The future of the automotive sector

Emerging battery value chains in Europe

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Abstract

This battery study analyses the ramping-up of lithium-ion battery cell production in Europe. It outlines lithium-ion battery technology, the value chain, location factors, the innovation system and the employment effects. The report aims to identify the strengths, weaknesses, opportunities and threats of Europe as a location and its global role in battery cell production. A location matrix identifies attractive European locations for battery cell production plants and compares Europe's competitiveness with the main players USA, China, South Korea and Japan. European demand scenarios are calculated and Europe is expected to meet its demand until 2030, and even build up export capacities, provided that all the projects that have been announced can be successfully implemented. Then it will also be able to increase its share in global production at the expense of China. An analysis of the technical innovation system identifies the interplay between the actors and the framework conditions which will stimulate battery cell production in Europe. Analysis of the employment effects paints a diverse picture of job losses and job creation alongside a high demand for retraining.

1. Introduction

With the policy framework unfolding over the last ten years and being put into place for the next ten to twenty, the transition to electric mobility has become inevitable. Examples of such a framework are:

- The European Commission in July 2021 put forward the 'Fit for 55' package of legislative proposals including setting a -100% CO_2-standard for new cars by 2035. This implies that all sales of cars in the EU would have to be either battery electric vehicles (BEV) or fuel cell electric vehicles (FCEV) (EC COM(2021) 556).
- Over the past three to five years automakers themselves have continuously raised their ambitions concerning the share of electrified car sales they are planning for in 2030. Across the board the range is between 70 per cent and 100 per cent.

So, there is no question about the 'if', the question is only about 'how' to cope with the transition to electric mobility. This working paper sheds light on the case of battery production, one pillar of the transition, which is of particular importance for the future of the European automotive industry. This paper thus focuses on battery cell production in Europe, analyses the status quo and outlines the future developments that can be expected up to 2030. It is thereby limited to lithium-ion batteries (LiB) for automotive applications, as that is seen to be the dominant technology in the next decade.

Section 1 outlines the status and development of battery technology and the battery value chain, while section 2 addresses battery production in Europe and the strategies of European original equipment manufacturers (OEMs). Section 3 analyses the cost structure of cars, comparing battery electric and internal combustion engine (ICE) vehicles, section 4 adds an innovation system analysis while section 5 looks at the employment effects. Section 6 evaluates what is at stake for the European automobile industry and section 7 concludes.

2. Status and development of battery technology and the battery value chain

This report is focused on lithium-based batteries as this technology has been identified to be the dominant technology until 2030 (Zubi et al. 2018). This section does not claim to provide a complete consideration of all technical specifications but is rather intended to lay the foundation for a subsequent evaluation of the European battery cell manufacturing industry.[1] As there are currently different types of lithium-ion battery cells used in BEV, it is not only important that Europe is able to build up its own local battery cell production but also whether it relies on the right technology and can serve global demand. Therefore, the assessment of competitiveness is preceded by a brief technical consideration.

2.1 Status quo of LiB technology

Figure 1 presents the construction of a lithium-ion battery, including the positive and negative electrode, the electrolyte, the separator and two current collectors. During discharging, lithium ions, Li+, flow from the negative electrode (the anode) through the electrolyte to the positive electrode (the cathode). The separator allows the flow of lithium ions between the two electrodes while blocking the flow of electrons within the battery. During charging, the flow is reversed (Miao et al. 2019).

An analysis of the recent scientific and industrial literature on lithium-ion battery technology identifies the composition of the cathode as the most important differentiating factor. The most commonly used cathode materials in vehicle applications are lithium iron phosphate (LFP), lithium nickel cobalt aluminium oxide (NCA) and lithium nickel manganese cobalt oxide (NMC). Lithium titanium oxide (LTO) and graphite represent the common anode materials in LiB. Graphite remains the material of choice due to its high energy density, abundance and low cost (Miao et al. 2019). Table 1 provides an overview of the most commonly used cathode materials in lithium-ion batteries in use for electric vehicles and their respective characteristics.

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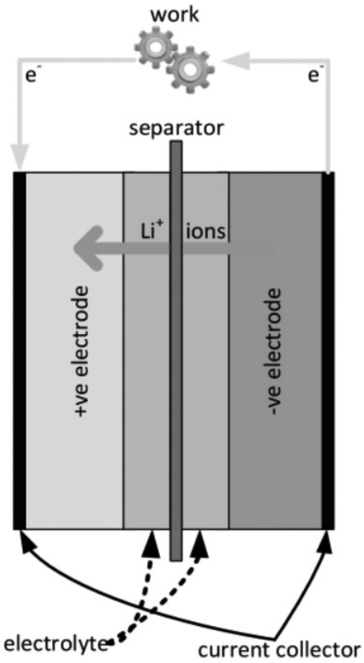
[1] We do not discuss the potential of non lithium-ion technologies, such as sodium-ion battery technology, which are being researched but whose market entry is highly uncertain before 2030 (Schwarzer 2021).

Figure 1 **Lithium-ion battery construction**



Source: Miao et al. 2019.

Table 1 **Overview of status quo lithium-ion battery technology for electric vehicles**

Cathode	**LFP** **[$LiFePo_4$]**	**NCA** **[$LiNiCoAlO_2$]**	**NMC*** **[$LiNiMnCoO_2$]**
Anode	Graphite	Graphite	Graphite LTO
Specific energy [Wh/Kg]**	90-190	200-270	150-270
Full cycles	2000	1000-1500	1000-2000
Safety	Very high	Low to Medium	Medium to High
Cost	Low	Medium	Medium
Further advantages	Eco-friendly materials (cobalt free)		Tailored solutions through varying proportions of nickel, manganese and cobalt
Applications	Electric vehicles, e-bike, projections for power supply systems	Electric vehicles, projections for grid connected use	Electric vehicles, PHEV, portable electronics, power tools, medical devices
Electric vehicle application	Minor interest so far	Minor interest mainly from Tesla	Dominant application

* The characteristics depend on the individual ratio between nickel, manganese and cobalt.

** Specific energy is an indicator of how much energy a battery contains per kilo of weight; it is considered at cell level throughout this paper.

Source: M-Five own illustration based on Zubi et al. 2018, Marscheider-Weidemann et al. 2021, Miao et al. 2019 and Lima 2020a.

There is no universally favoured technology to date. With regard to applications in BEV, the specific energy affects the range per charge. The number of full cycles indicates after how many cycles the performance of the battery drops to 80 per cent of its original value. Safety refers to the thermal stability of chemicals; that is, their decomposition at higher temperatures. Costs are largely determined by the raw materials used which is why low-cobalt compositions show a cost advantage. With high specific energy, long life and moderate to high safety at moderate cost, NMC is the predominant application. NCA shows high specific energy at moderate cost, but lower lifetime and safety compared to NMC. LFP shows the advantages of long life, very high safety and low cost, but suffers from lower specific energy, thus making it of minor importance for automotive applications so far. In general, the cathode composition affects the specific energy, cost and sustainability of a battery; the anode affects the charging performance (Volkswagen AG 2021).

LFP, NCA and NMC cathodes as the dominant solution for battery electric vehicles

For the dominant NMC cathode, the composition of nickel, manganese and cobalt can vary in different specifications. Today, in addition to the original NMC111, manufacturers are also making NMC622 and NMC811, with the three digits referring to the proportions of nickel, manganese and cobalt (Batteries Europe 2020). Over time, development has moved from equal composition from the three materials towards more nickel content (i.e. from NMC111 to NMC622). The increase in nickel at the expense of manganese and cobalt results overall in higher specific energy and lower cost: nickel is considered the key to high energy but suffers from low stability; manganese adds high thermal stability; while cobalt is considered the most expensive and toxic material to eliminate (Ding et al. 2019).[2] The reduction in cobalt content is confirmed by analysis by Agora Verkehrswende (2021a), which examined 147 BEV models introduced to the German automotive market between 2017 and 2021. While NMC111 and NMC532 dominated in 2017, NMC622 was most popular in 2018, 2019 and 2020 while, for 2021, NMC811 was expected to become dominant in BEV model launches.

In addition, there is already extensive research on cobalt-free cathodes known as NMX. In July 2021, the Chinese battery manufacturer Svolt announced the start of its series production of NMX cells which are composed of 75 per cent nickel and 25 per cent manganese (SVOLT 2021). The absence of cobalt and the reduction in nickel makes these cells both sustainable and cheap. A further recent development is the announcement by the German cathode manufacturer BASF of the production before the end of 2021 of NMC271 cathodes with high manganese content (Lima 2020b). This indicates that, after reducing the cobalt content, the next step is to reduce the nickel content which will allow a further price reduction, comparable to LFP. This change in composition is the result of a lively discussion

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2. In the case of NCA cathodes, a further distinction can be made between NCA15 and the newer NCA5. Again, the trend is towards a reduction in the cobalt content (Marscheider-Weidemann et al. 2021).

about rare and thus expensive and critical raw materials, security of supply and fair working conditions.

NMC as the most commonly used cathode; LFP as promising parallel application

Tesla announced at its Battery Day 2020 that it will take a diversified cathode approach in future, including LFP cathodes due to their low cost, high availability and long cycle life advantages. Nickel and manganese-rich cathodes are being reserved for long-range vehicles and high-nickel cathodes for mass-sensitive applications (Tesla 2020). Similarly, Volkswagen announced at its Power Day 2021 that it will use LFP cathodes for entry-level vehicles, high manganese cathodes for the volume segment and NMC cathodes for specific solutions (Volkswagen AG 2021). A similar strategy is being pursued by Daimler (Schaal 2021a). Among battery producers, the Chinese companies CATL and Gotion High Tech in particular are focusing on LFP cathodes and are continuously raising their performance: CATL reports a 20 per cent price reduction compared to NMC811; while Gotion High Tech is significantly decreasing the gap in specific energy between LFP and NMC cells (Marklines Database). Overall, continuous improvement in the performance of LFP cells and a stronger focus on the availability of scarce and expensive raw materials are leading to the increased importance and awareness of LFP technology.

The producer side (not only for LFP, but for LiB cells in general) is currently strongly dominated by Asian companies, which were the first to enter the market in LiB cells and which started to develop competences in this area as early as the 1990s. Whether European companies will be able to catch up and achieve technological leadership as well as significant market shares is discussed in section 3.

