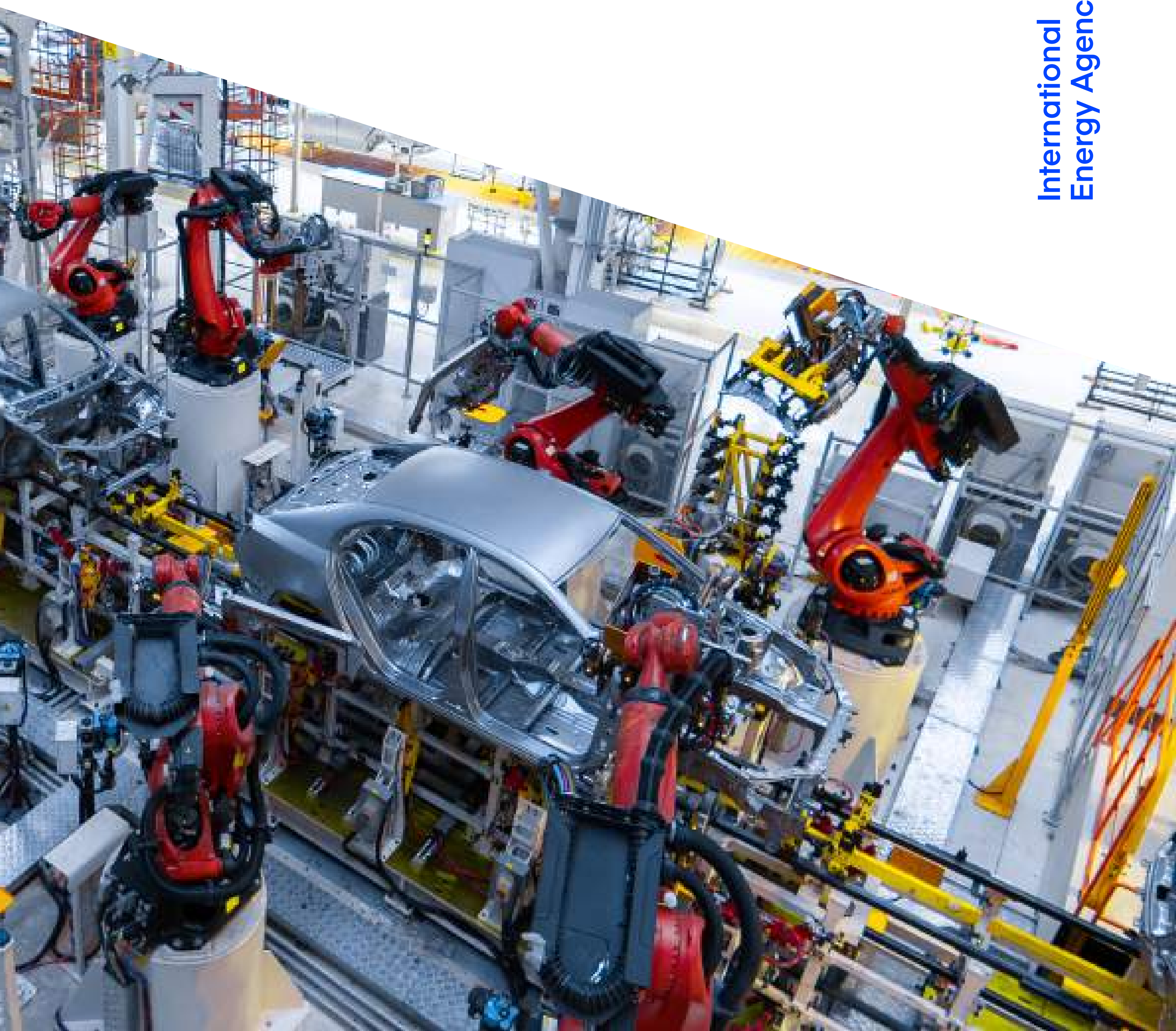
What Next for the Global Car Industry?

An Energy Technology Perspectives Special Report



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Foreword

In modern history, few innovations have been more consequential than the car.

Today, cars are central to the lives of millions of people around the world. The market for cars is one of the largest for a single product, and this product represents the single largest source of oil demand, a key trend that the International Energy Agency (IEA) has tracked closely for decades. What's more, car manufacturing is a pillar of the economy in many countries today, directly employing over 10 million people across the world – while supporting millions of additional jobs elsewhere in the supply chain, from steel and aluminium production to component manufacturing.

Yet as we look at the data, we can see that the car industry is undergoing major changes, which merit close attention for their implications for energy and economies. Three fundamental shifts are underway – in terms of the geography of car production, in terms of the regions that are driving sales growth, and in terms of the technologies being chosen by consumers. This is posing challenges for many internationally renowned carmakers, which have honed their craft over decades of manufacturing focused on internal combustion engine cars.

The geographic shift in global car production has been led by China, which more than doubled its output between 2010 and 2024 to account for 40% of global car manufacturing capacity today. In 2024, China overtook the European Union to become the world's largest car exporter, propelled by significant investments in the manufacturing of electric cars and their batteries.

