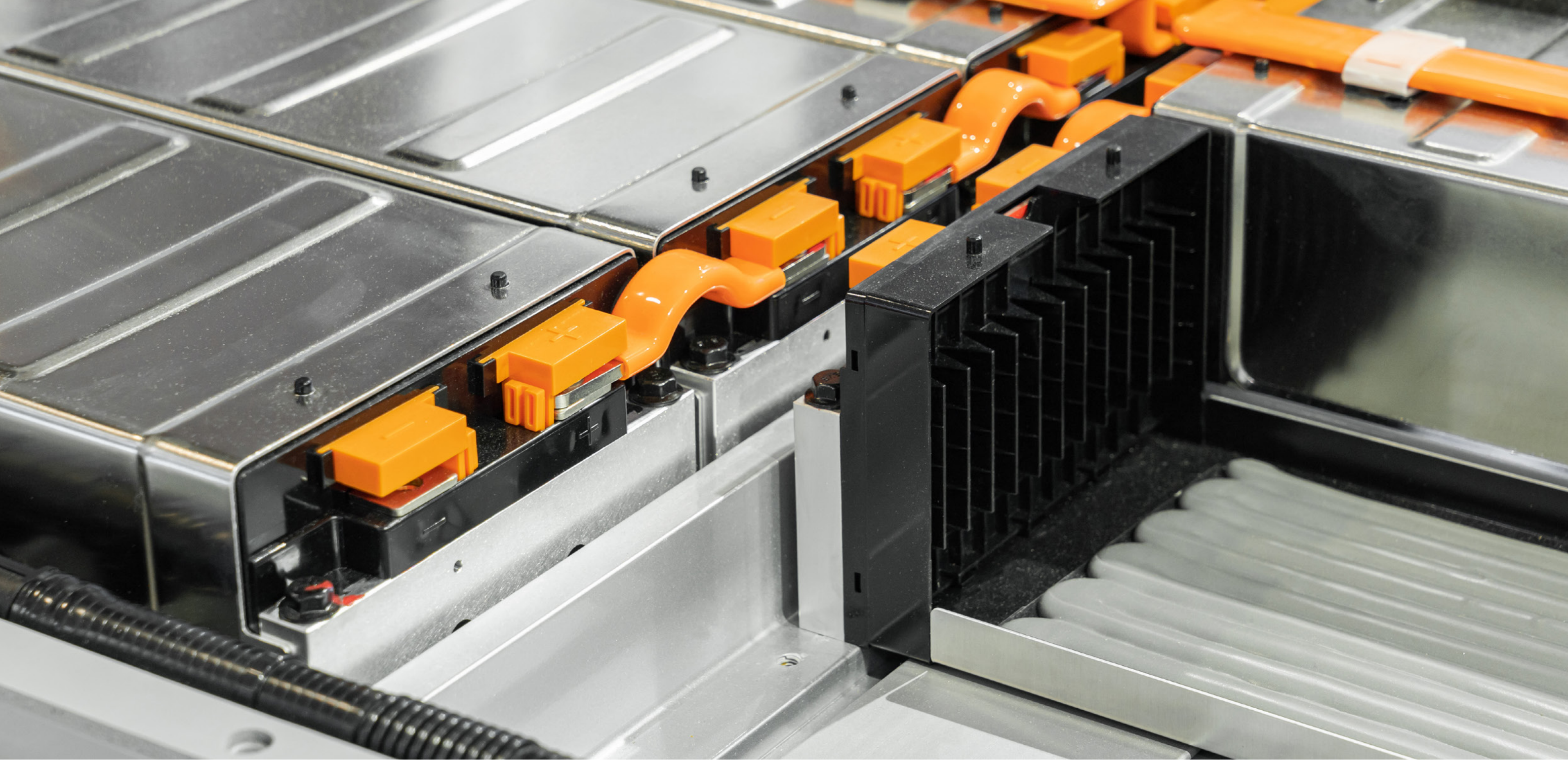
PART I

POWERING CHANGE

How batteries can foster the electric vehicle revolution



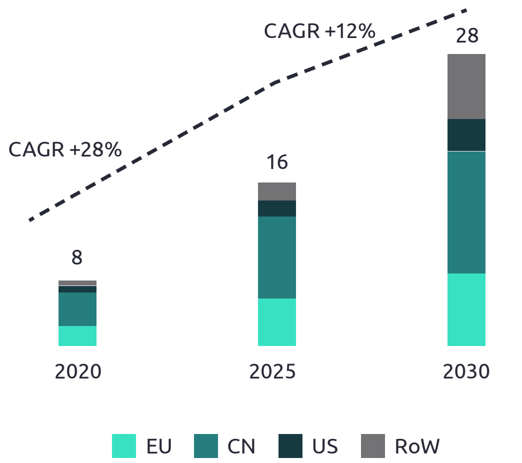
A burgeoning market shaped by major trends

According to the European Environment Agency (EEA) batteries in electric vehicles are a key technology for designing a sustainable transport system and achieving long term climate protection targets in the transport sector.[1]

An increasingly vibrant market for battery-powered electric vehicles will make a tangible contribution to improving the standard of living and air quality, especially in cities.
In addition to improving the quality of life, electromobility also offers important industrial opportunities. After all, the most valuable component of electric vehicles is the battery. Compared to a fuel tank, an electric vehicle battery is much more complex. It also represents a major stake of the total value of an electric vehicle. When looking at the entire