EV demand. In the race to electrification, development of the battery supply chain is going to be a clear competitive advantage.

There is a huge amount at stake. The fate of individual OEMs could be decided by the alliances they make with particular battery suppliers and the overall strategy they implement – whether it is full vertical integration, keeping suppliers at arm's length or a variety of approaches across markets. That's why it's never been more important to understand the fast-developing battery supply chain, including its current and future capacity.

4. Battery Raw Materials and Minerals

4.1 Lithium Suppliers

The term 'lithium-ion' battery generally refers to the use of lithium as the cathode material, as lithium ions move between the cathode and anode during discharge and recharging. However, lithium-ion batteries actually include many different metallic elements essential in improving battery performance and safety.

The main four elements used in automotive lithium-Ion batteries are lithium, manganese, cobalt and nickel. Other metals such as copper, aluminium, iron and also non-metallic elements such as graphite are also used.

Lithium is not considered a rare mineral and is found in most continents. However, around 52% of known global reserves are in Chile, where most plants are based along with China, the US, Canada and Australia. Australia has had the highest production; however, Chile is expected to take the lead. However, Chile's so-called 'Lithium Triangle' is creating a war on water, and a recent drought in Chile has exacerbated these environmental tensions. This is because water is vital in the mining of minerals, in the transporting of crushed ore as slurry, and in the processing.

The lithium mining and extraction market is quite consolidated with the majority of volume produced by the top four or five companies.

Table 4.1 Leading Global Lithium Suppliers

Company
Albermarle
Sociedad Química y Minera de Chile (SQM)
Livent Corp.
Tianqi Lithium Industries Inc.
Ganfeng Lithium

Source for all tables and figures in this section unless noted otherwise: Automotive from Ultima Media

4.1.1 Albemarle

Albemarle is one of the leading lithium mining and processing companies, and provides lithium metal in the form of ingots, foil, rods, or anodes in a multitude of sizes and thicknesses for primary and secondary lithium batteries. A current focus of the company is research and development in creating a rechargeable lithium battery with lithium metal abode, rather than the more conventional foils and rods, which increase surface area.

Albermarle's primary mining operations are in Chile's northern region. However, Albemarle is also involved in a joint venture with China's Tianqi Lithium to develop the Australia Greenbushes mine and processing plant in Western Australia.

Table 4.1.1 Albermarle Lithium Mines

Location	Details
Salar de Atacama, Chile	Lithium mine
Clayton Valley near Silver Peak, Nevada, USA	Lithium mine
Greenbushes, Australia	JV Lithium mine with Tianqi Lithium
Wodgina, Australia.	Albemarle had also revised a deal to buy into the Wodgina lithium mine owned by Mineral Resources' and has delayed building 75,000 tonnes of processing capacity at Kemerton, also in Australia.

4.1.2 Sociedad Química y Minera de Chile (SQM)

Chile's Sociedad Química y Minera de Chile (SQM) is one of the largest providers of lithium with primary production facilities in the Attacama desert in Chile. Thanks to the growth in demand for lithium and the plan to fully exploit Chile's reserves, SQM has large expansion plans and is likely to fare well over the next few years. In 2018, China's Tianqi Lithium Corporation purchased a 23.77% stake in SQM from Canadian mining company Nutrien Ltd.

Table 4.1.2 SQM Lithium Mines

Location	Details
Atacama, Chile	Lithium mine
Forestania Greenstone Belt in Mt Holland, Western Australia	The Earl Grey lithium project, also known as the Mt Holland lithium project. It is owned by Kidman Resources (50%) and SQM (50%) under a JV named Covalent Lithium.

4.1.3 Livent Corporation

Livent Corporation produced lithium which supplies a wider range of industries and products including electric vehicle batteries, energy storage batteries, agriculture, aerospace, pharmaceuticals lubricating greases, and polymers for tyres.

Table 4.1.3 Livent Corporation Lithium Mines

Location	Details
Salar del Hombre Muerto, Fenix, Argentina	Lithium mine
Gumes, Argentina	Processing plant
Carolina, U.S.	Processing plant
Zhangjiagang, China	Processing plant
Jiangsu, China	Processing plant
Telangana, India	Processing plant
Bromborough, UK	Processing plant

4.1.4 Tianqi Lithium Industries Inc.

Based in China, Tianqi Lithium Industries produces lithium carbonate and derived lithium products of different grades including lithium carbonate, lithium hydroxide, lithium metal and lithium chloride. In September 2016, Tianqi invested around $30m in Western Australia to build 24,000 tonnes of new capacity of lithium hydroxide.

Tianqi hold a minority interest in Talison Lithium, the largest lithium-ore owners based in Australia.

China's Tianqi Lithium also has a JV with Albemarle to develop the Greenbushes mine and processing plant in Western Australia.

Table 4.1.4 Tianqi Lithium Industries Inc. Lithium Mines

Location	Details
Sichuan, China	Lithium mine
Jiangsu, China	Lithium mine
Greenbushes, Australia	The Greenbushes lithium project is located in Greenbushes, Western Australia. It is owned by Chinese mining company Tianqi Lithium and operated by Talison Lithium, which is 51% owned by Tianqi Lithium

4.1.5 Ganfeng Lithium Co.

Based in Jiangxi province, China, Ganfeng Lithium is a leading lithium supplier. The company is primarily involved in lithium mining and provides both industrial grade and battery grade lithium metal, lithium carbonate and related lithium products. Even though the company is mainly active in upstream activities, since 2016 it is also involved in cathode production in the form of NCM precursors.

Table 4.1.5 Ganfeng Lithium Co. Lithium Mines

Location	Details
Sonoro, Argentina	Lithium extraction from Clay (under preparation)
Mt Marion, Australia	Owned by Neometals and Ganfeng Lithium
Cauchari-Olaroz, Argentina	Minera Exar S.A a 50:50 JV partnering Ganfeng with Lithium Americas starting in 2021
Mariana Lithium Brine, Argentina	JV with International Lithium Corporation Lithium extraction from Clay (under preparation)
Avalonia Lithium Pegmatite, Ireland	JV with International Lithium Corporation

Table 4.1.6 Ganfeng Lithium Co. M&A Activity

Company	Date	Details
RIM Australia	2015	Ganfeng acquired a 49% stake of RIM Australia, which owns lithium ore reserves of over 20mn tonnes.
International Lithium Corporation	2016	Ganfeng Lithium is ILC's joint venture partner, but also has a 11.64% ownership in ILC
Bacanora Lithium	2019	Ganfeng Lithium to buy 30% stake in London-listed Bacanora Lithium

Table 4.1.7 Ganfeng Lithium Co. OEM and Cell Manufacturer Supply Agreements

Company	Date	Details
BMW	2019	BMW have announced a €540m supply contract with Ganfeng Lithium to secure 100% of its expected supply of lithium hydroxide until 2025, extending its current relationship with Ganfeng. BMW's contract is not just about security of supply but is also about the ethical procurement of raw materials.
Volkswagen Group	2019	Audi has signed a memorandum of understanding with Ganfeng Lithium to guarantee the supply of lithium to the Volkswagen Group and its suppliers for the next 10 years in an attempt to alleviate any future battery supply chain issues.
LG Energy Solution	2019	LG Chem has signed a 3-year, 16,000 tonnes per year (tpy) lithium hydroxide supply agreement with Ganfeng Lithium

Table 4.1.8 Other Lithium Suppliers

Company	Location	Details
Lithium Americas	Canada	JV between Minera Exar S.A and Ganfeng starting in 2021 at Caucharí-Olaroz, Argentina. Lithium project at Thacker Pass, Nevada, US
MGX Minerals	Canada	50:50 JV between MGX and Eureka Resources to recover lithium from water produced at nonconventional oil and gas sites across the Marcellus and Utica shales
Nemaska Lithium	Canada	In July 2018, LG Chem signed a 5-year, 7,000tpy lithium hydroxide deal with Nemaska Lithium Nemaska Lithium owns the Whabouchi lithium project located in the James Bay area in central Quebec, Canada.
Galaxy Resources Limited	Australia	Mt. Cattlin mine, Western Australia
Mineral Resources	Wodgina, Australia	$1.1bn deal for 50,000 tpy of battery grade lithium hydroxide in the 1st stage and 100,000 tpy in the 2nd stage. Albemarle revised a deal to buy the Wodgina lithium mine owned by Mineral Resources' and delayed building 75,000tpy of capacity at Kemerton, Australia.
Pilbara Minerals	Pilbara, Australia	Pilgangoora lithium-tantalum project owed by Pilbara Minerals.
Kidman Resources	Forestania Western Australia	The Earl Grey lithium project, also known as the Mt Holland lithium project, is owned by Kidman Resources (50%) and SQM (50%) under a JV named Covalent Lithium.
Talison Lithium	Greenbushes, Western Australia	The Greenbushes lithium project is located in Greenbushes, Western Australia. It is owned by Chinese mining company Tianqi Lithium and operated by Talison Lithium, which is 51% owned by Tianqi Lithium.
Altura Mining	Pilbara, Western Australia.	The Pilgangoora lithium mine is located in the Pilbara region of Western Australia.
Mali Lithium	Bougouni, Mali	The Goulamina lithium project is owned and operated by Mali Lithium

Orocobre	Olaroz, Jujuy, Argentina	
Piedmont Lithium	North Carolina, US	In September 2020, Tesla signed a 5-year deal with Piedmont Lithium for Spodumene concentrate
Prospect Resources	Harare, Zimbabwe	The Arcadia lithium project is owned and operated by Prospect Resources

4.2 Cobalt Suppliers

For lithium-ion batteries and the raw materials used during their manufacture, it's mainly cobalt, rather than lithium, that has caused supply issues, and which has experienced extreme price volatility.

Cobalt mining companies have had a very difficult couple of years. Trade wars and warnings about longer-term supply shortages caused cobalt prices to spike in 2017 and 2018. Then in mid-2018, a surge of new cobalt supply resulted in oversupply, which led to cobalt prices collapsing. Cobalt prices then hovered around $30,000-35,000 per tonne in 2019 and 2020 but have started to spike again in 2021 hitting $50,000 per tonne in part due to a surge in battery demand due to increasing EV sales.

Total cobalt production in 2019 was 138,000 tonnes. In 2019, 75% of the world’s cobalt was produced from the politically volatile DRC. As much as 20% of that production is believed to be mined at unethical facilities where human rights are ignored and deaths commonplace.

Sourcing conflict-free cobalt that's not mined in the DRC is always going to be problematic. Furthermore, the DRC has imposed 10% royalties and a super profit tax of 50% on cobalt mining companies.

Cobalt is such a focus for OEMs that some have taken the relatively rare step of contracting directly with cobalt suppliers. Tesla and BMW, for example, are concerned about securing cobalt supplies from unstable regions and aim to hedge against price volatility as well as to improve visibility of labour and sourcing practices. Many manufacturers are also increasingly developing batteries that can eliminate cobalt altogether.

Table 4.2 Leading Cobalt Suppliers

Company
Glencore
China Molybdenum
Katanga Mining
Umicore
Eurasian Resources Group

4.2.1 Glencore

Glencore's total production was 27,400 tonnes in 2017 and the company aimed to reach 63,000 tonnes by 2020.

The company suffered losses in mid-2018 due to the collapse in price of cobalt which resulted in many customers reneging on fixed-price contracts. However, Glencore is not a cobalt 'pureplay' and also has interests in coal, copper, PGMs, zinc and nickel.

Glencore has also been looking to secure more direct contracts with OEMs in the battery supply chain. For example, it has been reported that Tesla is in negotiations to purchase cobalt from Glencore specifically for its Shanghai plant.

BMW has also signed a contract to procure cobalt from Glencore's Australian mines. Battery materials suppliers GEM and Umicore have also signed supply contracts with Glencore. In May 2019, Umicore signed a cobalt supply deal with Glencore of up to 12,000 tonnes per year. In October that year, Glencore revised its deal with Gem for the of supply cobalt hydroxide that equates to 61,200 tonnes of contained cobalt from 2020 to 2025.

Table 4.2.1 Glencore Cobalt Mines

Location	Details
Mutanda, DRC (temporarily closed due to problems sourcing sulphuric acid)	In 2017, Glencore paid Fleurette Group $960m for its stakes in Mutanda Mining and Katanga Mining.
Katanga, DRC	Through its ownership of Katanga Mining
Minara, DRC	
Mopani, Zambia	Expansion plan
Kamoto, DRC	In 2017, paid Fleurette Group $960m for its stakes in Mutanda Mining and Katanga Mining. Glencore now owns 86.33% of Katanga Mining)

4.2.2 China Molybdenum

China Molybdenum is partly owned by the Chinese government. Its total production was 16,419 tonnes in 2017 and was estimated to have increased to around 18,000 tonnes in 2018. China Molybdenum is not a 'pureplay' cobalt supplier and also has interests in copper, molybdenum, tungsten, phosphorus, niobium, and gold

Table 4.2.2 China Molybdenum Cobalt Mines

Location	Details
Tenke Fungurume, DRC	In 2017, China Molybdenum paid Freeport Cobalt $2.65 billion for its 70% stake in TF Holdings, which has an 80% stake in the Tenke Fungurume mine in the DRC

4.2.3 Katanga Mining

Cobalt production from Katanga Mining was 11,000 tonnes in 2018 and to set expand to 15-20,000 tonnes. However, this was impacted by a cobalt output ban until mid-2019 as a result of unacceptably high uranium levels.

Table 4.2.3 Katanga Mining Cobalt Mines

Location	Details
Kamoto, DRC	Copper & Cobalt

4.2.4 Umicore

Cobalt refining volumes reached an estimated 6,000-8,000 tonnes of cobalt in 2018.

Umicore is a processor of cobalt rather than a mining company. It not only refines cobalt but also recycles it as a significant share of revenues. Umicore is also involved in cathode and battery materials production. Because Umicore is not a 'pureplay' mining company, it is somewhat less exposed to price volatility and supply issues.

The company works with clients including LG Chem, as well as with Audi and BMW. In December 2019, Audi and Umicore announced a 'closed loop system' for cobalt and nickel, the materials recovered into precursor and cathode materials can be used in new battery cells**.** The companies claimed that over 90% of the cobalt and nickel in batteries for the Audi e-tron can be recovered and recycled, for example.

BMW Group has also formed a joint technology consortium with Swedish battery manufacturer Northvolt and Umicore to develop battery cell technology. The goal is to create a more sustainable battery value chain from R&D to production and recycling across Europe.

The recycling model is supported by the likeliness that these elements will be in short supply as battery production is ramped up.

Table 4.2.4 Umicore Cobalt Processing Plants

Location	Details
Jiangxi province, China.	Ganzhou Yi Hao Umicore Industries Co Ltd. (GYHU) is a joint venture in which Umicore owns a 40% share. This cobalt and copper refinery produces copper cathodes and cobalt salts and oxides
Wickliffe, Ohio, US	Umicore Specialty Materials Recycling (USMR) in Wickliffe refines and recycles cobalt- and nickel-containing secondary materials, such as superalloy scrap
Hoboken, Belgium	Recycling of precious metals such as Cobalt
Olen, Belgium	R&D and recycling of precious metals such as Cobalt
Kokkola refinery, Finland	in May 2019, Umicore signed a cobalt supply deal with Glencore, which is estimated to account for up to 12,000 tonnes per year of Glencore's cobalt supply. Umicore also acquired the majority stake of Freeport Cobalt's Kokkola refinery in Finland

4.2.5 Eurasian Resources Group (ERG)

ERG is a privately owned company and a relatively new entry to the list of cobalt companies, but the opening of a new facility with cobalt production of around 7,000 tonnes per year looks set to make it a leading player.

Table 4.2.5 ERG Cobalt Mines

Location	Details
Metalkol Roan Tailings Reclamation (RTR) project, DRC	in 2019, started production for copper and cobalt of 7,000 tonnes per year of cobalt with potential to step up to over 21,000 tonnes per year
Unknown	In March 2020, ERG announced it was planning a Nickel Cobalt Manganese (NCM) precursor material manufacturing plant. Phase 1 will have 90,000 tonnes per year

Table 4.2.6 Other Cobalt Suppliers

Company	Location	Details
Vale	New Caledonia	Cobalt produced of 5,811 tonnes in 2017. Vale has mines in Ontario's Sudbury Basin; Thompson Complex in Manitoba, Goro mine in New Caledonia
Sumitomo Metal Mining	Madagascar, Ambatovy, The Philippines	Owns 47.7% of the Ambatovy nickel-cobalt mine in Madagascar. Cobalt production in 2017 was 4,600 tonnes. It also has Cobalt plants in Ambatovy and The Philippines
Gecamines	DRC	Cobalt production of 4,167 tonnes in 2016. The company has minority interests in a number of major DRC mines, with companies Glencore, Freeport-McMoRan and Ivanhoe Mines
Glencore	DRC, Canada, Australia,	Produced as a side-product of Copper mining
Cobalt Blue	Thackaringa, Australia	LG Energy Solution is an investor in Cobalt Blue's Thackaringa cobalt project in Australia
Jinchuan Group International Resources	Ruashi, Africa	A copper and cobalt mine
Zhejiang Huayou Cobalt	DRC	in April 2018, LG Energy Solution signed a JV with Zhejiang Huayou Cobalt to establish precursor and cathode material production facilities with capacity of 40,000tpy, with potential to expand to 100,000 tonnes per year
BASF	DRC	'Cobalt for Development' pilot project supported by BMW Group, BASF SE, Samsung SDI and Samsung Electronics to promote responsible artisanal cobalt mining in the DRC
Korea Resources Corporation		Boleo project is an advanced stage copper, cobalt, zinc and manganese project located in Baja California Sur, Mexico
Pengxin International Mining Co	DRC	Shituru Mining Plant, DRC is estimated to produce 7,000 tonnes of cobalt hydroxide (containing 35% cobalt)

4.3 Nickel Suppliers

Global refined nickel production was around 2.184m tonnes in 2018. Around 24% of global nickel reserves are in Indonesia. The industry is fairly consolidated, with the world's ten largest producers accounting for over 60% of global output. In terms of regional production, nickel is fairly evenly spread around the globe, with the largest five production locations being in the Philippines, Russia, Indonesia, Australia and Canada.

Table 4.3 Leading Nickel Suppliers

Company
Vale
MMC Norilsk Nickel
Jinchuan Group Ltd.
Glencore
BHP Billiton Ltd.

4.3.1 Vale

Vale is among the top 3 mining companies in the world, primarily thanks to its iron-ore production which accounts for 74% of the company's revenues. Although only around 20% of revenues are from base metals such as copper and nickel, Vale is one of the largest nickel producers at 244,000 tonnes of production in 2019. The company plans to grow its nickel production to 400,000 tonnes per year over the mid-term, with a $1.7 billion investment to expand its Voisey's Bay site.

Table 4.3.1 Vale Nickel Mines

Location	Details
Voisey's Bay, Labrador, Canada	Nickel sulphide ore
Sudbury, Ontario, Canada	Nickel sulphide ore
PTVI, Indonesia	PT Vale Indonesia (PTVI)
VNC, New Caledonia	Vale New Caledonia (VNC)
Thompson, Manitoba, Canada	
Onca Puma, Brazil	

4.3.2 Norilsk Nickel (Nornickel)

Norilsk Nickel (Nornickel) is one of the largest producers of nickel with 215,000 tonnes of production in 2019. However, Nornickel is quite diversified and also produces palladium, platinum and copper, with nickel accounting for around one-quarter of its revenues. It does, however, have the largest nickel reserves in the world. In 2018, BASF and Nornickel signed a supply agreement deal to cater for growing demand for EV batteries. BASF will build a plant to produce cathode materials for batteries in Harjavalta, Finland, next to a nickel and cobalt refinery owned by Nornickel.

Table 4.3.2 Nornickel Mines

Location	Details
Norilsk, Russia	Polar Division of MMC Norilsk Nickel
Severonkel and Perchenganikel nickel mines, Kola Peninsula, south of Murmansk, Russia	Kola Mining and Metallurgical Company (Kola MMC)
Stakes in mines in Botswana (85% of Tati Nickel) and in South Africa (50% of Nkomati)	Norilsk Nickel Africa
Emily Ann, Maggie Hays, Western Australia	Norilsk Nickel Australia
Norilsk Nickel Harjavalta, Harjavalta , Finland	Refinery

4.3.3 Jinchuan Group

Jinchuan Group is China's largest producer of nickel, producing 150,000 tonnes in 2019. It is based in Gansu province, China and has operations in 24 international locations. The company also produces cobalt, copper, selenium palladium, silver and gold. The company is not only involved in upstream mining but milling, smelting, chemical processing and further downstream processing. The company also engages in trading of mineral and metal products. Through its subsidiary Metorex, Jinchuan International owns a number of large copper and cobalt mines in Africa.

Table 4.3.3 Jinchuan Group Nickel Mines

Location	Details
Kinsenda mine, DRC	Copper mine
Chibuluma, Zambia	Copper mine
Ruashi mine, DRC	Copper and cobalt
Musonoi project, DRC	Under construction
Lubembe project, DRC	Exploration project
Guangxi province, Fangchenggang	New project for nickel and cobalt
Indonesia	Joint venture with local partner for nickel and cobalt

4.3.4 Glencore

Glencore, based in Switzerland, is a major international player in base and platinum group metals as well as commodity trading. It had 124,000 tonnes of nickel production in 2019.

In 2013, Glencore acquired Xstrata, significantly expanding its metal resources business. Nonetheless, nickel represents only around 3% of Glencore's total revenues, with the main revenue derived from commodity trading business with coal, copper, PGMs, zinc, nickel, and cobalt.

Table 4.3.4 Glencore Nickel Mines

Location	Details
Sudbury, Canada	Nickel mine
Raglan, Canada	Nickel- Copper mine
Murrin, Australia	Nickel- Cobalt mine
Koniambo, New Caledonia	Ferronickel-mine
Nikkelverk, Norway	Nickel / cobalt refinery

4.3.5 BHP Billiton

BHP Billiton had 91,000 tonnes of nickel production in 2019. It is a highly diversified mining and resources companies with the vast majority of its operations coming from iron ore, copper, coal and petroleum, with nickel a relatively small part of its revenues.

Table 4.3.5 BHP Billiton Nickel Mines

Location	Details
Cerro Matoso mine in northwest Colombia	Nickel mine
Nickel West, (including Mt Keith, Cliffs and Leinster, Kambalda Kalgoorlie, Kwinana) Australia	Nickel mine
Yabulu, Australia	Nickel-cobalt refinery
Ravensthorpe, Australia	Ravensthorpe nickel mine and processing 100% Nickel Project facility (currently in development)
North Colombia	Integrated ferronickel mining and smelting complex

Table 4.3.6 Other Nickel Mining Companies

Company	Clients
Sumitomo Metal Mining Co	65,000 tonne production of nickel in 2018. SMM is more of a smelter, processor and refiner of copper, nickel, and gold in Japan. It invested in nickel mines and smelters in the

	Philippines, Indonesia, and New Caledonia. The company's major nickel assets include the Niihama Nickel Refinery in Ehime Prefecture, Japan and a 47.7% share ownership in the nickel-cobalt Ambatovy mine in Madagascar. It also sources nickel and cobalt from The Philippines
Sherritt International	63,000-tonne production of nickel in 2018. Sherritt is involved in mining and refining of nickel from lateritic ores with projects in Canada, Cuba, Indonesia, and Madagascar. Sherritt is invested in a 50/50 partnership in the Moa Joint Venture in Cuba with General Nickel Company and is a 12% operator-owner in the Ambatovy joint venture in Madagascar
Eramet	55,000 tonne production of nickel in 2018. Eramet is a mining and metallurgical group that has operations in 20 countries across three main products: nickel, manganese, and alloys. Nickel mining and refining is conducted in New Caledonia, Indonesia, and France
Anglo American	42,000 tonne production of Nickel in 2018. Anglo American is a major producer of platinum, diamonds, coal, copper, iron ore and nickel. The London-based company's nickel operations are located in Brazil and Venezuela. In 2010, Anglo American's gross revenues from nickel sales were approximately $426m
Minara Resources	39,000 tonne production of nickel in 2018. Wholly owned by Glencore International, Minara Resources is one of Australia's top nickel producers. Australia-based Minara operates the Murrin nickel-cobalt mining and refining project, which employs over 1,000 employees and contractors
Chemco	LG Chem has a 10% stake in Korea Zinc's nickel sulphate subsidiary Chemco
SNNC	Joint venture between POSCO and South Pacific Mining Company
First Quantum Minerals	Ravensthorpe Nickel Mine
Panoramic Resources	Savannah (East Kimberley), Lanfranchi, Gidgee, Copernicus mines
Independence Group	Long Nickel mine Kambalda, Australia
Western Areas	Flying Fox and Spotted Quoll mines, near Forrestania, Australia
Mincor Resources, MMG	Kambalda mine, Australia

Nickel Asia Corporation	
Aneka Tambang (Antam)	
Highlands Pacific	
Franco/Nevada	
South32	
Lundin Mining	

4.4 Manganese Suppliers

Global manganese production is around 18.5m tonnes annually. It is mainly focused in South Africa, which has around 78% of reserves, as well as in China and Australia. The majority of Manganese is used in steel production, and increasing volumes are largely dependent upon economic growth and therefore construction activity particularly in Asia. But the increasing demand from lithium-ion batteries is certain to increase demand and represent a growing proportion of growth.

While there are many companies producing manganese, only 2% are producing the manganese carbonate necessary for the production of high purity manganese used in EV batteries. Therefore, the supply chain could see real shortage in manganese compared to cobalt or lithium, with price spikes also more likely.

Table 4.4 Leading Manganese Suppliers

Company
South32
Anglo American
Consolidated Minerals
Eramet
Vale

4.4.1 South32

South32 is a highly diversified mining and metals company that produces alumina, aluminium, bauxite, energy and metallurgical coal, manganese, nickel, silver, lead and zinc in Australia, South Africa and South America.

In terms of manganese, South32 is one of the world's leading producers with operations in three main sites, including two in Australia with a 60% stake in Groote Eylandt Mining Company (Anglo American holds the remaining 40%). A second site is at Tasmanian Electro Metallurgical Company (TEMCO), which produces the ferromanganese used for manufacturing steel.

It has another site in South Africa with South Africa Manganese at the Hotazel mine, which is located in the manganese-rich Kalahari Basin, which is believed to hold 80% of the world's manganese ore reserves.

Table 4.4.1 South32 Manganese Mines

Location	Details
South Africa Manganese, Hotazel, South Africa	Manganese mine
GEMCO, Groote Eylandt, Australia	Manganese mine. 60% owned by South32 and 40% by Anglo American
TEMCO, Tasmania, Australia	Manganese mine producing ferromanganese, used for steel manufacturing

4.4.2 Anglo American

Anglo American is a highly diversified mining and raw materials company based in Johannesburg, South Africa and London, UK. The company produces platinum, diamonds, copper, nickel, manganese, iron ore and metallurgical and thermal coal. It has operations in Africa, Asia, Australia, Europe, North America and South America. In terms of manganese production, Anglo American holds a 40% stake in the Groote Eylandt Mining Company (GEMCO) which is also 60% owned by South32. Anglo American has a 40% shareholding in Samancor with sites in South Africa and Australia.

Table 4.4.2 Anglo American Manganese Mines

Location	Details
Barro Alto, Brazil Codemin, Brazil	
Sakatti Project, Finland	
GEMCO, Groote Eylandt, Australia	Anglo American, holds a 40% stake in Groote Eylandt Mining Company (GEMCO) and 60% owned by South32
South Africa	40% shareholding in Samancor
Australia	40% shareholding in Samancor

4.4.3 Vale

Vale is a highly diversified mining and metal company based in Rio de Janeiro, Brazil that produces iron ore, fertilizer, copper, nickel, ferroalloys, coal, manganese, cobalt and platinum group metals. Vale is the largest manganese mining company in Brazil and the vast majority of its manganese output comes from its Azul mine. Vale operates manganese mines and plants via its subsidiary, Vale Manganese and Mineracao Corumbaense Reunida.