At the same time, as a result of rising incomes and government policies, car ownership in emerging economies is growing quickly while demand in advanced economies has levelled off. The share of emerging and developing economies in total car sales worldwide grew from 20% in 2000 to 50% today.

In terms of technologies, the share of electric cars on the road is increasing rapidly worldwide. Electric cars accounted for more than a fifth of all cars sold globally in 2024, while sales of cars that exclusively run on internal combustion engines were significantly below their 2017 peak. This year, one in four cars sold worldwide is expected to be electric.

These changes have raised major questions about the future of the global car industry. The decisions facing incumbent carmakers today will shape their future competitiveness for decades to come, as well as the futures of companies across the broader car supply chain. They will also have implications for the wider energy sector, including oil, electricity and beyond.

Against this backdrop, I commissioned this report to provide a strong empirical basis to inform decision-making by governments and industry, highlighting the major opportunities and challenges ahead. It includes first-of-its-kind analysis based on a review of market data, costs and consultations with industry players. The focus is on understanding the implications of the major changes outlined above for economies and the energy sector. We fully recognise that consumers will choose their cars based on their own preferences and that carmakers may pursue strategies encompassing a wide range of technologies.

I would like to commend the talented and hardworking IEA colleagues who led this analysis – with special thanks to lead authors Leonardo Paoli and Elizabeth Connelly, overseen by Araceli Fernandez Pales, the Head of the IEA's Technology Innovation Unit, and IEA Chief Energy Technology Officer Timur Gül. Their work across a broad range of energy technologies provides valuable insights to inform discussions worldwide about the car industry and the energy sector.

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Executive Summary

Fundamental shifts are reshaping global car markets

The car industry is undergoing profound changes as electric car sales continue to rise and the geography of global car sales shifts. Global car sales approached 80 million in 2024 and have largely bounced back from their pandemic-related slump. Recent growth has been exclusively driven by sales of electric and hybrid cars, which made up around 45% of total car sales in 2024, while global sales of pure internal combustion engine (ICE) cars peaked in 2017 and have since fallen by 30%. By contrast, electric car sales grew more than 14-fold over the same period, reaching over one-fifth of cars sold globally in 2024. The geography of car markets is also on the move: China and other emerging economies now account for over half of global car sales, up from just 20% in 2000.

China's car production more than doubled between 2010 and 2024, when China overtook the European Union to become the world's largest exporter. Global car production today is lower than at its 2017 high, and its centres have shifted. China now accounts for 40% of total manufacturing capacity and Europe and North America for 15% each. India's car output has also grown and is now 25% above 2017 levels. By contrast, production in advanced economies has stalled or declined in the past decade, despite the European Union and Japan still relying heavily on export markets, which account for 40% or more of production.

How the incumbent car industry responds to these shifts will be critical for its future and that of industries across the supply chain – and for the energy sector as a whole. Passenger cars are the single largest source of global oil demand today, covering around one-quarter of total consumption, while electric cars are a small but growing driver of electricity demand. The use of alternative fuels, notably biofuels, represents 5% of energy use from cars today and is set to grow in support of policy priorities such as fuel diversification and emissions reductions. The extent and pace by which cars electrify, however, is what will affect future car manufacturing as well as the energy sector the most, and explains the focus of this report.

ICE sales will not fade quickly – car manufacturers must navigate transitions that move at different speeds

Even as ICE car sales are set to continue declining in China and advanced economies in aggregate over the coming years, they are likely to rise in other regions. Different regional technology mixes pose challenges for the global industry. Today, Japanese carmakers supply two-thirds of cars sold in Southeast

Asia and over half of those sold in the Middle East and India; European carmakers have a nearly 50% market share in Central and South America. Industry incumbents dominate ICE car sales in these regions, and the lack of recharging infrastructure is a bottleneck for electric car sales growth. But their market uptake cars is increasing in these regions nonetheless, challenging the market share of incumbents; imports from China make up 90% of electric car sales in emerging markets today.

New market-entrants are capturing an increasingly large share of the electric car market. Growth in electric car sales in recent years has especially benefited new pure-play electric car makers from China and US-based Tesla; some 45% of global electric car sales in 2024 were from such pure-play electric car makers. Chinese electric cars are cost-competitive domestically and increasingly abroad. Around 70% of electric cars sold worldwide are manufactured in China, thanks in part to government industrial policies, such as low-cost loans, that have supported manufacturing scale-up, strong supply chains and the development of advanced battery technologies. Two-thirds of battery electric cars sold in China in 2024 were cheaper than equivalently sized ICE cars.

Existing electric car manufacturing capacity is more than sufficient to supply global demand today, but some retooling or repurposing of capacity will be needed moving forward for countries to meet demand domestically. In China, electric car manufacturing capacity is currently about twice as high as domestic production. This means there is ample opportunity to cater to growing international markets, although this surplus capacity and fierce domestic competition has been hurting profit margins and made consolidation of the industry an important government priority. In Europe and North America, electric car manufacturing capacity is roughly sufficient to meet domestic demand today, although future growth in sales will require additional manufacturing lines. This does not, however, mean that new factories need to be built; past evidence suggests that repurposing ICE factories is possible without halting conventional car production, and retooling can be achieved within 1 year.