Box 1 **Greenhouse gas (GHG) emissions by lithium-ion battery technology production**

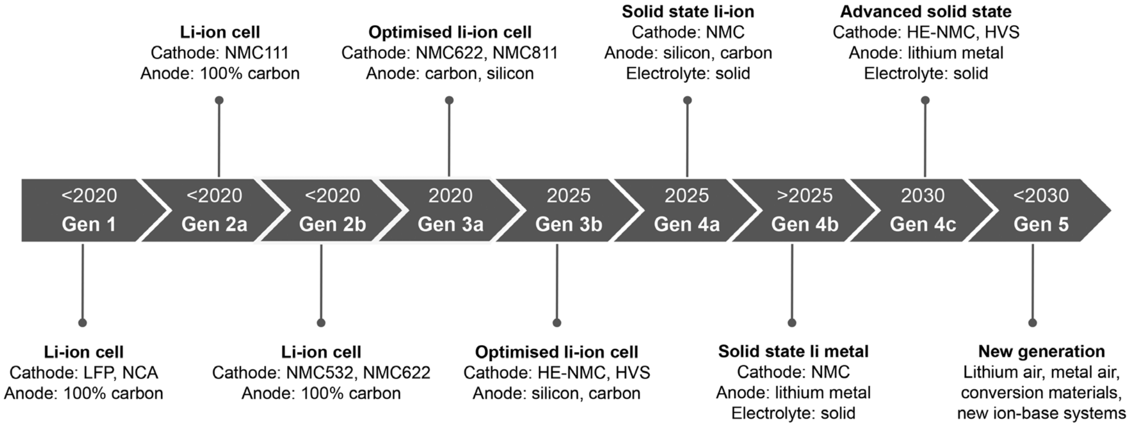
In a recently published study, the International Council on Clean Transportation (ICCT 2021a) analyses the life cycle GHG emissions of batteries, considering NMC111, NMC622, NMC811, NCA and LFP cathodes in combination with a graphite anode and the production regions of Europe, USA, China, South Korea and Japan. GHG emissions considered in the vehicle cycle consist of the production of the battery pack including upstream raw material extraction and processing, cell production and pack assembly. In addition, regionally and temporally adjusted carbon intensities and battery capacities are considered. Secondary use or recycling of the batteries is not taken into account as it is of minor relevance so far (which will change in the future; see section 3). The study shows that the carbon intensity varies depending on the battery chemistry. For Europe, the lowest kg CO_2 equivalents per kWh are generated by the production of the LFP graphite composition: 34 to 39 kg CO_2 equivalents per kWh. In descending order, NMC811 (53 kg), NMC622 (54 kg), NMC111 (56 kg) and NCA (57 kg) follow. In a comparison with the main producer countries, European production has the lowest GHG emissions (ICCT 2021a).

2.2 Development of battery technology until 2030

Following this general consideration of lithium-ion battery technology, this subsection provides an outlook on expected future developments up to 2030. Different materials for cathode, anode, electrolyte and separator are able to improve the battery further, making it cheaper, lighter and more powerful.

The literature consistently divides technological developments into five major generations as well as sub-generations. These are shown in Figure 2 and thus provide a comprehensive overview of past and future expected developments in LiB cell technology. HE-NMC refers to high-energy NMC composition; HVS to high-voltage spinel.

Figure 2 **Categorisation of lithium-ion batteries**



Source: M-Five own illustration based on Batteries Europe 2020.

An estimate by Marscheider-Weidemann et al. (2021) confirms Generation 2b with NMC622 as the current state of the art in the automotive industry, while Generation 3a with NMC811 is in the process of commercialisation.

Generation 2b as current state of the art; generation 3a in the process of commercialisation

With the beginning of the third generation, the optimised lithium-ion cell, the composition of the anode changes. Part of the graphite is replaced by silicon, which is the most promising anode material for achieving high performance due to its high theoretical capacity. However, challenges such as volume expansion during discharging and charging must be overcome before implementation (Zhao and Lehto 2020).

The fourth generation is characterised by the introduction of a solid electrolyte, leading to the so-called solid-state battery in which the flammable liquid electrolyte is replaced by a solid electrolyte that acts as an ionic transport support and separator. As a result, these batteries have the advantages of increased safety, durability, energy density and a reduction in volume, among others (Ding et al. 2019). However, only with the introduction of the lithium metal anode can the full potential of solid electrolytes be exploited.

With generation five, expected after 2030, a move away from lithium-ion batteries towards lithium-air or lithium-sulphur is expected as lithium-ion batteries will have reached their natural limit in specific energy while new batteries with higher specific energy will reach market maturity (Ding et al. 2019).

As already mentioned, production is strongly dominated by Asian companies at present. The introduction of new generation technologies is the subject of extensive research and development activities which are also taking place in Europe and offer an opportunity to gain market share, capture value in Europe and contribute to provide high-skilled employment. However, competitors are also active in this field.

To gain further insight into the expected major developments up to 2030, a roadmap analysis has been conducted. Roadmaps highlight long term strategic and technological development and serve as a guideline for future technology development. A large number of roadmaps on lithium-ion batteries already exist but differ in their focus and design. Both industry and academia roadmaps are considered; moreover, combined roadmaps have been developed, providing shared expertise. In general, industry roadmaps tend to contain quantitative outcomes and key performance indicators while academic roadmaps take a qualitative perspective. The presence of a large number of industry roadmaps in addition to academic ones suggests that it is no longer a pure research topic but already the subject of practical implementation.

The previous analysis focused on the materials used, so the following short roadmap analysis is a complement to Table 1 in focusing on selected characteristics such as specific energy, full cycles, safety and cost. Table 2 compares and subsequently evaluates two selected roadmaps (by 2025 and 2030) with regard to the development of battery technology for BEV today, considering a European perspective and focus on lithium-ion batteries.

Table 2 **Analysis of battery roadmaps**

Roadmap	Status quo	Expected development by 2025	Expected development by 2030
• "Battery Innovation Roadmap 2030" • EUROBAT (2020) • Association of European automotive and industrial battery manufacturers • *Industry*	• Cathode: NMC111, NMC532, NMC622, LFP, LMO, LCO and NCA (Gen 2a, 2b) • Anode: C, LTO (Gen 2a, 2b) • Specific energy: 250 Wh/kg • Full cycles: >3500 • Recycling efficiency: 50%	• Reduced cobalt content with increased nickel content in the cathode • Carbon and silicon as high capacity material in the anode • Focus on range, fast charging, safety and cost	• Cathode: NMC622, NMC811, HE-NMC, HVS, solid-state (Gen 3a, 3b, 4a) • Anode: C + Si, Si + C (Gen 3a, 3b) • Specific energy: 450 Wh/kg • Full cycles: >10 000 • Recycling efficiency: 80-85%
• "Strategic Research Agenda batteries" • Batteries Europe (2020) • European Technology and Innovation Platform on Batteries (ETIP) • *Industry & academia*	• Gen 3b with liquid electrolyte • Specific energy: 250 Wh/kg • Full cycles: 1000 • Cost per cell: 125 €/kWh • Recycling efficiency: cobalt and nickel = 50%, copper = 90%, lithium = 35%	• Gen 4a with solid electrolyte	• Gen 4b, 4c with solid electrolyte and lithium anode • Specific energy: 450 Wh/kg • Full cycles: 2000 • Cost per cell: 70 €/kWh • Recycling efficiency: cobalt and nickel = 60%, copper = 95%, lithium = 75%

Source: M-Five own illustration.

Major developments expected in specific energy, full cycles, cost and recycling

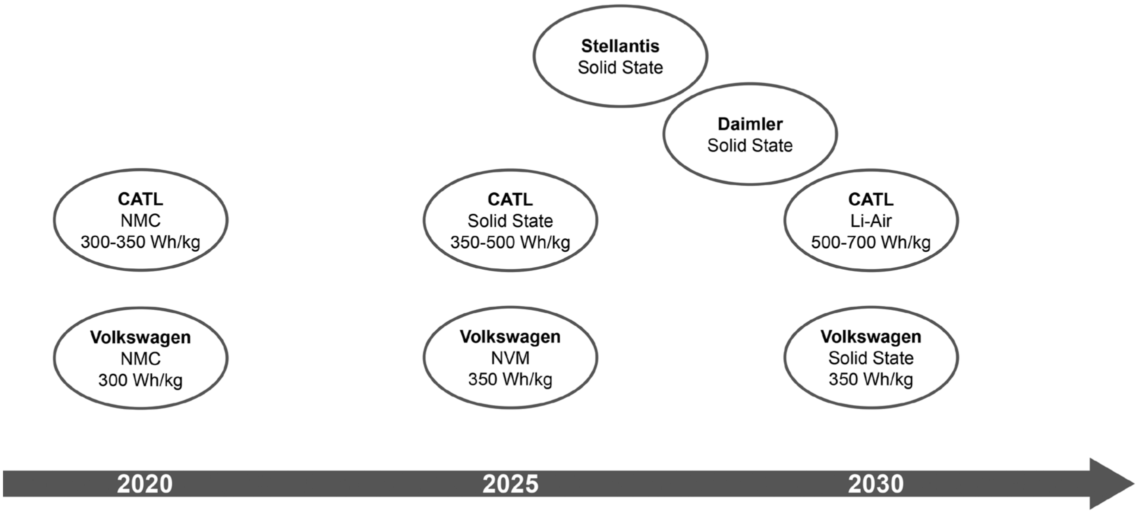
Major changes are expected in the characteristics of specific energy (determining the range), full cycles (determining the lifetime), cost and recycling. The lower limit for specific energy in 2030 is up to 320 Wh/kg; the upper limit assumes about 450 Wh/kg which is almost a doubling compared to the status quo. The number of full cycles should be viewed with caution in terms of application as it differs for automotive application and (second life) stationary applications.

The first roadmap highlighted in Table 2, from EUROBAT, considers lithium-ion batteries in general; the second, from Batteries Europe, refers to automotive applications in particular. Lithium-ion batteries in electric vehicles achieve 1000 cycles today and will reach 2000 by 2030 (Armand et al. 2020), while in stationary applications they achieve 5000 cycles today and 10 000 by 2030. With an estimated average range of, currently, about 350 km and 1000 full cycles, 350 000 kilometres are feasible. Both parameters are expected to increase significantly by 2030. The cost per cell and pack will reduce while recycling rates will increase by 2030.

Overall, the development of battery technology until 2030 consists of changes in materials for cathode, anode, electrolyte and separator and thus improved performance characteristics such as specific energy and full cycles. Decreasing costs will open up the mass market, while increasing recycling rates will strengthen the security of supply and sustainability of the battery.

Lastly, announcements of technology developments by European OEMs and global battery producers are considered. An overview of activity drawn from press releases is shown in Figure 3, although many companies do not publish such performance indicators.

Figure 3 **Timeline of announced lithium-ion battery generations**



Source: M-Five own illustration based on press releases.

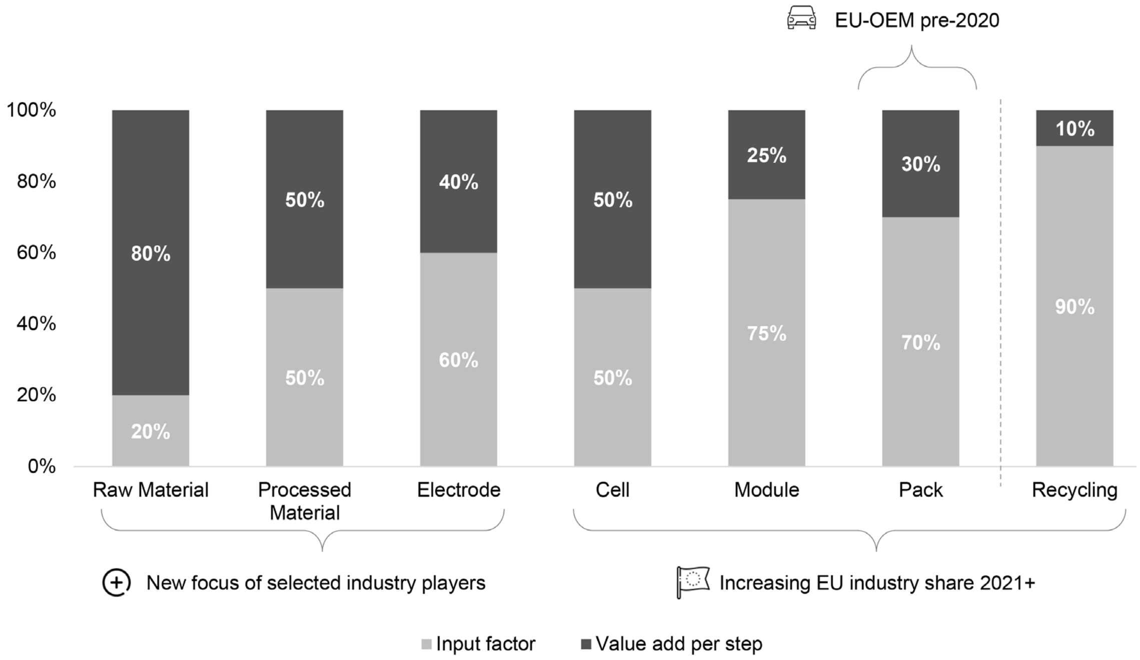
By 2020, Volkswagen is seeking to deliver NMC811 cathodes with an anode containing 80 per cent graphite and 20 per cent silicon, reaching a specific energy of 300 Wh/kg. By 2025, with a nickel vanadium manganese cathode and a combined graphite and silicon anode, 350 Wh/kg is expected. By 2030, the solid-state battery will have been introduced, offering the advantages of increased safety, durability and energy density. Stellantis and Daimler expect their solid-state battery by 2026 and 2028, respectively. On the producer side, CATL expects to deliver its solid-state battery by 2025 with a high voltage cathode and a lithium metal anode, reaching 350 to 500 Wh/kg. By 2030, CATL is expecting lithium air batteries with a major increase in specific energy of up to 800 Wh/kg.