battery value chain, including its production and recycling components, it becomes apparent that there is nothing insurmountable preventing a broad market diffusion of batteries, which will likely enter a crucial ramp-up phase in 2020-2030+. Member of the European Parliament (MEPs) are even projecting a 700-fold increase in recyclable lithium batteries from 2020 to 2040.[2]

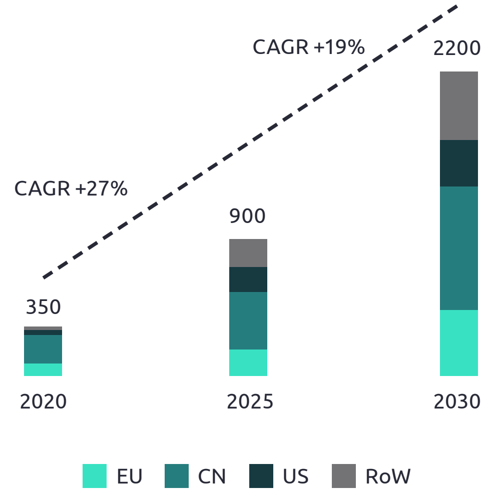
Global electric vehicles market

(Millions of new vehicles sold)



Battery demand

(in GWh)



Including PHEV and BEV; Summarizing Light-duty Vehicles (i.e., Passenger Cars), Bus and Trucks Sales, assumptions consider growing average battery size per vehicle within the next years; sales are based on the International Energy Agency STEPS Scenario, STEPS is the Stated Policies Scenario.

Global EV market growth drives worldwide battery demand in GWh[3]

[1]EEA (2021) [2]Europäisches Parlament (2020)
[3]WEF (2019), STEPS (2022), International Energy Agency (2022)