Table 4.4.3 Vale Manganese Mines

Location	Details
Azul mine, Pará, Brazil	Manganese mine
Urucum mine, Mato Grosso do Sul, Brazil	Manganese mine
Minas Gerais, Brazil	Manganese mine, ferroalloy plant
Bahia, Brazil	Ferroalloy plant

4.4.4 Eramet

Eramet, based in Paris, France is a leading mining and metallurgical company which produces various alloys for a wide range of industries and applications. Through its subsidiary, La Compagnie Minière de l'Ogooue (COMILOG), the company extracts manganese ore from the Moanda mine in Gabon and produces high-grade manganese alloys for batteries, recycling, agrochemicals, and electronics.

Table 4.4.4 Eramet Manganese Mines

Location	Details
Moanda, Gabon, Africa	Subsidiary COMILOG

4.4.5 BHP Billiton

BHP Billiton is headquartered in Melbourne, Australia and produces a wide range of raw materials such as iron ore, copper, potash, coal, oil, gas amongst other raw materials and commodities. In terms of manganese mining operations, it has two in Australia and one in South Africa. Furthermore, the company has two iron ore mines in Brazil and Australia; five copper mines in Peru, Australia and Chile; coal mines in Australia, Colombia, and the US; a potash development in Canada; and oil and gas from sites in the Gulf of Mexico, Australia, Pakistan, the US and the UK.

Table 4.4.5 BHP Billiton Manganese Mines

Location	Details
Australia	A 60:40 JV between BHP Billiton Australia TEMCO a producer of manganese alloys
Australia	A 60:40 JV between BHP Billiton Australia & GEMCO a producer of manganese ore.
South Africa	A 60:40 JV between BHP Billiton South Africa and Samancor Integrated, a producer of manganese

Table 4.4.6 Other Manganese Mining Companies

Company	Details
Assmang	Based in South Africa, Assmang is involved in iron ore, manganese, and chrome ore mining. It is jointly controlled by African Rainbow Minerals and Assore The company has assets at Nchwaning and Gloria mines, Black Rock, near Kuruman, Northern Cape Province of South Africa
Xiangtan Electrochemical Scientific	The company is the largest producer of manganese dioxide in China and also produces electrolytic manganese metal, battery materials and other related energy materials. The company expanded into cathode materials in 2016
South Africa Manganese	South Africa Manganese, one of the company's four operations in South Africa, is made up of Metalloys and Hotazel Manganese Mines. Notably, the Hotazel mine is located in the manganese-rich Kalahari Basin
Autlan	One of the country's largest producers is Autlan creating a variety of manganese products, e.g., manganese ferroalloy and manganese derivatives
Jupiter Mines	Another Australian firm, Jupiter Mines, operates the Tshipi Borwa open-pit mine, which is located on a large and homogenous ore body in the southern portion of the Kalahari manganese field. The mine is designed to produce 2.4 million tonnes per annum (mtpa) of 37% manganese ore grades
Consolidated Minerals (Consmin)	Consmin Operates in the exploration, mining, processing, of manganese ore at operations in Australia. Consmin also holds a 90% stake in Ghana Manganese Company, which runs a mine in Nsuta, Ghana. Consmin signed a 10-year supply deal with China's Ningxia Tianyuan Manganese Industry in 2018

5. Battery Component Suppliers

Positioned between the suppliers of raw elements and the battery cell manufacturers are the individual battery components such as the cathode, anode, electrolytes and separators. This is a relatively niche area with only handful of companies specialising in these specific component areas. The vast majority of these companies are based in Japan or China, with only a few from outside Asia, including several in North America.

This dominance means that even as battery cell, module and pack assembly plants are created in other regions, the upstream supply chain will still be reliant on Asian suppliers of cell components until they can be developed in other regions.

5.1 Cathodes Materials

The lithium cell's overall performance depends heavily upon the quality of the cathode material, making quality control critical in this application. For this reason, many of the leading battery cell manufacturers, including LG Chem, Panasonic and BYD, have their own in-house cathode materials production capabilities.

Table 5.1 Leading Cathode Materials Manufacturers

Company	Location	Clients
Umicore	Korea, China, Poland	Samsung SDI, LG Chem, Panasonic, Sony
Nichia	Japan	Panasonic, Sony, Hitachi, ASEC Envision, LEJ
Toda Kogyo	Japan	
Beijing Easpring	China	Samsung SDI, LG Chemicals, Sony, Hitachi SKI, Panasonic, BYD, Lishen
Ningdo Jinhe	China	Samsung SDI, LG Chemicals
GEM	China	
Shanshan Energy	China	CATL, Panasonic, Lishen
Xiamen Tungsten	China	
Kingray New Materials Science & Tech	China	Panasonic

Source for all tables and figures in this section unless noted otherwise: Automotive from Ultima Media

5.1.1 BASF

BASF is reported to be building a lithium cathode production facility at its Schwarzheide site in Brandenburg, Germany, close to where Tesla is building its EV and battery plant. The €500m investment will allow the production of cathode materials for 300,000 vehicles a year. BASF currently has a cathode materials plant in Finland. The company also has involvement in NiMH, LFP, NCM and electrolytes and R&D focus on developing Li-S and Li-air cathode materials

5.1.2 Guoxuan High Tech

Guoxuan High Tech not only builds lithium-ion batteries but also conducts R&D and cathode materials for cells. In May 2020, Volkswagen acquired a 26.5% share in the company as the carmaker sought to strengthen its capacity of battery cells but gains further control of the upstream supply chain.

5.1.3 Johnsson Matthey

Johnsson Matthey (now owned by Cummins) announced a €135m investment in a cathode materials plant in Konin, Poland with production expected from 2022 with an expected capacity of 10,000 tonnes per year of eLNO, it's next generation ultra-high energy density cathode material.

5.1.4 Aluminium Foil

Within lithium-ion cells, aluminium foil is used as a current collector for the cathodes. Market leaders in aluminium foil production for battery applications are Sumitomo Light Metal Industries and Nippon Foil, both from Japan.

Table 5.1.1 Leading Aluminium Foil Manufacturers

Company	Location	Clients
Sumitomo Light Metal Industries	Japan	Panasonic
Nippon Foil Mfg	Japan	

5.2 Anode Materials

The leading companies manufacturing anode materials are all based in Japan and China, with major manufacturers including Hitachi and BTR Energy serving major battery manufacturers globally.

There are some key investments beyond Japan and China. LG Chem, for example, has invested in Korean anode producer GS E&C.

Besides the leading players (see table 5.2), other smaller producers of anode active materials include Mitsubishi Chemical (Japan), LS Mtron Carbonics (South Korea), ShanshanTech (China) and Tokai Carbon (Japan).

Table 5.2 Leading Anode Materials Manufacturers

Company	Location	Clients
Hitachi Chemicals	Japan	Samsung SDI, LG Chem, Panasonic, Hitachi
BTR Energy	China	Samsung SDI, LG Chem, Panasonic, Sony and BYD
Nippon Carbon	Japan	
Ningbo Shanshan	China	LG Chem, Sony, Lishen, BAK and BYD
Hunan Shinzoom Technology	China	BYD, CATL and Far East First
Jiangxi Zeto New Energy Tech	China	BAK Battery

5.2.1 Copper Foil

Copper foil is used in current collectors for anodes in lithium-ion cells. The three leading companies are all Japanese.

Table 5.2.1 Leading Copper Foil Manufacturers

Company	Location	Clients
Furukawa Electric	Japan	
Nippon Foil Mfg	Japan	
Nippon Denkai	Japan	AESC Envision
Doosan Corporation	Hungary, Luxembourg	

5.3 Electrolytes

Electrolytes are the liquid medium between the anode and cathode in the battery. These components are also highly concentrated in Asia, specifically China and Japan, including CapChem Technology and Mitsubishi Chemicals

There are, however, some new entrants to electrolytes for lithium-ion batteries, including LG Chem (South Korea), DuPont (US) and Daikin (Japan).

Table 5.3 Leading Electrolyte Manufacturers

Company	Location	Clients
CapChem Technology	China	Samsung SDI, Panasonic, Sony, BYD, Lishen, BAK and Coslight
Tinci Materials Tech	China	Sony, BYD, CATL, Guoxuan, Wanxiang, Coslight
Guotai-Huarong (GTHR)	China, Poland	Samsung SDI, LG Chemicals, ATL, Lishen, Panasonic
Panax-Etec	China	Samsung SDI, LG Chemicals
Mitsui Chemicals	Japan	LEJ
Ube	Japan	Panasonic
Mitsubishi Chemicals	Japan	Panasonic, Sony, Hitachi, AESC
Ningbo Shanshan	China	LG Chem, Sony, Lishen, BAK and BYD
Do-Fluoride Chemicals	China	BYD and King Long

5.4 Separators

The separator is the part which isolates the anodes and the cathodes in a battery; the separator forms the catalyst for the movement of ions from cathode to anode on charge, and the reverse on discharge.

The market for separator manufacturing is led by Japan, with companies including Asahi Kasei and Toray Tonen supplying major battery manufacturers. A large and growing number of manufacturers are also in China. The US has a small presence in this market, while entrants for electrodes and ceramic separators include Evonik and Litarion in Germany.

Table 5.4 Leading Separators Manufacturers

Company	Location	Clients
Asahi Kasei	Japan	Samsung SDI, LG Chemicals, Panasonic, Sony, Hitachi, AESC Envision
Toray Tonen	Japan	Samsung SDI, LG Chemicals, Sony
SKI	Japan	Samsung SDI, Sony
Celgard	US	LG Chemicals, Panasonic, AESC Envision
Entek	US	
Senior Technology Material	China	LG Chem, BYD, Guoxuan, Lishen, CALB
Victory Precision Manufacture / Suzhou Greenpower New Energy Materials	China	BYD, LG Chem, CATL, SDI
UBE	Japan	Hitachi, AESC
Jinhui Hi-tech	China	BYD, BAK
BNE	China	CALB, Coslight
Cangzhou Mingzhu	China	BYD, CALB., ATL, and Lishen
Shanghai Energy New Materials	China	Samsung SDI, LG Chem, ATL, BYD
Zhongke Science and Tech	China	LG Chem, BYD, Lishen, BAK
Donghang	China	Narada, Guangdong Great Power
Newmi Tech	China	LG Chem, Lishen, Coslight
Sinoma	China	BYD, ATL, Eve Battery
SK IE Technology Company (SKIET)	South Korea, China	

6. Battery Cell Market and Production

6.1 Largest Global Battery Cell Companies

Battery cell manufacturers have rapidly risen to prominence within automotive battery supply chains as producers of the key component of lithium-ion batteries. The success of any OEM's electrification strategy relies heavily upon the partnerships, alliances and joint ventures forged with battery cell manufacturers.

These companies, some of whom have only recently entered the automotive industry, are emerging as leading tier-1 suppliers and manufacturing integrators as carmakers ramp up electrification plans. The technology developed by the battery cell manufacturers has the potential to make them 'kingmakers' in the automotive value chain, and in helping to determine the success of electric vehicle programmes.

The largest battery cell manufacturer by current capacity is South Korea's LG Energy Solution (an independently run spinoff of LG Chem), supplying a diverse range of OEMs across the world. But other manufacturers are fast adding capacity, including the remarkable growth of China's CATL. All of the top five battery manufacturers, including LG Energy Solution, BYD, Panasonic, CATL and SK Innovation, are expanding plants globally, including in Europe and North America.

One of the most striking aspects of the leading battery cell manufacturers is that almost half (44%) of current capacity is controlled by Chinese-owned companies, and some 93% of capacity is controlled by Asian companies. North American and European OEMs pushing towards electrification are thus almost completely reliant upon these Asian battery suppliers. However, battery cell companies are fasting expanding their capacity in global regions, while a number of new players and startups are emerging.

The full database of cell plants can be downloaded from our website here:
https://www.automotivelogistics.media/focus/electric-vehicles
https://www.automotivemanufacturingsolutions.com/technology/emobility

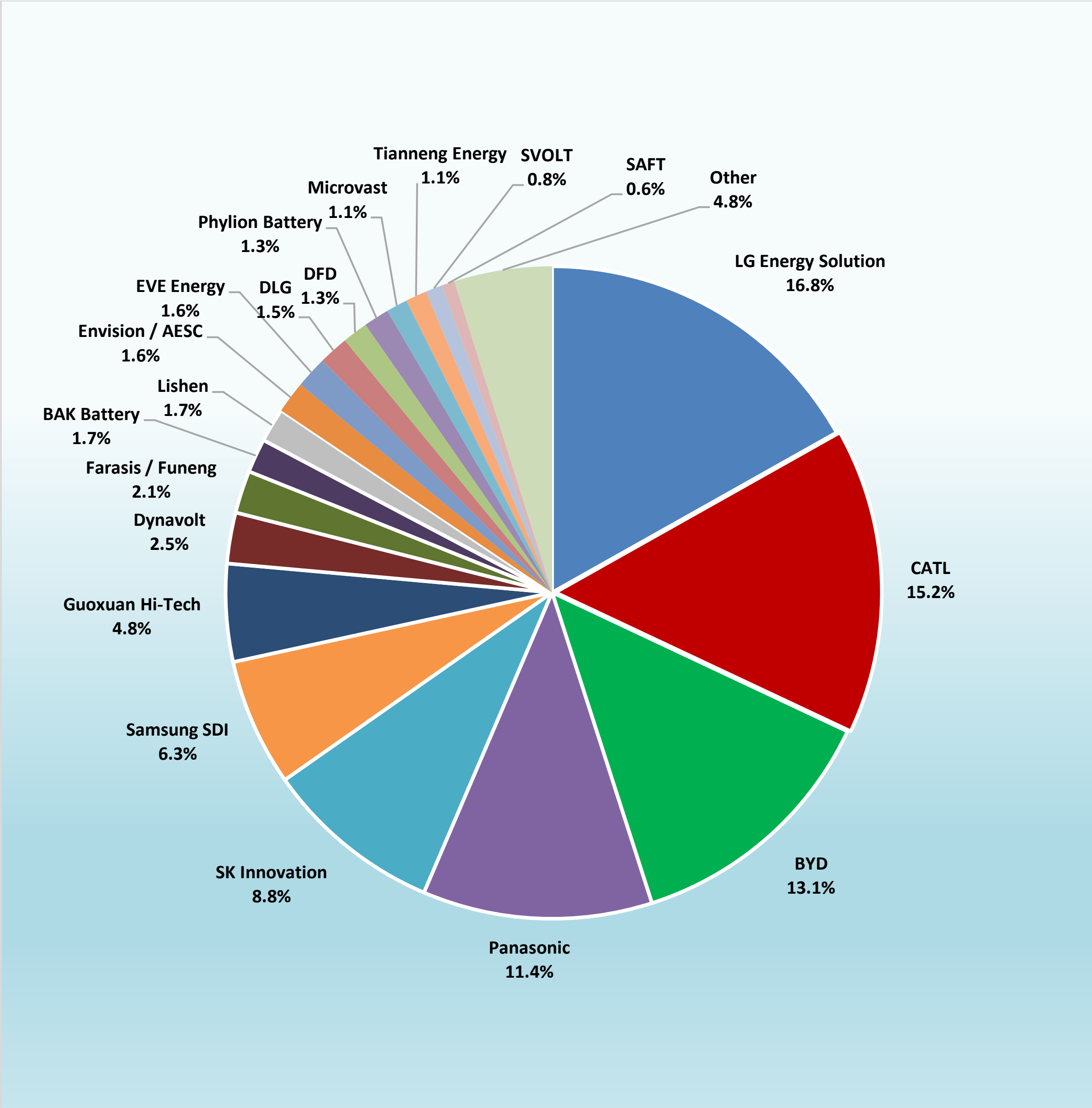
Table 6.1 Top 20 Lithium Battery Cell Manufacturers 2020

Rank	Company	Country	Capacity In 2020*	Plants 2020	OEMs supplied (not exhaustive)
1	**LG Energy Solution (LG Chem)**	South Korea	80 GWh	5	FCA, Ford, Geely, General Motors, Hyundai, Jaguar, Renault-Nissan-Mitsubishi (RNM), Tesla, VW, Volvo
2	**Contemporary Amperex Technology Co. Limited (CATL)**	China	72 GWh	5	BAIC, BMW, Daimler, Dongfeng, Foton, GAC, Geely, Honda, Hyundai-Kia, Nanjing Golden Dragon, RNM, SAIC, Stellantis, Toyota, Volvo, VW Group, Xiamen King Long, Yutong, Zhongtong
3	**BYD**	China	62 GWh	6	BYD, Changan auto, Toyota, Great Wall Motor, Dongfeng Motor, Chery Auto, NIO and Xpeng Motors.
4	**Panasonic**	Japan	54 GWh	9	BMW, Ford, Honda, Tesla, Toyota,
5	**SK Innovation (SKI)**	South Korea	42 GWh	5	Daimler, BAIC, Hyundai, Jaguar Land Rover, Ferrari, Kia, VW Group
6	**Samsung SDI**	South Korea	30 GWh	13	Akasol, BMW, Hyundai-Kia, JAC, Stellantis, Volvo, VW Group
7	**Guoxuan High Tech Power**	China	23 GWh	5	Ankai Bus, BAIC Motor, Dongfeng Motor, JAC, Jianghuai Automobile, Jinlong, Shanghai Sunwin, Shenwo, Zhongtong, Zoomlion
8	**Dynavolt**	China	12 GWh	2	
9	**Farasis/Funeng**	China	10 GWh	1	BAIC, Changan, Great Wall, Jiangling
10	**BAK Battery**	China	8 GWh	1	
11	**Lishen**	China	8 GWh	1	Dongfeng, JAC, Geely, Jinlong, Kandi Tech, Zhongtong, Qingyuan, FAW
12	**Envision AESC**	China	7.5 GWh	3	Nissan
13	**EVE Energy**	China	7.5 GWh	1	Geely, Kia Motors
14	**DLG**	China	7 GWh	2	
15	**DFD**	China	6 GWh	1	
16	**Phylion Battery**	China	6 GWh	1	
17	**Microvast**	China	5 GWh	1	Foton, Hengtong, Jinlong, Zhongtong
18	**Tianneng**	China	5 GWh	1	
19	**SVOLT**	China	4 GWh	1	Great Wall
20	**SAFT**	France	3 GWh	2	Stellantis
	Others		23 GWh		
Total			**475 GWh**		

*Installed capacity expected by the end of 2020

Source for all tables and figures in this section unless noted otherwise: Automotive from Ultima Media

Figure 6.1 Top 20 Lithium Battery Cell Manufacturers Production Capacity Share 2020



6.2 Battery Cell Manufacturing Plants

Some 74% of current battery cell manufacturing capacity is located in Asia and that dominance is likely to continue. Currently, around 13% of capacity is in Europe and 10% in the US (the majority of which is currently Tesla's joint venture with Panasonic).

However, rising EV demand in Europe, along with regulations to encourage local battery supply, will lead to considerable growth in European battery cell manufacturing plants and the wider upstream supply chain. We predict that Europe will more than double its plant capacity share from 15% in 2020 to 33% by 2030 and reach a capacity of 950 GWh. Capacity in Asia, meanwhile, is expected to rise to 1,620 GWh.

As of 2020, there were 14 current gigafactories for batteries in Europe, while we estimate that around 33 new plants have already been announced or are under construction. There will doubtless be many more to reach the expected demand for batteries.

North America will also experience a rapid rate of growth, albeit from a lower starting point. Sales of EVs are expected to rise faster over the next decade, with the Biden administration likely to tighten fuel economy standards and encourage more investment in electrification. The new USMCA protocol will require higher rules of origin for vehicle components including for batteries, which will further encourage OEMs and manufacturers to source batteries within North America.

Twelve new gigafactories have been announced in the US along with the existing nine. There are currently no existing or planned gigafactories outside of the US in North America, however OEMs including GM and Ford are investing in EV production capacity in Canada and Mexico, for example.

By 2030, we expect North American battery production to grow in line with the market, for its market share to remain constant at around 10%.

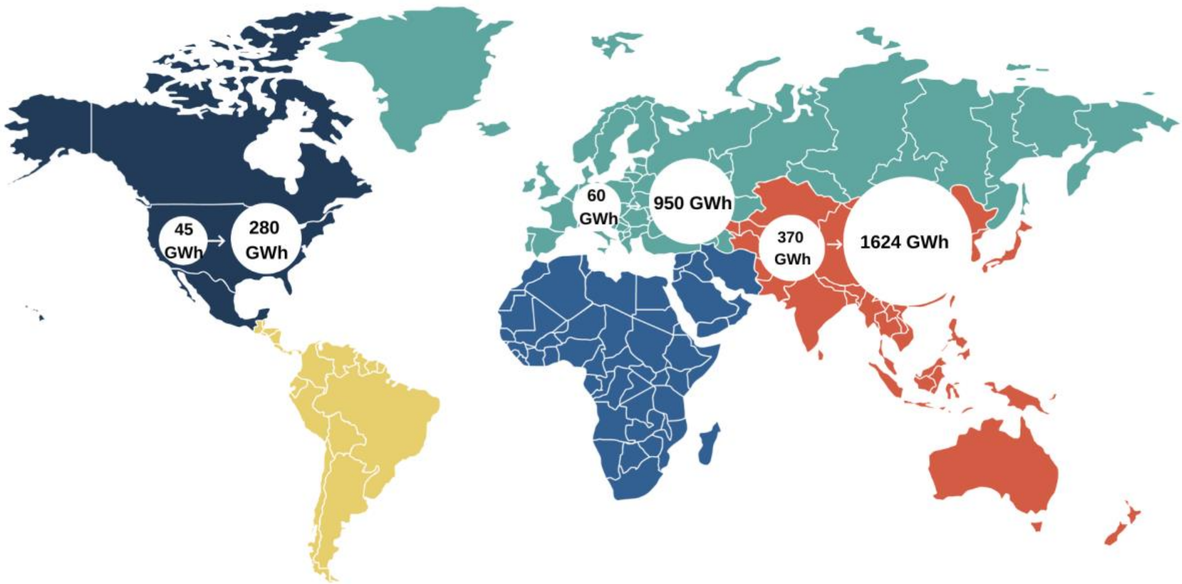
Of course, there is no guarantee that all of the plants announced will come to reality or reach the high-capacity levels promised. Some companies are startups that will need to finance hugely capital-intensive projects. In other cases, suppliers from China and other countries might struggle to break into new markets in Europe or the US. However, we do expect demand for battery capacity to grow, and those suppliers who are able to produce and supply battery cells are likely to have ready customers.

Table 6.2 Lithium Battery Plants and Production Capacity Forecast by Region 2020 vs 2030

Region	Current plants	Future plants being built*	Total current + future plants*	2020 capacity (GWh, % share)	2030 capacity (GWh, % share)
Asia Pacific	**101**	**57**	**158**	**370 GWh (77%)**	**1,624 GWh (57%)**
Europe	**14**	**33**	**47**	**60 GWh (13%)**	**950 GWh (33%)**
N. America	**9**	**12**	**21**	**45 GWh (10%)**	**280 GWh (10%)**
Global	**124**	**102**	**226**	**475 GWh**	**2,854 GWh**

*Factories under construction or announced

Figure 6.2 Lithium Battery Production Capacity by Region 2020 vs. 2030



7. Top 20 Battery Cell Company Analysis

The full database of cell plants can be downloaded from our websites here:
https://www.automotivelogistics.media/focus/electric-vehicles
https://www.automotivemanufacturingsolutions.com/technology/emobility

7.1 LG Energy Solution Overview

At the end of 2020, LG Chem spun off its battery business as LG Energy Solution, an independently run but still 100% owned subsidiary of the South Korean company. LG Energy Solution produces lithium-ion batteries for automotive and consumer electronics, and part of the wider LG Group conglomerate.

LG Energy Solution is currently the largest automotive battery supplier by production capacity volume in 2020. It was one of the first suppliers to get involved in automotive batteries with the contract to supply General Motor's Chevrolet Volt at the beginning of the EV revolution in 2008. LG Energy Solution now supplies multiple OEMs including Volkswagen, Audi, Renault, Nissan, GM, Ford, Hyundai-Kia, Geely/Volvo and Tesla.

The company has strong expansion plans under way. It is expanding its Nanjing plant and a second plant alongside this by 2023. Its Wroclaw, Poland plant is also rapidly expanding form its current 45 GWh to 70 GWh by 2022.

LG Energy Solution has stated that it needs to expand to at least 170 GWh to meet growth targets. It has recently announced that its Ultium joint venture with GM, which is currently building a 30 GWh plant in Lordstown, Ohio, will build a second US factory in Spring Hill, Tennessee to open by late 2023.

Table 7.1.1 LG Energy Solution Battery Cell Plants

Plant location	Start Date	Capacity	Details
Wroclaw, Poland	H1 2018	45 GWh 2020 65-70 GWh later	Rapid growth up to 65-70 GWh potentially subject to investigation into the planned €95m of polish state aid to LG Energy Solution to expand the plant
1st plant, Nanjing, China	2016	20 GWh 2020 35 GWh 2023 60 GWh 2028	Cells only, not battery packs
Holland, Michigan, US		3 GWh 12 GWh 2023 24 GWh 2028	Mainly supplies Chevrolet and Stellantis
Ochang, Seoul, South Korea	2010	12 GWh	
Hai Phong , Vietnam	2020	-	JV with VinFast
China	2021	10 GWh	50:50 JV with Geely Automobile Holdings
2nd plant, Nanjing, China	By 2023	28 GWh 2023 35 GWh 2028	2nd plant next to the 1st Nanjing plant
Ultium (GM + LG Chem) Lordstown, Ohio, US	2022	30 GWh	$2.3bn Ultium JV with GM to build a battery cell assembly plant
Ultium (GM-LG Chem) 2nd plant, Spring Hill, Tennessee, US	2023	30-40 GWh (capacity unconfirmed)	$2.3bn Ultium JV with GM to build a battery cell assembly plant. Capacity expected to be similar to Lordstown
North Maluku, Indonesia	2024	-	$12bn agreement with CATL
Total in 2020		80 GWh	

Source for all tables and figures in this section unless noted otherwise: Automotive from Ultima Media

LG Energy Solution currently appears to be the Volkswagen Group's primary battery supplier; however, the carmaker has also diversified its supply base so as not to rely upon any one supplier. It now has supply contracts with Samsung SDI, SKI in North America and CATL for China.

LG Energy Solution and GM have formed a joint venture called Ultium Cells, which uses a low cobalt chemistry that the companies claim will help them achieve the holy grail of $100 per KWh. LG Energy Solution and GM are investing more than $2.3 billion to build a state-of-the-art 30 GWh battery cell manufacturing plant in Lordstown, Ohio. A second plant has been announced and is set to begin construction in Spring Hill, Tennessee, and is expected to have a similar scope and capacity as the plant in Lordstown. In fact, LG Energy Solution's CEO has commented that together the two plants will have have capacity of 70 GWh.

As the largest lithium-ion battery supplier, LG Energy Solution has also taken steps to ensure security of supply for the raw materials it needs in the form of lithium, cobalt, nickel and manganese.