The technological leadership of CATL also underlines the current lead of Asian manufacturers in general. The technology shift to the fourth generation of lithium-ion batteries, the solid-state battery, is associated with major challenges and a high level of expertise. As a result, various strategic partnerships and investments can be observed. While European manufacturers are now entering the market and catching up on current technologies, the introduction of the fourth generation of LiB enables European players to join this market from the very beginning and gain significant market share. The next generation of LiB technology is seen as a great opportunity to compete with Asian manufacturers from the outset and is therefore already in focus.

2.3 Cost and value chain at battery level

The production of a lithium-ion battery can be divided into sequential activities, each consuming resources and creating value. Figure 4 depicts the LiB value chain for automotive applications. The European Commission assumes by 2025 a market value for the European battery value chain of 250 billion euros (European Commission 2020a). Given this magnitude, it is not surprising that OEMs are starting to focus on expanding and integrating further parts of the value chain, primarily upstream integration. In addition to this value chain, there are also upstream and downstream industries, such as mechanical and plant engineering, closely linked to battery cell production and the creation of additional value for Europe.

Figure 4 **Value chain at battery level**



Source: M-Five own illustration based on Sharova et al. 2020.

Figure 4 shows a highly simplified representation of the value chain, considering only one input factor and one output factor at each step. It shows the value added per activity at each step on top of its specific input factor. In the last step of manufacturing, the pack, the input factor accounts for 70 per cent of the revenue while the value added at this step represents 30 per cent of the revenue. Each step includes the previous steps as input factors. Before 2020, European OEMs focused only on pack integration. Since 2021, cell and module are increasingly in focus, as cell manufacturing in particular is a high value contributor. In addition, the upstream integration of raw and processed materials is also becoming important as it is increasingly clear that bottlenecks will occur at these stages while securing access and gaining control over this part is crucial.

Recycling is not yet fully integrated into the value chain. However, it will be an important aspect in the future from the point of view of raw material supply, environmental friendliness and user acceptance, as well as the development of a competitive European battery cell industry. In the future, value creation is expected to shift from modules and packs as well as integration to raw materials and their processing (CLEPA 2021). The reasons are the increasing automation and scaling of cell production, the decreasing importance of modules as a separate component and the increasing importance of raw material supply and cell chemistry.

Raw materials are the very beginning of the production process and represent high value add. Regarding the different types of lithium-ion batteries, the main raw material requirements include lithium, nickel, manganese, cobalt and graphite. A comparison by Marscheider-Weidemann et al. (2021) of global raw material production in 2018, with a view to the raw material demand for lithium-ion batteries in that year, shows that lithium and cobalt account for the highest shares of production today, each with a share of eight per cent of production. The demand estimated by the sustainable scenario 2040 exceeds the 2018 production for lithium and cobalt while production for nickel, manganese and graphite would be sufficient. The greatest increase in demand is expected for lithium and nickel since the latter is being chosen to substitute for scarce and expensive cobalt in NMC cathodes. In the IEA's 'Stated Policies' scenario, lithium demand increases 12-fold from 2020 to 2040; and even 43-fold, to 859 kilotonnes (kt), in its 'Sustainable Development' scenario. Nickel increases 12-fold and 41-fold respectively, to 3287 kt in 2040.

However, such future projections are subject to large uncertainties due to the development of future battery cell chemistries. The increase in overall demand for lithium-ion batteries can be partially offset by the use of less lithium-intensive cathode chemistries. The growing demand for raw materials due to the increased ramping-up of electric mobility is leading to more intensive discussions about potentially critical raw materials and security of supply in Europe. There is an important difference between the general availability of raw materials on earth and the current extraction possibilities. While overall an adequate supply of raw materials is assumed, temporary shortages and price increases are expected due to the extremely long and bureaucratic opening time for new production facilities (Fraunhofer ISI 2020; NPM 2021).

Lithium, cobalt, nickel and graphite as critical raw materials

European OEMs have no core competence in raw material extraction and thus depend on mining and refining companies abroad.[3] Overall, the extraction of raw material is often geographically localised and oligopolised, with Europe using its resources only to a limited extent and being heavily dependent on imports (Sharova et al. 2020). Lithium is concentrated in Australia and Chile; cobalt in the Democratic

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[3] European mining activities are about to start. Current projects and the emerging phenomenon of NIMBYism are discussed in Box 2.

Republic of the Congo; nickel in Indonesia; and graphite in China. It is worth noting that mining for these materials does, in some countries, involve regimes not averse to using child labour, the impact on workers' health and safety, etc.

The processing of these minerals is highly concentrated in China (IEA 2021). A secure value chain and sufficient access to raw material provides the main challenges of the future, a point which is emphasised by high price volatility.

One possible strategy could be upstream integration up to raw material extraction, for example in Europe, as well as the development of recycling capacities in the sense of developing the circular economy.

The next step in the value chain is material processing which is closely linked to raw material extraction. In order to secure supply, exploit cost potentials and develop individual technological advantages, the trend is towards reducing the content of critical raw materials and integrating the upstream value chain. As demand increases, cell manufacturers are opening new production sites close to potential customers (Sharova et al. 2020).

The battery cell, the fourth step in the chain, is manufactured by placing the cathode, the anode, the separator and the electrolyte in an aluminium case. Due to their experience in consumer electronics and initial automotive projects, Asian companies currently dominate this step (Sharova et al. 2020). A battery cell forms the basic unit of a lithium-ion battery, with multiple cells being combined into a frame that builds the battery module. Multiple modules form the battery pack which is installed into the electric vehicle (Samsung SDI 2017).

After reaching their end of life in BEV applications, used batteries can enter either the second last step in the value chain, the second life, or the last step, recycling. There is also a discussion on re-x, based on re-use, re-manufacture and re-cycle (Battery LAB 2021). Remanufacturing extends the first life by replacing or exchanging damaged components. Recycling is required to recover raw materials and thus enable security of supply and sustainability.

There is, to date, no standardised recycling process present, with no thorough economic process for cathode materials and no industrial recycling solution available for anode materials (Battery LAB 2021). However, the need for recycling has been recognised both in politics and in industry; moreover, technical feasibility is a given. The absence of economic feasibility requires legislative support. The European Commission proposes material recovery rates of 90 per cent for cobalt and nickel in 2025, increasing to 95 per cent in 2030; and 35 per cent for lithium in 2025, increasing to 70 per cent in 2030 (European Commission 2020b).

Another important aspect that must not be neglected is the quality requirement ensuring that recycled materials flow back into the LiB value chain and preventing downcycling (Transport & Environment 2021b). However, a distinction must be made between material recovery rates and the mandatory minimum shares of recycled content in a battery, which are 12 per cent for cobalt, 4 per cent for lithium and 4 per cent for nickel from 2030; and 20 per cent for cobalt, 10 per cent for lithium and 12 per cent for nickel from 2035 (European Commission 2020b).

Recycling as an opportunity for European industry

The LiB recycling market is estimated at 1.5 billion dollars in 2019, 12.2 billion dollars in 2025 and 18.1 billion dollars in 2030 (Markets and Markets 2021). According to the latest announcements, the German cathode manufacturer BASF wants to push ahead with the recycling of nickel and cobalt, as these raw materials for batteries will not be available in sufficient quantities in the future and the focus clearly is on establishing a circular economy. The French Automotive Cell Company ACC even claims that recycling 'will be the new "mine"' (Witsch 2021b). In general, recycling is expected to increase with the rising demand for lithium-ion batteries, stricter regulations and volatile and rising raw material prices. The contribution of recycling to raw material demand is, however, only estimated at 40 per cent for cobalt and 15 per cent for lithium, nickel and copper in Europe by 2040 (Fraunhofer ISI 2021).

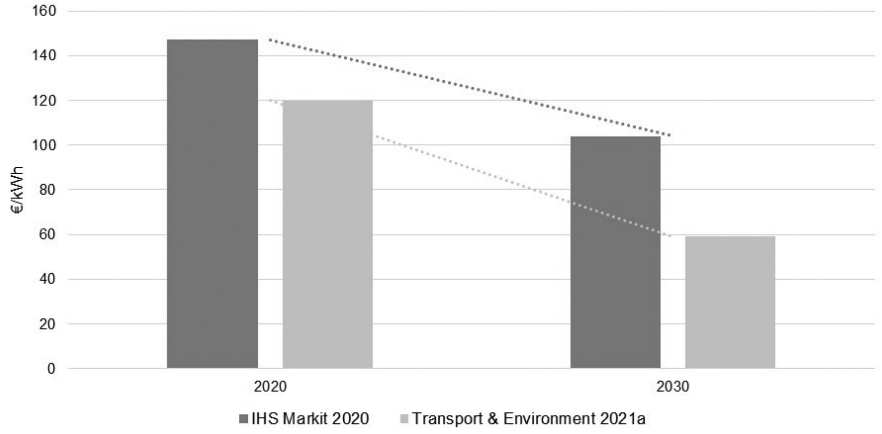
The value of recoverable material for a standard 70 kWh battery is estimated at 600 euros for LFP and 1300 euros for NMC cells. This shows the opportunity for Europe to develop a valuable market for battery raw materials, establish a local circular economy and thus strengthen the entire European industrial system. At the same time, it shows that the recovery of iron in LFP cathodes is not economically viable and requires legislative support if green batteries are preferred.

So far, seventeen recycling plants with a total capacity of 33 kt per year have been announced within Europe. These are mainly pilot plants that initially recycle production waste in addition to the batteries. Although established Asian companies have so far held a leading position in recycling, it is assumed that Europe, as the dominant market for environmentally friendly and highly efficient battery recycling, could meaningfully replace them (Fraunhofer ISI 2021).

2.4 Cost at cell level

This section addresses cost developments in lithium-ion battery cells. Cell costs are often referred to in terms of the pack prices charged to manufacturers. Overall, the price per kWh has fallen significantly and this trend is expected to continue in the future. The main drivers are the increase in the volume of production, new pack designs, new cathode chemistries and falling manufacturing costs (Transport & Environment 2021a). However, volatility in raw material costs could counteract these trends and may increase pack prices in the future.