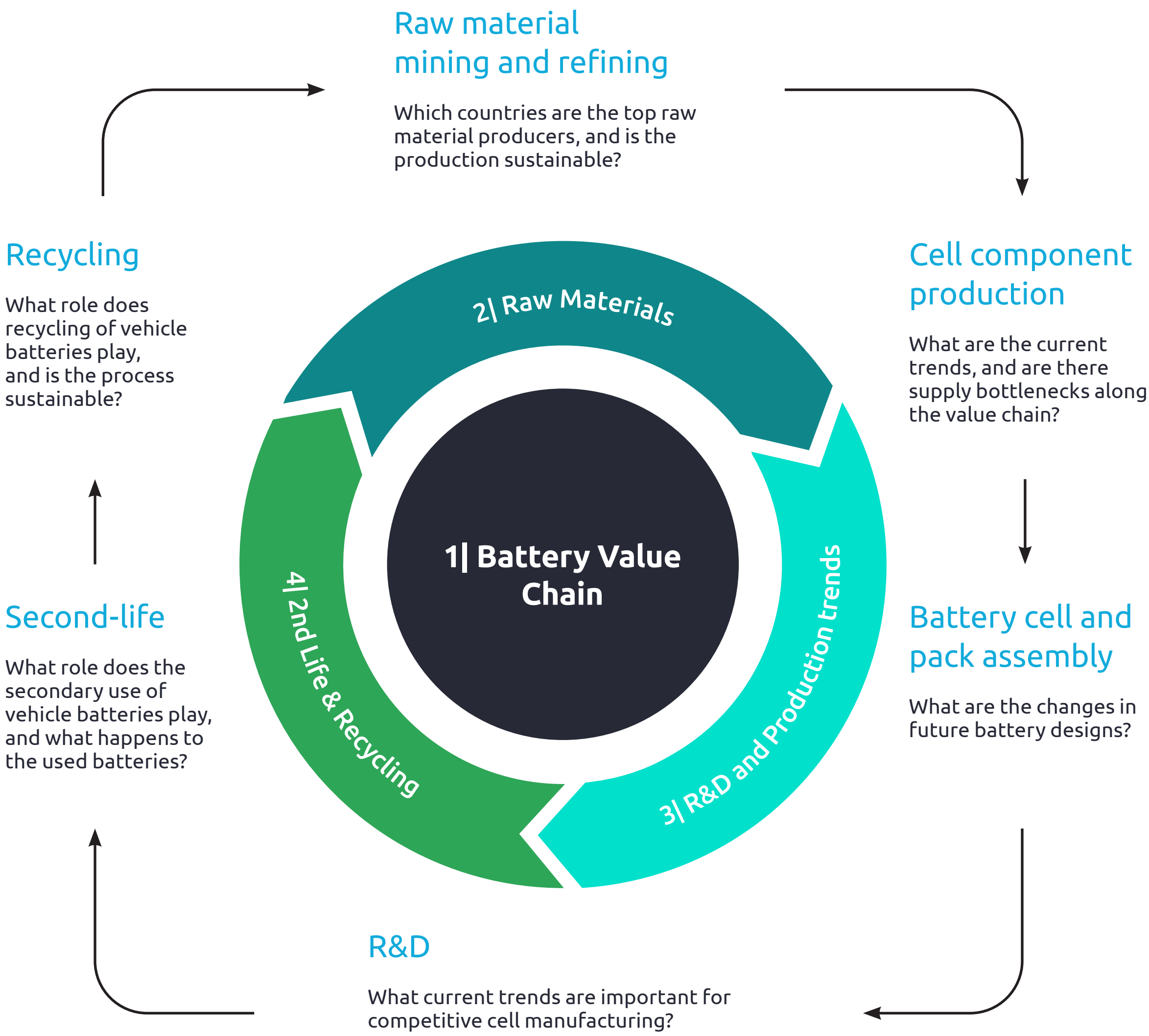
Since a tidal wave of demand for batteries is predicted, companies are getting ready to take advantage, with growing investment in R&D for both product and manufacturing.

Growing demand not only triggers more production, it also kindles technological innovation (e.g., longer-lasting batteries that can be charged faster). This in turn lowers costs and increases the demand for batteries. The adoption of battery electric vehicles (BEVs) will continue to increase as the vehicles become more affordable for the average consumer. This will be facilitated by economies of scale, enabling a higher number of manufactured goods with better quality and lower cost. As a result, it will become necessary to strengthen and diversify the battery supply chain, especially where raw materials are concerned.