Table 7.1.2 LG Energy Solution Battery Cell Supply Agreements

OEMs
Audi, Ford, Geely, GM, Hyundai-Kia, Jaguar, Renault-Nissan, Stellantis, Tesla, Volkswagen Group, Volvo

Table 7.1.3 LG Energy Solution Battery Material Suppliers

Component	Company
Cathodes	L&F, Umicore, LG Chem, Reshine New Material, Beijing Easpring, Hunan Shansha, Ningbo Jinhe, Bamo-tech
Anodes	Shenzhen BTR, Hitachi Chemical, Mitsubishi Chemical, Shanghai Shanshan, Kimwan Carbon
Separators	Toray, Asahi Kasei, SKI, Celgard, Zhongke Science & Tech, Newmi Tech, Shanghai Energy New Materials, Shenzhen Senior tech
Electrolyte	Guotai Huarong. Panex Etec, LG Chemicals

Table 7.1.4 LG Energy Solution Raw Material Supply Agreements

Raw Material	Details
Cobalt	LG Energy Solution is an investor in Cobalt Blue's Thackaringa primary cobalt project in Australia. These strategic moves and publicly revealed and clear intentions to secure future supply for LG Energy Solution's planned expansion in EV battery production
Cobalt	in April 2018, LG Energy Solution signed a JV with Zhejiang Huayou Cobalt to establish precursor and cathode material facilities with capacity of 40,000tpy, potentially expanding to 100,000tpy. There are 2 facilities, in Zhejiang Province and Jiangsu Province. Huayou is a refiner with cobalt mining & processing assets in the DRC

Lithium	In July 2018, LG Energy Solution signed a 5-year, 7,000tpy lithium hydroxide deal with Nemaska Lithium
Lithium	In August 2018, LG Energy Solution signed a 3-year, 16,000tpy lithium hydroxide supply agreement with Ganfeng Lithium starting in 2019
Nickel	LG Energy Solution has a 10% stake in Korea Zinc's nickel sulphate subsidiary Chemco
-	LG Energy Solution has also invested in Korean anode producer GS E&C

In October 2019, the South Korean government announced an initiative to invest 2.2 trillion won ($1.85 billion) by 2030 to help stimulate development of EVs, hydrogen cars and autonomous vehicles to ensure the country remains a global leader in these advanced technologies.

LG Energy Solution is part of a strategic initiative of the three largest Korean battery manufacturers (LG Energy Solution, Samsung SDI and SK Innovation) to jointly create a 100 billion won fund to procure next-generation battery technologies and support promising companies.

In October 2020, LG Chem announced that it would spin off its battery division. It predicts the business will generate around $26 billion annual revenue by 2024. The move would also raise much needed investment capital for the rapid expansion expected in EV battery cell production.

There have been reports that Tesla is interested in buying a stake in the spinoff. This would fit Tesla's strategy for more vertical integration to secure an its battery supply.

In December 2020, LG announced it had completed development of an all-new Module Pack Integrated Platform (MPI) that allows the assembly of battery packs without using modules but instead using only individual cells. Battery costs can be reduced by 30%, and energy density is increased by 10%. This approach is similar to competitor CATL's cell-to-pack technology and BYD with the blade battery.

7.2 BYD Overview

Based in Shenzhen, China, BYD (Build Your Dreams) is fairly unique in the automotive industry in being an automotive OEM that produces electric cars and buses along with its own battery cells fully in house. BYD produces batteries for vehicles and energy storage applications. Its investors include Warren Buffett.

BYD has a 'vertically integrated' model that Tesla is increasingly moving towards. In 2020, the company grouped a number of subsidiaries under Fudi Industry, including its battery supplier division BYD Lithium Battery Co, as the brand through which it intends to sell battery cells and technology to other OEMs.

BYD has rapidly expanded its annual battery capacity from 16 GWh in 2017 to more than 60 GWh in 2020. It has significant new capacity in the pipeline as well.

Table 7.2.1 BYD Plants

Plant location	Start Date	Capacity	Details
Plant 1 Shenzhen, Guangdong, China	**2018**	**8 GWh in 2020**	
Plant 2 Shenzhen, Guangdong, China		**8 GWh in 2020**	
Plant 1 Xining, Qinghai, China	**2018**	**24 GWh in 2019** **36 GWh in 2028**	
Huizhou, China	**2018**	**2 GWh in 2018**	**Investment of RMB 10 billion ($1.55 billion), to produce lithium-ion cells, modules and complete battery packs**
Bishan, Chongqing, China	**2020**	**20 GWh in 2020** **36 GWh in 2028**	**JV between BYD and Changan Automobile**
Manaus Industrial zone, Amazonas, Brazil	**2020**	**18,000 modules a year**	**Lithium-ion phosphate batteries for electric busses**
Plant 2 Xining, Qinghai, China	**Planned**	**20 GWh**	

Xi-an, Shaanxi province, China	**2023**	**30 GWh**	
Total in 2020		**62 GWh**	

BYD also supplies batteries to other OEMs and has partnered on joint ventures with OEMs including with Toyota and Changan Auto on battery plants. It also has battery supply agreements with Toyota and Changan, Great Wall Motor, Dongfeng Motor, Chery Auto, NIO and Xpeng Motors

BYD is looking beyond China to growth in Europe where it is also considering setting up cell production.

Table 7.2.2 BYD Battery Supply Agreements

OEM
BYD, Changan auto, Toyota, Great Wall Motor, Dongfeng Motor, Chery Auto, NIO and Xpeng Motors.

BYD's establishment of Fudi Industry Co is a particularly interesting development as it differs from the previously exclusive supply agreements between battery suppliers and OEMs. But just as OEMs are diversifying their battery supply base, battery suppliers are also diversifying their client base, as this expansion of capacity also helps achieve the necessary economies of scale required to be competitive in battery production.

7.3 Panasonic Overview

Based in Osaka, Japan, Panasonic produces batteries for electric vehicles and also for its wider consumer electronic group. It is one of the leading automotive battery manufacturers and Japan's number battery manufacturer, perhaps best known in the battery space for its links with Tesla.

The Gigafactory 1 joint venture in Nevada, US which is 25% owned by Panasonic, is a highly successful partnership with Tesla. Panasonic makes the cells which Tesla then uses to make battery packs for its EVs.

Gigafactory 1 is currently the largest single battery facility in the world with a theoretical maximum capacity of 39 GWh, although the plant is currently understood to be operating at around 35 GWh production. Panasonic's wider network of cell plants also supplies Tesla models from Japan. The company is furthermore ramping up production in China, and is diversifying its customer mix to other OEMs, including Toyota.

Table 7.3.1 Panasonic Battery Plants

Plant location	Start Date	Capacity	Details
Gigafactory 1, Nevada, US	2016	35 GWh in 2019 Plans to ramp this up to 39 GWh in 2021	JV with Tesla 25% owned by Panasonic
Kasai City, Himeji, Japan	2020	4 GWh in 2020 8 GWh by 2023 20 GWh by 2028	Prismatic cells
Suminoe, Osaka City, Japan	2010	10 GWh in 2020 20 GWh by 2023	Mainly 18650 cells for Tesla Model S and Model X
Sumoto, Japan	2017	1 GWh currently 5 GWh by 2023	
Suzhou, Jiangsu, China	2012		Consumer electronics lithium batteries
Wuxi. China	2012		
Beijing, China	2012		
Dalian, China. 1st plant	2018	2 GWh in 2020 10 GWh in 2023 22 GWh in 2028	
Dalian, China 2nd pant	2019	2 GWh in 2020 (est.)	
Tokushima, Japan	2022	Batteries for 500,000 vehicles per year	Prime Planet Energy & Solutions Inc.is a JV between Toyota and Panasonic to build hybrid batteries
Norway	-		Panasonic signed an MoU with Equinor and Norsk Hydro on plans for a joint venture production plant
Total in 2020		54 GWh	

Table 7.3.2 Panasonic Battery Supply Agreements

OEM
BMW, Ford, Honda, Tesla, Toyota

Table 7.3.3 Panasonic Battery Material Suppliers

Component	Company
Cathodes	Nichia, Sumitomo Metal Mining, Umicore, Xiamen Tungsten
Anodes	Hitachi Chemical, Shenzhen BTR, Toya Tanso
Separators	Asahi Kasei, CapChem, Ube
Electrolyte	Mitsubishi Chemicals, Ube, CapChem, Guotai Huarong

7.3.1 Panasonic-Tesla JV

The joint venture with Panasonic is widely regarded as one of the most successful partnerships in the EV supply chain, although it is understood to have not yet achieved profitability. Some fault lines have also started to appear between Tesla and Panasonic. Tesla CEO Elon Musk has blamed Panasonic cell production at the Nevada Gigafactory for holding back production of its most affordable model, the Tesla Model 3, which is crucial for Tesla's volume growth and profitability.

The carmaker has already been diversifying its supply chain to manufacturers beyond Panasonic. For the Shanghai Gigafactory 3, which produce the Model 3 and the newly planned Model Y, Tesla has contracted with LG Energy Solution and CATL cells at least for the first three years. However, the plan is to produce its own battery cells on site – another sign that Tesla could split even further from Panasonic.

7.3.2 Panasonic-Toyota Partnership

To avoid overreliance on Tesla, Panasonic has been establishing new OEM relationships. It is now working with BMW and Honda and has established a joint venture with Dalian Levear Electric Co. to manufacture lithium-ion automotive batteries in China.

Most significantly, it formed a joint venture with Toyota in January 2020 called Prime Planet Energy & Solutions (Toyota 51%, Panasonic 49%) to develop and produce lithium-ion and next generation batteries such as solid-state batteries.

The partnership helps both parties move ahead in the EV race. Panasonic is too reliant upon Tesla and lagged its rivals LG Energy Solution, BYD and CATL. Toyota, although advanced in hybrids (which use NiMh batteries), and well ahead in fuel cell vehicles, has been behind the curve in terms of EVs and lithium-ion batteries.

Such close alliances on batteries between OEMs and battery suppliers are becoming increasingly the norm, especially at very large scale, as it also reduces the investment risk for the large capital expenditure required. It's also important to understand that batteries produced by the JV will be sold to other OEMs.

Panasonic and Toyota already have a joint venture called Primearth EV Energy to produce smaller capacity NiMH batteries for Toyota's range of hybrid vehicles. Primearth EVs NiMH production in Japan operates at a capacity of 1.3m units annually: 500,000 units in Ohmori, 300,000 in Sakakuji, and 500,000 in Taiwa, northern Japan.

7.4 Contemporary Amperex Technology Co. Limited, (CATL) Overview

Based in Ningde, Fujian Province, China, CATL is a major player that started by supplying Chinese and other Asian OEMs with batteries and increasingly working with international OEMs. CATL was formed in 2011 as a spinoff of the Hong Kong based Amperex Technology and is a relatively young player compared to other more established Asian players such as LG, and Samsung. CATL is now also 1% owned by Honda.

China's CATL is already one of the world's largest lithium-ion battery manufacturers and China's largest battery manufacturer.

CATL issued an IPO and currently has a market capitalization of RMB 256 billion ($36.1 billion). The IPO generated significant capital which CATL then used to expand cell production, with a new plant under construction in Germany and plans expected in the US as well.

CATL's main business is domestic demand in China, but its rapid growth and potential new deals with Tesla and others could change that.

Table 7.4.1 CATL Battery Plant Locations

Plant Location	Start Date	Capacity	Details
Ningde, Fujian Province, China		30 GWh in 2020 50 GWh in 2023 100 GWh in 2028	Primary cell production base
Changzhou, Liyang, Jiangsu, China	2018	18 GWh initially 36 GWh later	2 joint venture companies with SAIC for cell and pack production
Xiapu County, Ningde, Fujian Province, China	2020	-	CATL-FAW joint venture
Wuhan, China	2020	9.6 GWh	50/50 joint venture between Dongfeng Motor
Xining, Qinghai, China		15 GWh	
Zhaoqing, Guangdong, China		25 GWh	
Guangzhou, Guangdong, China	2021	10 GWh	JV with GAC for cell and pack production of 400,000 units a year
Jingzhou, China	2021	10 GWh	CATL JV with Zhejiang Geely Holding Group (49% Geely, 51% CATL)
Erfurt, Thuringia, Germany	2022	14 GWh initially, 60 GWh by 2026 100 GWh later	BMW played a major part in helping in establishing CATL in Germany as BMW was the first customer
Yibin, Sichuan, China, 2nd plant		15 GWh initially 30 GWh by 2024	JV with Tianyuan Group with a CATL 15% stake. Capacity of 40,000 tonnes of battery materials (not lithium cells)
Indonesia	2024	-	$12bn agreement by LG/CATL
Total in 2020		72 GWh	

Table 7.4.2 CATL Battery Supply Agreements

OEMs
BAIC Motor, BMW, Daimler, Dongfeng, Foton Motor, GAC Group, Geely, Honda, Hyundai, Nissan, Nanjing Golden Dragon, Renault-Nissan-Mitsubishi, SAIC Motor, Stellantis, Toyota, Volvo, VW, Xiamen King Long , Yutong Bus, Zhongtong Bus, Trailer Dynamics

The company's ambition was for global lithium-ion production capacity of 50 GWh by 2020, a target that we estimate that it has reached. CATL have also stated that it is aiming for 120-137 GWh of total production capacity by 2022.

Whilst OEMs have increasingly turned to CATL batteries because they are among the cheapest, some customers suggest that they have a lower energy density and quality compared to Panasonic, SKI or LG Energy Solution batteries. Battery density has been one of the major concerns for electric vehicle manufacturers for markets in Europe and North America, where longer driving ranges are considered critical for success.

One of the major challenges for CATL will be to match the quality of South Korean and Japanese competitors. As its quality increases, however, CATL will be tough to compete with given its growth, scale and low cost.

In China, the company has grown rapidly both in supply and production capacity, including forming joint ventures with SAIC, GAC Group and Dongfeng. One factor that could temper its recent growth is the ending of a subsidy linked to using Chinese domestic battery suppliers, which had been in place since 2015, and primarily benefitted CATL and BYD. The policy helped stimulate Chinese domestic battery companies in a fledging EV market. For example, for its electric Kona model to qualify for subsidies in China, Hyundai switched battery suppliers from its usual supplier, LG Chem, to CATL.

Tesla, which has a production plant in Shanghai, had been using both Panasonic and LG Chem, which has ramped up battery production in China. To qualify for subsidies, Tesla had also agreed supply in China with CATL. However, with the subsidies now removed, and Tesla scrambling to obtain as much battery cell capacity as it can, the carmaker looks likely to continue to maintain a diversified supply and eventually more of its own in-house production.

7.4.1 CATL Global Expansion

CATL is pushing its expansion further overseas. One of its most important global customers has been BMW, whose supply agreement with the company has helped to encourage it to invest in its upcoming plant in Erfurt, Germany. In November 2019, BMW announced it would procure €7.3 billion worth of batteries from CATL over the period 2020-2031, increasing a previous agreement in 2018 by more than €3 billion.

CATL is likely to soon become the main supplier for Nissan EVs such as the Sylphy and EV Kangoo and Renault is likely to also do the same. Renault and Nissan have previously been supplied by a mixture of LG Energy Solution and AESC.

In January 2017, CATL also announced a strategic partnership (and 22% acquisition of) Finland's Valmet Automotive, collaborating on project management, engineering and battery pack supply for hybrids and EVs.

CATL has also had to cooperate with global OEMs to ensure it meets standards not only in technology but also in business practices. Daimler has said it uses CATL as a supplier after the company cooperated with the carmaker's monitoring system to ensure ethical business practices, for example not using child labour.

In August 2020, CATL stated that it had available $2.75 billion in funds for overseas acquisition, which it would target both upstream and downstream. For example, CATL has already purchased an 8.5% stake in Australian mining company Pilbara Minerals.

In 2021, CATL acquired an 8% stake in Neo Lithium, a Canadian mining company for $8.5 million The Canadian company holds mineral and surface rights to a newly discovered lithium salar and brine reservoir complex in Argentina.

7.4.2 CATL Battery Technology

CATL has until recently focused mainly on prismatic cells LiFePo (lithium iron phosphate) for low-cost applications in EVs. This is in part because they can be kept cool with just a heatsink, which means that additional cooling systems are not required. But CATL has also been transitioning rapidly to the more conventional lithium-ion battery cells that most EV manufacturers favour.

CATL have also announced that is it developing batteries with no cobalt or nickel, which Tesla has also said that it plans to do.

CATL also supplies NMC (lithium nickel manganese cobalt oxide) batteries mainly for electric buses and trucks and energy storage applications.

CATL has developed 'cell to pack' (CTP) technology that simplifies the pack integration process by eliminating the modules and packing cells tighter, which could achieve a higher energy density than other batteries. In July 2020, CATL announced it had signed a supply agreement for 300KWh lithium-ion phosphate CTP batteries for Trailer Dynamics and its first electric semi-trailer model, the Newton eTrailer.

CATL has also pushed towards carbon neutral battery cell production using a combination of hydropower, solar and wind to power its production facilities.

7.5 SK Innovation (SKI) Overview

Based in Seoul, South Korea, SK innovation (SKI) is part of the SK Group, the country's third largest conglomerate. SKI produces lithium-ion batteries for automotive, energy storage and consumer electronics and one of the three South Korean battery giants along with LG Energy Solution and Samsung SDI. A relatively new player in battery manufacture, SKI has rapidly been expanding its global production and customer base.

The company has planned to increase its global battery cell capacity from 40 GWh in 2020 to 60 GWh in 2022, 125 GWh in 2025 and 200 GWh by 2030. It is investing billions to expand battery plants in China, Hungary and the US. In January 2021, for example, it announced that it would build a third plant in Hungary, in Iváncsa, 50km southwest of Budapest, which will eventually have capacity for 30 GWh. It has an existing plant and a second under construction in Komárom, close to Hungary's border with Slovakia.

Major OEMs have signed agreements with SKI, including Daimler, which will procure €20 billion worth of battery cells from SKI by 2030. SKI also became a strategic supplier for Volkswagen Group in 2018 and is reportedly in talks with the OEM about a possible joint venture. It has already set up JVs with carmakers in China, including with Beijing Automotive Industry Corporation (BAIC) and another Chinese partner. It is a strategic investor in Chinese energy firm EVE Energy.

SKI Innovation has agreed with Hyundai to establish a sustainable ecosystem for electric vehicle batteries. This would include sales under battery as a service (BaaS), battery management solutions, re-use and recycling. It is also part of a strategic initiative together with LG Energy Solution and Samsung SDI to jointly create a 100 billion KRW ($90m) fund to procure next-generation battery technologies and support promising companies.

In May 2021, SKI announced a memorandum of understanding for a joint venture with Ford called BlueOvakSK to develop battery production in the US achieving up to 60 GWh starting in the mid-2020s. Ford stated that its global electrification plan requires at least 240 GWh of battery cell capacity by 2030, or equivalent to around 10 average size gigafactories (and the same level of new capacity that VW Group has also recently announced that it would build in Europe). Of this total, around 140 GWh is likely to be required in North America, with the remainder for other key EV regions such as Europe and China. Not all of this production capacity will come from SKI, and Ford is likely to continue pursue a strategy of diversification with other suppliers as are other major OEMs. For example, Ford also has battery supply agreements with LG Chem and Panasonic outside of North America.

Table 7.5.1 SK Innovation Plants

Plant location	Date	Capacity	Details
Changzhou, Jiangsu Province, China	**2020**	**7.5 GWh 10 GWh 2028**	**JV with BAIC**
Yancheng, China	**2021**	**20 GWh**	**JV with EVE Energy**
Jeungpyeong, Chungcheongbuk-do, South Korea		**3 GWh 10 GWh in 2023**	
Seosan, South Korea		**3.9 GWh Expanding to 4.7 GWh by 2022**	
Komarom, Hungary Plant 1	**2020**	**7.5 GWh, 23.5 GWh by 2023**	**JV with EVE Energy**
Komarom, Hungary Plant 2	**2022**	**9.8 GWh (option up to 16 GWh)**	
Ivancska, Hungary Plant 3	**2024**	**Eventually 30 GWh**	
Commerce, Georgia, US	**2022**	**9.8 GWh, 20 GWh in 2023**	
2nd US Plant, Georgia, US	**2023**	**11.7 GWh**	
US	**From 2025**	**-**	**JV with Ford**
China	**-**	**20 GWh to 25 GWh**	**JV with EVE Energy**
Total in 2020		**42 GWh**	
Component plants producing LiBS and CCS			
Jeungpyeong, Chungcheongbuk-do, South Korea		**360m m2 of LiBS**	
Changzhou, China	**2020**	**500m m2 of LiBS JV with BAIC Motor and Beijing Electronics**	
Województwo Śląskie, Poland	**2021**	**340m m2 of LiBS 130m m2 of CCS**	

Table 7.5.2 SK Innovation Battery Supply Agreements

OEM	Details
Volkswagen, Daimler, Hyundai, Kia Motors, Ford, BAIC, Jaguar Land Rover and Ferrari	

7.5.1 SKI US Ban

SKI's North American expansion plans came close to being derailed following a ruling in February 2021 by the US International Trade Commission before a settlement was reached. LG Energy Solution had previously filed an intellectual property theft case against SKI in the US. The ITC upheld LG's claim that ex-LG employees had used knowledge they gained at LG in their new roles at SK Innovation. and the ITC therefore imposed a 10-year ban on SKI for the importation, domestic production and sale of electric vehicle batteries within the US.

The ITC did, however, grant a four-year reprieve to satisfy existing supply agreement with Ford for the electric F-150, and two years to supply Volkswagen, which it will supply in Chattanooga, Tennessee.

However, the case transcends a simple dispute between the two companies and involves the future of North American EV production with huge implications for domestic auto jobs. The banning of SKI was viewed politically as highly damaging to other potential investors of battery cell plants and a huge set back to the overarching goal of developing a domestic battery supply chain in the US – a goal in which it is widely perceived to be behind the curve. The US's environmental targets depend upon transitioning to EVs, and it simply does not have the required battery capacity to supply the EV plans of OEMs. Such was the strategic importance of this situation that the president, Joe Biden, signed an executive order to investigate the securing of critical resources vital for national security, including EV batteries, rare metals and semiconductors.

Consequently, strong political pressure was applied to reach an out-of-court settlement that would allow SK Innovation to continue to build and operate its two plants in Georgia, US. and to help towards America's development of a domestic EV battery supply chain. The agreement arrived in April 2021 and was for SK Innovation to pay LG Energy Solution $1.8 billion in damages. SK Innovation will also pay a 'running royalty' to LG Energy Solution.

7.6 Samsung SDI Overview

Based in South Korea, Samsung SDI is a subsidiary of the larger group Samsung Electronics. It produces lithium-ion batteries for automotive and energy storage systems. As well in South Korea, where it supplies Hyundai, it has played a key role as a supplier for OEMs in Europe, including the Volkswagen Group, BWM, Jaguar Land Rover and Volvo Trucks.

In 2015, Samsung SDI acquired Magna Steyr's battery pack division, which it renamed SDI Battery Systems. Samsung SDI is involved in both cell and the pack production. It has since expanded its production based in Europe, including a plant in Hungary and a second under construction (although there is controversy over whether the Hungarian government violated EU state aid rules with its plan to provide €108m). In February 2021, Samsung SDI raised $900m to fund the expansion of the two plants in Goed, Hungary.

The company has signed significant agreements in Europe, including a €2.9 billion supply contract with BMW, and a cumulative 13 GWh of cells and modules to German battery systems provider Akasol (a company BorgWarner is set to acquire) over the period 2020 to 2027.

Samsung SDI is also investing $1.15 billion to expand its battery production facilities in China.

Table 7.6.1 Samsung SDI Plants

Plant Location	Date	Capacity	Details
Plant 1, Goed, Hungary	2020	2.5 GWh in 2020 12 GWh by 2023 20 GWh by 2028	
Ulsan, South Korea	2020	3 GWh in 2020 23 GWh by 2023	
Xian, Shaanxi Province, China	2020	2 GWh in 2020 25 GWh by 2023 32 GWh by 2028	
Cheonan, South Korea			
Cheongu, South Korea			
Gumi, South Korea			
Tianjin, China			
Wuxi, Jiangsu Province, China			
Bacninh Province Yenphong District, Vietnam			
Seremban, Malaysia			
Noida, India			Production & sales

Premstatten, Graz, Austria	**2015**		**Samsung SDI Battery Systems (SDIBS) former plant of Magna Steyr battery systems**
Auburn Hills, Mi, US			**Production & sales**
Plant 2, Goed, Hungary	**2021**	**7.5 GWh**	
Total in 2020		**25 GWh**	

Table 7.6.2 Samsung SDI Battery Supply Agreements

OEM	Details
Akasol, BMW, Fiat, Hyundai-Kia , JAC, Porsche, Volkswagen, Volvo Group	

Table 7.6.3 Samsung SDI Battery Material Suppliers

Component	Company
Cathodes	Samsung SDI, L&F, Ecopro, Umicore, Reshine New Material, Beijing Easpring, Ningbo Jinhe
Anodes	Shenzhen BTR, Hitachi-Chem, Mitsubishi Chemicals, Shanghai Shanshan
Separators	Toray, Asahi Kasei, SKI, Shanghai Energy New Materials
Electrolyte	Panax-Etec, CapChem, Guotai Huarong, Tianjin Jinniu

7.7 Guoxuan High-Tech Power Energy Overview

Guoxuan High-Tech (often referred to as the brand name GXGK) is based in Hefei City, Anhui Province Hefei, China and is a battery supplier to a number of Chinese OEMs including BAIC Motor and JAC, as well as to global OEMs including General Motors and VW, the latter of which now owns a share of the battery maker.

Table 7.7 Guoxuan High-Tech Power Energy Plants

Plant location	Date	Capacity	Details
Qingdao, China	**2018**	**8 GWh in 2020** **15 GWh in 2023** **20 GWh in 2028**	**LFP batteries exclusively for BAIC**
Hefei, Anhui, China		**13.5 GWh**	
Kunshan, China			
Nanjing, China			
Wuhan, China			
Total in 2020		**23 GWh**	

With current production capacity of 23 GWh, Guoxuan is the most prominent Chinese battery supplier behind CATL and BYD, with plans to increase battery manufacturing capacity to 100 GWh by 2025.

In May 2020, Volkswagen acquire 26.5% of the company for €1.1 billion. The investment represented VW's first partial ownership of a Chinese battery manufacturer, as the carmaker seeks both to increase battery cell capacity and supply in its largest market, as well as to gain more control over its own supply chain. Guoxuan not only produces lithium-ion batteries but is vertically integrated as an important supplier of cathode materials for batteries, as well as in producing separators, battery packs and battery management systems.

7.8 Dynavolt Overview

Based in Guangdong, China, Dynavolt produce lithium-ion batteries and currently ranks seventh in our global list of battery cell suppliers. However, a large proportion of its production output is for energy storage applications rather than automotive, including recent agreements with companies including Wynnertech and Durion. However, Dynavolt has the production capacity to become a major player in automotive.

Table 7.8 Dynavolt Plants

Plant location	Date	Capacity	Details
Fujian, China	2017	6 GWh rising to 10 GWh	
Hubei, China	2017	6 GWh rising to 15 GWh	
Total in 2020		12 GWh	

7.9 Farasis Energy / Funeng Technology Overview

Funeng Technology is wholly owned by Farasis Energy, a start-up battery manufacturer in which Daimler has invested. Based in Chancheng District Foshan, China, Funeng is a battery provider to Beijing-based BAIC Motor, Jiangling, Changan, Great Wall, Ruili and Changhe. It has also passed quality audits to become an approved supplier to Daimler. In March 2019, Funeng passed the German Daimler group's VDA6.3 process quality audit system and became an approved supplier to Daimler.

Table 7.9 Farasis Energy & Funeng Technology Plants

Plant location	Date	Capacity	Details
Farasis Energy Plants			
Bitterfeld-Wolfen in Saxony-Anhal Germany	2022	6 GWH rising to 10 GWh	Farasis agreed with Daimler to supply 140 GWh of batteries over 2021-27.