The car industry is a key contributor to many economies

The car manufacturing industry and supporting sectors account for 2-6% of GDP in major car-producing countries. The world's largest car manufacturers – China, the European Union, Japan, Korea and the United States – together account for around 80% of the direct value added in global car manufacturing. Many other sectors also contribute to the manufacturing of a car, from steel and aluminium production to the suppliers of vehicle parts and components. In major car-producing economies, for every dollar of output from the car industry, about USD 0.7 of value added is generated in the economy to support production.

Car manufacturing directly employs over 10 million people globally today, nearly half of whom are in China and the European Union. Indirect employment in related industries also adds to the significance of the car industry as an engine of jobs. For example, in Japan, the automotive industry directly supports around 900 000 jobs, but this grows to 1.4 million jobs when including those in upstream industries, such as materials and equipment supply. Jobs in manufacturing of vehicle components, which are tradeable and more labour intensive than vehicle assembly, tend to be concentrated in countries that neighbour centres of vehicle assembly and have lower labour costs, such as Mexico, Poland and Thailand.

The car industry is rooted in regional production centres, so its evolution directly impacts its suppliers

The car industry tends to operate in clusters where vehicle assembly, automotive supplier and materials plants benefit from proximity. This is because the required volumes are very large – with the car industry accounting for 6% of steel and 17% of aluminium demand globally, with even higher shares in the European Union, Japan, Korea and the United States. Automotive industrial clusters today closely reflect regional vehicle priorities: Detroit in the United States and Nagoya in Japan each have 1 battery factory, whereas Shanghai in China has 26, with a production capacity of about 200 gigawatt hours. That is over 5% of the global total and more than current capacity in all of Europe.

The automotive supplier market is worth about USD 1.3 trillion today, equivalent to 40% of the global market for cars. Over two-thirds of the market is related to components other than the powertrain, while around 20% are ICE-specific. The market for electric vehicle-specific components represents just 10% of the overall market, but the share has grown nearly sevenfold since 2019. The global market for ICE-specific and non-powertrain components is dominated by suppliers headquartered in Europe, Japan, Korea and North America. In contrast, for battery related-components, Chinese companies command around 80% of global manufacturing capacity. Exports of other automotive components from China are also growing.

Batteries are key to regional differences in manufacturing costs – and to the value created in regional economies

The direct cost of manufacturing a battery electric car is higher than producing an ICE car, mostly due to battery costs. Powertrain components and the battery also account for the main difference in economic value created by manufacturing. In the European Union, for example, over 90% of engines and parts for ICE cars are produced domestically, compared to just over 40% of batteries and parts for battery electric cars. This difference is less pronounced in the United States, where a higher share of both engines and batteries are imported, albeit from different regions. Japan and China have domestic supply chains for both ICE and battery electric car manufacturing, meaning there is hardly any difference in levels of domestic value creation. The ability to produce batteries competitively is the main determinant of regional EV manufacturing costs.

As battery manufacturing scales up in different regions, policy support will need to strike the right balance between competitiveness and domestic value creation. Full domestic self-sufficiency is rare in the car industry, and importing components may provide a short-term boost to the competitiveness by significantly cutting production costs. The powertrain represents around one-third of the estimated retail price of a battery electric car, and the battery about one-quarter. As such, even in regions where all battery components are imported, most of the economic value associated with car manufacturing is retained through vehicle design, assembly and non-powertrain component manufacturing. Still, there are strategic benefits from developing a domestic battery industry over time, as its value extends beyond the car industry. China's recent announcement of export controls on batteries, components and machinery is a reminder of the potential risks that stem from a concentrated supply chain.

China's car industry has a significant cost advantage, but there are opportunities to close the gap

Producing cars in China is cheaper than in advanced economies, especially for electric cars. Producing a small SUV in China is over 30% cheaper than in advanced economies for both ICE and battery electric powertrains. Large-scale manufacturing operations and vertical integration are the key reasons behind China's cost competitiveness; lower energy prices and labour costs also contribute, but to a lesser degree.

Lower powertrain costs explain nearly 40% of the manufacturing cost difference for electric cars in China compared with advanced economies. Average battery cell prices in China are over 30% lower than in Europe and over 20% lower than in the United States. China achieved this cost advantage through economies of scale, experience, access to supply chains for critical minerals, and successful innovation in lithium iron phosphate (LFP) battery chemistries, a lower-cost battery alternative. Prior to 2018, China and the United States had cumulatively produced similar quantities of EV batteries and offered similar battery pack prices, but by 2024 China had produced over six times as many, with battery packs priced more than 20% lower than in the United States.