According to the IEA (2021), global automotive battery production reached 160 GWh in 2020 (up 33% from 2019) and the average cost declined 13%. The global average for battery packs reached a price of USD 137 per kWh. Battery production continues to be dominated by China, which accounts for over 70% of global cell production capacity. The country also produces about half of all batteries for light-duty vehicles. Many of these vehicles are produced to meet domestic demand. In fact, China accounts for the largest share of demand at almost 80 GWh. But in 2020, Europe had the greatest increase (+110%), reaching 52 GWh.[4]

This point of view explores such key findings and shines a brighter light on the battery value chain, raw materials outlook, battery production trends, second-life use cases, and business models.

In the following section, the most important findings are summarized, followed by a more detailed presentation in the chapters.



Battery Value Chain

[4]International Energy Agency (2021)

What are the current trends and are there supply bottlenecks along the value chain?

Even today, temporary supply bottlenecks with various causes exist along the value chain. Such bottlenecks can be found in battery raw materials and cell production. The production and delivery of BEVs have their own hurdles to overcome. A major impediment in the EV supply chain is the lag in battery cell manufacturing.

There is a need to augment and scale the existing supply chain. Many companies are aware of this and are countering the risk through, for example, supplier diversification, strategic industry collaborations along the value chain, research collaborations, joint ventures, and in-house production to secure capacity and favorable pricing.

These examples indicate a trend in which automotive component suppliers are readily investing in eMobility solutions; this trend will continue over the next decade as companies prepare for widespread BEV adoption. These efforts, supported by policymakers, should be maintained in the future to reduce the supply dependencies of the industry. In order to do this, it's essential that the automotive sector develops a flourishing - potentially regional - battery supply chain.

"Battery production and raw material extraction are fundamental levers for a sustainable EV value chain."

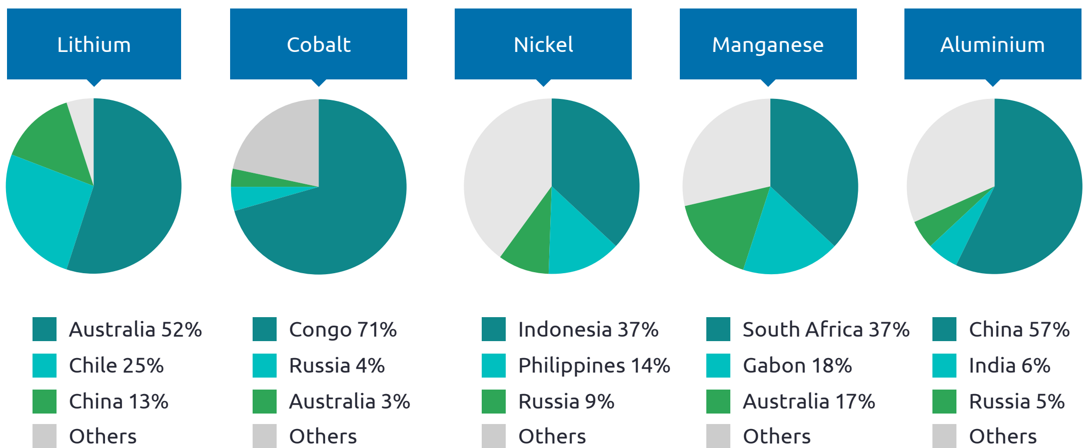
- Sebastian Tschödrich, Executive Vice President, Head of Automotive Global

Which countries are the top raw materials producers and is the production sustainable?

Raw materials have always represented a large portion of the total costs for batteries both at the cell and the system level. However, recent price increases in many materials such as lithium, nickel, manganese, and cobalt are only exacerbating the challenges that OEMs face. As a result, price reduction at the battery system level has been slow to take effect in the automotive industry.

Irrespective of the cost factor, the extraction of raw materials and the production of technical components are associated with environmental and social risks. These risks grow in severity in countries where weaker state institutions introduce more lenient legislation. In the value chain of e-vehicles, the impacts of battery production and raw material extraction represent environmental flashpoints. Both the high demand for raw materials and the complexity of production processes are to blame. Often, the result is inadequate local environmental, social, and safety standards and the lack of control and regulatory mechanisms worsen the corresponding impacts.