Figure 5 **Expected battery pack price in €/kWh (nominal)**



Source: M-Five own illustration.

Figure 5 shows estimated prices for battery packs in €/kWh from 2020 to 2030. While IHS Markit (2020) expects a rather small price reduction to 104 €/kWh in 2030, Transport & Environment (2021a) provides a lower figure of 59 €/kWh in 2030.[4] The range between the two shows that prices are influenced by various factors such as chemistry, volumes and negotiations and thus differ.

In general, up to 2020, it was economies of scale and learning effects as well as minor improvements in cell chemistry that drove this drop in prices. By 2030, however, fundamental improvements in cell chemistry are expected which can lead to significant performance improvements and even greater cost and price reductions. Nevertheless, the cost of lithium carbonate increased by 72 per cent, lithium hydroxide by 47 per cent and cobalt by 58 per cent in the first quarter of 2021 (Transport & Environment 2021a). These increases emphasise both the volatility of raw material costs and the relevance of cathode chemistry as the cathode contains active materials that are the most cost sensitive. The future development of the cathode is not only aimed at increasing the specific energy, but also at switching to abundant, cheap, price-stable, environmentally friendly and risk-free raw materials.

By 2020, the battery was accounting for about 30 to 40 per cent of the total cost of a BEV (Sharova et al. 2020). The cell accounts for about 75 per cent of the price of the pack (Transport & Environment 2021a). The cell, the basic unit of the battery, can be further divided into its individual components: the cathode represents about 32 per cent of the cost and takes the largest share, followed by the anode (22 per cent) and the separator (14 per cent).

The costs at cell level can also be broken down differently: 65 per cent are attributable to material costs, 20 per cent to production costs and 15 per cent

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[4] Personal communication with Chinese experts reveal a Chinese cost target for cells of 30 dollars/kWh in 2030. At such cell costs, the price of battery packs may well stay below even the lower pack prices anticipated by T&E.

to distribution, administration and general costs as well as profit (Stanek and Hackmann 2020). The high share of material costs underlines the importance of cheap and available raw materials to facilitate the expected developments with regard to future price reductions.

2.5 Cost structure of cars

Section 2.4 on the cost at cell level has shown that battery costs are expected to decrease in the coming years. This decrease is expected to be accompanied by a reduction in the pre-tax selling price of BEV in general. In addition to falling battery costs, the switch to dedicated platforms for BEV and higher production volumes are further driving this development.

There are four main characteristics identified as determining the pre-tax retail price of a BEV. First, platform choice; second, battery price; third, driving range; and fourth, vehicle efficiency (Transport & Environment 2021a). The cost difference between ICEV and BEV today varies with the size of car and is the highest for the small A and B segments of the market. By 2024 to 2026, price equality is expected in all segments, first of all in light vans and lastly in the B segment.

Regarding cost structure, it has to be considered that, while prices for BEV are declining, prices for ICE cars could potentially increase. The expenditure entailed by improving the combustion engine in line with stringent CO_2 emission regulations and the Euro 7 standards potentially entering into force by 2025 will, according to one study, increase ICE prices significantly (Transport & Environment 2021a). This study treats such an increase as a given but the effects of these regulations and standards are as yet unclear. If CO_2 standards, in particular by 2025, are not tightened, given the expected high market uptake of electric vehicles, the pressure to invest in efficiency gains for ICE remains very limited as the CO_2 standards can simply be fulfilled by electrification. Thus we would rather anticipate stable ICE prices than increasing ones.

The value structure of BEV can be analysed by looking at the individual components and their cost shares in manufacturing in isolation, similar to the component analysis in section 5 on the employment effects. For BEV, the share of the battery manufacture cost is forecast to decrease, from 36 per cent in 2020 to 29 per cent in 2035. At the same time, the cost share of Advanced Driver Assistance Systems (ADAS) is increasing, from 4 per cent in 2020 to a forecasted 10 per cent in 2035. The highest cost share over time is calculated for the battery, followed by vehicle integration. In comparison with ICEV, the electric drive including the battery is more costly and reaches a higher share than the ICE and its powertrain. Also a study on sustainable mobility in Germany confirms the growing importance of electric mobility components including the battery and of ADAS components (NPM 2021).

2.6 Outlook on future value chain adaptations

Recently, two new technologies have been discussed that would make parts of the value chain shown in section 2.3 redundant: cell-to-pack; and cell-to-chassis. Cell-to-pack technology dispenses with the modules and integrates the cells directly into the battery pack. Cell-to-chassis dispenses with modules and packs altogether and integrates the battery cells directly into the chassis of electric cars. The latter technology is expected to be launched by CATL before 2030; the former is already in use (Schaal 2020). By eliminating modules and packs, more cells can be installed in the same space as the weight and volume of inactive materials are reduced, resulting in higher specific energy. According to CATL, the use of cell-to-pack technology can increase energy density by 15 per cent and reduce costs by 30 per cent (Marklines Database). LFP batteries in particular profit from this technology as they provide sufficient thermal stability and safety to be implemented without modules and thus compensate for their disadvantage in specific energy performance. CATL and BYD are currently pursuing this strategy.

Box 2 **European raw material supply**

The discussion on critical raw material supply in section 2.3 and the increasing demand and production of lithium-ion battery cells in Europe leads to rising interest in establishing an own, independent European raw material supply chain. Mining and refining are by now concentrated in only a few countries abroad and thus materials supply could pose a threat to the emerging industry in Europe. Lithium mining projects – such as the zero carbon lithium project by Vulcan Energy in the Upper Rhine Valley, the Project by CEZ group and European Metals in the Czech Republic and the Wolfsberg project by European Lithium in Austria – are currently coming into focus (Mining Editor 2022). The advantages of such projects are in the possibility of a completely localised and independent European value chain and the preservation and development of employment and value creation in Europe. In addition, the unique selling point of European-made batteries could be environmentally friendly, sustainable batteries for which the EU is currently developing a battery passport and which could best be guaranteed by European raw materials extraction.

On the other hand, there is strong opposition observed among the population to projects of this kind, with concerns about deforestation, dust, noise and environmental pollution. Local resistance can be observed for example at the Jadar Valley in Serbia, in Covas do Barosso in Portugal or in Caceres in Spain. Whether the local supply of raw materials is necessary or is optional for a successful European battery cell production needs to be evaluated by further research.

3. Battery production in Europe and the strategies of European OEMs

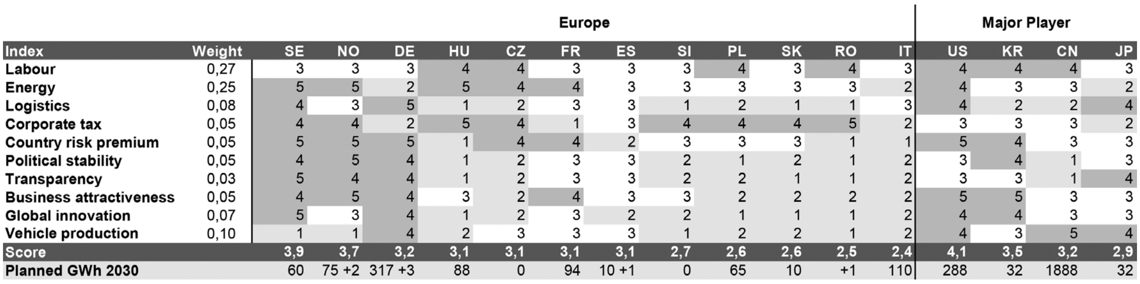
After the technical foundation was laid in section 2 on the status and development of battery technology and the battery value chain, section 3 presents the results of a location analysis for battery cell production plants and a comparison with the location decisions that have been made in practice.

3.1 Location decisions for battery cell production

The location matrix in Figure 6 shows an evaluation of twelve European and four non-European countries based on the framework conditions that are considered relevant for the establishment of battery cell production plants. The selected European countries play an important role in the European automotive industry today, or will do so in the future, and thus already fulfil a basic requirement. To enable a global comparison, the world's major players in battery technology – the USA, South Korea, China and Japan – are included in the analysis. Thus, attractive and expected locations for battery cell manufacturing in Europe may be identified. Ten indices describe the attractiveness of the country, with each index potentially consisting of several individual values. In order to reflect the importance of the individual index for location decisions, a weighting is applied.

The idea, the selection of the indices and the chosen weighting are based on a reference project of the National Platform for electric mobility from 2016 (NPE 2016). This report updates and adjusts the data to provide more accurate and up-to-date results on the competitiveness of Europe as a location. The matrix is to be understood as a relative consideration of the countries in comparison with each other. The scores from one to five are calculated by dividing into quartiles the results across all the countries considered and then awarding one point if the respective country's score is below the first quartile and five points if it is above the fourth quartile. A value of five thus corresponds to the highest score. The final score is then calculated by multiplying the country’s score for the respective index by the weighting in row two. The matrix is expanded to include the planned capacity in GWh for 2030 that has been announced so far.

Figure 6 **Location matrix**



		Europe												Major Player			
Index	**Weight**	**SE**	**NO**	**DE**	**HU**	**CZ**	**FR**	**ES**	**SI**	**PL**	**SK**	**RO**	**IT**	**US**	**KR**	**CN**	**JP**
Labour	0,27	3	3	3	4	4	3	3	3	4	3	4	3	4	4	4	3
Energy	0,25	5	5	2	5	4	4	3	3	3	3	3	2	4	3	3	2
Logistics	0,08	4	3	5	1	2	3	3	1	2	1	1	3	4	2	2	4
Corporate tax	0,05	4	4	2	5	4	1	3	4	4	4	5	2	3	3	3	2
Country risk premium	0,05	5	5	5	1	4	4	2	3	3	3	1	1	5	4	3	3
Political stability	0,05	4	5	4	1	2	3	3	2	1	2	1	2	3	4	1	3
Transparency	0,03	5	4	4	1	2	3	3	2	2	1	1	2	3	3	1	4
Business attractiveness	0,05	4	5	4	3	2	4	3	3	2	2	2	2	5	5	3	3
Global innovation	0,07	5	3	4	1	2	3	2	2	1	1	1	2	4	4	3	3
Vehicle production	0,10	1	1	4	2	3	3	3	1	2	2	1	2	4	3	5	4
Score		3,9	3,7	3,2	3,1	3,1	3,1	3,1	2,7	2,6	2,6	2,5	2,4	4,1	3,5	3,2	2,9
Planned GWh 2030		60	75 +2	317 +3	88	0	94	10 +1	0	65	10	+1	110	288	32	1888	32

Source: M-Five, INACD.

Overall, the purpose of this location matrix is twofold. First, to provide a ranking on potential European locations where battery cell manufacturing could be located; and, second, to provide a global comparison of European countries in respect of the major players and global competitors.

Within Europe, Sweden and Norway show the highest overall scores. These countries offer cheap and green electricity in addition to a very attractive investment environment in general. However, the automotive industry is not present at all in Norway and is only rather limited in Sweden. This is matched by the announced production capacity in the mid to upper range. The highest planned production capacity in Europe is reported for Germany, which ranks third in the location matrix. In particular, the high level of vehicle production and the associated automotive technology infrastructure make Germany an attractive location for further investment in this sector. With regard to planned capacity by 2030, Germany is followed by Italy, France and Hungary. In terms of rank, Germany is followed by Hungary, the Czech Republic, France and Spain in fourth place.