The gap in battery production costs can be bridged with sufficient time and investments. The cost of an equivalent battery cell fully produced in Europe would be 70% higher than one produced in China today. Access to low-cost components and critical minerals account for 30% of the cost difference, but another half is due to manufacturing efficiency and automation. Comparable rates of battery production efficiency can be reached outside of China if factories ramp up production and gain experience. Recent investments in cheaper LFP chemistries across advanced economies may shrink the cost gap further, but the recent export controls risk slowing the deployment of advanced LFP chemistries outside China if enacted.

Additional direct manufacturing costs do not fully explain the higher prices of electric cars outside China. The cost gap between electric and ICE cars exists in all markets, but the gap between respective retail prices and direct manufacturing costs varies due to differing pricing strategies, competitive pressures and indirect costs (such as overhead and R&D). For example, in China, the difference between the retail price of the electric and ICE version of a small SUV is similar to the difference in direct manufacturing costs; in Germany, the retail price difference is more than double the manufacturing cost difference.

Strategic priorities for boosting competitiveness in electric car manufacturing

There are no easy responses for incumbent manufacturers to the challenges posed by the major shifts in global car markets. Many are currently working to balance their portfolios in a way that leverages their strengths in producing ICE and hybrid cars, while also improving competitiveness in EVs. The latter can rely on five strategic priorities for public and private sector actions:

- **Achieve economies of scale and foster learning-by-doing**. In countries with large ICE manufacturing operations, policy measures to create dependable, mass-market demand, such as sales targets for EVs, can drive investment and help to build experience as manufacturing ramps up.
- **Scale up domestic battery manufacturing and develop related skills**. Sharing scale-up risks through partnerships, prioritising workforce skills and fostering a domestic ecosystem to supply and maintain equipment can support nascent battery manufacturing capacity through the difficult start-up phase.
- **Prioritise the most competitive battery chemistries.** Attracting investment in manufacturing today's cost-competitive battery chemistries close to car assembly centres is a near-term priority, but remaining at the technological frontier will require continued R&D on innovative battery designs.
- **Secure dependable supply chains for critical minerals.** In the near term, the focus must be avoiding shortages, but diversified supply chains will be key to future competitiveness. Co-operation with mineral-producing and processing countries can support this aim while providing partners with economic opportunities, as can technological and regulatory developments to increase local minerals supplies, reduce demand and increase recycling.

- **Minimise energy costs where they matter most**. Energy costs can influence decisions about where to locate new manufacturing plants, especially in upstream supply steps such as material production and battery component manufacturing. Electricity market design and power purchase agreements can help reduce costs and price volatility.

Introduction

The global car industry has operated under relatively stable conditions for many years, with the world's largest car manufacturers originating from the European Union, Korea, Japan and the United States, and, more recently, the People's Republic of China (hereafter 'China'). Their outsize role builds on decades at the forefront of technological innovation around the internal combustion engine (ICE), as well as highly integrated and optimised supply chains that allow for vehicles and their components to be produced at low cost. Over the past 15 years, however, this business model has increasingly been challenged by the roll-out of electric cars,[1] which have steadily become more prominent in government plans to address key policy goals, including improving air quality, reducing emissions and bolstering energy security. While other technology approaches to address these goals exist or are otherwise possible, such as biofuels or synthetic fuels that could be used in ICE vehicles, the global market for electric cars has developed rapidly in recent years. In 2024, more than one in five cars sold globally had an electric powertrain, up from just 4% only 5 years earlier. The vast majority were sold in the world's largest car markets – China, Europe and the United States; in China, one in ten cars on the road is now electric.

The technology required to master electric vehicle (EV) production is sufficiently different to that needed for ICE vehicles to enable new manufacturers to enter the market. For example, the Chinese company BYD, today the world's largest electric car manufacturer, was originally a battery manufacturer. The technological shift that comes with electric cars has the potential to transform the industry in a way that is unparalleled in recent history.

This IEA Special Report, released as part of the IEA's *Energy Technology Perspectives (ETP)* series, aims to provide technology and market insights to assist decision makers in government and industry who are seeking to identify mechanisms for producing electric cars competitively. The first chapter introduces the car industry today, summarising major market trends in terms of sales, production and trade, and presenting the role of the car industry for jobs and economic growth. The second chapter focuses on the implications of a shift to electric cars and the structural differences between electric and conventional ICE car manufacturing, as well as providing an overview of the policy landscape and differing corporate strategies for electrification. In the third chapter, the analysis of

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[1] Electric cars are defined as passenger light-duty vehicles equipped with an electric drivetrain unit powered either exclusively by a battery (i.e. battery electric vehicle or BEV) or by a combination of a rechargeable battery and an internal combustion engine (i.e. plug-in hybrid electric vehicle, PHEV).

electric car manufacturing is deepened to cover the new centres of electric car manufacturing, the impacts for automotive parts and component suppliers – most notably with regards to batteries – and the potential for repurposing or retooling existing production capacity for electric car production in different regions. The fourth chapter presents new analysis quantifying the cost gap in electric car production between manufacturers in China and in the rest of the world, detailing the key factors that make a difference to cost competitiveness in different regions. The fifth chapter then distils this analysis to identify different tools for boosting cost competitiveness in electric car production today and outlines strategic priorities for government and corporate decision-making in the near- and medium-term.