The most often used battery raw materials are lithium, cobalt, nickel, and manganese. They are all theoretically available in sufficient



Top three countries in raw materials production[5]

[5]U.S. Geological Survey (2022)

quantities worldwide.
However, temporary shortages or price increases for individual raw materials cannot be ruled out.For example, there is a possibility that new production sites will need to be developed, raw materials mining will not meet rising demand, and exports from the producing countries will not be sufficient.

In the extraction of lithium from salt lakes in Chile, Argentina, and Bolivia, water usage in a region with water scarcity is one of the main problems. However, research is needed on the specific impact of lithium extraction on the groundwater level and alternative, more water efficient methods. Closely related to this issue are conflicts with local Indigenous populations.[6]

Precarious working conditions can occur in supply chain constellations with missing E2E transparency regarding mining conditions and raw materials extraction. International due diligence initiatives, including their enshrinement in law, are sensible starting points. Better conditions, on the other hand, can be achieved by relocating production. To this end, MEPs call for future factories to be built on abundant brownfield sites so as not to contribute to the irretrievable destruction of farmland, forests, or water protection areas. To be sustainable, we need to think holistically about sustainability.[8]

Companies should be aware of these ethical and environmental challenges.

What current trends are important for competitive cell manufacturing?

According to the European Commission, Electric car batteries fall into the category of traction batteries. Nowadays, they are

[6]U.S. Geological Survey (2022) [7]Tagesspiegel (2022) [8]ÖDP Bundesverband (2022)

subject to many mass-market requirements. In the context of the European Green Deal, one of the European Commission's goals is to minimize the environmental impact of batteries and increase the penetration of electric vehicles.
In addition to the environmental compatibility of the battery value chain, other requirements play a role in the production of batteries, such as price reductions, scalability, performance, energy content, service life, and safety. Gigafactories that are currently being built must be flexible and scalable to meet the requirements of future battery technology and demand.

Batteries should e developed according to a recyclable design for a sustainable circular economy. However, as with the conventional battery manufacturing process to date, Li-ion batteries have a complex structure in which individual cells are assembled into modules, which in turn are assembled into a battery pack. Due to their complicated structure, their disassembly and the associated risks are not only slow and tedious, but the recycling of lithium-ion batteries is also more time-consuming and consequently expensive. This is because battery cells often use adhesives to bond the modules and the package together, which can only be dissolved with molecular organic compounds during the recycling process. This complicates the recovery of used materials. Furthermore, compositions are not labeled, which makes it difficult to identify and classify battery chemistry.
Mandatory legislation or policies are needed to drive recycling efficiency and standardization.

In addition to the policy measures for increasing the efficiency of recycling, there are practical applications. For example, there is much talk about Design for Recycling (DfR). This term is used to refer to a holistic approach to recycling end-of-life (EOL) products, optimizing the consumption of energy and materials. As an aspect of eco-design, it gives manufacturers a roadmap to develop their products with recycling in mind. A strategy that embraces DfR should consider the use of modular design, reduction of disassembly operations, the use of simple and all-purpose tools, and the use of reusable fasteners.

Today, battery design is increasingly moving to a "cell-to-pack" design.

Unlike the previous conventional battery manufacturing process, in which battery cells are first combined into modules and these are then combined into a battery pack, cell-to-pack technology (CTP) is used to directly integrate cells in the battery pack. This eliminates the intermediate step of module formation, resulting in significantly higher volume and mass integration efficiency, as well as space and weight savings.

All this is a step in the right direction. However, electric vehicle production and battery assembly is still in its infancy at many traditional automakers. For many, standardization of solutions has not yet been achieved. Additionally, each manufacturer follows its own battery design, which leads to many manual steps in EV battery assembly. As a result, while ramping up production, EV manufacturers often encounter battery production bottlenecks.

To meet future demand, battery manufacturers also need to fully automate their processes and increase process speed. Automation of battery production is key to improving assembly reliability, ensuring quality and traceability, and controlling battery costs. Gigafactories should leverage Internet of Things (IOT) technology to keep pace with the demand for data. Furthermore,
the use of digital twins enables second-life and other use cases that facilitate the recycling process.