Two large discrepancies between the calculated score and production capacity are visible in Figure 6. One is for the Czech Republic which, despite its high score, has not yet reported any production facilities; and the other is for Italy which scores the lowest but still has the second largest planned production capacity. The Czech Republic offers an attractive investment environment which is matched by negotiations being currently ongoing with two potential investors for a battery cell plant, one of which is VW according to the government (Reuters 2021). In Italy, on the other hand, there is a rather uncertain and unstable financial and political environment, as well as lower levels of automotive production. However, high levels of government support and funding are able to compensate for the uncertainty and lack of stability and the country has been able to attract two large cell plant investments from Itavolt and Stellantis (Schaal 2021b; Randall 2021a). The example of Italy shows the major importance of government support and subsidies. However, this support can be put into very different sectors of the economy and thus it cannot be integrated into the location matrix in general.

Another limitation of the matrix is that the indices measured today are compared with the production capacities expected for 2030. Today's location decisions take expectations about the future development of a location into account and this cannot be reflected in the matrix. In addition, there is no guarantee that today’s announcements will be successfully operating at full capacity by 2030.

In a global comparison with the major players, the United States is in the lead followed by South Korea, China and Japan. The result of the United States also represents the highest overall score, while the results achieved by South Korea, China and Japan are equivalent to those of the European analysis. This indicates that the environment in Europe is competitive. Regarding the planned GWh capacity by 2030 of the four non-European countries, China shows by far the highest value followed by the United States, South Korea and then Japan.

A global ranking similar to the location matrix presented here has been conducted by BloombergNEF (2021) including the categories of (1) raw materials; (2) manufacturing; (3) environment; (4) regulations, innovation and infrastructure; and (5) battery demand. China ranks first according to the presence of major investments, control over raw materials and strong demand, both locally and globally. China is followed by the United States, Germany, Sweden and Canada. European countries appearing in the top 30 ranking are (in descending order) Germany, Sweden, Finland, Norway, France, the United Kingdom, Poland, Czech Republic, Hungary and Slovakia. This ranking underlines that European countries are competitive and becoming increasingly important in this industry, but supports also the view that R&D tends to be done within the 'core' of European automotive value chains. The development of the European battery cell industry is the subject of the following subsection.

3.2 European battery cell production

After the theoretical considerations, this subsection focuses on the announcements for European production made by the industry so far. M-Five maintains an Innovators and Actors Database (INACD) tracing the eco-system of mobility transformation and thus containing the players in automotive technology innovations as well as those offering new mobility services. INACD also includes the networks established between the players as well as the innovators and actors in the battery domain.

According to the INACD database, 25 plants are currently operating in Europe or have been announced, while six further plant announcements have been observed albeit without concrete information on production capacity. Total cell production capacity of 157 GWh has been announced by 2023 and up to 900 GWh by 2030. In almost all cases, production begins with a planned capacity lower than the maximum, with this then being expanded along the ramping-up curve of electric mobility.

From the published information on planned production capacities and planned employees, an average figure of 58 employees per GWh across all production plants may be derived.[5] Applying this employment intensity to the 2030 capacity results in around 52 000 directly created jobs in the cell industry. Significant indirect job creation, both upstream in the supply chain and downstream in areas such as logistics, recycling, pack manufacturing and re-use are expected but have not been quantified in this research project.

A closer look at the announced production plants for battery cells reveals that both Asian and American manufacturers are pushing into the European market while European companies are building up their own local production capacities, thus increasing competition in the local market. According to our database, 50 per cent of the GWh production capacity by 2030 has been announced by companies based in Europe and the other half by companies based abroad. Both types of investment increase employment and financial capital in Europe and also strengthen the European battery innovation system (see section 4). At the same time, employment creation within foreign-owned production may be limited to direct manufacturing jobs in Europe and local indirect employment, while many jobs such as R&D, management and marketing often remain in the home country. A major challenge for European companies is that, while foreign, established companies such as Tesla or CATL have already successfully set up several production facilities, many European companies are just entering the market and starting operations. They are more familiar with the market and regional conditions but have less experience at ramping-up cell production.

It should also be remembered that there are hurdles to scaling up and that not all announcements may actually be implemented.

Regarding the technological considerations outlined in section two, European manufacturers have so far focused on NMC high power and next generation solid-state cells. However, price seems to complement, or even replace, performance as the main criterion for cell selection. As a result, the focus is shifting from NMC to cheaper LFP cells since the latter have caught up in performance and now attain the minimum level required. Given the increasing demand for LFP cells for lower-end and entry-level vehicles, including from major European OEMs such as Volkswagen and the volume brands of Daimler, it will be an important decision whether this market should also be served by European manufacturers in the future or whether it will be left exclusively to Chinese companies. The Serbian company ElevenEs has taken a decision acknowledging the potential of LFP and recently announced that it will build the first LFP battery gigafactory in Europe, which is expected to start construction by 2024 and produce up to 16 GWh in the final expansion stage (Randall 2021b).

To complement the supply side, Figure 7 considers and compares the demand side for Europe. M-Five's estimate of European battery demand is divided into a low demand scenario and a high demand scenario to account for uncertainty in the expected market penetration of electric vehicles (passenger cars). Annual

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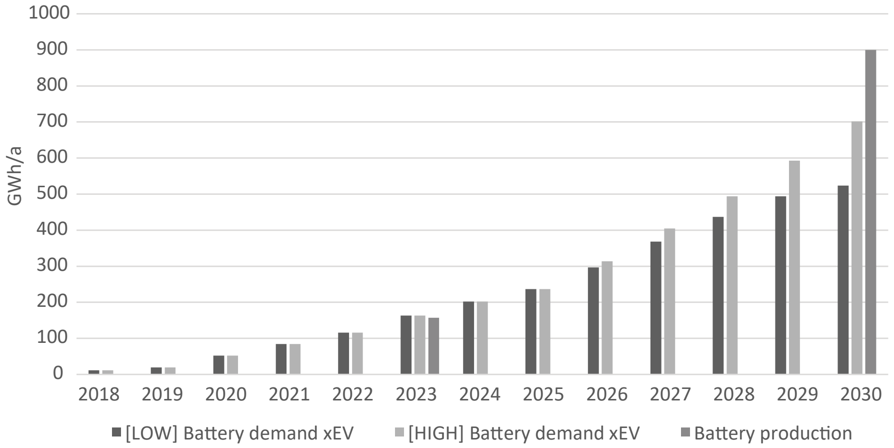
[5] Excluding two outliers, the range of observed employment intensities of planned European battery cell manufacturing sites is between 21 and 98 employees per GWh. This shows both the variety of manufacturing plans and the uncertainty still associated with the plans.

production data on the base of vehicle production sites is considered until 2021 (Marklines Database) and then projected until 2030. Following the rebound from the pandemic, the overall production level in Europe is assumed to remain slightly below the 2018 level until 2030. The share of electric vehicles (both BEV and PHEV) in overall car production is estimated at 28 per cent in 2025 in both scenarios; but 53 per cent in 2030 for the lower scenario and 71 per cent for the higher one.

Estimates for the lower scenario are in line with ICCT (2021b) projections to meet the average new car fleet CO_2 emission reduction of 50 per cent in 2030 (compared to 2021 levels). The estimates for the higher scenario are derived from our own calculations based on EEA CO_2 monitoring data from 2020 and our own assessment of EU countries according to their individual shares in electrification,[6] to meet an average new car fleet CO_2 emission reduction of 55 per cent compared to 2021 levels. The higher share of electric vehicles will lead to a higher demand for lithium-ion battery cells. The share of BEV within electric vehicles is estimated at 82 per cent in 2030. Once electric powertrains become cost-competitive (which we expect in the mid-2020s), BEV will become increasingly attractive to car buyers. Battery capacities for BEV and PHEV are estimated at 75 kWh and 13 kWh each in 2030. This then leads to a lower demand of 524 GWh of battery cells for cars and an upper demand of 702 GWh in 2030 compared to the announced production of up to 900 GWh.

Figure 7 **European battery cell demand and production**



Source: M-Five own illustration and calculation.

Figure 7 shows that the increasing production capacity will be able to meet the increasing demand. For both scenarios, there is the possibility of over-capacity. This could be used to meet additional demand through the increased electrification of buses and trucks as well as to build up export capacities (for net car exports

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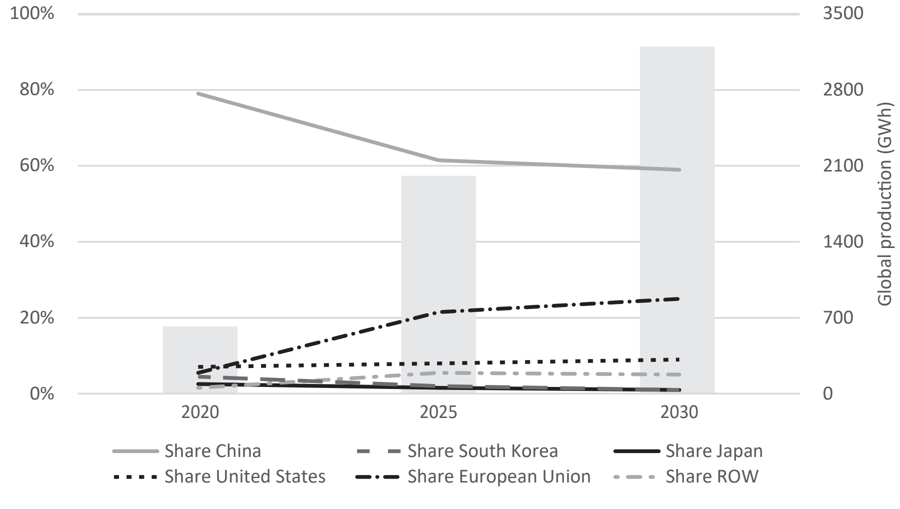
[6] Denmark, Finland, France, Germany, the Netherlands and Sweden are classified as ambitious countries with a share of 89 per cent electric vehicles in new registrations in 2030.

or direct battery exports). It is assumed that the European Union will be able to meet its own demand by 2025 and even build up an export capacity (European Commission 2020a). However, depending on the speed of electrification of buses and especially trucks, even more capacity might be needed as such applications require much larger batteries.

Projected European demand can be further broken down into regional demand. Based on current BEV sales, but also including the factors that influence these, such as GDP per capita and supporting policies, four groups can be identified. These are northern, western, southern and eastern Europe, with northern countries classified as innovators and early adopters; western countries as early majority; southern countries as late majority; and eastern countries as catching up (Transport & Environment 2021c).

In a global perspective, production volume is expected to be about 620 GWh in 2020, rising to 2008 GWh in 2025 and to 3200 GWh in 2030 (Transport & Environment 2021a; VDMA 2020). China accounts for the largest share, with around 80 per cent of production in 2020, and is able to keep its leadership until 2030. Europe is, however, increasing its share in global production at the expense of China. The other major production countries – the United States, Japan and South Korea – seem rather constant (Transport & Environment 2021a; VDMA 2020). Global battery cell production and the share of production capacity by country/region is illustrated in Figure 8.

Figure 8 **Global battery cell production and share of production by country**



Source: M-Five own illustration based on Transport & Environment 2021a; VDMA 2020.