Chapter 1. The global car industry in context

Highlights

- Global car markets are undergoing potentially transformative changes. Car sales reached a high point in 2017 and have bounced back from a pandemic-related drop due to sales of electric and hybrid cars; sales of conventional cars have continued to fall. Growth has shifted to emerging economies including China since the turn of the century, with around half of all sales now in these regions.
- Global car production has grown unevenly since the pandemic. China's car output reached a record 27 million in 2024, 30% higher than in 2019, while India's output grew 30% to almost 5 million cars. US production approached 2019 levels in 2024, whereas production in the European Union and Japan remained under pre-pandemic levels, due to lower domestic sales and exports.
- Exports from the four largest car-producing regions represent 20% of global car production. Electric cars now account for over 15% of global car trade, up from less than 4% in 2019. China overtook the European Union to become the world's largest car exporter in 2024, exporting 20% of output, up from about 3% in 2019.
- The global market for cars amounts to around USD 2.9 trillion per year, making it one of the largest markets for a single product. The car industry accounts for around 6% of gross value added by manufacturing, or around 1% of global GDP in 2024. The European Union, Japan, Korea, China and the United States account for around 80% of the value added in global car manufacturing.
- The car industry adds value in other sectors, such as steel, for which it represents over 10% of demand in advanced economies. In the European Union, for each EUR 1 million in motor vehicle sales in 2022, an average of EUR 1.4 million more was generated across the economy to support production. If direct and indirect value addition from car manufacturing are combined, the contribution to global GDP is around 3%. Irrespective of where a car is produced and the share of imports, more value tends to be generated downstream than upstream.
- Over 10 million people worldwide are directly employed in the car industry, more than ever before. Job distribution differs depending on output and level of automation. The industry also supports jobs upstream, and in service and retail.
- Car manufacturing remains rooted in regional industrial clusters, such as Detroit, Nagoya or Shanghai. While the former 2 each have 1 battery factory, Shanghai has 26, with a capacity of about 200 GWh – more than 5% of the global total.

Introduction

The first chapter of this report introduces the car industry of today and the major trends affecting the development of its supply chains. It provides an overview of vehicle sales, production and trade globally, and highlights the challenges facing traditional centres of car production. It then explores the contribution of the car industry to the global economy, including as a major employer. Finally, a series of data visualisations present geospatial data on industrial clusters for car manufacturing in Europe, China, Japan and the United States.

1.1 Macro trends in the global car market

Car sales are rising globally but stagnating in established markets

At the global level, car sales rose for decades until 2017, interrupted only by the fallouts of economic crises. After 2017, however, total sales started to decline, gradually at first and then dropping precipitously during the Covid-19 pandemic in 2020. Global car sales grew again in 2021 and almost returned to pre-pandemic levels in 2024, but this growth was not uniform across all types of cars. Most notably, sales of conventional ICE cars have not recovered since the pandemic; sales in 2024 were over 30% lower than in 2017, suggesting that 2017 may represent the all-time peak in ICE car sales.

On the other hand, sales of hybrid and electric cars[2] are higher today than in 2017. In 2024, sales of hybrid cars were three times the level in 2017, having grown more than 20% compared to 2023. Electric car sales grew more than 14-fold between 2017 and 2024, and represented more than one-fifth of car sales globally in 2024. Sales of electric cars have exceeded sales of hybrid cars since 2020, which remained at a share of less than 10% of global car sales in 2024.

In Europe, the world’s third-largest car market, sales were hit hard by the pandemic, falling by about 25% year-on-year in 2020 and then recovering only slowly. In 2024, total sales of 14.5 million cars were still nearly 15% below pre-pandemic levels. In North America, a surge in sales to 18 million cars meant the market returned to just below pre-pandemic levels. Overall, recent trends suggest that potential for further growth in car sales in advanced economies is rather limited. Not only have car ownership rates been relatively constant for decades, but consumers are also holding on to their cars for longer – in Europe, for example, cars were roughly 10% older in 2022 than in 2013. Increases in economic activity are therefore not necessarily going to translate into a growing market, unless additional vehicle scrappage policies or purchase incentives are introduced.