Zhenjiang, Jiangxi province, China	2021	20 GWh up to 120 GWh	Joint venture with Geely Holdings
Funeng Technology Plants			
Ganzhou, Jiangxi province, China	2016	10 GWh in 2020 25 GWh by 2023 35 GWh by 2028	
Shunyi, Bejing. China		8 GWh	BAIC Joint venture
Total in 2020		10 GWh	

7.10 BAK Battery Overview

Based in Shenzhen, China, BAK Battery is active in the development, production, sales and recycling of lithium-ion power batteries and cells, as well as consumer digital batteries. Its products cover batteries, modules and packages, and are used in passenger cars, buses, logistics vehicles and special vehicles. It has existing major lithium-ion plants in Shenzhen and is expanding in Zhengzhou and Chengdu.

Table 7.10 BAK Battery Plants

Plant location	Date	Capacity	Details
Shenzhen, China		8 GWh	
Zhengzhou, China	2023	15 GWh	
Chengdu, China	2028	20 GWh	
Total in 2020		8 GWh	

7.11 Lishen Overview

Lishen is a Tianjin, China-based manufacturer of batteries and battery applications, including in energy storage, communications and in automotive. It has a lithium-ion battery cell plant in Tianjin, which it is planning to expand. The company provides cell modules, battery packs and BMS.

Table 7.11 Lishen Battery Cell Plants

Plant location	Date	Capacity	Details
Tianjin, China		8 GWh in 2020 20 GWh by 2023 42 GWh in 2028	
Wuhan, China	Planned		
Qingdao, China	Planned		
Total in 2020		8 GWh	

7.12 Envision AESC

Envision AESC is based in Shanghai, China with close links with Nissan.

AESC was originally formed in 2008 as a JV between NEC Corporation, NEC Tokin and Nissan to supply Nissan with batteries for hybrid and electric vehicles. As of 2014, AESC was the second largest global battery supplier in 2014.

However, this exclusive and binding battery supply arrangement was called into question as prices of alternative battery suppliers became more competitive than AESC and Nissan preferred to have more flexibility in securing capacity. In 2019, Nissan and its partners sold the majority of its battery production unit to Chinese renewable group Envision Energy Group, although the carmaker retains a 25% stake.

This is significant because Nissan clearly wanted to exit the battery production business, but still have AESC as a supplier at arm's length. After acquiring AESC, Envision will build a new plant In China and quadruple its production capacity from 27.5 GWh. The company has also said that it expects to reduce the costs of manufacturing lithium-ion battery cells for EVs to around $50 per KWh by 2025.

Table 7.12.1 Envision AESC Plants

Plant location	Date	Capacity	Details
Sunderland, UK	**2010**	**2.5 GWh**	
Smyrna, Tennessee, US	**2012**	**2 GWh, 3GWh 2023, 8 GWh 2028**	
Zama, Kanagawa, Japan	**2009**	**3 GWh**	
Wuxi, Jiangsu, China	**2021**	**8 GWh by 2023, 20 GWh by 2028**	
Total in 2020		**7.5 GWh**	

Table 7.12.2 Envision AESC Battery Supply Agreements

OEM
Nissan, Alfabus, JLR

Table 7.12.3 Envision AESC Battery Material Suppliers

Component	Company
Cathodes	Mitsui Kinzoku, Nippon Denko, Nichia
Anodes	Hitachi-Chem, Kureha
Separators	Asahi Kasei, Celgard, Ube
Electrolyte	Mitsubishi Chemicals

7.13 EVE Energy Overview

Based in Huizhou City, Guangdong, China, EVE Energy sells batteries to OEMs including Geely and Kia Motors, for which it has agreed to supply 13.48 GWh of batteries. The company is developing close ties to South Korea's SKI Innovation. Late in 2020, SKI took a 49% stake in EVE Energy Asia, a subsidiary of EVE Energy, and the plan to co-manage EVE's EV battery plant in Huizhou, China. Another joint venture with SKI will see a second plant open in Yancheng. The two companies are set to announce build additional factories in China.

Table 7.13 EVE Energy Plants

Plant location	Date	Capacity	Details
Huizhou, China		7.5 GWh in 2020 15 GWh in 2028	
Jingmen, Hubei, China	2021	11 GWh (6 GWh energy storage and 5 GWh power batteries)	
China	2022	20 GWh to 60 GWh	JV between EVE Energy and SK Innovation
Huizhou, Guangdong, China			JV between EVE Energy and StoreDot
Total in 2020		7.5 GWh	

7.14 DLG Overview

Based in the Fengxian District of Shanghai, DLG Electronic Technology is a lithium-ion battery solution provider covering multiple sectors, notably consumer products, energy storage as well e-motorbikes and e-bikes, and potential for electric vehicles, too. The company has several plants in China, including two for lithium-ion cells in Shandong.

Table 7.14 DLG Plants

Plant location	Date	Capacity	Details
DLG	DETSD, Shandong, China	2 GWh	
DLG	DSD, Shandong China	5 GWh	
Total in 2020		7 GWh	

7.15 Do Fluoride Chemicals (DFD) Overview

Do Fluoride Chemicals is a chemicals company that has developed its lithium-ion battery business. Up to now, its primary application has been for energy storage, however the company has stated its ambition to grow further in the electric vehicle battery market.

Table 7.15 DFD Plants

Plant location	Date	Capacity	Details
Do Fluoride Chemicals (DFD) / KORE Power	China	6 GWh	
KORE Power	Texas, Arizona or Florida	12 GWh	
Total in 2020		6 GWh	

7.16 Phylion Battery Overview

Phylion Battery specialises in lithium-ion batteries mainly in electric and hybrids, as well as in e-bikes, scooters and energy storage. Its main customers include Chinese car manufacturers Dongfeng, Chery, Changan and SAIC-GM-Wuling. The company has also announced plans to open lithium-ion battery plants in India, South-east Asia and Europe.

Table 7.16 Phylion Battery Plants

Plant location	Date	Capacity	Details
Suzhou, Jiangsu, China	2016	6 GWh to 25 GWh by 2022	
Chuzhou, Anhui, China	2019-2022	6 GWh to 28 GWh	
Maharashtra, India		Battery components, eventually cells and battery packs	JV with India's Pinnacle Industries
Total in 2020		6 GWh	

7.17 Microvast Overview

Microvast was formed in 2006 to develop EV batteries with short charging cycles. It has primarily targeted the Chinese commercial vehicle market, including trucks and buses, but it has plans to grow further in the passenger vehicle market. Specialist vehicle manufacturer Oshkosh has invested in the company, for example. In February 2021, the company announced that it will merge with investment firm Tuscan Holdings with a view to going public and raising more funds.

The company is expected to start operations at a new plant in Germany this year, where it will assembly packs from battery cells build in China.

Table 7.17 Microvast Plants

Plant location	Date	Capacity	Details
Phase 3 (2019) Huzhou, China	2006-2019	5 GWh	Planning to reach 9 GWh by 2022
Brandenburg, Germany	2021	1.5 GWh up to 6 GWh	Cell production and battery pack assembly
Clarksville, Tennessee, US	2022	2 GWh	
Total in 2020		5 GWh	

7.18 Tianneng Energy Overview

The Tianneng Group, based in Zhejiang, China, produces mainly lead-acid batteries across ten production sites across China. Its subsidiary Tianneng Energy Technology consolidates all of the group's lithium-ion production. It has established a plant for lithium-ion batteries, with plans to further increase production in Zheijiang. It has also formed a joint venture with SAFT, a subsidiary of French energy firm Total that has partnered with PSA (now Stellantis), to produce lithium-ion batteries in Europe, with a plant set to open in Changxing.

Table 7.18 Tianneng Energy Plants

Plant location	Date	Capacity	Details
Zhejiang, China	2020	5 GWh in 2020 10 GWh in 2023 15 GWh in 2028	
Changxing, China	2021	5.5 GWh by 2021	SAFT 40:60 JV with Tianneng Energy Technology (TET)
Total in 2020		5 GWh	

7.19 SVOLT Overview

Based in Wuxi, in China's Jiangsu province, SVOLT Energy technology is a spinoff from Chinese OEM Great Wall, suppling the OEM and others with batteries. SVOLT has ambitious expansion plans, and in February 2021, announced that it was investing in an increased number of global sites and raised its production capacity target from 100 GWh to 200 GWh by 2025, the majority of which is in China.

In November 2020, the company confirmed that it would build two plants in Germany by 2023 in Saarland: a module and pack assembly factory as well as a cell factory with 24 GWh production capacity.

Great Wall has also established a joint venture with BMW to produce Mini models in China, including electric versions, which should provide further opportunity for growth with the premium OEM.

Around half of SVOLT's 3,000 employees are involved in R&D with two sites in China and three research centres. The company is also researching solid state batteries.

SVOLT claims to be among the first companies to bring to mass production to cobalt-free, high nickel lithium-ion batteries, with the first vehicle fitted with the technology in 2021.

In 2020, SVOLT was reported to have signed a supply agreement for 7 GWh worth of batteries with PSA, although this has yet to be confirmed.

Table 7.19 SVOLT Plants

Plant location	Date	Capacity	Details
Changzhou, Jiangsu province, China	November 2019	4 GWh in 2020 12 GWh in 2021, 18 GWh later	JV With Chinese Great Wall
Suining, Sichuan, province, China	2022	20 GWh	
Huzhou, Zhejiang province, China	2022	20 GWh	
Jintan, China		18 GWh	
Hunan province, China		40 GWh	
Hubei province, China		40 GWh	
Uberhelm, Saarland, Germany	End of 2023	6 GWh rising to 24GWh	€2bn investment in a new plant for cell module and pack production
US	-	unknown	
Total in 2020		4 GWh	

7.20 SAFT Overview

France-based SAFT is a division of energy giant Total. The company is well-established as a consumer electronics battery manufacturer and is now expanding to automotive batteries. It has established a significant joint venture with PSA Group (now Stellantis), the Automotive Cell Company (ACC) to build battery gigafactories with capacity for 8 GWh each in France and Germany by 2024, respectively, expanding significantly over the decade. The French and German governments have also given backing to the project.

PSA's merger with FCA to form Stellantis could give the battery maker an opportunity to scale further across the group.

SAFT has also established a joint venture with Chinese battery manufacturer Tianneng, with which it is set to open a new factory in Changxing.

Total's plans for SAFT are also a clear sign that the energy is diversifying its oil and gas business to benefit from an electrified future in automotive.

Table 7.20 SAFT Battery Cell Plants

Plant location	Date	Capacity	Details
Jacksonville, Florida, US	**2011**	**4,800,000 cells / year (approx.. 1 GWh)**	**Batteries for energy, industry, transportation, military & aerospace**
Changxing, China	**-**	**~2GWh currently 5.5 GWh later**	**SAFT 40:60 JV with Tianneng Energy Technology (TET)**
Hauts-de-France, France	**2023**	**8 GWh initially 24 GWh by 2030**	**JV Automotive Cell Company involving SAFT and Stellantis**
Rhineland-Palatinate state, Kaiserslautern, Germany	**2024**	**8 GWh initially 24 GWh by 2030**	**JV Automotive Cell Company involving SAFT and Stellantis**
Total in 2020		**3 GWh**	

8. Other Significant Automotive Battery Cell Companies and Plants

8.1 Evolving OEM Strategies

A notable shift over recent months has been how major OEMs are revising upwards their medium-to-longer term battery demand requirements, and how as a result more are pursuing in-house or joint venture partnerships to meet this demand. Increasingly, OEMs are aiming to develop battery technology and secure supply more directly, notably Tesla but also Volkswagen Group, GM, Stellantis and Ford.

Table 8.1 Major OEM Battery Demand and Future Strategies

OEM	Date	Capacity needed	Details
Ford	2030	240 GWh	Partly achieved with JVs with SKI, but also through supply agreements with LG and Panasonic
GM	-	-	GM is expected to have at least 70 GWh of capacity through its Ultium JV with LG Chem, with which it is developing and building batteries. It is also expected to use the Ultium EV platform on global EV models
Stellantis	2030	250 GWh	Mostly likely to be through Automotive Cells Company (ACC) a JV between Total subsidiary SAFT and Stellantis
Tesla	2030	3,000 GWh	Mostly in-house, but the stated intention is to continue with current partnerships with Panasonic, and supply form LG chem, CATL and EVE Energy) to ensure diversity of supply for the foreseeable future
VW Group	2030	240 GWh (Europe only)	VW currently supplied by LG Chem, CATL and SK Innovation, but this target is likely to be achieved by ramping up in-house and joint venture production

*Note: Tesla's target is significantly more than other OEMs. Most forecasts, including our own, suggest total global battery capacity will be in the 2,000-3,000 GWh range by 2030

8.2 Tesla

As the leading EV OEM, Tesla does not produce its own battery cells, but that is increasingly set to change.

In Tesla's current JV with Panasonic in Nevada, it would appear that Panasonic manufactures the cells, and Tesla then assembles them into modules and packs. Up to now, Tesla has sought to diversify its battery supply base from its initial Panasonic-only supply agreement. Today, the OEM uses cells from Panasonic, LG Chem for North America and

Europe and CATL for China (and are also in advanced talks with EVE Energy as a battery supplier in the Chinese market)

However, during Tesla's September 2020 'Battery Day', the company revealed its aim to develop and manufacture in-house cells from 2021. It already started some pilot production lines in Fremont, California and there are also plans for battery production at its planned factory in Austin, Texas and its new German plant in Grünheide, near Berlin.

Table 8.2 Tesla Plants

Plant location	Date	Capacity	Details
Gigafactory 1, Reno, Nevada, US	2016	35 GWh	JV with Panasonic as the cell supplier to Tesla
Gigafactory 2, Buffalo, New York	2017	2 GWh battery production for solar plant (not automotive)	This plant produces photovoltaic solar cells unrelated to automotive
Gigafactory 3, Shanghai, China	Dec 2019	Target of 15 GWh battery production by 2023	Batteries and cars. Battery packs assembled using cells from various suppliers, including Panasonic, LG Chem and CATL (and possibly also EVE Energy)
Gigafactory 4, Grünheide, Germany	2021	Battery capacity TBA 100-250 GWh	Tesla's new plant will produce the Model Y, Model 3 and batteries. Elon Musk has said this will become the largest battery plant in the world
Fremont, California		Pilot plant initially, but Up to 10 GWH	Currently a vehicle assembly plant, Tesla indicated a pilot battery production line would be built for in-house cell production
Austin, Texas, US		-	Cybertruck, Semi, Roadster, Model Y but also battery cell production to further integrate the supply chain
Total in 2020		35 GWh	JV with Panasonic

8.3 Volkswagen Group

Volkswagen Group does not currently manufacture its own batteries, but recent announcements indicate that this strategy will change to a more vertically integrated supply model.

The group currently relies upon cell supplies from LG Chem, CATL, Samsung SDI and SK Innovation. Initially, Volkswagen had a 50:50 joint venture with Sweden's Northvolt for a new plant in Salzgitter, Germany. However, the carmaker recently announced that it would buy out Northvolt's share of this joint venture.

At the Volkswagen Group's 'Power Day" in March 2021, the OEM also announced a radical plan to have six cell plants in Europe by 2030 with a capacity totalling 240 GWh. Along with the Salzgitter plant already under construction, that would mean five further 40 GWh plants, including locations expects in southern Europe as well in central and eastern Europe.

Table 8.3 Volkswagen Group Plants

Plant location	Date	Capacity	Details
Salzgitter, Germany	2024	40 GWh	VW Zwei (formerly Northvolt VW JV)
Europe	By 2030	40 GWh	
Europe	By 2030	40 GWh	
Europe	By 2030	40 GWh	
Europe	By 2030	40 GWh	
Europe	By 2030	40 GWh	
Total in 2020		0 GWh	

8.4 Northvolt Overview

Northvolt is a rapidly growing Swedish start-up which is ramping up production capacity and has secured important supply agreements with OEMs including Volkswagen Group and BMW.

Northvolt is set to open its first major cell production centre in Skelleftea, Sweden this year, as part of a joint venture with ABB Technology Ventures. The plant will begin with 8 GWh capacity with plans to increase this up to 40 GWh in 2024; it will also carry out R&D and recycling. Northvolt will provide €1.6 billion of the €4 billion needed for the project, while the European Investment Bank is providing a €350m loan. Siemens and truck manufacturer Scania have also invested €10m each into the project.

Northvolt also had an important JV with the Volkswagen Group, with which it planned to build a new battery plant in Salzgitter, Germany with a planned initial capacity of 16 GWh in 2024, with potential to increase to 40 GWh. A pilot line for battery cell production is currently being set up at VW's own Salzgitter plant. Volkswagen has since bought out Northvolt's share of the joint venture.

Northvolt senior executives have also indicated that, if located in areas with cheap electricity from renewable sources, as is the case for its Swedish plant, the company could develop up to seven potential other sites for battery production.

BMW Group has also formed a joint technology consortium with Northvolt and Umicore, a Belgian company developing battery materials, to work on cell technology for electrified vehicles in Europe. The cooperation will have an emphasis on creating a complete, sustainable value chain for battery cells, from R&D, raw materials and production through to recycling.

Table 8.4 Northvolt Plants

Plant location	Date	Capacity	Details
Northvolt Ett, Skelleftea, Sweden	**2021**	**8 GWh initially in 2021 24 GWh in 2023, up to 40 GWh in 2024**	**JV with ABB Technology Ventures. Also funded by a €350m loan from the European Investment Bank The plant will also recycle batteries**
Northvolt Zwei, Salzgitter, Germany	**2024**	**16 GWh increasing to 40 GWh at an unspecified date**	**Formerly JV with Volkswagen, which the OEM has taken over**
Total in 2020		**0 GWh**	

Source for all tables and figures in this section unless noted otherwise: Automotive from Ultima Media

8.5 GS Yuasa Overview

GS Yuasa Corporation, based in Kyoto, Japan, was established in 2004 by the merger of Japan Storage Battery and Yuasa Battery. The company develops and manufactures batteries and power supply systems for a wide range of special applications. It produced lithium-ion cells in Japan, though primarily for marine and aerospace applications so far; in the automotive market, it is currently more involved in lead acid and hybrid batteries.

Table 8.5 GS Yuasa Plants

Plant location	Date	Capacity	Details
Inobanba-cho, Nishinosho, Kisshoin, Minami-ku, Kyoto, Japan	**2007**		**Lithium Energy Japan (GS Yuasa / Mitsubishi JV) Mainly batteries for hybrids**

Osadano-cho, Fukuchiyama City, Kyoto Japan	2009	20m cells / year	Blue Energy Co. (GS Yuasa / Honda JV) Mainly for hybrids
Osadano-cho, Fukuchiyama City, Kyoto, Japan, 2nd plant	2023	30m cells / year	Blue Energy Co. (GS Yuasa / Honda JV) Mainly for hybrids
Total in 2020	-		

8.6 Primearth EV (PEVE) Overview

Based in Japan, Primearth EV was formed in 1996 as a joint venture between Toyota (80.5%) and Panasonic (19.5%). The company supplies nickel hydride batteries, lithium-ion batteries and BMS (battery management systems) to OEMs. In 2019, Primearth EV Energy announced it would move beyond NiMH batteries and would develop high-capacity lithium-ion batteries at its Japanese plants.

Table 8.6 Primearth EV Plants

Plant location	Date	Capacity	Details
Shizuoka Prefecture, south of Tokyo, Japan		200,000 Li-Ion batteries	
Omori, Kosai, Japan			NiMH batteries Li-Ion batteries
Miyagi, Taiwa, Japan	2019 2020	200,000 Li-Ion batteries 200,000 Li-Ion batteries	3 factories for NiMH batteries 2 factories for Li- Ion batteries
Sinogy China			Sinogy Toyota Automotive Energy System (STAES)
Jiangsu, China	2021	100,000 batteries a year	NiMH batteries
Total in 2020		~2.5 GWh	1.4 NiMH, 200,000 Li-Ion

Table 8.7 Other Significant Automotive Battery Cell Companies and Plants

Company	Plant location	Date	Capacity	Details
Akasol	Langen, Germany	2018	300 MWh up to 800 MWh	BorgWarner to acquire Akasol
AMTE Power	Thurso, Scotland		1 GWh-5 GWh	
AVIC Lithium Battery Co.	China			
Bollore	Ergue-Gaberic, France	2009	500 MWh	
CBAK Energy	Dallan, China		2 GWh	
China Aviation Lithium Batt ery Co., Ltd) (CALB)	Luoyang, China		1 GWh in 2020 2 GWh in 2023 10 GWh in 2028	Supply to King Long, Zhongtong Bus, Dongfeng Motor
China Aviation Lithium Batt ery Co., Ltd) (CALB)	Jiangsu, China			
Cenat New Energy / Evergrande	Shanghai, China			
Cenat New Energy / Evergrande	Jiangxi, China			
Cenat New Energy / Evergrande	Jiangsu, China			
Cenat New Energy / Evergrande	Guangxi, China			
CITIC Guoan Group	Beijing China			CITIC Monguli Power Technology Co. Ltd
Coslight	Chongqing, China	2019	4.5 GWh	lead-acid and lithium-ion batteries for telecommunications and energy storage.

Coslight	Harbin, China	2020	4.4 GWh	lead-acid and lithium-ion batteries for telecommunications and energy storage.
Desai Battery Technology Co.	China			energy storage.
Dongguan Large Electronics	Dongguan, Guangdong, China	2002		Consumer applications only
Energy Absolute	Thailand	2019	1 GWh phase 1 50GWh phase 2 by 2022	
Gangfeng Lithium China		2019	100 MWh	Pilot plant for solid state batteries
GrePow	Shenzhen, China			Consumer, sports, vehicles
Guangzhou Fullriver Battery New Technology	Guangzhou, Guangdong, China			Consumer & industrial applications only
High Star	Taizhou, Jiangsu, China			
High Star	Suzhou, Jiangsu, China			
Hyperbat	Coventry, UK	2019	Up to 100,000 vehicles	JV between Williams Advanced Engineering and Unipart Manufacturing
HZM Electronics	Zhongshan, Guangdong, China			Consumer applications only
Imperium3	Imperium, New York, US		3 GWh rising to 15 GWh thereafter.	Consortium of C4V, C&D Assembly, Primet Precision Materials, Magnis

				Resources, Kodak, Boston Energy and Innovation, and CMP Advanced Mechanical Solutions
Innolith	Basel, Switzerland			Batteries for EVs & energy storage
Inverted Energy	Okhla, Delhi, India	2020	100 MWh	
Johnson Controls Power Solutions,	Holland, MI, US			Hybrid batteries
Leclanche	Willstatt, Germany	2019 2024	200 MWh 2.3 GWh	Marine, Bus, Truck, Construction & Agriculture, GSE, Rail, Stationary & Specialty.
Leclanche	Gujarat, India	2020	1.5 GWh	Exide Industries & Leclanché joint venture
Liacon GmbH	Ottendorf-Okrilla, Dresden, Germany	2019	300 MWh	
Lithium Energy Japan	Japan			Batteries for Mitsubishi. Lithium Energy Japan (GS Yuasa Mitsubishi JV)
Penghui Power /Guangzhou Great Power Energy & Tech	Guangzhou, China	2019	1 GWh rising to 4 GWh and then 10 GWh in 2028	
Perfect Amperex Technology	Dongguan, Guangdong, China			Consumer applications only
Shandong Winabattery	Old Plant, Minquan, China	2016		
Shandong Winabattery	New Plant, Minquan, China	2020		3 Billion Ah

Shenzhen Eastar Battery	Shenzhen, Guangdong, China,			Consumer & automotive ancillary batteries
Shenzhen HLC Battery Technology	Shenzhen, Guangdong, China			Industrial applications only
Shenzhen Kayo Battery	Dongguan, Guangdong, China	2014		Consumer applications only
Shenzhen Waterma Battery	Shenzhen, China			Automotive, energy storage
Sunlight	Xanthi, Northern, Greece			Mainly lead acid battery production, but some Lithium batteries for motive applications.
Tenpower	Plant 1, Zhangjiagang, China		1 GWh	
Tenpower	Plant 2, Zhangjiagang, China		1.5 GWh up to 5 GWh in 2022	
Tesvolt	Germany	2020	255 MWh	for Energy Storage applications
Tohoku Murata Manufacturi ng	Motomiya Plant, China			
Vaillant, Shandong Weineng Environment al Protection Power Technology Co.	Shouguang City, China			
XALT Energy	Michigan, US		0.7 GWh	Electric buses and marine batteries

Xiangyang Ahead Cell Technology	Xiangyang, Hubei, China			
Yinlong	Zhuhai, Guangdong, China			
Youlion	Suzhou, China		2.5 GWh in 2020 6 GWh in 2023	
Zhuoneng New Energy Corporation	Shenzhen, Guangdong, China			
A123/ Wanxiang	Hangzhou, Zhejiang, China	2021	Plans to increase up to 80 GWh	
Akasol	Detroit region, Michigan, US	2021	400 MWh	Batteries for commercial vehicles. BorgWarner to acquire Akasol
Akasol - Gigafactory 1	Darmstadt, Germany		Up to 800 MWh 2GWh in 2021	BorgWarner to acquire Akasol
Adani	Gujarat, India	-	-	
Amara Raja	Hyderabad, India	2021?	500 MWh	
Amperex Tech (TDK)	Gurumgram, Haryana, India	2021	1 GWh	
AMTE Power & InfraNomics	Australia			
Ather Energy				
Britishvolt AMTE Power	Blyth, near Newcastle, UK	2023	35 GWh	£2.6 billion of investment with AMTE Power. Plans to build a solar park alongside the factory
BHEL / Libcoin	India		1 GWh initially up to 30 GWh	Consortium between BHEL and Libcoin
Blackstone Resources	Eisenach or Braunschweig, Germany		initially 100 million battery cells	
BMZ / Terra & others	Karlstein, Germany		34 GWh	Batteries for e-buses, e-forklifts, e-vehicles e.g.