One reason for this shift of production shares away from China and towards Europe is the proximity to target markets and OEMs. This proximity enables a reduction in transport costs which are non-negligible due to the weight and necessary safety factors in the transport of lithium-ion batteries. It also increases security of supply, with the recent pandemic and the current chip crisis drawing attention to vulnerabilities in global supply chains. In addition, Europe's strength in mechanical and plant engineering is equally attractive to both Asian and European cell manufacturers (VDMA 2020).

While the highest battery demand by far is observed in China, the highest growth rate in demand is observed in Europe (World Economic Forum 2019). This leads to the assumption that Europe entered the market late but is now on the rise and both increasing its share of demand as well as of production.

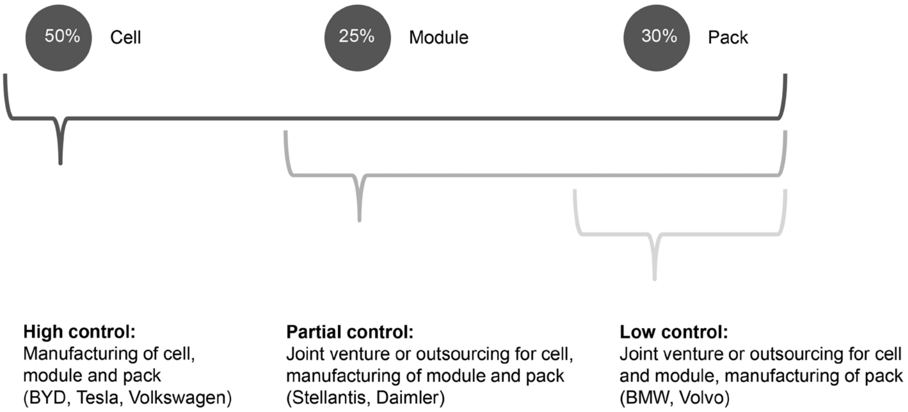
3.3 Different approaches to controlling the battery value chain

Different strategies are being pursued by European OEMs to capture and control shares of the battery value chain. At one extreme, a company may control the entire value chain from raw material extraction to pack integration. In the other case, a company might outsource all previous steps and focus only on vehicle integration. In between, partial control of the value chain is observed by entering into partnerships and joint ventures.

The focus of European OEMs over the last three years has shifted from pack integration to upstream cell production, not least due to the high value-added share of the cell in the overall battery but also due to the insight that BEV sales will increase sharply during the first half of the 2020s. In addition, this approach increases security of supply through localisation and the opportunity to form unique technological selling points. Furthermore, it enables the company to keep its employees, which is why upstream integration, for example in the production of battery cells, is also being pushed by works councils. As early as 2014, and following the discussions initiated in co-operation with a few council members by Bormann et al. (2014) at several German manufacturing sites, works councils have placed emphasis on participating in e-mobility developments or even transforming their sites into e-mobility powerhouses. Various strategic options along the value chain have emerged out of such a discussion. Figure 9 shows three main strategies and the companies pursuing them, making reference to the respective steps of the full value chain as explained in section 2 (see Figure 4).

Among European OEMs, some companies with moderate to medium-size volumes of car sales, such as BMW or Volvo, find their dominant strategy in having low control of the value chain while focusing on vehicle integration. BMW recently announced that it feels vindicated for not entering the market as a battery cell manufacturer. There is a robust supplier market with no monopoly, oligopoly or bottlenecks. Moreover, the company is still able to define requirements and needs in its research centre and pass these on to its suppliers (Matthes and Fasse 2021). However, the head of the BMW works council is less satisfied with the strategy of the purely external procurement of battery cells, especially with regard to the associated employment effects (Wermke 2021). In contrast, Daimler recently announced it would join the ACC joint venture between Stellantis and TotalEnergies for European cell production. The company will develop and produce battery cells and modules in Europe while exploiting benefits such as ensuring security of supply, economies of scale and the ability to offer superior and tailored battery technologies. Moreover, this investment is expected to strengthen the competitive position of the whole European industry (Daimler 2021). Volkswagen is going one step further and has announced not only the planning of six European gigafactories with a total capacity of 240 GWh (Volkswagen AG 2021), but also the intention to encompass the entire value chain in the future, from mining and refining to cathode production (Volkswagen AG 2019).

Figure 9 **Control of the value chain**



Source: M-Five own illustration based on Marklines Database.

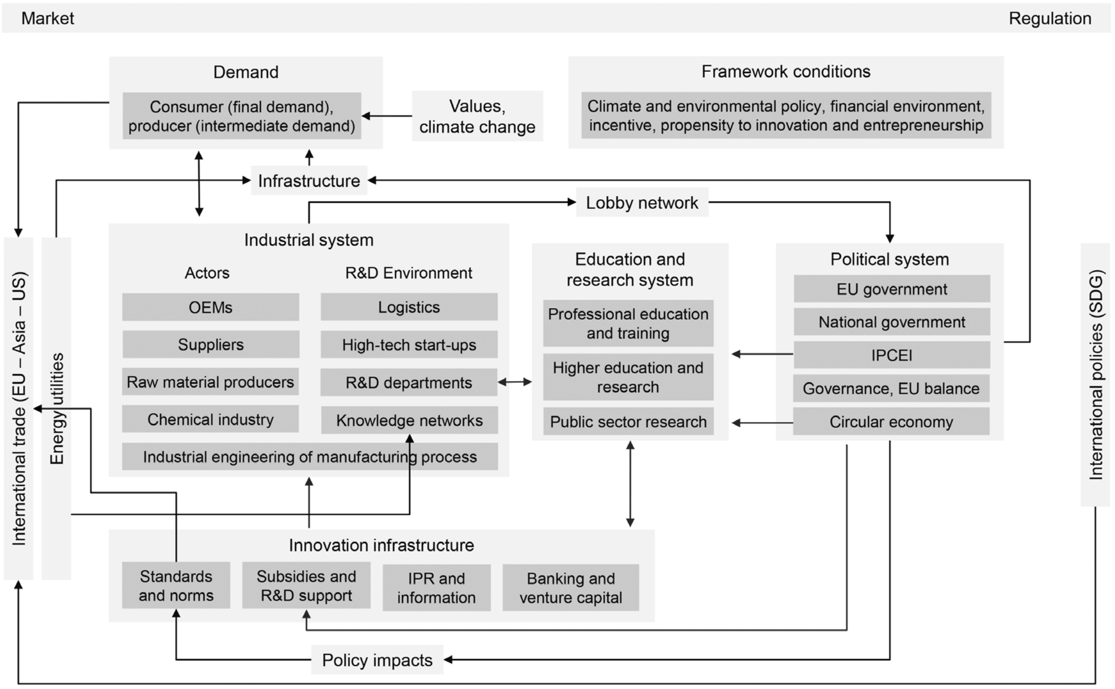
In general, we can identify the size and influence of the works council as one driver in OEMs choosing to set up their own battery cell production capacities. Negative employment effects are expected from the conversion of production from ICEV to BEV, so the demand for own battery cell production facilities close to established production sites may be expected to increase.

Another strategy that BYD is pursuing successfully, and for which Dyson was originally also aiming, is downstream integration in which battery manufacturers enter into vehicle production. However, Dyson had to discontinue its electric car project for economic reasons (Schaal 2019). The discussion about the integration of battery cell production into the OEM value chain eventually also leads to this value creation being taken away from powertrain-dependent suppliers. The shift to electric mobility is therefore also accompanied by a shift in value creation, away from the supplier and towards the car manufacturer. Mercedes, for example, has announced that it will significantly increase the vertical range of manufacture for the next generation of electric cars and thus switch from outsourcing to in-house production (Gerster 2022). This development thus leads to a movement of jobs rather than a complete avoidance of job losses. The employment effects are considered in more detail in section five.

4. Innovation system analysis

Innovation system analysis originally researched the capability of nations to create and implement innovations (Arnold et al. 2001). The concept has been transferred to the sectoral analysis of the automotive industry and describes the interaction between markets, regulations and various types of interacting networks (Schade and Krail 2012). This paper uses the concept to elaborate the technological innovation systems (TIS) of battery technology for vehicles (see Figure 10). Overall it reveals that Europe offers a very attractive, and in many adjacent areas already successfully operating, environment for the production of battery cells.

Figure 10 **Technological innovation system analysis of battery cell manufacturing**



Source: M-Five own illustration.

The development of innovations is framed by their environment with the market (including domestic and international) on the one side and, on the other, regulation reflecting national and international policy objectives. In the case of battery manufacture, such framework objectives include European climate targets but also green growth objectives as electric vehicles and their batteries may constitute an element of green growth.

Several elements of the political system directly address the achievement of European battery innovations; that is, the classification of battery manufacturing as an Important Project of Common European Interest (IPCEI) and the provisions for establishing a circular economy in Europe which support the establishment of a European resource base for batteries via an emphasis on the need to establish a battery recycling industry.

These elements stimulate the education and research system to direct its efforts towards battery related innovations (e.g. materials science, recycling, production processes) and thus support the industrial system and its various R&D departments by developing new technologies and manufacturing processes for vehicle batteries.

Looking at two of the parts of the wider innovation system – that is, the political system and the education and research system – political efforts (guidelines, financing and research capacities) have, in recent years, led to the development of viable and effective system elements in Europe which are capable of supporting a potentially successful European-level innovation in battery technology.

The industrial system needs to establish and improve the networks between OEMs and their suppliers: the chemical industry to provide the materials for the battery (e.g. anode, cathode) in the right quality; the machine engineering sector to develop the production machines and plants for the batteries; and the logistics sector as lithium batteries do, at some stage of their production, have to be handled and transported as a regulated dangerous good. Together with the start-up scene within Europe or outside Europe but in connection with European actors, the industrial system has also made progress towards forming a European battery industry, as documented by the plans identified in this study to ramp-up production capacity to up to 900 GWh in Europe by 2030 for use in electric vehicles.

In recent years, even raw material producers have seemed to emerge in Europe, planning to produce lithium from mining in south-east Germany and the Czech Republic (Erzgebirge) as well as from the innovative 'mining' of thermal waters in the Upper Rhine Valley.

Finally, the infrastructure side of EVs and batteries is developing through interaction between the transport sector and the energy utilities and even the large oil companies which have started to develop the Trans-European charging system, consisting of different levels of charging stations with up to 350 kW power for long-distance trips and regional networks with lower power but regionally extended coverage. However, the development stage of public charging networks differs between European regions and not all regions are yet prepared, or are even preparing for, the domestic car fleet converting gradually into an all-electric fleet. Nevertheless, the political system is also acting on the issue of charging to ensure minimum coverage of charging stations via the revised alternative fuel infrastructure directive (AFID), as part of the 'Fit for 55' package from July

2021, and the to be revised TEN-T guidelines, as part of the extended ‘Fit for 55’ regulations.

5. Employment effects

The previous section emphasised that both the European Union and national governments are providing strategic and financial support to attract and keep the automotive industry in Europe. This is especially true in respect of emerging battery cell production, which is seen as one opportunity to preserve the jobs in the automotive industry affected by change. The major transformation taking place in this industry is, however, not limited to the driver of electrification but also reflects the ongoing automation and digitalisation of both production and driving. It is challenging to disentangle and isolate these drivers in terms of their individual impact on employment.