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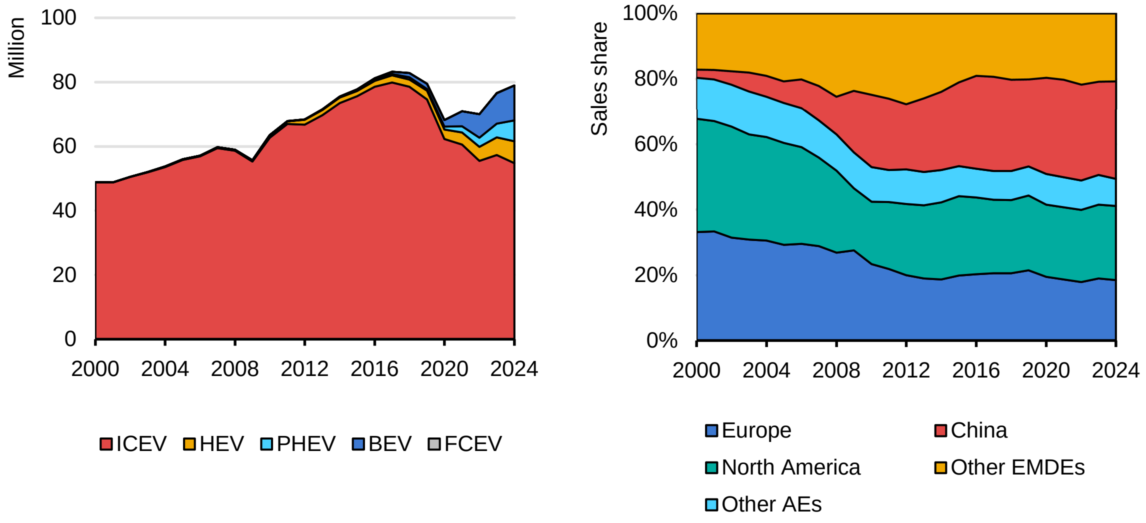
[2] Electric cars refer to battery electric and plug-in hybrid electric cars.

Figure 1.1 Global new car sales by powertrain and region, 2000-2024



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Notes: ICEV = internal combustion engine vehicle; HEV = hybrid electric vehicle; PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle; FCEV = fuel cell electric vehicle. AEs = advanced economies. EMDEs =emerging markets and developing economies. “HEV” includes only full hybrid electric cars (FHEV). “ICEV” includes both conventional ICE cars and mild-hybrid electric cars (MHEV), typically featuring 48V hybrid powertrain architecture).

Sources: IEA analysis based on Marklines and EV Volumes.

In emerging markets and developing economies (EMDEs), car sales have remained around the same level as before the pandemic, with very low growth in some of the largest markets, such as Indonesia and Brazil. The market potential is significant nonetheless: car ownership rates in these markets are still well below the levels observed in advanced economies, suggesting that the increasing economic activity in these countries could lead to an increase in car sales, especially where public transport options are limited.

Hybrid electric cars are occupying a growing share of the market

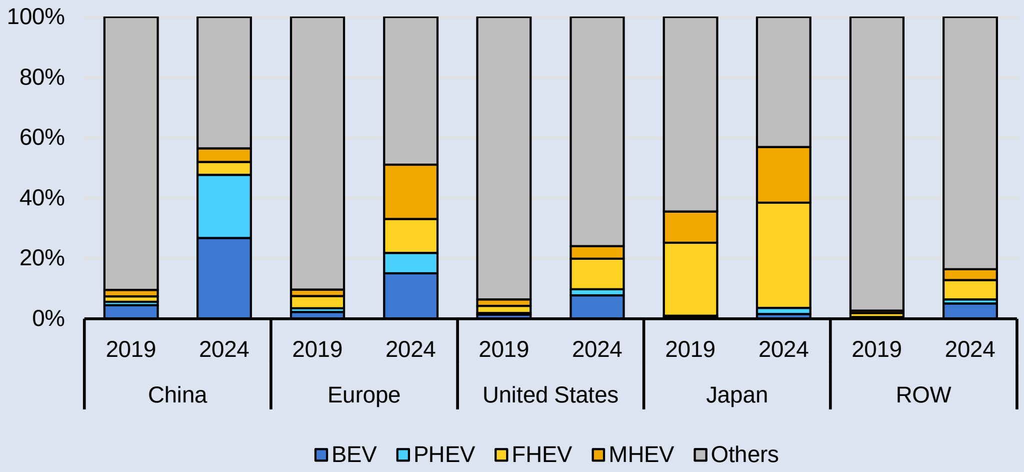
Hybrid electric vehicles (HEVs) are vehicles with both an ICE and a type of electrified powertrain that features smaller batteries and lower electric motor power compared to plug-in hybrid electric and full battery electric vehicles. Their smaller batteries and lighter electrification compared to their plug-in equivalents reduce manufacturing costs and reliance on critical minerals, while still delivering fuel savings and emissions reductions. HEVs fall into two categories, based on the level of electric assistance:

- Mild-hybrid electric vehicles (**MHEV**) use low-voltage electric motors (typically 48 V) that can only completely power the vehicle in very limited conditions, paired with small batteries (usually under 1 kWh) that enable features such as start-and-stop, acceleration assist and moderate regenerative braking at a lower cost. As the contribution of the electric motor is limited, and fuel savings are generally low (between 5% and 15% depending on motor voltage and hybrid architecture), these vehicles are often classified as ICE vehicles.

- Full hybrid electric vehicles (**FHEV**) use high-voltage electric motors (typically over 200 V) that can power the vehicle with the engine off for short distances. These are typically paired with a 1-2 kWh battery, and their higher electric power supports stronger regenerative braking and delivers more substantial fuel savings compared to conventional cars, depending on driving mode (20-30% on average under the Worldwide Harmonized Light Vehicles Test Cycle (WLTC) and up to 40% under urban driving conditions).