				Streetscooter, e.Go, KION, Eurabus
CBAK Energy	Nanjing, China		2 GWh up to 8 GWh	
Do Fluoride Chemicals (DFD) / KORE Power	Texas, Arizona or Florida - TBC, US		12 GWh (energy storage applications, may not include auto)	
Envision AESC	Wuxi, Jiangsu, China			
FREYR	Mo I Rana, Norway	2022	Ramping up to 40 GWh	JV with 24M Technologies Inc.
Gangfeng Lithium China	China	2019	100 MWh. pilot plant for solid state batteries	
Geely Holding Group	Jingzhou, China	2023	6 GWh	CATL Geely Power Battery Co. Ltd JV with 49% Geely, 51% CATL
GM / Solid Energy Systems (SES) J-V	Woburn, Massachusetts, US			
GSR Capital	Trollhättan, Sweden	2021	Eventually 400,000 to 500,000 battery packs a year (~20 GWh- 25 GWh)	Supplying National Electric Vehicle Sweden (NEVS)
HBL Power	India	Planned		
Hero / Electrovaya	India	Planned		
High Energy Batteries	India	Planned		
Imperium3	Townsville, Australia	2022	Up to 18 GWh in 3 stages of 6 GWh	

Inobat	Voderady, Bratislava, Slovakia	2021	0.1 GWH in 2021 10 GWh by 2024	
Italvolt	Italy	2024	35 GWh rising to 70 GWh	
Jiangsu Fengchuen New Energy Power Technology/ Sichuan Lvran Technology Group	Qindao, China	2021	Phase 1 0.5 GWh Phase 2 4 GWh Phase 3 8 GWh	JV
Jiangsu Tafel New Energy Technology	Jiangsu, China,	2021	3 GWh by 2021 6 GWh by 2022	
JSW Energy	India	Planned		
Li Energy	Thondi, Tamil Nadu, India	2021		
Listrom	North Rhine-Westphalia, Germany	-	30 GWh	3bn Euro investment. Magnis Resources Ltd. (MR), MOU with WiN Emscher-Lippe
Lithium Werks	Changzhou, Jiangzu, China			
Lithops / FAAM	Teverola, Napoli, Italy,	2021	200 MWh ramp up to 2.5 GWh	For military, industrial & storage applications
MARII	Malaysia	Planned		
McNair	Dongguan, Guangdong , China	Planned		
Mercedes	Germany	Planned		
Monbat (EAS Batteries)	India	Planned		
Morrow Batteries	Arendal, Norway	2024	32 GWh	$4.5bn investment J-V of Agder Energi and Statkraft

National Power	Beijing, China	Planned		
Penghui Power / Guangzhou Great Power Energy & Tech	Changzhou, Jiangsu , China	2021	2 GWh	
ProLogium	Taiwan	2020		Collaboration with NIO
ProLogium	Taiwan	?	5 GWh	Collaboration with WM Motors
Reliance	India	planned		
SEAT / Iberdola	Spain			
Sichuan Energy Investment Huading Guolian Power Battery Industrial Base	Sichuan, Chengdu. China	2021	10 GWh	
Sunwoda	Nanjing, China			Supplying Renault-Nissan 2020-2026
Tata Chemicals	Dholera, Gujarat, India		Up to 10 GWh scaling up to 50 GWh.	$600m investment
Toshiba Corporation	India	2021		Suzuki, Toshiba, and Denso have formed a JV battery manufacturing plant
Verkor	France	2023	16 GWh in 2023 50 GWh at a later date	They aim for a 'fast follower' approach whereby they use existing lithium-ion technology
Vision	Jingshan, Hubei, China	2021	10 GWh to 30 GWh	

Zorlu / GSR Capital	**Turkey**	**2022**	**25 GWh**	**500,000 EV batteries per annum**

9. Companies Providing Battery Management Systems (BMS), Thermal Management Systems (TMS) and Battery Pack Cases

The battery cell and the chemistry contained therein usually get the most attention in terms of the lithium-ion battery supply chain and is understandably where many OEMs and battery manufacturers are focusing development and production investment. However, there are other key parts to the overall EV battery architecture and software, with many companies – including OEMs and tier suppliers – pursing added value service and technology.

A single raw battery cell (which is slightly larger than a consumer 'AA' battery) on its own is of little use in a vehicle. An EV needs a usable battery pack with a battery management system (BMS) and a thermal management system (TMS) to ensure safe charging, to monitor individual cells, regulate temperature and control demand discharge under a wide range of driving scenarios and atmospheric conditions. The overall battery pack case enclosure is also important in thermal management and ensuring the reliability of individual cells.

The battery pack together is a very sophisticated piece of hardware and chemistry, as well as software, all of which plays a critical in battery and EV performance.

Table 9.1 Leading Battery Management Systems (BMS) Companies

BYD
CATL
Eberspächer
Ficosa
G-Pulse
Hella
Idneo Engineering Services Company
Leclanche
LG Chem
Lithium Balance
Nuvation Energy
NXP Semiconductors
Panasonic Corporation
Renesas Electronics
Robert Bosch
Roboteq
SVolt
Tesla

Other: Analog Devices, AVL LIST, Battery Systems, Calsonic Kansei Corporation, Continental, Denso Corporation, Elithion, Hitachi, Horiba Mira, Infineon Technologies, Intel Corporation, Ion Energy, Johnson Matthey, Marelli, Maxim Integrated Products, Midtronics, Mitsubishi Electric, Navitas System, Orient Technology, Preh, Ricardo, Samsung SDI, Silicon Labs, ST Microelectronics, Texas Instruments, Toshiba Corporation, Vitesco Technologies

Source for all tables and figures in this section unless noted otherwise: Automotive from Ultima Media

Table 9.2 Thermal Management Systems (TMS) Companies

Borgwarner
Calsonic Kansei
CapTherm Systems
Continental
Dana
Gentherm
Hanon System
LG Chem
MAHLE
Robert Bosch
Samsung SDI
Valeo
VOSS Automotive

Table 9.3 Battery Pack Companies

ArcelorMittal
Constellium
Thyssenkrupp
EDAG Group
Gestamp
Hitachi
SGL Carbon
Voestalpine

10. Disruptive Battery Cell Technologies

OEMS and battery manufacturers are investing significantly in electrification through a variety of lithium-ion battery technology, capacity for which this report focuses on. However, there is investment in applications for a range of other electric vehicle battery technology, notably for 'solid state' batteries and hydrogen fuel cells, as well as other types of batteries.

Solid-state lithium batteries feature solid electrolyte lithium (rather than liquid), which have higher thermal stability and can tolerate higher temperatures, with higher voltages, have greater range and shorter charging times. A number of companies are developing solid-state batteries, including small cells (which are cheaper to produce) but also larger cells that would be more suitable for EVs.

Toyota, together with Panasonic, has more than 1,000 patents for solid-state batteries. Other OEMs including Nissan and Volkswagen are also investing in the technology. Volkswagen has invested $300m in QuantumScope, a US-based specialist in solid-state batteries.

The technology, however, is still under development and is not ready for commercial use in electric vehicles. Toyota has said that it would have a working prototype with solid-state technology as early as this year, however it would not be until 2025 that such vehicles would enter production. Vacuum and consumer product manufacturer Dyson, which had been set to launch an EV based on solid-state battery technology, abandoned the project in part because of the time it would take to make the technology viable alongside supporting the capital investment needed to develop an EV (Dyson continues to develop this battery technology, however).

While solid state could be a disruption in EV batteries, we do not expect it to play a large role in battery capacity and supply chains over the next 5-10 years.

Other technologies are in play too, including lithium-sulphur batteries and even aluminium-air batteries, which could offer potential in the longer term, but are unlikely to supplant the current drive to increase lithium-ion battery production capacity.

There is also investment in hydrogen fuel cell technology, with carmakers including Toyota and Hyundai already putting vehicles on the market. Fuel cells might also be more effective in the long run for electrifying commercial vehicles. However, it currently lacks the fuelling infrastructure to be a mass alternative to electrification.

Table 10.1 Companies Developing Potentially Disruptive Battery Cell Technologies

Company	Details	Battery Type
Solid Power	Investment, from Ford, BMW, Hyundai, Daimler, Samsung, Volta Energy Technologies	Solid State
Quantum Scape	$300m investment from VW. Claims a battery that can charge to 80% in 15 mins.	Solid State
BlueSolutions	Investment from Daimler	Solid State
Innolith	Energy density of 1000 Wh/kg,	Lithium-ion
Ionic Materials	$65m investment from Renault-Nissan-Mitsubishi	Solid State
Libtec consortium	Honda, Nissan, Toyota, Panasonic	Solid State
ProLogium	Enovate	Solid State
SVOLT		Solid State
AMTE Power		Silicon anode
Enovix		Silicon anode
Enevate		Silicon anode
Hibar Systems	Acquired by Tesla	Lithium-ion
Sila Nanotechnology		Silicon anode
OXIS Energy		Lithium-S
Métalectrique Research & Development (MAL)	LG Chem, Sanyo, Johnson Matthey, the UK MoD (DSTL) and Southampton University	Aluminium-Air
Maxwell Technologies	Acquired by Tesla, Maxwell is a specialist in ultra-capacitors and Tesla is interested in its dry electrode / solid state batteries	Lithium-ion, Solid State
NanoGraf	Graphene anode manufacturer	Lithium-ion
Kreisel Electric	Collaboration with Shell	Lithium-ion
QuantumScape	Recently listed on the stock exchange and partnering with VW	Solid state
Dyson	Dyson continues with investment in solid state technology despite abandoning its EV car project.	Solid state
SES		Solid state
StoreDot	Collaboration with EVE Energy. Daimler, BP, Samsung and TDK have invested	Silicon anode
Foxconn	Limited production by 2024	Solid state
Toyota	Limited production by 2024	Solid state

Source for all tables and figures in this section unless noted otherwise: Automotive from Ultima Media

11. Battery Pack Assembly Plants

Battery pack assembly plants take the raw individual battery cells (just slightly larger than an individual 'AA' consumer battery) and combine them into 'modules'; these modules are then combined into complete battery packs, incorporating the BMS, TMS, and enclosure to create a usable battery system. This is referred to as battery pack 'integration'.

OEMs often consider that they can achieve product differentiation and competitive advantage on everything that goes on top of the basic battery cell, including the BMS and pack assembly. For example, two OEMs may well use the same CATL cells, but with better software and thermal management, they can often eke out a few percentage points further range or quicker charging – factors that often influence consumers in purchasing one vehicle over another. Overall, battery pack assembly is a key competitive advantage for OEMs.

Depending on the OEM, the battery pack assembly plant and location may vary. Some smaller start-ups will arrange for pack assembly to be outsourced to a third party or have the cell manufacturer provide this service. Larger volume OEMs will often arrange for the battery pack assembly to be located close to the vehicle production site or even right alongside the assembly line to minimise logistics costs and improve supply chain efficiency – but also to keep the control of the critical pack assembly process in-house and retain it as a competitive advantage.

Table 11.1 Battery Pack Assembly Plants

Company	Location	Date	Details
ATW Automation (owned by Tesla)	Germany		Acquired by Tesla to assembly battery packs for the upcoming vehicle assembly plant in Berlin
Audi	Brussels, Belgium		Audi primarily uses LG Chem cells. Audi is one of the few EV OEMs that assembles the modules and packs itself in its own assembly plants. 3 GWh output in 2020
BMW			For its existing generation of electric and hybrids BMW has mostly used Samsung SDI cells (with the exception of A123 Systems previously for its ActiveHybrids) but has signed an agreement with CATL batteries for its next generation of EVs, including the iNext series. In its efforts to diversify its supply base, BMW has also formed a technology consortium with

			Swedish battery manufacturer Northvolt and Belgian battery materials specialist Umicore
	Dingolfing, Germany (Competence Centre for E-drive Production)		BMW invested $100m in this plant to design, develop and manufacture its core electric drive components including the power electronics, BMS and the vehicle electrical system using cells supplied by Samsung SDI
	Munich, Germany		Part of the vehicle assembly plant will be used to assemble battery modules
	Leipzig, Germany		Part of the vehicle assembly plant will be used to assemble battery modules from 2021
	Regensburg, Germany		Coating of cells from 2021, full battery assembly from 2022
	Spartanburg, South Carolina, USA		Hybrid battery assembly and production of hybrid versions of BMW X3 and X5
	Tiexi, China		BMW Brilliance Automotive (BBA) JV plant includes a high voltage battery centres, and was recently expanded to build battery modules, including for the new BMW iX3 EV
	Thailand		Localised battery production with the Dräxlmaier Group for BMW 5 series PHEVs
BMZ GmbH	Karlstein, Germany		TerraE consortium co-founded by BMZ. Production of up to 80m lithium-ion batteries with a total capacity of around 4 GWh annually potentially rising to 8 GWh
Bolloré	Ergue-Gaberic, France		Bolloré assembles battery packs for its buses with a manufacturing capacity of 300 MWh
BorgWarner/ Romeo Power Technology	Vernon, California, US	2019	60:40 joint venture and BorgWarner investment in Romeo, which launched a battery pack plant in 2017
BYD			BYD is highly vertically integrated designing, producing and assembling in-house the complete electrical power train system including cells, modules and battery pack
	Shenzhen, China		14 GWh in 2018
	Qinghai, China		12 GWh in 2018, 24 GWh in 2019
	Huizhou, China		2 GWh in 2018
	Xi’an, Shaanxi, China		From 2023 up to 30 GWh battery production

	Chongqing, China		From 2023 this is JV between BYD and Changan Automobile. 5 to 6 GWh first stage, 10 GWh second stage
	Amazonas, Brazil		18,000 battery modules assembly per year for buses
Continental		2008	LG Chem has been Daimler's primary supplier of battery cells. Daimler then assembles its own battery packs at 9 locations throughout the world, sometimes with subsidiaries like its 100%-owned Deutsche Accumotive, and in some cases through JVs with local partners. Daimler has also signed a supply agreement with CATL, not specifying any specific models yet
Daimler	Nuremberg, Germany		333 MWh lithium-ion batteries for HEVs such as Mercedes S400 BlueHYBRID
	Kamenz, Germany plant 1	2019	Deutsche Accumotive develops, and assemble LG Chem cells and have produced 70,000 lithium-ion batteries packs since 2012 for Mercedes and Smart
	Kamenz, Germany plant 2	2012	
	Stuttgart-Untertürkheim, Germany, plant 1		
	Stuttgart-Untertürkheim, Germany, plant 2		
	Sindelfingen, Germany		
	Beijing, China		Joint-venture partner BAIC have added battery production at an engine factory
	Bangkok, Thailand		Battery production with local partner Thonburi Automotive
	Tuscaloosa, Vance, USA		Near the Mercedes SUV plant, which will build electric SUVs from 2022
	Jawor, Poland		Battery assembly facility for EQ range
Ford	Valencia, Spain		
	Rawsonville, MI, US		

Ford Otosan	Kocaeli, Turkey	2022	Battery packs for E-transit
Geely	China		JV with Geely Automobile Holdings
GM	Brownstown, Michigan, US	2010	Original battery assembly plant for Volt production. Today assembles battery pack for hybrids and replacement packs for aftersales
GM (Ultium JV)	Lordstown, Northeast Ohio, US	2021	$2.3bn JV between LG and GM to build a 30 GWh battery cell assembly plant in Lordstown
GS Yuasa	Miskolc, Hungary	2017	500,000 batteries per year
Hyperbat	Coventry, UK	2019	Up to 100,000 vehicles
Jaguar Land Rover	Hams Hall near Birmingham, North Warwickshire, UK	2020	Jaguar Land Rover Battery Assembly Centre
Johnson Matthey Battery Systems (Cummins)			One of Europe's largest lithium-ion battery systems suppliers, processing over 70m cells a year and supplying volume production of batteries for global markets. Tier supplier Cummins acquired the company in 2018
	Poland		Battery cell manufacture and pack assembly
	UK		
Kreisel Electric	Freistadt, Austria		800 MWh battery pack factory that supplies BMW, VW and McLaren Automotive with battery packs and electric powertrains for orders up to 10,000 vehicles. Kreisel currently has a supply agreement with Samsung SDI
Microvast	Brandenburg, Germany	2021	Ramp up to 8-12 GWh. Assembles battery packs with cells imported from China
Northvolt	Gdansk, Poland		Production site for battery modules and energy storage solutions. An increased investment will mean an initial capacity of 5 GWh in 2022 and potential for 12 GWh
Renault - Nissan - Mitsubishi	Sunderland, UK	2013	Nissan designs and manufactures battery packs in-house for its own use for Nissan Leaf and e-NV200 van. Cells provided by AESC Envision.
	Flins, France		Renault
	Blainville, France		Renault vans
	Barcelona, Spain		Nissan battery assembly. Factory is slated to close

	Kusatsu City, Japan		Mitsubishi Outlander PHEV battery pack is designed in house by Lithium Energy Japan, a JV between GS Yuasa, and Mitsubishi Corporation
Scania	Södertälje, Sweden	2023	For Scania trucks and buses. Cells will be supplied by Northvolt.
Stellantis	Nersac, France	2021	Pilot plant as part of ACC JV with Saft before ramping up battery production in 2023
	Trnava, Slovakia		Batteries for multiple brands
	Hauts-de-France, France	2023	Cell manufacture and pack assembly through ACC JV with SAFT and PSA/Opel. Initially 8 GWh eventually 24 GWh
	Kaiserslautern, Germany	2023	Cell manufacture and pack assembly through ACC JV with SAFT and PSA/Opel. Initially 8 GWh eventually 24 GWh
	Mirafiori complex, Turin, Italy	2020	€50m initial investment to build a battery assembly 'hub'
	Zaragoza, Figueruelas, Spain		
Tesla	Gigafactory 1, Reno, Nevada, US	2016	JV with Panasonic 23 GWh 2020 35 GWh future
	Gigafactory 2, Buffalo, New York	2017	This plant produces photovoltaic solar cells unrelated to automotive
	Gigafactory 3, Shanghai, China	Dec 2019	Batteries & cars. Target of 15 GWh battery production by 2023. Battery packs assembled using cells from various suppliers, including Panasonic, LG Chem and CATL
	Gigafactory 4, Grünheide, Germany	2021	Tesla's new plant will produce vehicles Model Y Model 3. and batteries. Battery capacity TBA 100-250 GWh. Elon Musk has said Tesla will make the plant the largest battery plant in the world.
	Fremont, California		Pilot plant initially, but Up to 10 GWH. Currently a vehicle assembly plant, Tesla indicated a pilot battery production line would be built for in-house cell production
	Austin, Texas, US		Cybertruck, Semi, Roadster, Model Y but also battery cell production to further integrate the supply chain

Valmet Automotive	Salo, Finland	2021	Modules and battery packs
Valmet Automotive	Uusikaupunki, Finland		Modules and battery packs and vehicle contract manufacture
Volvo	Ghent, Belgium	2020	XC40 Recharge and battery pack assembly
	Vigo, Spain		Battery assembly
	Ridgeville, South Carolina, US	2021	
VW	Salzgitter, Germany	2020	12 GWh potentially increasing to 30 GWh in JV with Northvolt
	Wolfsburg, Germany		Up to 500,000 EV battery packs per year
	Brunswick, Germany		Battery module assembly
	Ingolstadt, Germany		Audi reported to build battery plant

Source for all tables and figures in this section unless noted otherwise: Automotive from Ultima Media

12. Automotive OEM Hybrid & Electric Vehicle Assembly Plants

In analysing the battery supply chain, it becomes increasingly apparent that the location of EV assembly plants is very important, perhaps even more so than with conventional ICE powertrains. The weight of the batteries, regulation around the movement of hazardous goods, and the security of supply and localisation of the supply chain are all critical factors intertwined with the chosen location of plug-in hybrid and electric vehicle assembly plants.

Furthermore, the battery sourcing model varies within those parameters, for example with some OEMs importing batteries completely from outsourced companies, whereas other OEMs such as Audi and Tesla assembly the batteries in the same actual plant as the vehicle itself.

OEM strategies also vary in terms of how they produce electric vehicles in plants. Many OEMs have and continue to opt to add EVs alongside existing ICE models, including GM, BMW and recently Volvo Cars. However, more OEMs are following the VW Group approach (and of course that of a pure EV OEM like Tesla), which includes converting a number of plants into purely electric vehicle production sites, such as Zwickau, Dresden and Emden in Germany. GM and Ford are now also converting more factories to produce purely EVs. BMW, which has mainly favoured a flexible approach, is now developed a pure EV platform and will make its upcoming plant in Hungary a dedicated manufacturing site for EVs.

The table below details main assembly plant locations for variants of hybrid, plug-in and fully electric vehicles.

The full database of hybrid and EV plants can be downloaded from our website here -
https://www.automotivelogistics.media/focus/electric-vehicles
https://www.automotivemanufacturingsolutions.com/technology/emobility

Table 12.1 Summary of OEM Hybrid & EV Vehicle Assembly Plants

OEM	Number of Hybrid & EV Assembly Plants
VW Group	30
Toyota	28
Renault-Nissan-Mitsubishi	26
Stellantis	25
Daimler	19
BYD	18
Ford	16
Hyundai-Kia	14
Geely	14
BMW	13
Honda	11
SAIC	8
GM	8
BAIC	7
Dongfeng	7
Suzuki	7
FAW	6
JLR	6
Zotye*	6
Tesla	5
Chery	5
Volvo Group	4
JMC	4
Changan	4
Great Wall	3
Tata	3
Byton	3
Changjiang	3
Mahindra	3
NEVS	3
Wanxiang	3
Mazda	2
Other	100
Total	414

Source: Automotive from Ultima Media

*Zotye filed for bankruptcy in December 2020

13. OEMs and Battery Cell Supplier Database

As securing supply of lithium-ion battery cells is becoming critical, OEMs have been expanding and diversifying their battery suppliers to ensure competition and mitigate supply chain shortages. Just a few years ago, an OEM such as Volkswagen relied on single suppliers, such as Samsung SDI for the e-Golf, while today it has significantly expanded suppliers, including LG Chem, SK Innovation and CATL, as well as plans to build its own batteries. Tesla has also expanded its partnerships from working with Panasonic to wider array of suppliers, as well as investing further in building its own batteries and components.

The section identifies, where possible, which battery cell manufacture supplies which OEM. These relationships are not always transparent, and indeed they can vary even by model type. For example, Audi uses LG Chem for its e-tron electric SUV, but Samsung SDI for other variants of it. Nonetheless, a pattern of supply is emerging across the major battery players supplying OEMs.

It is worth noting as well that the leading battery suppliers for the large lithium battery packs that are used in in ‘full’ electric vehicles (usually around 50 KWh) are quite a different group of companies compared to the smaller batteries used in plug-in hybrids (typically around 10 KWh) and hybrids (around 1 KWh).

The full database by OEM can be downloaded from our website here:
https://www.automotivelogistics.media/focus/electric-vehicles
https://www.automotivemanufacturingsolutions.com/technology/emobility

Table 13.1 Summary of OEM Groups and Battery Cell Suppliers

OEM Group	Brands	Battery Cell Supplier
BAIC	BAIC, BAW, Foton	CATL
BMW	BMW, Mini, Rolls-Royce	CATL
BYD	BYD	BYD
Daimler	Mercedes-Benz, Smart, AMG	LG Chem, SK Innovation, CATL for trucks & buses
Ford	Ford, Lincoln	LG Chem, Panasonic, SK Innovation (US)
Geely	Geely, Volvo Cars, Polestar, Lynk & Co	CATL, LG Chem
General Motors	GMC, Chevrolet, Buick, Cadillac	Mostly LG Chem (in future Ultium JV with LG Chem)
Great Wall	Great Wall, Haval, Wey, Ora	Farasis Energy / LG Chem
Honda	Honda, Acura	Panasonic, CATL
Hyundai-Kia	Hyundai, Kia, Genesis	SK innovation, LG Chem, CATL for China
Mahindra	Mahindra & Mahindra	LG Chem
Mazda	Mazda	Primearth EV Energy (PEVE), Panasonic
Renault-Nissan-Mitsubishi	Renault, Nissan, Mitsubishi, Dacia, Infiniti, Lada, Samsung Motors, Datsun, Alpine, Venucia, Lada	Mitsubishi: Toshiba or Lithium Energy Japan Corp. (GS Yuasa & Mitsubishi JV) Nissan: LG Chem, CATL (China). Renault: LG Chem
SAIC	SAIC, Wuling, Maxus, MG, Roewe, Yuejin.	A123 Systems, CATL
Stellantis	Peugeot, Citroen, DS, Fiat, Chrysler, Dodge, Ram, Jeep, Lancia, Maserati, Alfa Romeo, Opel, Vauxhall, Abarth	LG Chem, CATL (SAFT JV with Total in future)
Subaru	Subaru	PEVE
Suzuki	Maruti Suzuki, Suzuki	Toshiba
Tata Motors	Tata, Jaguar, Land Rover	Jaguar: LG Chem, Samsung SDI from 2021 Tata: Tata AutoComp Systems Ltd.
Tesla	Tesla	Panasonic, LG Chem and CATL in China(& possibly EVE Energy) – in-house cells from 2021
Toyota	Toyota, Lexus, Daihatsu, Hino	Panasonic
Volkswagen Group	VW, Audi, Seat, Skoda, Bugatti, Porsche, Lamborghini, Ducatti, Scania, MAN	LG Chem, Samsung SDI and SKI For EU, CATL for China, SKI for North America from 2022. Northvolt in future

Source for all tables and figures in this section unless noted otherwise: Automotive from Ultima Media

14. EV and Hybrid Export Markets Analysis

Global trade of hybrids and electric vehicles is still a relatively small share of vehicle exports and imports. That number will have grown in 2020 with the global increase in electric vehicle sales, and further as more OEMs launch EVs that will be set for export, perhaps most notably in Europe, including Tesla, Volkswagen Group, BMW, Mercedes-Benz and Volvo Cars. China, though not a significant EV exporter as of 2019, is also set for more export growth.

The top table for electrified vehicle exports looks likely to be more fluid compared to ICE vehicles. Japan, Germany and the US were the largest exporters in 2019, however Japan's ranking was mostly because of the many Toyota, Honda and Mitsubishi hybrids manufactured in Japan – and relatively few plug-in hybrid and full electric vehicles.

While Germany has been relatively balanced between EV, plug-in and hybrid exports, the US has been third overall driven mainly by its EV exports – for which it was the largest exporter – and that has been down in large part to Tesla. While Tesla continues to increase output, it is also notably expanding its global footprint, having already launched production in China and set to start production in Germany.

The relatively low volumes have up to now also meant that smaller manufacturing countries have ranked higher for EV trade. Belgium, for example, was the second largest exporters of EVs in 2019, thanks mainly to production and export of the Audi e-tron SUV. Volvo Cars' recent launch of the XC40 Recharge EV will give Belgium a boost as well. Sweden, meanwhile, has been the third largest global exporter of plug-in hybrids thanks to a wide range offered by Volvo.

However, the larger automotive nations are likely to rise further up the ranks. OEMs in Europe are ramping up production of EVs quickly, with a raft of launches set from Volkswagen Group, BMW, Daimler, Porsche and indeed Tesla's new German plant. China, meanwhile, has seen EV exports rise to Europe, including Polestar and MG, as well as Tesla and BMWs. Other European brands including BMW Mini, Smart and Renault/Dacia are planning EV exports from China, while Chinese startups like Nio and Xpeng are targeting European markets in particular.