What role does the secondary use of vehicle batteries play and what happens to the used batteries?

In the relatively nascent electromobility market, used batteries have not yet played a major role. Electric car batteries contain valuable materials. Their recovery and recycling in the raw materials cycle is essential, especially since some of these materials are finite. Concepts for the secondary use of batteries are currently being tested and expected to reach mass market applications in the near future, followed by a significant increase in the availability of end-of-life EV batteries, approximately from 2025 onwards. These solutions will evolve in step with the recyclable materials market ramping up in the next 10 to 15 years.[9]

Viable business models would require that second-life batteries are available at a low enough cost with sufficient residual performance and can be effectively reintegrated into the value chain. Questions of standardization and warranty (for example, through appropriate operator and owner models) must be taken into account in any viable economic business model. But whether this can be achieved is still the subject of hot debate.

To realize this, it is imperative that second-life batteries hold sufficient power to meet the requirements of most secondary applications and avoid being consigned straight to recycling. However, the recycling of vehicle batteries is now considered technically feasible and is currently being implemented industrially in pilot plants, leading to formal regulation. For instance, the recycling of lithium-ion batteries (Li-Ion) from end-of-life vehicles is regulated within the European Union by Directive 2006/66/EC. Recycling efficiency for lithium-ion batteries will reach 65% in 2025 and could be as high as 70% in 2030. The recycling efficiency of a recycling process is obtained by relating the mass of secondary raw materials recovered (output fractions) to the mass of spent batteries fed into the process (input fractions).[10]
This directive was adopted by the plenary on March 11 and will represent Parliament's negotiating position with EU governments on the final form of the legislation. The European Parliament now agrees that managing the full lifecycle of the battery will enable the EU Green Deal to be achieved.

Furthermore, Simona Bonafè, rapporteur for the EU's Circular Economy Package, pointed out that 700 times more lithium batteries are waiting to be recycled between 2020 and 2040.[11] [12] Currently, three different methods are used to recycle batteries from e-vehicles: pyro-metallurgy (smelt solution), hydrometallurgy (aqueous solution), and direct recycling (recover-functional solution) of raw materials.

[9]Fraunhofer (2020) [10]Europäisches Parlament (2020) [11]European Commission (2022) [12]Open Access Government (2022)

Advantages of second life and recycling e-car batteries:

Avoiding supply bottlenecks and dependencies and the risk of a shortage of raw materials

In the field of e-batteries, the world market is currently extremely dependent on China. China is the main importer of most raw materials. All manufacturing steps, from the import of minerals to the export of battery cells, are dominated by Chinese companies. At certain times – such as during the COVID-19 pandemic – the impact of such dependencies along the supply chain for the global market is felt more keenly than ever. Improved recycling and a resulting circular economy could provide more stability.[13]

Increasing range and acceleration capability

Previously, batteries that no longer deliver the desired range or acceleration capability in traction applications could still find use in extended, second-life applications such as energy storage systems.

Increasing sustainability

The secondary use of batteries via second-life or recycling is attractive because the carbon footprint associated with battery production could be significantly lower than new batteries. However, the recycling of lithium-ion vehicle batteries creates more challenges for safe and environmentally friendly recycling than regular device batteries. One reason for this is that Li-Ion batteries are much larger and heavier and have much more stored energy than device batteries.[14]

The potential reduction of costs

The growing interest in the reuse of batteries also comes down to, of course, their potentially low costs. But it's worth noting that this is only possible if used batteries meet the requirements for safety, reliability and a minimum residual life for secondary applications.