The fuel-saving potential of HEVs means they can be used by carmakers to comply with CO_2 emission and fuel economy standards in many car markets. With a lower purchase price than electric cars, hybrid electric cars appeal to many consumers looking for an efficient vehicle with a small purchase price premium that can be used with conventional refuelling infrastructure. In 2024, hybrid electric car sales (including both FHEVs and MHEVs) reached 12.5 million – more than 15% of global car sales. Sales of MHEVs, which have a lower purchase price than equivalent FHEVs, have grown markedly in recent years. In 2024, they accounted for 45% of global HEV sales.

Car market shares by powertrain in selected markets, 2019 and 2024



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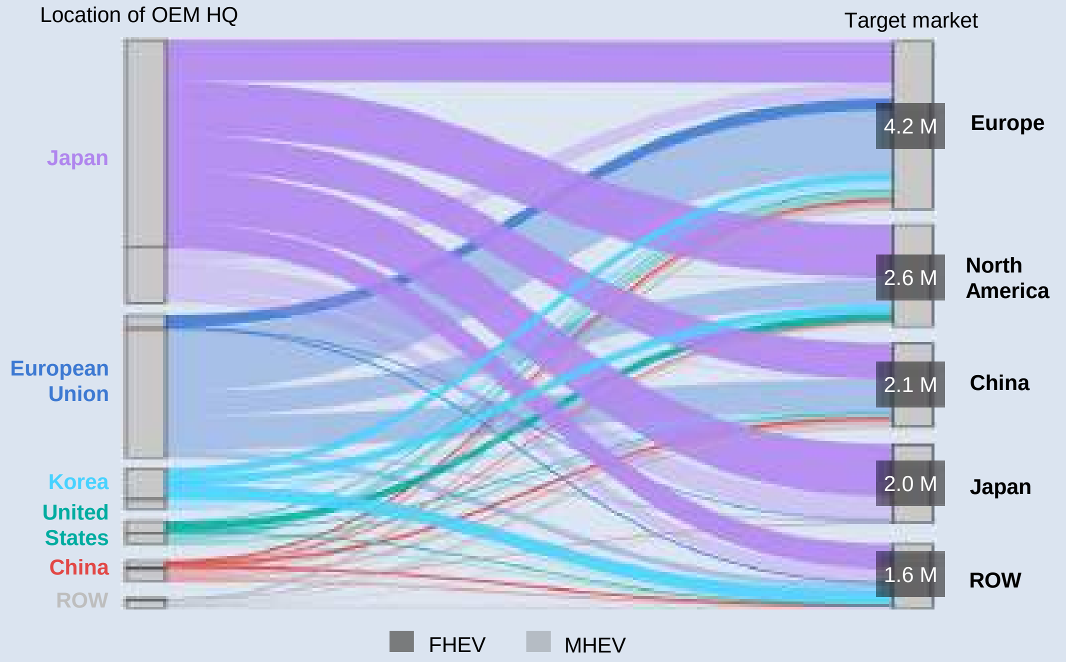
Notes: ROW = Rest of World; BEV = battery electric vehicle; PHEV = plug-in hybrid vehicle; FHEV = full hybrid electric vehicle; MHEV = mild-hybrid electric vehicle. "Others" includes internal combustion engine cars and fuel cell electric cars.
Sources: IEA analysis based on Marklines and EV Volumes.

Market uptake of full and mild-hybrid electric cars has historically been highest in Japan, where they represented more than half of domestic sales in 2024, up from 35% in 2019. In Europe, carmakers have been offering an increasing number of hybrid electric models in their lineups, with 80 FHEV and 150 MHEV models available in 2024, over twice the level seen in 2019. As a result, their market share reached nearly one-third of car sales in the region in 2024. The European HEV market is primarily made up of mild hybrids and is the world's largest market for that technology. North America and China are also both significant HEV markets, with Japanese and EU carmakers currently leading global FHEV and MHEV sales, respectively. In the US market, sales of HEVs – primarily from Japanese carmakers, who have pioneered HEV technology – are higher than those of any other electrified powertrains.

Global hybrid electric car sales shares by location of original equipment manufacturer headquarters, type of hybrid and target market, 2024