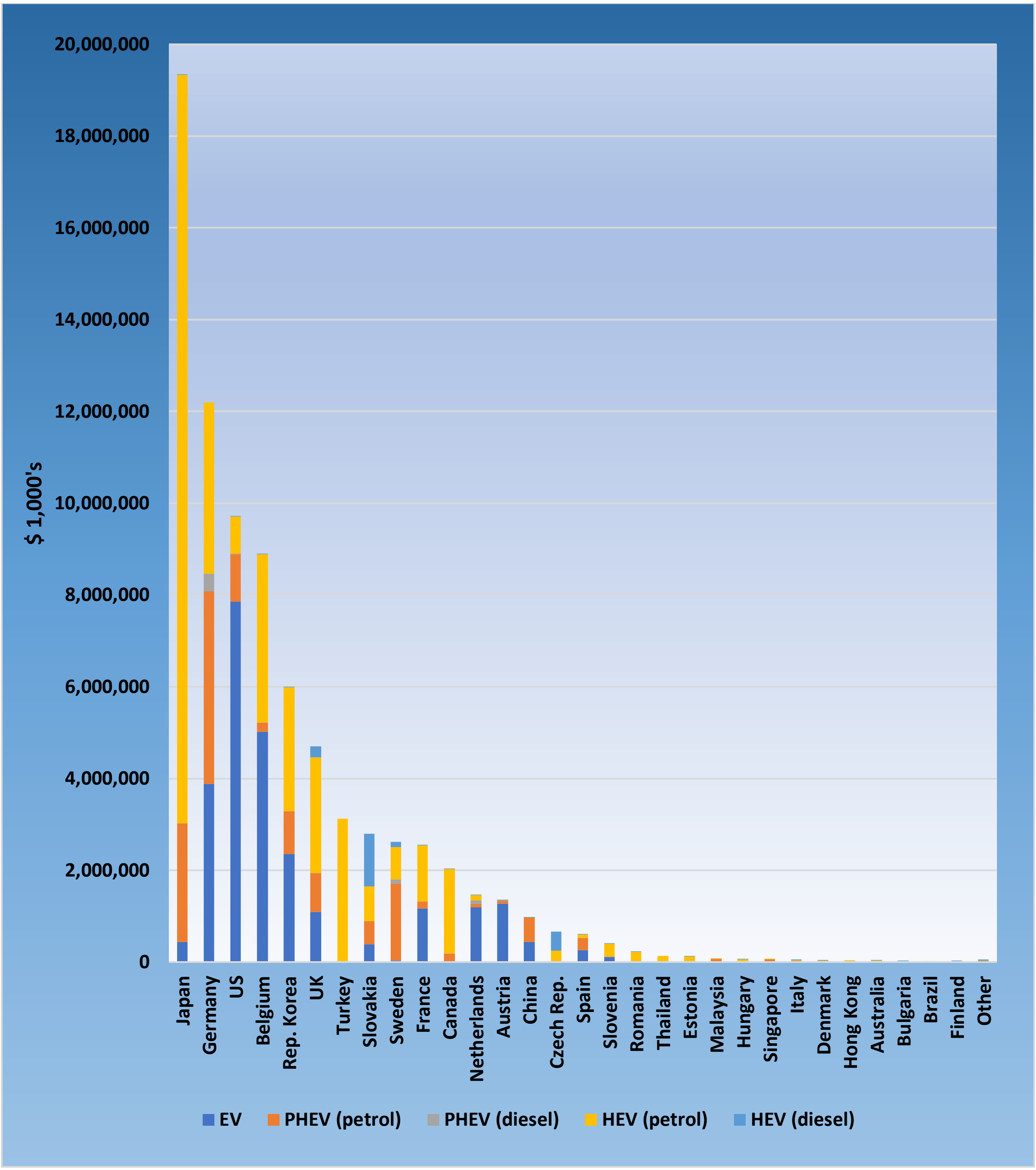
Exporting electric vehicles may not happen in as large a volume as they do for ICE vehicles, however. Heavier vehicles bring higher shipping and logistics cost, and in some cases added complexity (although not as significant as with batteries, see appendix). The high cost of production and components, however, will also likely encourage more OEMs to localise EV production. It is likely that as battery plants and capacity increase, OEMs will be produce EVs on a highly regional strategy. The Volkswagen Group, for example, will soon be building EVs on its MEB platform alone across seven plants in Germany, Czech Republic, China and the US.

Table 14.1 Top 30 Electric and Hybrid Vehicle Exporting Countries 2019

HS Code Type	870380 EV	870360 PHEV (petrol)	870370 PHEV (diesel)	870340 HEV (petrol)	870350 HEV (diesel)	Total XEV (all variants)
Japan	$431,470k	$2,588,951k	$17k	$16,315,948k	$63k	$19,336,449k
Germany	$3,885,103k	$4,200,662k	$374,583k	$3,730,496k	-	$12,190,844k
US	$7,858,135k	$1,025,244k	$18,345k	$802,390k	$7,442k	$9,711,556k
Belgium	$5,017,975k	$198,311k	$791k	$3,672,757k	$884k	$8,890,718k
Rep. Korea	$2,353,736k	$939,425k	-	$2,690,724k	$55k	$5,983,940k
UK	$1,096,333k	$837,637k	$987k	$2,524,478k	$236,865k	$4,696,300k
Turkey	-	-	-	$3,124,196k	-	$3,124,196k
Slovakia	$383,252k	$507,773k	$22k	$761,767k	$1,140,847k	$2,793,661k
Sweden	$38,443k	$1,666,162k	$96,854k	$700,938k	$114,113k	$2,616,510k
France	$1,165,716k	$157,095k	$501k	$1,225,421k	$1,849k	$2,550,582k
Canada	$3,079k	$180,740k	$339k	$1,846,548k	$83k	$2,030,789k
Netherlands	$1,191,949k	$78,880k	$73,865k	$117,182k	$9,771k	$1,471,647k
Austria	$1,268,625k	$67,532k	$2,447k	$7,800k	$16,853k	$1,363,257k
China	$438,082k	$522,937k	$15k	$8,754k	$14,262k	$984,050k
Czech Rep.	$3,258k	$9,483k	$149k	$235,622k	$419,936k	$668,448k
Spain	$259,671k	$269,440k	$1,417k	$73,888k	$3,898k	$608,314k
Slovenia	$112,967k	$4,410k	$117k	$286,346k	$104k	$403,944k
Romania	$1,069k	$5,629k	$325k	$220,431k	$1,088k	$228,542k
Thailand	-	-	-	$129,075k	-	$129,075k
Estonia	-	-	-	$122,262k	$361k	$122,623k
Malaysia	$93k	$73,657k	-	$648k	-	$74,398k
Hungary	$6,860k	$5,978k	$424k	$46,750k	$4,948k	$64,960k
Singapore	$1,551k	$52,967k	$48k	$1,635k	-	$56,201k
Italy	$22,024k	$7,184k	$186k	$11,328k	$3,539k	$44,261k
Denmark	$15,265k	$7,438k	$2,972k	$4,368k	$336k	$30,379k
Hong Kong	$18,355k	$5,813k	-	$6,804k	-	$30,972k
Australia	$1,873k	-	$160k	$25,633k	$367k	$28,033k
Bulgaria	$309k	$6,494k	$215k	$12,990k	$2,017k	$22,025k
Brazil	-	-	-	$18,567k	-	$18,567k
Finland	$5,444k	$5,110k	-	$4,891k	$1,758k	$17,203k
Other	$27,627k	$2,177k	$1,715k	$19,440k	$4,193k	$47,227k
Totals	$25,176,794k	$10,838,178k	$576,477k	$22,434,129k	$1,985,569k	$61,003,222k

Source: International Trade Centre (ITC), Automotive from Ultima Media

Figure 14.1 Top 30 Electric & Hybrid Vehicle (X)EV Exporting Countries 2019 ($ 1000's)



Source: International Trade Centre (ITC), Automotive from Ultima Media

15. Automotive Battery Re-Use and Recycling Companies

The issue of what happens to a vehicle's lithium battery after its useful life is an increasingly important question. Considering the emission and resource impact of battery production, this is of course an important environmental concern. However, it will also likely be a strategic supply strategy.

As OEMs ramp up volumes in the race to electrification, recycling and reuse will be important to avoid shortages of some metals such as cobalt, nickel and manganese. In the long run, the percentage of lithium-ion batteries and materials that can be recycled and re-enter the value chain will be important.

Generally, the lifetime of an automotive vehicle battery is intended to be at least 8-10 years. It is only considered to be beyond its useful life when its capacity reduces to 70% or below original levels. However, that does not mean that the battery is of no-value and must be recycled, as there are also other uses that the battery might have outside the vehicle.

15.1 Re-using EV Batteries for A Second Life

The performance of the battery will eventually drop below an acceptable level for a critical application such as an EV, where weight, size and performance are major issues. However, the battery can still have a useful second life for many years in other applications.

Some OEMs, such as Nissan and BMW, has re-used batteries in production operations, such as powering automated guided vehicles or forklifts. But batteries are also used in small scale or local level power storage in domestic and commercial buildings for back-up power, or in remote locations where there is no mains power.

Batteries could also be combined in large quantities for grid or utility scale energy storage applications. These achieve 'load levelling' or smoothing of the output of inherently fluctuating renewable energy sources such as photovoltaic solar panels and wind turbines to create a more consistent input to the electricity networks and are thus vital components in making renewable energy sources viable.

By re-using batteries in this way, not only does it moderate the price of electricity from the grid, but it also effectively reduces the environmental impact of the battery's original manufacturing process by extending the battery's useful life.

There is also a financial factor. Repurposing batteries means that they will hold considerable value for reuse rather than going straight to recycling.

Table 15.1 Examples of OEMs Re-Using EV Batteries in Other Applications

OEM	Re-Use and Second life
Audi	Energy storage test installation at EUREF research campus, Berlin
	'Audi Brand Experience Centre' at Munich airport uses old Audi EV batteries for energy storage
BJEV	EV-charging, backup power
BMW	Grid-scale energy storage, EV-charging
	BMW re-purposes EV batteries at many global plants
BYD	Grid-scale energy storage, backup power
Changan	Backup power
Daimler	Grid-scale energy storage, C&I energy storage
General Motors	Remanufacturing
Great Wall Motor	Backup power
Honda	Renewable energy storage partnership in Europe with Societe Nouvelle d'Affinage des Metaux (SNAM)
Hyundai	Grid-scale energy storage, C&I energy storage
Renault Nissan Mitsubishi	C&I energy storage, EV-charging, residential energy storage, grid-scale energy storage
	Nissan-Sumitomo Corporation JV with 4R Energy Corporation for re-use or less critical applications such as forklifts, golf carts and streetlamps
	Energy storage project with Smarthubs/Connected Energy in West Sussex, UK
	Energy storage project with Advanced Battery Storage in Douai, France
	Nissan repurposes batteries at North American facilities
PSA	C&I energy storage
SAIC	Backup power
Toyota	C&I energy storage, grid-scale energy storage (NiMH)
VW Group	C&I energy storage
Volvo	Residential energy storage
	Energy Storage project with Volvo Buses in partnership with Stena Recycling subsidiary Batteryloop
	Energy Storage with Volvo Buses and Stena Fastigheter

Source for all tables and figures in this section unless noted otherwise: Automotive from Ultima Media

15.2 Recycling Automotive Batteries

In an ideal battery supply chain, batteries will move through their useful lifecycles and then in a 'closed loop' to recycling, from which raw materials are extracted and fed back into the production of new battery components. That would make the production process more environmentally friendly and also reduce demand on the supply chain for raw materials as battery volumes ramp up.

However, the recycling of lithium-ion batteries is a relatively new and emerging industry. Much of the recycling landscape is primarily in Asia, for example, which means that most batteries used in other markets will need to be sent to Asia for processing. China accounts for more than two-thirds of all recycling facilities handling the roughly 100,000 tonnes of batteries currently being recycled. South Korea is second with around one-sixth of global recycling. The industry is otherwise highly fragmented with a 'long tail' of many other smaller players attempting to enter this burgeoning market.

However, these figures are inexact and fluid due to the nature of how lithium-ion battery recyclers stockpile them for recycling for when metals prices are more favourable. That leads to fluctuations in recycling activity and the share across regions.

Table 15.2 Leading Automotive Battery Recycling Companies

Company	Location
Green Eco Manufacturing Resource (GEM)	Shenzen, China
Hunan Brunp Recycling Technology	Hunan Province, China
Quzhou Huayou Cobalt New Material	Quzhou, China
Ganzhou Highpower Technology	Shenzen, China
Guangdong Guanghua Sci-Tech	Guangdong, China

Table 15.3 Other Lithium-Ion Battery Recycling Companies

Company	Plants
ACCUREC Recycling	Mülheim, Germany, Krefeld, Germany
AEA Technology	Sunderland, UK
AERC Recycling Solutions	Allentown, Pennsylvania, US, West Melbourne, Florida, US, Richmond, Virginia, US
AkkuSer Oy	Nivala, Finland
American Manganese	Surrey, British Columbia, Canada
Anhua Taisen Recycling Technology Co.	Hunan province, China

BASF	BASF, Eramet, and SUEZ have partnered as part to develop a closed loop recycling process for lithium-ion batteries
Batrec Industrie	Wimmis, Switzerland
Battery Recycling Made Easy	Cartersville, Georgia, US
Battery Resourcers	Worcester, Massachusetts, US
Battery Solutions	
Dowa Eco-System Co.	
Duesenfeld	Wendeburg, Germany
Ecobat	
Eramet-Valdi	Commentry, France
Euro Dieuze Industrie-SARP	Dieuze, France
Fortnum	Harjavalta, Finland Ikaalinen, Finland
Ganfeng Recycling Technology Co	
Ganfeng Lithium	Mexico
Glencore International	Sudbury, Canada, Rouyn-Noranda, Canada Kristiansand, Norway
Green Technology Solutions	Blacksburg, South Carolina, US
G&P Batteries	Darlaston, UK
Hydro-Northvolt, supported by government enterprise Enowa	Joint venture for a pilot plant in Fredrikstad, Norway
International Metals Reclamation Company (INMETCO)	
Johnson Matthey	MoU with Stena Recycling
JX Nippon Mining and Metals Co.	
Li-Cycle Corporation	Kingston, Ontario, Canada Eastman Business Park, New York, US
Lithion Recycling Inc.	
Metal Conversion Technologies	
Neometals	Ontario, Canada
Nippon Recycle Center Corporation	Osaka, Japan, Aichi, Japan, Miyagi, Japan
Northvolt	Vasteras, Sweden
OnTo Technology	
G&P Service	
Raad Solar-=Mahindra Electric	
Raw Materials Company Inc.	

Recupyl	Grenoble, France, Singapore
Retriev Technologies Inc.	Trail, British Columbia, Canada, Baltimore, Ohio, US, Anaheim, California, US
Sitrasa	
SNAM	Saint Quentin Fallavier, France
Sony Electronics Inc. - Sumitomo Metals and Mining Co.	
Stena Recycling	173 locations in 7 EU countries
Tata Chemicals Limited	
Tes-Amm Singapore Pte Ltd	
Tesla	Nevada, US
Umicore	Wickliffe, Ohio, US Hoboken, Belgium Olen, Belgium
Urecycle Group Oy	
VW	Salzgitter, Germany
Ziptrax	

16. Conclusions: Local, Strategic Supply

The global environmental and regulatory push, especially in Europe, China and increasingly in North America, will drive rapid electric vehicle growth over the next decade. This increase requires a commensurate ramping up of battery gigafactory capacity and the wider lithium-ion battery supply chain across regions.

There is a lot at stake. Without enough battery cell capacity, major automotive producing countries risk falling behind in the race for electrification. Without a well-developed and secure battery supply chain, EV production will ultimately be over dependent on supply from a limited number of countries, mostly in Asia. As the current semiconductor shortage demonstrates, that would leave manufacturers and economies vulnerable. This is not just an economically strategic issue, but arguably one of national security, just as energy supply has been.

With the battery comprising as much as 30-40% of the vehicle cost, OEMs and suppliers could also see their existing control of technology and production threatened, with new competitors and market entrants liable to gain share. But the opportunity is also so huge as to require investment, technology and capacity from all stakeholders – with many likely to profit as well.

There are a number of key takeaways from this report:

The Battery Supply Chain Will Become Increasingly Local

As volumes ramp up, manufacturers and suppliers are investing in regional battery production capacity, with the EU currently set to see the most significant growth in cell capacity. Huge investments are also set for China, which already dominates EV battery production. At the strategic level, governments and regulators are pushing to localise battery supply chains both to ensure the security of supply as well as to gain from the economic value and compensate for the loss of industry and jobs built around internal combustion engine powertrains. The EU has set a roadmap of sustainability of raw material production and energy used in battery manufacture. In the US, the Biden administration's recent executive order to review supply chains, including EV batteries and semiconductors, is a clear example of how seriously governments are taking the issue of supply chain disruption and security.

OEMs Will Seek a Diversity of Cell Suppliers

As EV volumes ramp up, leading automotive OEMs are increasingly moving away from single sourcing agreements with battery cell suppliers to a more flexible, multi-sourcing model across a mix of suppliers, and in some cases joint ventures and investments to build cells and components in house. This diversification is another feature of securing supply, but also being able to maintain competition, cost and quality. If one supplier suddenly makes a technological step forward, for example, an OEM can switch or vary suppliers.

Batteries Are Not Commoditised

There is considerable competitive advantage to be had by developing and commercialising a specific battery technology. That is because, for now, at least, lithium-ion batteries are far from being commoditised. There are multiple chemical formulations that make for differing price and performance propositions, including for battery cost, range and charging. OEMs will consider these factors depending on product and even regional strategy when choosing a particular battery type and supplier. Carmakers are also investing billions more into their own battery research and development, hoping to gain advantages in electrification.

OEMs Want to Have More Control of the Battery Supply Chain

It is no coincidence that many OEMs and other stakeholders in the EV value chain are looking at vertical integration of key operations – including establishing in-house operations to manufacture battery cells and getting more involved in upstream processes. OEMs including GM and Volkswagen have followed Tesla's example in establishing joint ventures with cell suppliers or even looking to produce cells entirely in-house – possibly with a view to even commercialise supply to other OEMs. Gaining visibility and control of the supply chain can be a competitive advantage both in coordinating volume ramp up as well as in preparing for and responding to supply chain disruption.

Tesla is also leading a charge – in ambition and strategy, at least – to take more control upstream, including directly mining minerals like lithium, as well as encouraging technologies that reduce or eliminate the use of cobalt or even nickel. Price spikes in mining such materials have caused OEMs to look more carefully at the upstream supply chain, in some cases taking a more active role in procurement, too.

Ethical Supply Chains are Strategic Supply Chains

As well as controlling costs and supply, OEMs are examining upstream supply chains more carefully to monitor emissions, fair trade and labour practices. The extraction of rare minerals and the energy used during battery production are increasingly under the scrutiny of environmentalists, regulators and consumers. Carmakers such as Volvo Cars, BMW and Daimler are demanding that cell and raw mineral suppliers conform to strict environmental and labour standards. Partly for this reason, manufacturers are also exploring ways to reduce or phase out cobalt, which has notorious supply and labour issues from the Democratic Republic of Congo.

Battery Packs Can Be as Important as Cells

Battery performance is not just down to the cell, but how the battery modules and packs are combined both in hardware and software integration, for example through battery management systems. The overall battery integration process is becoming increasingly important for OEMs, as in some cases such packs could gain more range and better performance even when using the same cell supplier. As such, the lines are increasingly blurring between battery cell supplier and module pack assembly. In response, some cell suppliers have developed 'cell-to-pack' technologies to optimise this process with the goal of reducing battery prices below $100 per KWh.

Lithium-ion May Not be the Only Solution – But Will Lead the Way for the Foreseeable

The rise in electric vehicle demand looks increasingly to be as sure a bet as possible, thanks to the heavy regulatory push and massive OEM investment in EV development. However, the dominance of lithium batteries is not 100% certain. Certain technologies such as lithium-sulphur and solid-state batteries, hydrogen fuel cell, or even a left-of-field technology could upend the current trajectory of lithium-ion battery demand. Breakthroughs in faster charging times – or business models that depend less on them, like battery swaps – could further reduce the need altogether for such expensive batteries.

These risks could undermine the investment going into the global battery supply chain, including the many gigafactories currently in the pipeline, as well as the host of cell processing, battery pack assembly and integration across hundreds of facilities. However, while not every battery manufacturer is likely to achieve its stated GWh capacity ambitions, the demand and capacity requirement for lithium-ion battery is still very likely to rise significantly over the next decade. New technologies and alternatives will be important, too, but rather than sweeping away the lithium-ion supply chain, they are more likely to be part of an increasingly diversified electric powertrain strategy.

Electrification Is the Key to Keeping Automotive a Pillar Industry

It would not be an overstatement to say that the next decade of transition towards electrification will be the most profound in the automotive industry's history. The environmental implications are immense. At the same time, the business opportunities are vast for an industry currently worth some $3 trillion, and which still plays such a key role in many countries' prosperity, individual freedom and personal mobility. The success of the battery supply chain will be pivotal in both the automotive industry's transformation and maintaining its role as a pillar industry.

Appendix

A. Expert Interviews

Interviews by Daniel Harrison, Automotive from Ultima Media. The transcripts have been lightly edited for clarity.

A.1 Henrik Fisker, CEO, Fisker

Interview in March 2020. An article based on this interview was also published by Automotive Manufacturing Solutions: https://www.automotivemanufacturingsolutions.com/emobility/fisker-sees-its-chance-as-ev-production-models-reconfigure/40599.article

Fisker is a start-up electric vehicle company founded and run by Henrik Fisker, a Danish designer who has designed a number of iconic cars for BMW, Aston Martin. The company is a successor to Fisker Automotive, a relatively early EV startup that launched an electric vehicle back in 2008, and later filed for bankruptcy. Today, Fisker has confirmed manufacturing agreements for two vehicles: Magna Steyr will supply both an EV platform and well as produce the Fisker Ocean electric SUV at its factory in Graz, Austria, starting in late 2022. The carmaker has also signed an agreement with Foxconn, which manufactures the iPhone, to jointly develop an EV under the Fisker brand, which Foxconn will build.

Daniel Harrison: We note a varied approach in the battery supply chain. Some OEMs have taken a vertically integrated model, some completely rely on a third-party supplier. Is Fisker developing its own battery cells in house?

Henrik Fisker: Well, yes and no. Yes we are doing that, but it won’t go into our initial production vehicles.

Daniel Harrison: You are developing a solid-state battery, potentially, is that correct?

Henrik Fisker: Yes but let me give you a bit of background. Normally developing a vehicle from the ground up takes anywhere from 4-5 years from the first sketch to all the concept phase to development to testing, durability testing, supply chain. So, let’s say that’s four years and then after that you’ve got a seven-year life cycle. So now you’re looking at 11 years. The reality is that although there is a lot of exciting battery development out in the world, if you haven’t already finished the development and tested it for the last three years it is not likely to come into your vehicle over the next coming years. So that’s the first part of it.

The second part of it is that you need to have a supply chain and a manufacturing setup that gets you into the mass production that you need. So with all this in mind, I think what's really happened in the electric vehicle industry is that we have an initial phase were Tesla came in, used Panasonic, which is an existing technology which is not proprietary. At that point we – Fisker Automotive at the time – had launched the Fisker Karma, about a year ahead of the Tesla Model S, and we used A123 batteries, which was a small company that had tried to do something new and then obviously went out of business which obviously caused us to go out of business because we didn't have a battery. And at that time, I'm looking back to 2012, there wasn't really any supply chain that could offer us a battery, and that became obviously detrimental for us.

Fast-forward to today, and there is a global supply chain that has been established which is comprising of five large battery companies: LG Chem, Samsung, SK Innovation, CATL in China, and then you've also got BYD. All of these battery manufacturers are pretty much making the same cell technology, with some little variation. But essentially, if you use LG Chem batteries, and let's say LG Chem for some reason was unable to supply you, you would be able to use Samsung cells and have a similar performance in your vehicle. So that now allows you to dual source.

Now obviously you have Panasonic out on the side. They are offering their battery cells to other companies but really it's mainly Tesla that is using them. And that's because they are small cylindrical, and it takes a lot more effort to cool them and design a system around them. Obviously something Tesla has mastered but there might not be a lot of other car companies that want to go through all that development to do that. But the performance is pretty similar to what the other battery companies are doing.

We are at a stage where we have a kind of established a usable battery cell. What now becomes a difference is partly hardware, the pack design and cooling. That can make a slight difference in the overall energy density of the pack: how much energy you can get into the same size of pack. But I believe that the real big differentiator is the software, the battery management system, and what you do around it and how you actually deliver the energy and what you do with that battery management and how it pushes the limits of what's in the pack. And that's where you see some differentiator between Tesla and some of the other manufacturers out there.

If you look at Tesla, obviously they have the largest electric vehicle volume right now and have been working on battery cells with Panasonic producing them for a long time, so it looks like they have the lowest price. Normally in the last let's say 50 to 70 years, if any new entrant came into the market, it would be impossible for that new entrant to make a vehicle that would compete with the bigger carmakers like Toyota, Ford, GM etc. And the reason is that they all had the volume, and therefore they all had the supply chains set up with the right volume and the right cost base, because they had the volume. Now what is happening with electrification is that nobody has any real volume, except for Tesla. At this point in time, there is no car manufacturer, including Toyota, or whoever you mention, that makes over half a million electric vehicles a year. Now to truly get volume and get to where we are with gasoline cars and say when can we make an electric car which is cheaper or at least the same price as a gasoline car, you would probably need to have a supply chain for over a million electric vehicles a year. And at this point, nobody has that.

Now I just wanted to tie-in the development of solid-state battery technology. Just like in normal traditional gasoline OEMs, R&D departments are always working to improve it, and the same is happening in electrification. You are going to see two types of development. One is the development to improve the current technology, which can happen in three ways. One is improving the cell which most likely is mainly done by the battery makers because they understand everything about the chemistry. There may be some electric carmakers that are dabbling into that as well.

The second part is improving the pack itself, which is hardware, and that is probably happening a lot at the carmakers. And then the third part is the battery management system which is another area of improvement.

Now all these together can probably see improvement of 5% or 10% maybe every two years, something like that and that can be done and implemented in vehicles that are just coming out. If you launch a vehicle next year, two years later you can improve that vehicle with the battery technology you already have.

Some independent battery makers mainly, and some carmakers, are now looking into new solid state technologies, which a lot of people believe will be the future of battery technology because it can make a 50% or 100% improvement, which you probably can't make with current technology.

The issue here is that solid-state technology for pretty much everybody is still in the lab, at an early stage. We can build cells and get them to work, but they are not complete cells, meaning they are not fully optimised and ready in a small pilot line where you can make thousands of them consistently and up into a battery pack and test them in the car. Nobody is at the level. It is going to be at least 3-5 years at best case scenario, and I would probably go towards five years. That's best case. Other companies like Toyota are saying it's 10 years out [Editor's note: Toyota now plans to have a vehicle with solid state batteries in

production by 2025]. So I would say that any vehicle that comes out over the next five years most likely will have some derivative of today's battery technology.
What is going to become important, in my view, over the next 5-7 years is how to get the pricing down on the batteries to the same price or perhaps a better price than a similar gasoline vehicle. And the only way you can do that is to create a supply chain that has a million units a year. Now traditionally in the car industry, we have thought about that as having to be a giant car company like GM or Toyota, and you have to build that many vehicles. And once you get there, then nobody else can get there because they are all too small.

But what I think has changed with electrification is that, compared to a gasoline engine where the gasoline engine is a big part of the brand DNA of the car, I would argue that for an electric vehicle, neither the electric motors nor the battery is necessarily an important brand DNA of the car. That means that you could potentially share these parts between carmakers and get to that million volume between several carmakers. But it would mean that those carmakers who do share, they are able to more quickly get into the price points and the profit margins they need to sell these vehicles, and to get to the right price point and get the right profit because they now jointly have the volumes.

We have entered into a consortium like that, which we are not able to make public right now for competitive reasons. But that's our differentiator that we are going into a consortium like that where we are joining in the supply chain, where we can get into the pricing we need, because jointly with several other groups we are in a price point where we can offer an electric vehicle which is in my view is as good price, if not better than a similar gasoline vehicle. And that's a different approach. It's kind of the new sharing economy.

What it also means for us is that we won't have the battery supply chain issue when it comes to having enough capacity, because through this consortium we are already booked out for many years with a guaranteed supply. And that supply does come from those existing large battery makers and that's really our differentiator and I think that's going to be very important over the next 5-7 years. Sure, after maybe 7 or 10 years, there will be enough batteries for everybody and everybody will get close to the same pricing. But I think the winners and the losers, or at least those that get ahead of everybody else, will be determined in the next 5-7 years.

Daniel Harrison: On that point, you said initially you would launch the Fisker Ocean with batteries from an existing battery manufacturer. I'm not asking you to name them, but is that correct?

Henrik Fisker: That's correct. It's one of the five battery manufacturers that are really the biggest in the world.

Daniel Harrison: What we find most interesting about the battery supply chain is that it is structured in a very different way geographically. For example, in the past, you tended to source powertrain components, and you're right, the brand DNA of the engine was very much synonymous with the branding of the car. Nowadays with EVs that's commoditised to an extent. We see with VW with its MEB electric only platform being licensed to Ford and other smaller start-ups. And you're right that common platform allows that platform sharing. The sharing of the investment, but also the risk of developing that platform. Is that the way you see the industry heading, to much more shared common platforms?

Henrik Fisker: Absolutely. And I think there are several reasons for that. The first is what I mentioned earlier to be able to get to electrification fast enough and make money on it and lower the price point. That's one reason.