> *"Second-life solutions are an important step of the transformation towards a circular economy."*
>
> *- Siegfried Adam, Director, Digital & Sustainable Mobility*

[13]BMZ (2020) [14]Öko-Institut e.V. (2011)

1

ELECTRIC DREAMS: THE BATTERY VALUE CHAIN OF A MORE SUSTAINABLE FUTURE

> *"Global electric car sales indicate a reduction in consumers' range anxiety."*
>
> *- Dr. Philipp Haaf, Director, Head of Electric Mobility*

With growing concerns about climate change and environmental degradation, sustainability has become a strategic priority for automotive organizations. One of the central components of this is electrification: many OEMs decided to switch to electric vehicles within the next years and enable climate neutral passenger transportation. Key to achieving this is improving the internal battery supply; that includes optimizing production, repairing, recycling, and significantly reduced battery costs.[16] The automotive OEMs' strategies are already reflected in global electric vehicle sales, which are beginning to conquer the mobility market at a rapid pace. Even though 2021 was a difficult year for automotive OEMs, who faced challenges such as a global chip shortage, global electric car sales have more than doubled over the past 12 months (6.6 million in 2021 compared to 3.0 million in 2020).[16] Batteries are critical to further the largescale adoption of electric vehicles. They store electrical energy and are the equivalent of a fuel tank in a combustion engine. Compared to a fuel tank, however, an electric vehicle battery is much more complex and represents a major stake of the total value of an electric vehicle. Furthermore, batteries are a key differentiating factor for automotive OEMs due to the so-called "range anxiety" of drivers. Range anxiety refers to concerns about the mileage an electric can provide between charge stops, and the overall fit of an electric vehicle into their daily lives.

[15]Volkswagen (2022) [16]EV-volumes.com

1.1 The battery and its value chain: the heart of the electric vehicle

Today around 99% of the EV batteries used in electric vehicle powertrains are lithium-ion batteries. This is because lithium-ion batteries (Li-Ion) are characterized by a high energy density, the ability to endure many charging cycles, and a high current capability, high power-to-weight ratio to name a few. Within the range of Li-Ion batteries, there are several compositions that differ by the metal dopant that is used. These compositions come in different price points, have different ranges, and are constantly evolving with technological advancements.

The production of the li-ion batteries is complex, which is also reflected in the supply chain that consists of four steps that are shown below.The first step is raw material mining and refining. This includes the exploration of raw materials and their production, processing, refining, and conversion into materials that can be used in the development of the cathodes and anodes of batteries. We take a deeper look at the raw material section of the supply chain in chapter two.

Cell component production is the second step and covers the production of the main components of a Li-Ion battery: the cathode, anode, electrolyte, and separator. The cathode serves as the source of lithium-ions and determines the capacity and the average voltage of a battery, whereas the anode stores and releases lithium-ions from the cathode. The separator prevents contact between cathode and anode and electrolytes are the medium that facilitates the movement of the ions.[17]

The third step of the supply chain is battery cell and pack assembly, which starts with the battery cell assembling into group cells that have similar operating parameters in the first place. These batterycell groups are then welded to a module, tested, and later inserted into pack housings. This step is repeated several times until all modules are inserted. These modules are then integrated with other battery management and power components.

The fourth step is system integration with the vehicle. This is the last process step before operational life, in which the battery is integrated into the vehicle. This involves connecting the battery to the vehicle's powertrain and other application verticals, such as energy storage, electronics, and other sub-systems.

Closing the circle of the battery value chain after production and integration are the operational life, recycling, and second-life phases. Learn more about recycling and second-life use cases as a business opportunity in Chapter 4.

[17] Samsung SDI (2022)

1.2 The battery value chain ecosystem is emerging

The increasing demand for electric vehicles and current supply chain bottlenecks in the semiconductor chip market are forcing OEMs to rethink their strategy on how to source Li-Ion batteries. In general, the spectrum of strategies being considered ranges from low control and completely outsourced battery pack production to a third-party supplier to full control with in-house capabilities to be able to produce a battery. Until recently, most OEMs focused on exclusive agreements with single third-party suppliers that carried all the risks that a partnership with high dependency can come with. In addition to that, outsourcing an element that accounts for a majority of the total vehicle value is another clear risk. To avoid such risks, there are two clear trends emerging. Firstly, OEMs are increasingly diversifying the supply chain by signing agreements with multiple battery suppliers to reduce dependency on a single supplier. OEMs are paying very close attention to the geographical aspects of diversification and are building up strategic near-shore relationships in Europe or US to decrease dependency to Asia, reduce the carbon footprint for raw material extraction and better secure delivery chains in the case of crisis. Even more interesting is the second trend – that OEMs are moving away from low control to total control, as evidenced by the increasing number of partnerships and joint ventures between battery manufacturers and OEMs.