Several studies have been published that analyse and quantify the impact of electrification on employment (Wagner et al. 2019; CLEPA 2021; Schade et al. 2020; Agora Verkehrswende 2021b; BCG 2021; Fraunhofer IAO 2020; Fraunhofer IAO 2019; Ifo Institut 2021). This report does not provide a further calculation but analyses the different outcomes – from high job losses to job gains – and thus identifies the differences in assumptions and perspectives that lead to these outcomes. As batteries are the focus of this working paper, we limit our considerations to highlighting the importance of battery manufacturing to overall automotive employment.

In any analysis of the employment effects within the automotive industry, three perspectives may be identified as relevant:

- the sectoral dimension;
- the regional dimension;
- the skills dimension.

Even though some studies conclude that the net employment effects are rather small, tremendous structural changes are taking place across all three dimensions which, ultimately, balance out, giving the overall rather modest effects when viewed generally.

5.1 Consideration of changes within sectors, regions and skills required

The sectoral dimension can range from a narrow view of jobs in powertrain manufacturing to a comprehensive view including adjacent industries such as charging infrastructure. The regional dimension ranges from changes within a country to a broad European perspective. The skills dimension highlights whether the same employees whose jobs are at risk can benefit from the creation of new jobs and how much retraining is required in this process. The choice of the scope considered within each dimension is a decisive factor for the resulting employment outcome and thus also one reason for the differences in forecasts.

The underlying assumptions across all the dimensions include production volume, sales volume, productivity, in-house value added, the production share of PHEV and BEV, and import and export figures. How crucial these assumptions are is shown by the analysis of employment at Volkswagen, which concludes that employment in vehicle manufacturing is expected to fall by 12 per cent by 2029 in the company, although only a small part of this is due to product change per se; the larger part is due to changes in production volumes, production locations and process improvements (Fraunhofer IAO 2020).

The existence of a full European battery value chain is assumed as a given in most studies and identified as a key component for a successful transformation. The great importance of establishing European battery cell production results not only from the labour perspective but rather from enabling upstream value creation and multiplier effects across the existence of the entire battery ecosystem (Fraunhofer ISI 2020). See section 4 on the innovation system analysis for further details here.

Overall, the personnel requirements for the production of the conventional powertrain are 70 per cent higher than for the electric counterpart (Fraunhofer IAO 2020). The production of the battery cell is, moreover, highly automated which is why the compensating employment effect is limited. At the same time, BCG (2020) has calculated that the labour hours per vehicle for BEV correspond to 99 per cent of those for ICEV for a premium passenger car. Only the distribution of labour hours between tier one suppliers and OEMs vary, depending on the extent of BEV component outsourcing (cell, module, pack, electric motor and transmission, and power electronics).

Finally, even if the employment effect of electrification is limited the question remains open as to the counterfactual against which the impact on employment ought to be measured. If the counterfactual is business-as-usual then it is arguable that employment would shrink as well. Such a strategy would result in significant market share loss and also end up with less employment due to the lack of demand and competitiveness beyond European borders.

5.2 The sectoral and national dimensions of jobs and skills

Employment in the automotive industry can be broken down to employment per individual component. The common result of various studies is that, while a narrow view of individual components shows job losses, a holistic view across all components shows job gains. The electrification trend reveals losses that are offset by the automated and autonomous driving features which, overall, leads to increases in the value created per car (i.e. by its endowment with ADAS components). The most significant assumption for all scenarios is the existence of a full European battery value chain, from raw material processing to assembly.

In the scenario focused only on electric vehicles (in line with the 'Fit for 55' package), the study by CLEPA (2021) results in a net effect of -244 000 FTE jobs in 2035 compared to 2020. This study concludes that the trend of electrification puts powertrain employment at risk. Even assuming a full European battery value chain, the different powertrain technologies are not able to offset each other in terms of employment. The main reasons identified in the study are higher automation, lower levels of manual labour and the very short adjustment time. Despite the latter, sticking too long to ICE and PHEV implies that large proportions of the value chain, and thus jobs, would be located outside the EU.

A further extension to adjacent industries, identifying the sectoral employment effects of a transition to sustainable mobility in Germany, concludes a loss of 128 000 jobs in conventional road vehicle production (ICE) in 2035 while the sector producing electronics, including batteries and cells, would gain 67 000 jobs (Schade et al. 2020).

A similar analysis of the employment effects across various sectors closely related to the automotive industry in Germany, taking into account six identified trends, confirms these results (Agora Verkehrswende 2021b). There are large job losses among car manufacturers (-70 000 jobs), powertrain-dependent suppliers (-95 000 jobs) and in maintenance and repair (-15 000 jobs). At the same time, powertrain-independent suppliers are experiencing strong growth in employment (+95 000 jobs). Related industries, such as plant engineering and services, energy production, energy infrastructure and recycling, are also expected to see positive employment effects (+110 000 jobs). This leads to a net effect of +25 000 jobs between 2020 and 2030. Overall, a loss of jobs in the automotive sector caused by the trend towards electrification is noted, alongside the compensation in full by parallel developments.

The broad sectoral dimension has also been analysed in an overall approach taking a European perspective, including core automotive industries (OEMs, ICE-focused and non-ICE suppliers, maintenance and repair) as well as adjacent industries such as equipment and services, energy production, energy infrastructure and recycling (BCG 2021). The main findings confirm the German study in terms of major losses in OEMs (-220 000) and ICE-focused suppliers (-280 000) but compensated significantly, although not in full, by gains in non-ICE suppliers (+240 000), maintenance and repair (+20 000), equipment and services (+15 000), energy production (+60 000), energy infrastructure (+120 000) and recycling (+10 000). The net effect is a loss of 35 000 jobs.

Regarding the wider trends, the impact of changes in market volume (-70 000 jobs), technology evolution (+65 000), product mix (+250 000), productivity gains (-230 000) and the shift to electric vehicles (-630 000 and +580 000) have all been identified. Analysis of the studies shows a very mixed picture and thus underlines the interdependence of many sectors that are affected by many of the trends developing at the same time, each with different and opposing effects on employment. In general, however, it can be derived that the larger the scope – that is, the more industries and the more trends are taken into account – the smaller will be the expected losses in employment. The loss in ICE component manufacturing cannot be fully compensated by establishing battery cell manufacturing facilities. However, this does come with many positive multiplier effects that increase additional employment in adjacent upstream and downstream industries (e.g. the deployment of charging infrastructure and upgraded electricity grids). Moreover, it is not the only transformation of the automotive industry that we expect by 2030.

5.3 The regional effects

Within the European Union, and even within a country, the differences in employment effects can be significant. For example, the south-west of Germany is strongly affected by job losses in the ICE sector but also benefits from the settlement there of new battery cell production (although eastern Germany is expected to benefit most). Further, at regional level the compensating effects of the transition to electric cars versus ADAS may prevail: some regions in Germany facing substantial losses in ICE-related jobs are compensating for this via their regional IT and electronics industries that will provide ADAS components (Wagner et al. 2019).

Analogously, the employment effects across the EU as a whole look much more differentiated than at national level. The loss in ICE-related supplier jobs is estimated to be highest for Germany (122 000), followed by Italy (66 000) and Spain (64 000). The gain in BEV-related jobs is highest for Germany (39 000 FTE), followed by Spain (37 000 FTE) and France (26 000 FTE). Regarding the net employment effect, France is the only country which slightly increases its total employment by 2040 compared to 2020, although the Czech Republic shows net zero changes. Looking at regions of the EU, one study concludes that the phasing-out of ICE vehicles is expected to have higher effects on eastern European countries while western European ones will play a key role in developing electric vehicle technologies (CLEPA 2021). This regional consideration is, however, limited to a very narrow sectoral dimension, comparing the employment effects only in the ICE and BEV segments.

5.4 The skills effects

The trend towards electrification will also shift skills requirements. Overall, 2.4 million positions with dedicated training needs are identified across Europe: about 1.6 million employees remain in their same job profile and require only on the job training; 0.6 million employees require retraining and relocation in a similar job profile; and 225 000 employees require reskilling and relocation with a new job profile (BCG 2021).

The consequence is that sizable employment transitions will occur over time between industries, occupational fields and regions, leading to a diverse picture of job losses, job creation and job upgrading, but emphasising throughout the primary need for continued training.

Table 3 summarises this chapter by providing an overview of the key characteristics of the studies analysed.

Table 3 **Comparison of employment studies**

Study	Period	Value chain	Focus	Country	Trend	Net employment effect
Wagner et al. (2019)	2015-2035	National cell production	Employment per component, full vehicle	GER	Automation, electrification, productivity, market volume, technology, mobility behaviour	+42 000
CLEPA (2021)	2020-2040	Full EU battery value chain including processing of raw material	ICE and BEV supplier, powertrain component	EU	Electrification	-417 000 in radical scenario; -275 000 in electric vehicle-only scenario; +122 000 in mixed technology scenario
Schade et al. (2020)	2018-2035	National cell production	Transport industry	GER	Automation, electrification, productivity, market volume, technology, mobility behaviour	+234 000 (total economy)
Agora Verkehrswende (2021b)	2020-2030	National cell production	Automotive and adjacent industries	GER	Market volume, technology, product mix, productivity, electrification, job migration	+25 000
BCG (2021)	2019-2030	EU cell production	Automotive and adjacent industries	EU	Market volume, technology, product mix, productivity, electrification	-35 000

Source: M-Five own illustration.

6. Synthesis: What is at stake for the European automotive industry?

The main findings of the previous sections are presented here to outline the possible evolution of European battery cell manufacturing for automotive applications and to identify the strengths, weaknesses, opportunities and threats that can be expected up to 2030.

In 2014, a study on the future of the German automotive industry on behalf of the German parliament identified seven strategic challenges, one of which was the electrification of road vehicles and thus the need to build-up the full battery value chain in Germany (Schade et al. 2014). These seven challenges have converged and most authors now quote the last few years and the decade ahead as the period of the greatest transformation of the automotive industry, with three intertwined mega-trends influencing it: decarbonisation; electrification; and digitalisation. We would also add the emergence of new mobility services as a fourth mega-trend that involves changing ownership and mobility patterns. This paper focuses on one essential element of electrification: battery cell manufacturing, evaluating its importance for the European automotive industry and for competitiveness and employment.

In the short term, the industry in Europe should and is expected to enter the lithium-ion battery cell market. Currently the focus is on optimising NMC technology, whose material composition will be improved by a further reduction of the cobalt content, partly followed by a reduction of the nickel content, making it more cost effective. At the same time, energy density will continue to increase. Market entry into NMC manufacturing is important for Europe to catch up and gain insights into production ramp-up and large-scale battery (cell) production. In the long term, towards the mid to late 2020s, the introduction of solid-state technology, initially with graphite and silicon anodes, and later with lithium metal anodes, is expected. This shift in the technology would provide Europe with the opportunity to establish technological leadership.

A parallel development of battery technology is the route of the further improvement of the specific energy of LFP cathodes to exploit their advantages in terms of more environmentally friendly raw materials, lower costs, higher safety and longer life. Here, China has been a major pioneer so far and its technology might be simply imported to Europe since the development of European manufacturing has been focused on NMC. Improvements in LFP technology could reduce the market size for the NMC technology preferred by the European battery industry. The first European LFP battery cell production plant, in Serbia, has recently been announced and is also backed by EU funds.