But I also think there is more of a trend reason socially in our society. I'm 56, and when I grew up, I would talk to my friends about what type of suspension the car had, how many cylinders the vehicle had, how many valves it had. And I remember even some vehicles when we had 4 valves, and the size of the engine, and was it rear wheel drive, front wheel drive. I think we are moving into a society where those things just aren't that interesting, especially for younger people. Of course, we still have some enthusiasts out there who are still interested in that, But the reality is that the majority of younger people, it is just less and less of an interest. I don't think if anyone knows if their vehicle has Macpherson suspension or Brembo brakes, or if they even care.

And for sure, I don't think they even care about what platform is under their vehicle. I mean, there is already platform sharing today between many vehicle brands. Some of the luxury brands like Rolls-Royce and Bentley, they are both largely sharing platforms with their German partners [BMW and Volkswagen Group, respective]. And I don't think anybody cares. What people care about is that they work really well. And the brand is clearly stated through design, quality of materials and the customer service. And now I think what we are moving into is the next level. I think once we had the smartphone, it changed the mindset of people. The type of service they expect, the type of interaction they expect. I think what's happening in the car industry is we are going to go through another huge turn where customers are going to expect a lot of more interaction digitally from the carmakers.

Obviously I have seen Tesla starting with that, and I think that's going to put a ripple effect into the rest of the car industry. And because of that, I think the customer is not going to care what type of battery cells is in the car. They are not going to care if Bosch makes this electric motor, or the car company itself makes it, or if it is made by Siemens or somebody else. The hardware in vehicles in the future, in my view, is going to be less and less important in the sense that it can easily be shared. And I think it's going to be very hard for anybody to charge a premium just by saying to the customer, 'Actually, we stamped that platform ourself,' or 'We spent $3 billion developing it over the past five years'.

I don't think you can sell that to the customer, except of course if you up in the supercar segment with McLaren and Ferrari and all these guys, where you paying a premium for carbon fibre chassis and all that. But I think if you are talking about mass market vehicles, that will change dramatically and I think you will end up with much more platform sharing. Maybe some of the large companies in the world will end up being the providers of these platforms and the base engineering for a lot of other car companies. I could totally see that happening.

Daniel Harrison: Up to now, OEMs have traditionally built ICE powertrains in house, such as the engine and gearbox, usually in the same region or country if not at the same plant in some cases. The battery supply chain, at least right now, appears to be much more dispersed regionally. The top five battery cell companies you mentioned are almost entirely located in China, Japan and South Korea. The materials, like lithium, cobalt, manganese and nickel are largely in those regions and Africa as well, particularly the cobalt. And of course, we have had huge supply chain disruption recently due to the Coronavirus outbreak. Is this supply chain dispersion an opportunity or a risk in terms of that supply chain security?

Henrik Fisker: Well, I think it's a little bit by default, because electrification has been very slow. I mean when Fisker started way back in 2007, and Tesla was there, there was only really two companies. During the last 7 years [up to 2020], even when you look at the global sales of electric cars, they have been very slow. My prediction is that the big uptake, when we really pass 10m vehicles per year, is probably going to happen around 2022 or 2023.

What is happening so far is there simply hasn't been enough reliable prediction of volumes for the supply chains to move, let's say, out of Korea. China has built it up internally because it is pushing electrification. I think you will see more local battery production. LG Chem has just put up a plant in Poland. I believe Samsung have announced a plant in Germany [Editor's note: Samsung SDI is investing in a second factory in Hungary]. Then you've got Northvolt in Sweden.

Over here in the US, SK have announced a factory is going to be up and running in a couple of years in Georgia. I think what you are seeing is as the volume of electric cars increases, you are going to see more local battery production. And the simple reason is also that batteries are such a large component, so heavy that they are very expensive to transport. It simply doesn't make sense, once we get to high volume, to transport batteries from continent to continent. So that's the first part.

The second part that you mentioned, the raw materials, they may still have to be shipped. Until recently, I sat on the board of a cobalt company, a mining company, in Canada. Its whole philosophy was to source locally because of the issues they have had around Congo, kids and slavery, and those are things the car industry is becoming of aware of. One thing customer demand more than anything is sustainability and sustainable sourcing of products as much as we can. In these days of the internet, you cannot afford negative things coming out that you have sourced materials that are not made in the right way.

Cobalt was really a by-product of other mining, sourced mainly in Congo for other industries. We have just found one of the largest cobalt mines outside of Africa, in Idaho. It's still not up and running, but it will be in a few years. I foresee that some of these minerals and materials that we need, we are going to source them in other countries from where we get them right now. That's number one.

Number two, these materials might end up being shipped in a very raw form and be refined in countries where you are actually making the batteries. I think you are going to see the whole supply chain changing as you see more battery manufacturing in Europe and the US, for example. It will happen because once you get to a certain volume, you just need to. And then I think you are going to start looking into demanding more of the suppliers of the raw materials in terms of how these materials are mined."

Daniel Harrison: I think you're right, by necessity it doesn't make sense to ship those heavy batteries across continents and this will move towards more local supply.

Henrik Fisker: Coronavirus has also partly opened up the world's eyes to the necessity of not relying upon one region for sourcing certain parts. Of course, if you look back in time a 100 years ago, everything was local, and you didn't have these issues and now we have this global supply chain. But what we have go to make sure that we dual source and we able to get enough things locally in the face of disruption, whether that is a virus or politics or many things. The car industry is definitely waking up to this and companies are thinking about how they source in the future and how they de-risk themselves so that they aren't in this situation where maybe they have to close a factory for six months.

Daniel Harrison: With the disruption from Covid, which shut down plants and dealerships, what has it meant to Fisker, which doesn't have production or sales until 2022? Do you see this crisis as a problem as an opportunity? [Editor's note: question was near the start of global shutdowns in the first lockdown.]

Henrik Fisker: Well, for us, clearly it's not a problem, because we don't have any volume, we don't have any supply chain that needs to be fulfilled over the next six months. We are still in development. It's not really a problem for us as a business at this point in time. In fact, strangely enough, we have seen more investor interest, which is very strange, particularly from the financial markets. What we understand is that there are now investors that truly believe that electrification might accelerate because of this virus and the thought is that people are going to think more about our climate and a cleaner world generally. So, I think the opportunity is maybe for people to re-think generally about life, how we live, what we do with our planet. You know I think these things, not to be too philosophical, but clearly having a weak immune system and being susceptible to these types of infections or viruses doesn't come from nowhere. Pollution creates lung disease and weak immune systems. And I think it is time for the world to wake up to and do something about it. Let's face it, automotive is the most polluting of all the industries. Gasoline cars are just super polluting. And it is really mass transportation that needs to be changed. It's not the Ferrari driven once a week, but it's the mass transportation which is why it extremely important that we get affordable electric vehicles to market and that is what we are aiming to do.

A.2 Jon Beasley, Director, Technology and Projects, Advanced Propulsion Centre (APC)

Interview in March 2020. An article based on this interview was also published by Automotive Logistics: https://www.automotivelogistics.media/electric-vehicles/the-supply-and-demand-of-power/40650.article

The APC, established in 2013 in the UK, is dedicated to accelerating R&D and bringing low-carbon transport more quickly to market. It is part of a £1 billion ($1.42 billion) programme on propulsion technology, half of which has been funded by the UK government and half by industry. At the time of interview, £900m of the £1 billion had been committed to supporting projects, which are already in various stages of trials. Among the projects APC will support is the Britishvolt gigafactory, which is planned to be built in the north-east of England by 2023.

Daniel Harrison: Just to clarify what the investment from APC involves, when you say advanced propulsion, you mean across the wide range of powertrains, drivetrains that are available?

Jon Beasley: That's correct. There are five strategic technologies that the Automotive Council [a body made up of industry and government] identified. The first one was thermal propulsion systems. The second is electrochemical energy storage. The third is E-machines and power electronics. The fourth is light weighting. The fifth, which we don't touch really, is intelligent mobility and electronics– and that is done through our sister organisation Zenzic. APC focuses on the first four.

Daniel Harrison: "In our forecasts of the different types of electric, hybrid and alternative powertrains, was that there wasn't going to be a single clear winner. It's going to be a very pluralised outlook with multiple powertrains. That creates opportunities as well as challenges, of course. Do you see a clear winner, or do you agree with that outlook that there is going to be a mixture of powertrains?

Jon Beasley: Firstly, I would say that I agree with that synopsis. There is no single silver bullet. The different duty cycles that are required by the different market sectors are driving what I would say are the preferred and most appropriate technologies at this point in time. We are at the start of a journey. And if there are significant breakthroughs in fuel cell technology or battery technology, then you might see significant movement into other areas. At the moment, I would say, small-to-medium passenger cars are ripe for electrification – and I think electrification in its many forms. It could be a plug-in hybrid conversion type. Or it could be a full 'b', battery EV. I think the issue between those two is literally supporting infrastructure and the types of operations. If you have someone who does a lot of long-distance motorway travelling for their work, they might be exposed with a full electric vehicle. If you have someone that does short round trips with relatively multiple charge point opportunities, then an electric vehicle is perfectly adequate and acceptable and appropriate for those people.

So as technology evolves we will see some blurring of those lines as we go forward. I think also when you start to look at the heavy-duty sector, at the moment the electrification story is not as clear. We are seeing a lot of downsizing, and further efficiency improvements of conventional engines, so they are trying to reduce the impact already of today's product. And they are looking at alternative such as fuel cells, such as the range extended type scenario where they can have hybrid drive, perhaps, conventional drive. New conventional drive on motorways, but then a range extender in a city environment where you can run on electrification.

Daniel Harrison: What we are finding is that the transition to hybrid and electrification is fundamentally changing the automotive industry in the sense that conventional internal combustion engines powertrains have generally been produced in-house by the automotive

OEMs or through joint ventures perhaps between OEMS. And now the supply chain is having to be reinvented because the powertrains are being brought in by other suppliers that are sometimes outside of the traditional automotive supply chain. Is that a challenge or an opportunity?

Jon Beasley: It is both to be brutally honest. And you are right it does [change the supply chain]. I think what we will see going forward is the need to be a refinement of current internal combustion engines as it seeks its new role. For example, if it is to be a range extender, you would not necessarily want the current architecture of engine. You might want something slightly different which will operate at a single speed or not as often. Now, that could be a transitional play or organisation that already invested in significant manufacturing capability and capacity. They’re not going to rip that up right away or immediately. And another challenge they have got is the transition itself. When will the market appear? It won’t unfortunately finish one product on a Friday and start a new one on the Monday. There needs to be transitional periods. And I think for the supply chains and the manufacturers it’s a very difficult balance in fully understanding how that market is going to materialise.

Daniel Harrison: We are forecasting that transition is going to be extended over the next 10 perhaps 15 or 20 years. Even then you’re absolutely right, internal combustion engines will still feature in the majority of powertrains whether they are hybridised or pure ICE. I think the issue we are finding is that investment is shifting heavily away from ICE development. It’s even been reported that Daimler has stopped all investment in developing internal combustion engines, for example. Do you think there is actually a danger of, as you say, neglecting internal combustion engines and any efficiency savings that can be had there?

Jon Beasley: I think there is, but again this comes down to sectors. If you are in a sector where you can see there is a transitional roadmap. i.e. you’ve got medium-to-heavy vehicles in a passenger car orientation and you can see electrification coming, then you would be doing a lot more research and development in electrification and potentially how you change your engine, or if you use an engine at all. However, that’s not to say that would be appropriate for everybody. If you look at some of the heavy-goods vehicles and the off-highway vehicles especially, they still require large-duty cycles that electrification will not necessarily manage. Some of the excavators, some of the diggers that we have, for example, they still need the next generation engine to be more refined, to be more efficient. And to use the energy on the vehicle itself. I think that is the other thing to recognise. Electrification isn’t solely drive. It’s actually recouping energy on the vehicle, so it’s not as wasteful as they previously were.

Daniel Harrison: Let's move to the passenger vehicle, the consumer sector, because that is the majority of the market. What do you think are the major challenges in persuading the public to purchase electric vehicles? Is it range? Is it charging infrastructure? Is it total cost of ownership? What do you think is the major barrier there?

Jon Beasley: I would put it down, not as total cost of ownership,, I would put it down as affordability and ownership models. At the moment, from what I can see, electrified products are more expensive compared to conventional. I am actually just looking, I have put an order at the moment for a plug-in hybrid going forward and if I look compared to conventional vehicles, it's between £5,000 and £6,000 more expensive. But that is not a surprise when you bear in mind that at the moment it is essentially a two-engine vehicle. Now that drives us forward to: 'What technology is going to happen? And I think there is going to be a move away from the more modular solution i.e. where we put an engine and an electric motor together, to a more integrated perspective. I think as the technology starts to merge, it's literally bolt-ons that become integrated in things."

Daniel Harrison: As I mentioned earlier, it tended to be the case that OEMs produced internal combustion engines in house, which usually meant the supply chain was reasonably localised, for example OEMs within Europe would tend to source from piston and crankshaft manufacturers from somewhere within Europe. With hybrid and electric vehicle powertrains, it's somewhat different in that the battery cells, the battery components and the raw materials upstream are very much sourced from various parts of the world, especially in Asia and Africa for minerals. How do you see that very different supply chain developing?

Jon Beasley: There is a significant difference in the future supply chain. That's a fact. However, how that is then embedded into trade negotiations, and commercial agreements is yet to be fully understood. I think what you will see is, if you look at the cell level, there is going to be more cell manufacturing across Europe and the UK for sure. Because in terms of just-in-time delivery and flexibility of manufacture, that's what car assembly plants require fairly close. It's no good having a shipload of cells coming from the Far East and having to wait a month for those parts and your numbers changes and you need to flex. You can't do that. I think there is a challenge there.

The second piece relates to raw materials. And you're right. There are small pockets of rare earth suppliers. I don't see that from a long-term perspective. Now that electrification is taking hold, lots of research and development is happening at trying to find alternative solutions in terms of the chemistry, in terms of the fundamental architecture etc. And trying to design out some of the supply chain insecurity. There is a lot of effort going on to support that at the moment."

Daniel Harrison: OK and where do you see that realistically going? Are you referring, for example, to cobalt-free battery cells? Or are you thinking more of solid state, or even more esoteric technologies?

Jon Beasley: I think yes, the move to solid state gives us new opportunities in the future . I think we are already seeing battery manufacturers trying to change the level of cobalt and nickel in their products to reduce some of the dependency. I can see more and more of that coming to the forefront.

One thing I would like to add, when you said Esoteric technologies, the one thing we haven't talked about is hydrogen.

Daniel Harrison: Yes, that is very relevant in terms of fuel cell vehicles which run on hydrogen. I believe China and Japan are by the far the most prominent leaders in this technology. I think I am correct in saying that prospects are much more realistic in commercial vehicles such as buses, trucks and coaches, than passenger vehicles, because they are point to point, installing the infrastructure is more realistic.

Jon Beasley: I would agree with what you have just said. In terms of the heavy goods sector, that's a potential alternative fuel to a normal combustion engine. You still need a degree of electrification with fuel cells as well, but obviously with your balance of plant you can decide if you need larger batteries or small batteries, and how you utilise the fuel cell. I think the other thing to watch for though is if fuel cells start to get traction in terms of how they are seen as a solution, again just like I said, some of the technologies will blur. You could be in a scenario where they start to be seen in larger SUV-type vehicles going forward, as an alternative to electrification.

Daniel Harrison: That makes sense, when large SUVs can often be 2-2.5 tonnes. They are almost becoming like a small commercial vehicle in weight and size.

Jon Beasley: Correct. I don't see the lead off in that sector, but I can see it blurring if the technology is successful and affordable as it would then percolate down.

Daniel Harrison: You mentioned just-in-time supply chains. That's very relevant given what's has happened with coronavirus across the world [Editor's note: the issue continues to be relevant in 2021 with the semi-conductor shortage and supply chain disruptions]. Do you see just-in-time and just-in-sequence supply chains inevitably continuing, or do you see a re-adjustment or a re-assessment of the practicalities of 'lean manufacturing'?

Jon Beasley: I think that they will continue and the main driver for that again comes back to the affordability piece. If you remove just-in-time supply chains and move to higher levels of working capital, the car manufacturers will be further exposed. They are already exposed to trying to develop future electrification strategies and products for a changing marketplace. They are also currently faced with the uncertainty of when does that market shift and trying to almost have duplicate capacity available. Or look at how can they set their existing capacity to makes two types of products. I think if you then set on top of that the idea of significantly higher levels of working capital for parts to be shipped around the world, it would make it very difficult for them. And that affordability wouldn't be sustainable.

Daniel Harrison: The coronavirus crisis is of course the number one issue right now. How do you see that impacting the European demand side? We have a lockdown in virtually every European country [editor's note: reference is the first wave of lockdowns in spring 2020]. Clearly it is going to hit demand heavily now, but do you see it rebounding later in the year, or do you see it being a reduction in 2020 and beyond?

Jon Beasley: No, I see rebound. Firstly, obviously it's very distressing. But as you said, we have got a scenario where this is not purely a restriction of supply. It's actually a restriction of demand as well. Therefore, I see and I hope that this is a temporary lull, and that whatever the solution is for coronavirus, whether it runs out due to natural causes, or whether an antidote or a vaccine is found, I think that is overcome, we will start to move back to levels of normality. But of course, we won't forget the fragility of the system. We are beginning to fully understand that and it's bringing it home. But we will adapt and go back to the old ways. I can't see any significant shifts as a result of this. There might be more focus on supply chain security and robustness and how you can flex in the future, but fundamentally, I think we will return to normal.

A.3 Kevin Brundish, CEO, AMTE Power

Interview in January 2020 (prior to AMTE's announced partnership with Britishvolt). A version of this interview was also published by Automotive Logistics: https://www.automotivelogistics.media/electric-vehicles/powerful-alternatives-for-the-automotive-sector/40614.article

In 2013, AMTE Power acquired AGM Batteries, which changed its name to AMTE Power in 2020. AMTE is based in Thurso, Caithness, Scotland, and currently has a small battery cell factory (0.1 GWh per year), serving a number of industries including defence, consumer electronics and automotive, which is its largest business segment. As a smaller player, the company has not set out to compete with larger players on volume or price, but to work in more niche and tailored applications. It has also been developing pioneering new technology, such as sodium-ion batteries.

AMTE Power has recently partnered with startup Britishvolt to build what would be the UK's largest battery gigafactory, with capacity for 30-35 GWh per year. After originally planning the factory in Wales, the companies now intend for the plant to be in Blythe, Northumberland in the northeast of England, relatively close to Nissan's Sunderland plant. Construction is slated to start in 2021 with the first phase open by 2023, and completed by 2027.

Daniel Harrison: Can you start off my giving me a brief outline of your company's involvement in lithium-ion batteries specifically?

Kevin Brundish: Our battery business was formed in the late 1990s and it was a joint venture between three entities. It was the outset of lithium-ion as a product, a market, and as an industry. A UK invention, lithium cobalt-oxide originated from Oxford. The company that set up AGM was part of that founding license for Sony. That's when the plant was really put in play, and its role in the early stages was to help develop supply chains, new product lines and new 'recipes' as I would call them for the production of high-quality lithium-ion cells.

It spent a number of years assisting supply chain partners and then it went into the supply base itself in quite a narrow field of defence and some other areas such as oil & gas. AMTE bought [AGM Batteries] in 2013 when it had run its course in those markets essentially. We wanted to take it back to its origins and re-purpose it and rather than it being a pure manufacturer – we were looking to bring different products to market particularly due to the way automotive was going. There would be a whole host of markets that, including automotive, probably wouldn't want to buy the solution that was readily available and would look for something more specialist. That's effectively what we have been doing for a number of years. Looking at bringing a slightly different supply chain to the automotive and other markets.

Daniel Harrison: Can you divulge the sort of production volumes or capacity that you have currently [in early 2020]?

Kevin Brundish: We are a 0.1 GWh production plant. In the scheme of production, we are relatively small, but agile. It gives us some strengths in being able to adapt to a whole range of different product lines, rather than being purely optimised for one product line. To give some perspective on that, the UK market is being judged as anywhere between 35 GWh and 105 GWh, so you can see we are a fairly modest scale. But that also belies our business plan, which is not to try and compete on the same product lines, but to offer the alternative product lines.

Daniel Harrison: What percentage does automotive represent in your battery business?

Kevin Brundish: We have got a couple of broad markets, and automotive is the dominant one as it stands at the moment. I am going to say it's 70-80% of our business, but it's a fairly big proportion. We are seeing growth in other areas coming alongside and they offer us very good opportunity in our space as well. Some of the other markets we focus on are more around consumer electronics, defence, and aerospace.

Daniel Harrison: That's an interesting point to pick up on, as there are growth markets alongside the enormous growth expected in electric vehicles. How does your experience in those industries differ to the automotive space?

Kevin Brundish: My view on the market space is that as automotive has picked up pace and demand has gone to high growth levels, there are a number of other things to consider. When automotive manufacturers first began looking at lithium-ion, there were views that they would want better performance cells, but I think it has been recognised that the current product can fill a role within a vehicle if its engine is designed appropriately.

We are therefore seeing a combination of an existing supply chain that can provide a product in large quantities now, but there is an underlying expectation that there will be development and newer products coming in, which is where we feel we sit as a company.

The other dynamic that the automotive market has led is that because it is placing very big orders on the battery supply chain, it's tying in quite a lot of the suppliers. These are the new manufacturing sites coming along already keyed in with vehicle manufacturers. There are other markets that would have traditionally looked for those battery and cell providers to develop a product and continue to mature it, and they are not seeing that. Therefore, I think some of the consumer electronics and defence markets are looking for alternative products and continual evolution that might not align with what automotive is currently engaged with. We are seeing that side of the market dynamic as well. It's brilliant to be in this space because there aren't a huge amount of entities focused on products in those areas. Because mainstream automotive is so large, most people are focused, and it has left a fairly open space for companies like ourselves. Within that cluster, we have the niche vehicle manufacturers, who don't always want to buy the same product line that the mainstream vehicle manufacturers are looking at. There are a whole host of markets and clients who are looking for alternative products lines compared to the mainstream vehicle manufacturers that are buying up at the moment.

Daniel Harrison: That's a great point. Can you indicate which automotive manufacturers you have any arrangements with?

Kevin Brundish: It's quite tricky for me to disclose any particular names. But there is some publicly referenceable material about some of the people that we are working with, and it's quite varied. Mainly what we are looking at doing is helping the supply chain, for those that perhaps fall under the minimum order quantities, or those that are looking for different performance parameters from the cell. For those niche vehicle manufacturers, we have teamed up with a number on development programmes to find a solution.

Daniel Harrison: Yes, we see that Renault is a supporter of your sodium-ion project, although not an active partner. One of the issues we are finding is that 'battery supplier' is perhaps over simplified in the sense that the way cells are supplied is very different according to the supplier. For example, some battery suppliers supply just the cells, or the module, whereas some get involved in the battery pack assembly. What is your take on that? Does it vary in the industry?

Kevin Brundish: It does vary in a whole host of ways. Some vehicle manufacturers want to buy the cells and do all the integration themselves, seeing an element of competitive edge deriving from that. Some just don't have the capacity to put those skills in play, so rely more on integrators and battery assemblers, and there is quite a space and emerging players in that. I think the UK has a lot of competencies like that, with Cosworth, Ricardo, and similar companies sitting in that space. Where we sit? We actually do a little bit of everything as well. It's an interesting dynamic. It's one of those spaces where you might compete in one arena but be a partner and collaborator or even a supplier in another client base. But again, it really depends on the strategy of the vehicle manufacturer as to how that plays out.

Daniel Harrison: When you are supplying to automotive clients, what are the challenges you are finding? Is it one of price? Security of the raw material supply> Is it the current constraints of your production capacity?

Kevin Brundish: If I go back to your point about it being overly simplified, about what exactly that supply chain is, I think from our perspective we are obviously on the very modest volume side. The supply chain side is fine, and what we are trying to not do is provide a competitively priced product compared to a mass manufacturer. That just wouldn’t work, and we don’t have the volumes to match that.

What we therefore do is look at products where the demand levels are smaller, but there is a premium to be paid on the performance enhancements that we bring. Obviously there are challenges where we may provide a product that is harder to manufacture and therefore the way we price it would differ from cells that had come from a mass manufacturer. Some of those challenges obviously exist when understanding how cells are made, what goes into that manufacturing process, and why they are differ in price as they might do. Of course, we have issues of that nature. But actually, most of the companies we deal with are quite educated, and they have huge resources and expertise that fully understand the manufacturing processes and therefore fully understand why pricings vary. Those challenges are not really there for us, in the mainstream. We have got a very accommodating client base because we are providing products they have specified, and they need. We are either developing the solution for them or we have the solution for them, therefore all those upsides come from that.

Bringing any new product to market is a process that we have got the right skills to do, and that level of expertise isn’t something every industry player has. Big manufacturers don’t necessarily have all the skills to develop a new product. Whereas we do have the right skill base and client base. Once those challenges are overcome, it’s really a matter of tackling the commercial side early, and once people understand that, then the supply base is quite plausible. Obviously there is no point in looking at a potential product if it doesn’t meet the pricing and commercial expectations of the client base. Therefore, one of the things we are quite careful about is ensuring that we have the right engagements before we start that production process.

Daniel Harrison: A lot of has been of the transportation and logistics of moving large heavy batteries. They are often regarded as hazardous goods, according to particular regulations in certain countries and regions. Is that a major issue in supplying batteries to clients?

Kevin Brundish: We have a good mix of international clients, and of course we do ship products. Part of the new products we have been launching are looking at negating all of those challenges about hazardous goods. We have been working on developing a chemistry called sodium-ion, which can be transported as inert chemicals, because all the energy can be removed from that particular cell – falling outside of that hazardous good act. There are a lot of products that we can ship through more readily available means.

There are a couple of things when it comes to the sort of market position on shipping goods. The volumes being shipped are obviously large. They do fall under hazardous goods, but it's been going on for some time, so it does get done. There are a couple of things that don't always get picked out, however. One is that the amount of capital tied up on the high seas is going to go up and of course, there is a financial implication with that. The other thing we need to look at is the carbon footprint within this transportation. That is why in a lot of instances, you are now seeing in-country supply chains developing, because it can address those points about carbon footprint and cash tied up on transport.

What that is moving us towards is a growth of UK supply. Because we are operating within in country where our products differentiate us from everywhere else, we are seeing international opportunity. We have higher performing products than what you can typically buy off the shelf, therefore we are getting quite a lot of international interest as well as national. But just on the national side, there a particular interest in the fact that we are a battery and cell supplier ourselves, so we are getting some good growth opportunities.

Daniel Harrison: The industry trend at the high end is obviously towards these very large gigafactories to achieve economies of scale and low price, but from what you are saying, you are not trying to competing with them on price, but on the basis of quality for niche clients, would that be correct?

Kevin Brundish: We obviously have our own views on expansion and growth within the company that would encompass something along the lines of a larger factory [editor's note: AMTE has since confirmed gigafactory plans with Britishvolt], but you're exactly right. As a company, we aren't really positioning ourselves to compete against the very large manufacturers. We are looking at being the next generation of product and getting a decent supply level in play. Then if the demand, obviously the mainstream manufacturers could adopt the technology at that point under a license arrangement or something of that nature. Therefore, I think you're absolutely right, we are putting ourselves in a space which is not competitive with larger suppliers and could even provide a feeder of next generation technologies and products.

Daniel Harrison: Do you see sodium-ion as a steppingstone from existing lithium-ion technologies to the holy grail of yet-to-be commercialised solid state battery technologies?