Even between raw materials suppliers and battery manufacturers or OEMs long term supply contracts are more common or even considerations to source own raw materials. One example of such a collaboration between recycling and battery producers is the agreement and strategic investment between Li-Cycle and LG Chem/LG ES to deliver and recycle battery materials for about 300,000 electric vehicles.[18] Such collaboration models make suppliers share investment costs in R&D and provide OEMs important access to battery technology and the battery manufacturing process.

> *"Diversifying, localizing and in-sourcing are key priorities for European OEMs along the battery value chain."*
>
> *- Sebastian Tschödrich, Executive Vice President, Head of Automotive Global*

Key players in each sector

[18]Electrive 2021

Three examples which underpin this trend:

1. In 2021 Volkswagen intensified its funding of the Swedish cell producer Northvolt AB by investing a further €500 million to hold a stake of 20% in the company. The funds are to be used for capacity expansion in the fields of production, recycling, and R&D. Beside such cooperations, Volkswagen intensified their own efforts and will built 6 Gigafactories in Europe. The new strategic business unit PowerCo will bundle their activities around the battery value chain, with further investments of 20bn until 2030. The first factory built by Volkswagen will be in Salzgitter, and it is expected to go live in 2025.[19]

2. Volvo and Northvolt will build a gigafactory in Sweden with a potential 50 GWh capacity. The battery production is scheduled to be running in 2025, producing batteries for Polestar and Volvo, which are both owned by the Geely Group.

3. Another example for such a partnership is the Verkor initiative joined by Capgemini to built a fully digitalized 16 GWh Gigafactoriy in France. [20]

1.3 Recommendations for action

To state the obvious, there can be no electrified product portfolio without cutting-edge battery technology. In the coming years, the industry will experience a seismic shift in priorities. OEMs that do not optimize and prepare their value chain for a more sustainable future run the risk of becoming obsolete. A successful course correction is not only necessary, it is pressing. Reprioritizing a portfolio entails research and analysis, things that cannot happen overnight. As such, it is imperative businesses take action before the ship sails and opportunity is left on the shore.

A successful supply chain is diversified across the board. For OEMs, it all begins with geography. Delivery capabilities hinge upon maintaining diversified depots. Supply chains that can utilize a multitude of locations have better logistical options during times of crisis. But these facilities are only as useful as the resources they store. As such, OEMs should consider diversifying the location of their resources or even source locally. This helps to mitigate the impact of delivery shortages in certain regions.

To accelerate portfolio restructuring, OEMs can enter into partnerships with companies who have already proven their mettle in the industry. Strategic partnerships in battery production can lead to knowledge sharing for the inexperienced party and cost sharing for the one with expertise. Moreover, the success of project-specific partnerships has the potential to foster future developments and fast-track brand recognition. And since demand for batteries is ever increasing, all of this is necessary once an OEM takes those first steps.

Key considerations

The growing demand for batteries is being driven by new regulations and the cultural zeitgeist. Decarbonization is perhaps the defining feature of modern business and society at large. As such, OEMs should build for the future. When setting up their own production facilities, long-term demand should be at the forefront of their infrastructure plans. In Naypyitaw, Myanmar, local authorities built sixteen-lane-wide highways for a population that barely exceeded 340,000 people. This is because future redevelopment would be both costly and disruptive. OEMs would benefit from the same approach and should design now for long-term success.

[19] Volkswagen AG (2021) [20] Volvo (2022) [21] Capgemini (2021) [22] EENewseurop (2021)

Which countries are the top raw material producers, and is the production sustainable? Find out next week in chapter II of Powering Change, or download the full report now on our website.

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