Vertical and upstream integration can be expected along the value chain, enabling better control, ensuring high value-added and at least partially offsetting the losses in employment due to the shift to BEV production from more employment-intensive ICE production. An increasing build-up in recycling capability and capacity can be observed which could be accelerated by legislation in the future. This offers Europe the opportunity to become increasingly independent of volatile and rising raw material prices and security of supply risks, while generating additional value locally and establishing a leading market for green batteries.[7]

Europe appears to be an attractive location for future battery cell production and has already seen several announcements from various manufacturers. If they are implemented as planned by 2030 this would add up to 900 GWh of cell production capacity in Europe. However, there are hurdles to scaling on top of the risk of over-investment and battery 'bubbles', so not all announcements may actually be realised. Nevertheless, rising European demand for batteries and thus cells is accompanied by increasing European production, such that we expect a growing European share of global battery cell production.

With regard to the employment effects, sizable transitions will occur over time while the picture for jobs and skills is diverse. The transformation will have only a minor impact on the total number of jobs in the automotive industry overall, but major restructuring and a high need for skills must be expected.

Figure 11 provides a SWOT analysis identifying strengths, weaknesses, opportunities and threats for European battery cell production.

Figure 11 **SWOT analysis of European battery cell production**

Strengths	Weaknesses	Opportunities	Threats
▪ Strong automotive industry ▪ High European demand (sufficient market share for emerging players) ▪ Existing logistics ▪ Strong chemical and materials industry ▪ Attractive investment environment ▪ Access to talented workforce	▪ Lack of access to raw material mining and refining capacity ▪ Need to leapfrog along the learning curve of Asian manufacturers	▪ **Short term**: market entry and catch-up through optimisation of current technology ▪ **Long term**: increasing market share through solid-state and next generation technologies ▪ Building recycling capacity ▪ Localisation and control of supply chain ▪ Vertical and upstream integration of value chain ▪ Building export capacity	▪ Dominance of Asian suppliers ▪ Catching up takes time and entails high costs ▪ Time is short as Asian players are already building capacity globally ▪ Battery \`Bubble\`: not all subsidised projects will succeed ▪ Underestimation of potential of LFP technology

Source: M-Five own illustration and analysis.

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[7] It is also understood in China that green battery manufacturing will become a must, such that efforts will be and indeed are already being undertaken there to certify the sustainability of battery plants.

The significance of change in European car markets becomes obvious looking at the example of the German market by segment and by powertrain system. Across the ten segments of the market, the top-selling single model usually comes from Volkswagen and is currently the combustion engine version of the VW Golf, which sells more than 10 000 vehicles per month. In September 2021, however, Golf sales were down to 6886, with the Tesla model 3 middle class car ranked second with 6828 units sold, almost toppling the long-established number 1. The signal is clear that an electric car produced outside Germany is close to becoming the top selling single model in the country. This example also shows the importance of the capability of producing batteries in Europe as electric vehicle sales have already grown out of being a niche market and are on the verge of overtaking sales of cars with combustion engines.

The question of what is at stake can also be looked at from the opposite angle, i.e. what would be the counterfactual if Europe did not shift to battery and electric car production but followed the trend of production shares in 2020 with ICE remaining the dominant technology. It is true that our estimate of just 52 000 direct jobs being generated by the large-scale ramping-up of battery cell production in Europe up to 2030 cannot compensate all the job losses arising from reduced ICE production. This observation also holds when considering the indirect jobs created by logistics, recycling and pack manufacturing. This lost employment constitutes job losses by structural change. However, if industry in the counterfactual continued to focus on ICE production, sales can be expected to drop as the market continually shifts to electric vehicles due to decarbonisation policies, cost reductions driven by large electric vehicle markets outside Europe, in particular China, and value change among customers in favour of climate protection. In such a counterfactual, job loss would occur due to the steady losses of market share among European auto manufacturers. Such employment losses would be higher and irreparable compared with the losses due to structural change. These structural changes, while possibly painful in the short run, will allow European automotive and battery industries to remain at the forefront of technological development and to preserve their competitiveness.

Box 3 **Current geopolitical and economic challenges**

Recent crises such as the Covid-19 pandemic, the chip shortage and currently the Russian war on Ukraine highlight the major risks facing the automotive industry such as fragile global supply chains and a high dependence on foreign primary products. This is particularly true for the supply of raw materials. The prices for lithium, cobalt, copper and nickel have risen sharply in 2022 and pose a serious threat to a successful, cost-effective and competitive ramping-up of battery manufacturing and thus of electric mobility. While the reason behind lithium, cobalt and copper is high demand in the face of scarce supply, the price increase for nickel is directly related to Russia, which is responsible for about 20 per cent of the global supply of the class 1 nickel required for lithium-ion batteries. Uncertainties about future political developments are driving up prices (Economist 2022; Handelsblatt 2022).* However, most companies have long-term nickel contracts and should not be affected immediately by price increases.

Recent developments in battery chemistry, reducing the cobalt content and increasing the nickel content, could be extended by a stronger focus on LFP cells as these do not require cobalt or nickel. The consequences of concentrated raw material extraction and refining in only a few countries and the lack of European control along the entire battery value chain are currently becoming even more visible. These crises are taking place in an environment in which many important investment decisions along the value chain are currently being made and some are likely to be strongly influenced by these developments. As a result, we expect that there will be increased focus on the diversification of raw material sources and less reliance on single or only a few supplying countries, in particular Russia. As priorities shift from cost competitiveness to diversification, prices may rise in the long run.

The sanctions imposed on Russia are leading to a sharp rise in fossil fuel prices which, on the one hand, could drive electrification even further. On the other, technological advances and economies of scale in battery cell production, which have driven the fall in electric vehicle prices so far, could be counteracted by rising raw material prices inverting the trend of falling battery prices and thus leading to a slowdown in the ramping-up of electric mobility. This may affect European car production more, for example, than Chinese car production. If China takes over the Russian nickel supply originally intended for Europe, it will be able to supply its products at even lower cost and thus pose a threat to the overall competitiveness of the European industry (Handelsblatt 2022).

It is the responsibility of policymakers and industry to take these challenges as an impulse to develop strategic autonomy, secure access to raw materials and gain control over the battery value chain. In addition, a sourcing strategy that combines diversification and cost competitiveness is required. We expect that high and volatile raw material prices are currently the biggest threat to the electric vehicle industry. However, some increase in prices is likely to stimulate the mining industry to invest in new supply, in particular in Europe. We urge that such investment be made. Finally, taking these developments into account, there is an even stronger case for the accelerated development of battery recycling.

* However, experts expect at least a partial calming of currently exploding nickel prices, as it is short-squeeze activities which have continued to drive price developments on the market. The London Metal Exchange even temporarily suspended trading to avoid market panic (Economist 2022).

7. Conclusions and outlook

In the first decade of automotive electrification, the development and scaling-up of battery cell manufacturing largely took place outside of Europe; that is, in China and the United States. Initial European attempts in the industry (such as Li-Tec Battery GmbH) failed. Nevertheless, this decade was used by European industry and policymakers to stimulate and develop a European innovation system that has facilitated research into next generation cell technologies and to establish new co-operation between OEMs, suppliers, materials producers, research institutions and start-ups. That innovation system spans many European countries from Norway and Sweden to France and Germany to Spain, Slovakia and Hungary.

At the beginning of the second decade of automotive electrification, Europe is now on the right path to develop its own local battery cell manufacturing industry, although Asian and American manufacturers are also investing in factories in Europe. On the one hand, foreign investment strengthens the innovation system in Europe as it increases human and financial capital in Europe. On the other, however, it intensifies competition in the markets for electric vehicles and battery cells between European manufacturers and their global competitors. Employment in Europe of course benefits in general from both the investments of, and local production by, European as well as non-European battery cell manufacturers. While the direct employment effects are limited due to the high level of automation in battery cell production, there are further, indirect and positive employment effects in adjacent industries.

Vertical integration of the battery value chain in Europe is strongly recommended, starting with raw material extraction and refinement and introducing a circular battery economy with investment in recycling R&D and recycling capacities. Some recent projects seem to exemplify this trend, such as lithium mining in Zinnwald or the Upper Rhine Valley, or the recycling demonstration plants of BASF and Volkswagen. Important reasons are that (1) the battery logistics of new and used batteries are complex and costly, so ‘local’ European production will contribute to overall efficiency and cost advantages; and (2) higher recycling shares in the medium to long term mitigate the risk of raw material shortages and high raw material prices. We expect a substantial risk of short to medium term shortages in raw material supply and recommend early and broad coverage of sufficient supply, especially for lithium, nickel and cobalt. In the long term, new mines will be opened and, together with increasing recycling volumes as well as optimised chemical compositions, will lead to a relaxation in raw material markets.

The main risk in the battery domain seems to be the underestimation of the potential of LFP technology and the associated shift in focus in the market from performance to cost compared to NMC. If technological progress in LFP energy density continues, as we expect, the advantages of low cost and high safety will no longer be compromised by comparably lower energy density. Demand for LFP will thus increase and impede the economic success of some European NMC production plants. However, derived from the announcements made so far, NMC will continue to play the more important role in EU battery cell manufacturing. We do see the potential for European LFP production in lower-cost locations, such as the first announcement of an LFP production plant in Serbia. However, Chinese manufacturers in particular have major advantages in know-how that need to be caught up with in order to establish profitable European LFP production.

Regional imbalances in automotive value creation and employment in Europe are initially increasing with the shift away from the combustion engine towards electrification. However, in the long term we expect the often observed development of transformation in Europe in which production starts from the technologically advanced centres of Europe and shifts over time towards the periphery along with the maturing of the technology.

In the electric vehicle domain, the main risk seems to be the too-strong commitment to manufacturing PHEV in Europe, driven by the more positive stimulus for employment, while the environmental benefits, the policy focus, the technical readiness and the foreign competition are tilted towards BEV, making PHEV life on European and global car markets a short story only. In addition, there is a risk that new players entering the local market will be underestimated and exploit the BEV gap created by the concentration on PHEV to make more competitive offers, especially in the mid and high-end segments. This risk emerges not so much from pure imports (e.g. from China) but it does indicate that the local production of new entrants in Europe, such as Tesla, may challenge the European incumbents.

We do not see any risks in demand for electric vehicles: the main drivers of demand, price and technology developments, and the policy instruments and incentives to stimulate demand, as well as the sufficient supply of electrified models across all segments, are all a given. Currently there is a lead time from the order of an electric vehicle to delivery of up to one year. Additionally, our analysis has focused on the needs and status of batteries for electric car manufacturing. However, we expect strong movements to electrify both buses and trucks by 2030. This will increase the size of the battery market and will lead to additional demand for road vehicle cells and batteries in Europe.

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All links were checked on 27/05/2022.

Abbreviations

ADAS	Advanced Driver Assistance Systems
AFID	Alternative Fuel Infrastructure Directive
BEV	Battery Electric Vehicle(s)
EC	European Commission
FCEV	Fuel Cell Electric Vehicles
FTE	Full-time Equivalent
GHG	Greenhouse Gas
GWh	Gigawatt hour
ICE	Internal Combustion Engine
ICEV	Internal Combustion Engine Vehicle(s)
INACD	Innovators and Actors Database
IPCEI	Important Project of Common European Interest
IPR	Intellectual Property Rights
KWh	Kilowatt hour
LFP	Lithium Iron Phosphate
LiB	Lithium-ion Battery
NCA	Nickel Cobalt Aluminium
NMC	Nickel Manganese Cobalt
OEM	Original Equipment Manufacturer
PHEV	Plug-in Hybrid Electric Vehicle(s)
TEN-T	Trans-European Networks for Transport
TIS	Technological Innovation System

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