Kevin Brundish: Our work on sodium-ion brings slightly different benefits. It falls within the performance of the lithium-ion battery family but offers the replacement of lithium and therefore a cheaper supply chain. But there are also safety features to note. We can operate at more extreme conditions, and because we can remove the charge, there is an easier logistics angle. It has good market opportunities in transport potentially, but more often we would be looking at harsh climates, hot environments, or where safety is a very key feature. If you are looking at how the lithium-ion battery gives that up to provide its optimal theoretical performance, well it’s practical performance, and you are looking towards solid state. At the moment this isn’t a product that is readily available or in the mainstream, but there are continual developments and evolutions. Not only do we continue to monitor that progress, but we also actually actively work in that space with a number of companies. One good example is just to see how our plant could adapt to manufacturing something like solid state. As those products become more readily available or cross different markets, we are able to support the production of those.

Daniel Harrison: Just going back to the sodium-ion batteries that you are involved in developing, if they are cheaper and much safer, as you say, is it merely a matter of waiting for them to be developed and fully commercialised before they come to market realistically?

Kevin Brundish: Effectively, that’s right. There are two things. We obviously now have got the product to a certain maturity. As with certification it goes hand in hand with the market space about what you exactly do to certify the product. But broadly speaking, there is another aspect which is that you need to find that first market adopter. When you are not producing in enormous volumes, you have to ramp that volume up. That’s something that we have been working hard on. We have found early adopter markets that we are getting very strong traction with, and we hope that the current calendar year will see us gaining some traction and getting that product actually out onto the market. It really is just that commercial footing that we have got to manage and overcome. It’s a sort of a sales and certification process in reality, rather than a deep product development.

Daniel Harrison: Where do you see the main growth opportunities for AMTE specifically and for automotive battery applications more generally?

Kevin Brundish: I will go back to the two areas. The market space is niche vehicle manufacturers and consumer electronics – the area that we see a lot of growth. We have a lot of products, but specifically in niche vehicles we are seeing quite a lot of demand for high power products. I guess the implication for that is obvious, that it goes towards performance rather than cost etc. We are seeing a lot of demand in that space, and I think we see that as a very large growth area beyond where we are today.

A.4 Mireia Sentis, Supply Chain Lead, Battery and eDrivetrain at Vantage Power, Allison Transmission

Interview in February 2020. A version of this interview was also published by Automotive Logistics: https://www.automotivelogistics.media/electric-vehicles/a-vantage-point-on-power-supply/40620.article

Vantage Power, founded in 2011, is specialist provider of electrification and connectivity technology, which commercial vehicle powertrain manufacturer Allison Transmission acquired in 2019. Vantage Power has been involved in projects including retrofitting hybrid buses in the UK, and have developed batteries among other systems to support electric powertrains. Since being acquired by Allison, the division is playing a key role in commercial vehicle electrification across batteries, hybrid and electric design and integration.

Daniel Harrison: Can you briefly explain your role at Vantage Power?

Mireia Sentis: I have been working for Vantage Power for over seven years. I started in more of a technical role before moving into a commercial role around five years ago. My focus is on developing supplier relationships and sourcing complex components and systems for commercial electric vehicles. So, these could include battery components and a variety of system components, chargers, electric pumps, power steering systems, electric compressors, electric heaters amongst others.

Daniel Harrison: Are commercial vehicles the focus of the company because you think that is the area of growth or market development, or is that for other reasons?

Mireia Sentis: Both Allison Transmission and Vantage Power have commercial vehicle focus at their cores, and this is where we want to deploy our extensive experience. It is also worth noting that in terms of vehicle emissions and environmental impact, commercial vehicles are disproportionately responsible when compared to passenger cars, for example. As such, electrifying commercial vehicles has the potential to have a significant favourable impact.

Daniel Harrison: The research we have done so far shows that part of the challenge is that EV batteries are still a very new supply chain. It’s got to be developed, not just for the battery cells, the raw materials, the battery modules, the packs assembly, even the recycling after use. Is that a challenge that you also find?

Mireia Sentis: Yes, it is a new and evolving supply chain. We already have vast electrification experience and a volume of battery products in the field. For commercial vehicles, the volumes are still low, and the market still seems to be trying to identify the best battery technology for the harsh and demanding commercial vehicle duty cycles. That's where Allison and Vantage have a head start. We have over 17 years of experience integrating and optimising battery packs into commercial vehicles through the Allison H 40/50 EP electric hybrid propulsion system. That system supports transit applications, one of the most demanding and severe duty cycles for commercial vehicles.

The trend shows that passenger car OEMs, where most volume and battery supply commitments are right now, are the ones that drive technology developments and consequently, supply chain evolution. However, more and more we see CV OEMs and integrators entering strategic partnerships with battery suppliers, participating on the construction of a supply chain where we all could leverage the latest technology and economies of scale in the long term.

Daniel Harrison: That confirms our finding that while the investment and focus is on the large players building gigafactories, there are smaller battery suppliers who obviously can't compete on the economies of scale or price but can compete on performance. There may be particular niche applications, where for example a battery pack has a particular weight or size, or performance, that the big volume battery manufacturers cannot achieve because they are usually focused on the cheapest possible price. That suggests that batteries are not a commoditised product – quite the opposite, there are differences in quality and size and performance. Is that also where you see an opportunity in carving out a niche?

Mireia Sentis: Actually, that's a good point. Allison Transmission products are known for their quality and performance, these are their areas of differentiation in the market. For any current and future projects where we will be sourcing a 'battery type' product, Vantage Power goals will be to deliver a battery pack solution that achieves Allison Transmission levels of quality, reliability, durability, and safety.

Vantage Power has extensive experience in battery pack development, and we believe that when evaluating a battery solution, it is not just about the cost you pay today to the supplier, it is a more complex exercise where the total cost of ownership and value-added technology features to the final pack solution plays a big role. Therefore, the CV battery market where requirements are more demanding and also the volumes might not yet be ready for economies of scale could prove a niche opportunity, at least in the near-term planning horizon.

Daniel Harrison: Traditional automotive manufacturers and OEMs produce in house most of the powertrains – the engines, the gearboxes etc. However, many outsource hybrid and electric vehicle powertrains to third party companies. Different OEMs have a different involvement in the battery cell, battery module, battery pack assembly. There is a concern that they are losing a part of the value chain that can be 40% the value of the vehicle. Do you see that as a risk or opportunity?

Mireia Sentis: That is a very interesting point. It is something we have already seen and heard from the commercial vehicle OEMs we are working with. Currently vehicle OEMs are still exploring the most viable commercial strategy based on resources, capabilities and expertise. There seem to be two different approaches – we have seen strategic partnerships arising where vehicle OEMS, tier 1s and integrators as the main players collaborate to bring final electric powertrain solution into the market. It is generally popular for big vehicle OEMs or tier 1s to bring the whole value chain in house and this has been supported by recent company acquisitions.

There is a technology inflexion point and we all need to be aware that this will introduce new ways of sourcing and manufacturing. OEMs might lose a lot of the value chain, at least until the technology and solutions mature, but batteries are a unique product. To be able to design, manufacture, manipulate, service and sell battery products, any company doing any of the previous needs to have a proven history within the battery space. This will evolve over the time, but for the technology to mature, keeping battery development and value chains localised within those expert parties is required in the near term."

Daniel Harrison: For European production, most internal combustion engines were typically sourced usually from within Europe. Now you have a much more extended supply chain for battery cells being produced in Asia and the raw materials in a limited number of locations around the world. What do you see as the solution to that situation, if any?

Mireia Sentis: The vast majority of battery products including raw materials currently come from outside Europe and unfortunately we don't have much leverage in those areas. Europe is getting anxious about the potential of battery shortages and governments have started to support efforts to spur a European manufacturing industry. Asian suppliers have also seen an opportunity in international markets and have signed joint ventures and contracts with European OEMs for the supply of battery products for the long-term.

Regular communications with battery suppliers are critical. An important aspect of good control over your supply chain is finding the best ways of communicating with your suppliers, whether that's by phone, e-mails or video calls right now. Standard automotive supply chains might have been predictable for a while, but things are changing and we are also adapting and learning at the same time.

Daniel Harrison: How do you the coronavirus pandemic impacting your supply chain [editor's note: question is in reference to first wave of lockdowns in spring 2020]?

Mireia Sentis: We still don't know the full impact that this will have on the supply chain, or the electrification adoption curve in general. We have already found improvements from our Asian suppliers in the last few weeks. Now our European and other suppliers around the world are suffering from this pandemic. We are all experiencing an unprecedented situation. Many companies' plans might be affected because of the situation, but we also see opportunity in the challenges facing the industry.

Daniel Harrison: What do you think is the major challenge in the battery supply chain and the development of commercial electric vehicles?

Mireia Sentis: As a supply chain professional, this could be how to leverage the latest battery technology and how to position your company as a higher priority to battery suppliers. The global growth in EVs is now a reality and this will affect raw material availability and cost. Coming back to my point about volumes and who gets business priority, I think passenger car manufacturers are leading versus commercial vehicles because of the level of commitment translated into monetary investment or financial contracts that are able to support battery suppliers.

As we move forward with CV electrification developments, we might encounter supply chain bottlenecks at early stages due to technology accessibility and business cases, but I am convinced that we will overcome these. Firstly, because battery technology is one key long-term solution to cleaner global mobility. And secondly, because expert companies are already researching and developing an evolution of battery technology that could potentially solve future raw material sourcing issues.

A.5 Chip Breitenkamp, Ph.D. VP of business development, NanoGraf

Interview in October 2020.

NanoGraf is an anode materials startup, based in Chicago, Illinois, which is making a graphene silicone composite material aimed at improving energy density. It is already producing material and in the validation process with OEMs and battery markers for its technology. In June 2020, the US Department of Defense confirmed that it would provide a $1.65m grant to help develop its silicon anode-based technology, with a goal of increasing battery run time by 50-100% compared to traditional graphite anode lithium-ion cells.

Daniel Harrison: You have partnered with major automotive OEMs such as FCA, GM and Ford. What's the nature of that relationship? Do you have future or current supply agreements or this more at the R&D stage?

Chip Breitenkamp: Those particular relationships are at sort of two tiers. That is with the US ABC (US Advanced Battery Consortium), which is a consortium of the big three automakers, and the relationship that we have with them is longer term, strategic, almost like a research relationship. They have funded us to develop advanced anode technologies that could be used in US vehicles. Over the course of a few years, they have given us over $12m to do that research.

Separately from that though, we also have many other relationships with the EV OEMs, not just in the US, but also in Europe, Japan, Korea. We are in various stages of evaluating our material, or they are evaluating our material for use in batteries that would go into their vehicles. There is no supply agreement yet. Generally, for doing these types of deals with EV OEMs, the validation cycles are just very long. Our goal is somewhere around 2024-2025 timeframe, you would see our material in one of those batteries, and I think that's consistent with a lot of other advanced silicon technologies that are out there.

Daniel Harrison: So, your company is very much in the research stage, assisting OEMs in the longer term horizon for EV batteries.

Chip Breitenkamp: Well, I wouldn't necessarily call it research stage. Our technology is fairly mature in the sense that we make tonnes of our material now. The issue with getting our material into a battery, any material for that matter, is the long validation timeline. The batteries have to be optimised, then have to be tested over many years to be able to predict what it's going to do over a 10-year life of a car, so that just takes time. I would call them pre-commercial validations. Our primary technology is clearly mature in terms of what's out there for silicon technology.

Daniel Harrison: There is a trend between OEMs and battery cell manufacturers increasingly to have joint ventures, investing jointly in plants to mitigate the risk and share investment costs. Do you agree with that or have any plans along those lines?

Chip Breitenkamp: For us, our ultimate customer is the battery supply, and we have a number of joint development agreements with battery suppliers to do that type of research to get our material into their batteries. I think the strategy at the EV OEM level, for example with Toyota and Panasonic who have this joint venture, I think that really makes sense for them. The battery is the huge cost component of an EV, and so being able to have this kind of relationship, not only to lower risk, but to do what you can to compete on cost as well really makes sense. From our perspective, ultimately we are selling to a battery marker, so I am not sure that that type of arrangement is as applicable to us as it would be between a battery maker and an EV OEM.

Daniel Harrison: Where do you see the challenge within the battery supply chain, for example there have been some issues around the supply of raw materials like lithium, cobalt, nickel, manganese for example. Or is it more the ramping up of volumes at the gigafactory level. Where do you see the bottleneck?

Chip Breitenkamp: To be honest with, you, I think both of those present their own unique challenges. What we have seen, especially during Covid, there are tremendous supply chain risks. And if I am looking at this through the lens of a citizen, China has really spent the last decade dominating the battery supply chain and it is very strategic and very smart. Being able to have access to things like cobalt, lithium and even graphite, those are just not raw materials that we have much access to here in the US. For us, looking at it, it almost becomes a national security issue. If Covid had stopped all supplies of these materials from China, we wouldn't have access to them. And it kind of sets up a situation, almost like in the 1970s, where we didn't have control over oil and other things, and I think it is going to become that level of a national security issue, and I think Covid really highlighted that.

I think that second part of your question is also equally interesting because. Gigafactories take a lot of money to build and there has to be some amount of demand for those batteries to justify those investments. Obviously that has happened in Asia already, and it's happening in Europe as well. I think to see those kinds of gigafactories being built in North America, we are going to have to see that same sort of demand for EVs increase. We are starting to get there. I think Tesla has certainly accelerated that quite a bit, but there are other things we can do to stimulate that demand, which will then in turn spur the investments to make batteries in these gigafactories. So it's all interconnected and I see them all as bottlenecks.

Again, looking at this through a US and North American lens, some of these things are already starting to open up in Europe, as we have seen the battery supply chain move from Asia to Europe.

Daniel Harrison: Yes, we saw recently that Tesla revealed that it was aiming for vertical integration with plans to take on parts of the cell production and even the cathode production to bring it in-house. What do you make of that development?

Chip Breitenkamp: Yes, I think Tesla is going to basically accelerate a strategy that may trickle down to other EV OEMs. I think that some vertical integration is going to be a trend over the next five years. Tesla, specifically, laid out the problem pretty swiftly. They want to sell a lot more cars and you do the math in terms of how many batteries they are going to need to do that and you are looking at the supply chain and saying 'there's not enough lithium for us to do that'. OK, we are not going to wait around for someone to mine lithium for us, we are going to do it ourselves, you know then same with cathodes, maybe there is not enough cobalt out there. We need to start transitioning to higher nickel cathodes and maybe we need to be controlling the supply of that nickel to be able to make the number of cars that we need.

The second thing is being able to get the cost down to where we can really start to kick off that supply chain need in the US, because I think that's good for everyone. So for Tesla's 'battery day', I think we may look back on that day in five years as a turning point for a lot of different changes in the way that EV makers strategically think about the supply chain.

Certainly, for NanoGraf it was tremendously helpful, because everyone is starting to realise that performance is great, certainly we need performance, we need to push performance, we need to push the energy density of the batteries, but at the end of the day cost is just as important as performance. And there are lot of silicon-anode technologies out there. A lot of people have really focused on really highly engineering approaches to that, which just aren't going to be cost effective. And for NanoGraf that's something we have always been hyper focused on. We want to make the best performing material, but we want to make it in a way that going to be cost effective and is actually going to be able to be implemented at the volumes that are needed for electric vehicles. So 'battery day' was super interesting for us, it was kind of a shot in the arm as well.

Daniel Harrison: There is a question around whether it is even viable for North America to start mining raw materials for Tesla to try and move to that localisation of supply?

Chip Breitenkamp: My honest take on that was, first of all cobalt is its own piece, as cobalt doesn't really exist in north America, and most of that in the [Democratic Republic of] Congo. There is some nickel for example in Canada, but not nearly what they have in Indonesia, Australia and other parts of the world. Yes, they can absolutely mine lithium in North America, but I think what Tesla and Elon Musk were really trying to do at the end of the day was to kick the big lithium miners into gear and to basically tell them: 'If you are not going to go out and mine this, then we are'. I think there are only two big lithium producers, Albermarle and Livent, and I think they have really held back on production of lithium to try to keep the price high, which has really frustrated Tesla because they see a need for more of that mineral. I'm not sure how practical that is and I'm not sure how cost effective they could do it. I don't even know if they even understand the environmental implications like the regulations that are involved or how long it would take to get those permits. There is a lot of speculation again and that was sabre rattling a little bit. It's definitely making people think about it. At the end of the day, if it gets people to move and gets more raw materials out into the marketplace then it's going to be good in being able to get the cost down for electric vehicles which is ultimately what everyone's trying to do.

Daniel Harrison: NanoGraf says its silicon anode material enables faster charging and lasts 40% longer. Does that mean it extends the range of the battery or the capacity?

Chip Breitenkamp: Yes, that's exactly right, yes, so fundamentally silicon holds about 9-10 times more lithium than graphite, which is the incumbent anode material. By blending our material into the anode, that's exactly right, we can increase the capacity, anywhere between 20-40%, which actually translates into real miles driven. When you think about energy density, it is also a cost thing as well. Using a more energy dense material also means we can get the cost down. The secret sauce that we've really tried to push is adding graphene as a surface layer to our silicon core technology and that's really what sets us apart and makes us unique. Graphene of course is highly conductive, reduces the resistivity and that answers things like fast charging and with the silicon we get the added benefit of being to really increase the capacity of the battery."

Daniel Harrison: Do you see your technology as particularly valuable to specific end uses for electric vehicles? I am thinking of delivery and logistics vehicles and transport industries using commercial-level electric vehicles. Have you thought of or targeted that sector as well?

Chip Breitenkamp: I don't know that we have actually thought about that in terms of targeted marketing. When people are considering this transition from combustion engines to electric vehicles, I think that is still one of the bottlenecks. From a technology perspective, the batteries that we have today are quite great. I think the two things that we want to be able push is being able to drive faster or longer. For delivery vehicles, that means being able to deliver everything you need during the day and not have to recharge, but if you do, you want to make that as quick as possible. Right now, I could go to gas pump and fill my car up in 2-3 minutes. Even 15-20 minutes to charge could be the psychological deterrent for wanting to buy an electric vehicle. So anything we can do to reduce that and increase range is going to be helpful for all those applications. But yes, in terms of targeted marketing, I don't think that we have really thought about that at this point, but certainly it should help for all those applications.

Daniel Harrison: Given the silicon material that you use, which helps stabilise the active materials, does that make the battery less dangerous to transport, for example?

Chip Breitenkamp: In terms of safety, we don't really think about it in those terms. The things that make the battery 'dangerous' really have to more to do with the electrolyte and the cathode. What we can say is that graphene is not only electrically conductive, but also thermally conductive as well. So that's a really inherent, great property of being able to dissipate heat. When you are using the battery, when it's in the pack and being cycled and being used, being able to dissipate heat is a huge advantage in terms of safety. If we look at this from the safety perspective, that is sort of the angle that we use, because we know that graphene can dissipate heat. In terms of transportation, I don't know that graphene would really play much of a role there, but it certainly does during the use of the battery.

Daniel Harrison: By how much does NanoGraf's manufacturing process cut the price of producing a lithium-ion battery. Have you made a calculation along those lines?

Chip Breitenkamp: Yes, definitely. We know we can reach cost parity with graphite on a dollar per kilowatt hour in about a 500-1,000 tonne scale and that is not a whole lot when you consider Tesla right now uses 3,000 tonnes of silicon a year, in very small amounts in the batteries that Panasonic makes for them. So, once we get past that 1,000-tonne level, we actually start to become cheaper than graphite, and that's when you can start to see those cost savings. If you saw 'battery day' for example, Tesla talked about its metallurgical silicon approach – which I take issue with from a technology perspective – but they did show you how by including something more energy dense like silicone, you can actually start to cut the cost. That's where we know we can get to be cheaper than graphite at about a 1,000-tonne per year scale. To just to give you a little more perspective, the reason we can do that is because all of our manufacturing processes are very straightforward, they are easily scalable, they are wet chemistry processes, they don't require exotic gas or chemical vapour deposition technology. There is nothing inherently expensive about the manufacturing processes or the raw materials. So we can really capture the economies of scale pretty quickly and I think that's what sets us apart from a lot of other silicon anode technologies."

Daniel Harrison: What are the important battery innovations that you foresee on the horizon, and how might they affect the battery supply chain and /or the manufacturing process?

Chip Breitenkamp: When you look at the current state of lithium-ion batteries, I honestly don't see that changing for the next ten years. You know the current process of using high nickel cathodes and graphite-based anodes. For the cathode proportion of the battery, those technological advances are really sort of capped out at this point. All we can really do is start to remove cobalt, which is going to reduce the cost and remove some of the supply chain risk. But in terms of energy density, there's really nothing that can be done on the cathode side. I would say that silicon is going to be the driver for battery performance for the next five year, possibly even ten.

People are of course also talking about solid state batteries. Companies like Quantumscape, which has partnered with VW and recently went public, no one really knows what they have or how will it perform. There is certainly a lot of talk of solid state batteries, and we would need to have a whole other call to talk about that! But at a high level, there is a lot of scepticism about that technology, when it is going to be commercialised, and if it can even be commercialised for something like an electric vehicle. I think at best that's ten years away, and so I think that if you are looking at the current lithium-ion process, over the next decade silicon is going to be the big driver of performance and reduced costs. And that's why we think we are at a pretty good place at a good time.

B. Regulations Around Transporting Lithium-Ion Batteries

Among the challenges in producing and transporting lithium-ion cells and batteries are complications in transport, storing and handling them. Lithium batteries are classified as dangerous goods (DG) and are subject to UN Class 3 'Flammable Liquid' classification according to the United Nations Economic and Social Council's UN Recommendations on the Transport of Dangerous Goods (DG).

Transporting lithium-ion batteries as cells or as a complete battery pack is usually more restrictive and challenging than with the finished vehicle. Unlike a finished vehicle, a battery pack on its own will not have the battery management system operational to regulate and control the battery pack.

The rules for moving batteries vary by transport mode and in some cases by region.

Table B.1 Transport Modes Compared Regarding Movement of Lithium-Ion Batteries

Road: The European Agreement regarding the International Carriage of Dangerous Goods by Road (ADR) was created in Geneva on 30 September 1957 under the United National Economic Commission for Europe, and this was further amended and released on 19 April 1985.

In 2017 the ADR legislation was amended for electric vehicles: 'Dangerous goods that they (the vehicles) contain that are necessary for the operation of their equipment are not generally subject to the requirements of ADR, with the exception of lithium batteries which must meet the requirements of 2.2.9.1.7.' Details of the requirements for lithium batteries can be found under the 2.2.9.1.7 classification in the ADR manual.

Sea: Similar laws exist for the transport of dangerous goods for sea shipping issued as outlined by the International Maritime Dangerous Goods Code, which uses the International Maritime Dangerous Goods Code. These do require some extra precautions and monitoring of fire risks, including extra documentation. These regulations, which are amended almost every two years, do not pose significant challenges for transporting finished electric vehicles.

Rail: Rules are set in the Technical Instructions for the Safe Transport of Dangerous Goods by Rail, issued by the Intergovernmental Organization for International Carriage by Rail. While rail services in Europe allow the transport of ECVs with the right documentation, certain other countries – notably China – continue to have legislation in place that does not allow products containing lithium to be transported. In 2019 the Chinese government stated that it would lift the restrictions on the transport of lithium batteries by rail, and this includes products which contain lithium-ion batteries such as EVs. However, it is understood that this lifting has been delayed.

Air: Rules are laid out in the Technical Instructions for the Safe Transport of Dangerous Goods by Air, issued by the International Civil Aviation Organization. Current regulations state that no finished products containing lithium-ion batteries can be held in the cargo area of aircraft. EVs therefore must be shipped by air without batteries, which must then follow strict guidelines. No products containing over two grams of lithium can be held in the cargo areas of aircraft.

Source: ADR, IMO, ICAO, Automotive from Ultima Media

C. Glossary

AESC	Automotive Energy Supply Corporation
AGR	Annual Growth Rate
Anode	The electrode that releases electrons on discharge, the positive side.
BaaS	Battery as a Service
BMS	Battery Management System
BYD	Build Your Dreams. OEM and battery cell manufacturer
CATL	Contemporary Amperex Technology Ltd.
CAGR	Compound Annual Growth Rate
Cathode	The electrode that receives electrons through the discharge process
CSR	Corporate Social Responsibility
COVID-19	The official scientific name for the Coronavirus
CV	Commercial Vehicle
Electrolyte	A conductive medium enabling lithium ions to move from anode to cathode
Energy Density	The amount of energy (Wh) that a battery can deliver per unit of volume
EV	Electric Vehicle
FCA	Fiat Chrysler Automobiles
FCV / FCEV	Fuel Cell Vehicle / Fuel Cell Electric Vehicle
Gigafactory	A very large battery factory although there is no precise agreed definition, it usually refers to a factory above 1 GWh per annum
GWh	Giga Watt Hour = 1,000,000,000 watts per hour
HEV	Hybrid Electric Vehicle
ICE	Internal Combustion Engine
JV	Joint Venture
KWh	Kilo Watt hour = 1,000 watts per hour
LCO	Lithium Cobalt Oxide. Cathode material with a chemical formula of $LiCoO_2$. LCO has high specific energy and high cost due to high cobalt content.
Li-Ion	Lithium Ion battery
LFP	Lithium Iron Phosphate. A type of cathode material containing $LiFePO_4$. LFP is one of the safest li-ion battery cathodes, but with low specific energy.
M&A	Mergers & Acquisitions
MHEV	Mild Hybrid Electric Vehicle
mtpa	Million Tonnes Per Annum
MWh	Mega Watt Hour = 1,000,000 watts per hour

NCA	Nickel Cobalt Aluminium. Cathodes containing nickel, cobalt and aluminium.
NCM	Nickel Cobalt Manganese. Cathodes containing nickel, cobalt & manganese.
NiMh	Nickel Metal Hydride. A cheaper lower capacity battery technology to Li-Ion
NMC	Nickel Manganese Cobalt Cathodes containing nickel, manganese and cobalt
OEM	Original Equipment Manufacturer
PEVE	Primearth EV. Battery cell manufacturer.
PHEV	Plug-in Hybrid Electric Vehicle
PSA	Peugeot SA Group incorporating brands Peugeot, Citroen & DS
R&D	Research & Development
RNM	The Renault-Nissan-Mitsubishi alliance
ROI	Return On Investment
Separator	A barrier between the positive (anode) and negative (cathode) electrodes
SKI	SK Innovation. Battery cell manufacturer.
Terrafactory	A battery factory with a capacity over 1 TWh per year.
Ternary Battery	A type of battery whose cathode is typically either NCM or NCA
Tier Supplier	A company that supplies components for the vehicle, Tier 1's supply direct to OEMs. Tier 2's supply to Tier 1's. Tier 3 supply the raw materials.
TMS	Thermal Management System
tpy	Tonnes per year
X-EV	An umbrella term for all types of electric and hybrid vehicles
Wh/kg	Watt Hours per Kilogram. A measure of battery power density.

D. Credits

Ultima Media Ltd *part of* Süddeutscher Verlag
401 King Street
Hammersmith
London, W6 9NJ
www.ultimamedia.com
P: +44 (0)20 8987 0900

Disclaimer

All facts and figures are believed to be accurate at the time of publication; Ultima Media accepts no responsibility for inaccuracies due to future developments in the market or incorrect information provided by Ultima Media's sources. Ultima Media is unable to accept any legal liability for any consequential loss or damage, however caused, arising as a result of any actions taken on the basis of the information provided in this report.

Contact Details

Daniel Harrison (report author)
Automotive Analyst
daniel.harrison@ultimamedia.com
P: +44 (0)208 987 0946

Christopher Ludwig
Editor-in-Chief
christopher.ludwig@ultimamedia.com
P: +44 (0)208 987 0968