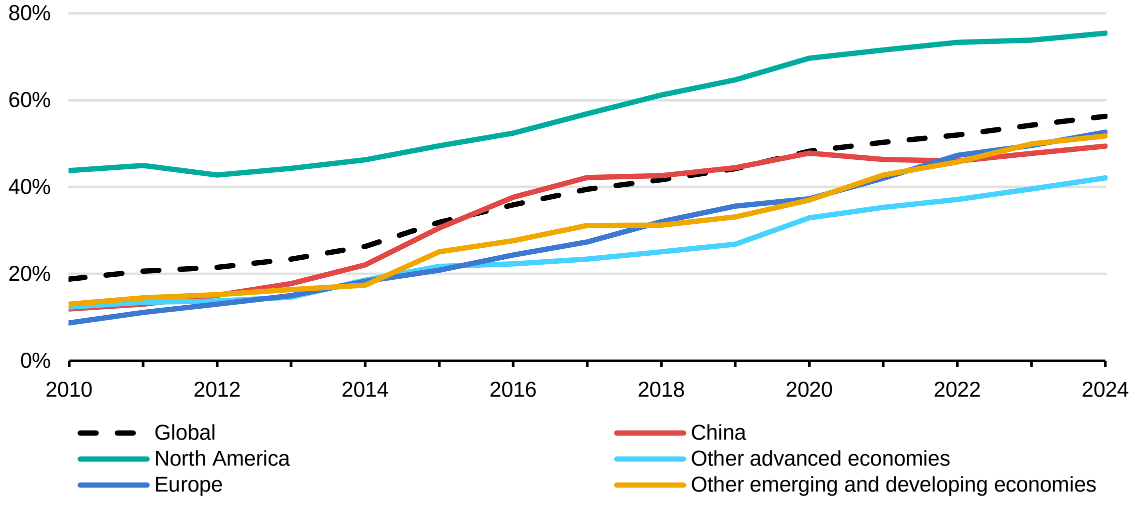
IEA. CC BY 4.0.

Notes: OEM = original equipment manufacturer; ROW = Rest of World; FHEV = full hybrid electric vehicle; MHEV = mild-hybrid vehicle.
Source: IEA analysis based on EV Volumes.

Car sales are increasingly shifting towards larger vehicles

In 2024, sales of SUVs (including pick-up trucks) represented 50% of global car sales, following decades of consistently increasing market share. Almost five times as many SUVs were sold worldwide in 2024 than in 2010. In 2010, half of global SUV sales took place in North America, but as SUV sales grew in other markets, the North American share fell to less than 30% in 2024. Sales of SUVs in China grew more than eightfold from 2010 to 2024, and their share among all car sales has also increased rapidly in Europe. Japan stands out for having relatively low shares of SUV sales, although they increased from 5% of total car sales in 2010 to almost 30% in 2024.

Figure 1.2 Sales share of SUVs and pick-up trucks by market, 2010-2024



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Notes: Sales share includes segments SUV-A to SUV-E and pick-up trucks.
Source: IEA analysis based on Marklines.

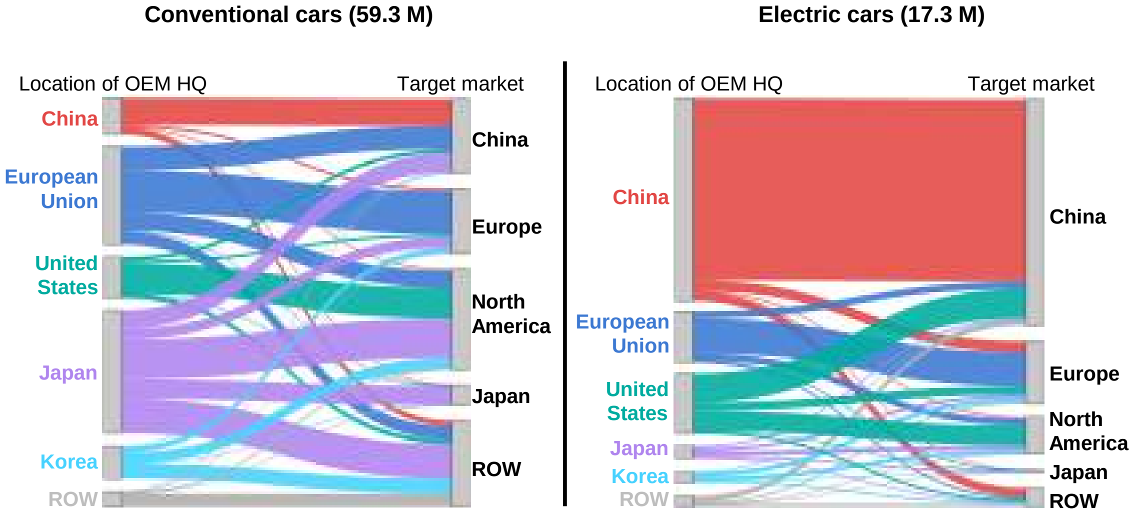
Beyond consumer preferences for larger cars, regulatory frameworks have also contributed to SUV sales growth. For example, the US Corporate Average Fuel Economy (CAFE) Standards set separate requirements for passenger cars and light trucks based on the footprint of the vehicle. Under this framework, SUVs are classified as light trucks, and the standards for model years 2012-2016 required greater efficiency improvements for passenger cars than for light trucks. Similarly, EU CO_2 standards for cars also included emissions target adjustments for carmakers selling heavier-than-average cars until 2025. Differentiated emission targets and the higher profit margins on larger models help explain why automakers have increasingly chosen to produce bigger cars. However, as the EU CO_2 standards enter the new enforcement period for 2025-2029, specific manufacturer CO_2 targets have been revised based on the latest market data. As a result, previous CO_2 emission allowances granted to manufacturers of heavier-than-average cars have been cancelled. See the box Cars are getting heavier despite material substitution efforts below for more on the impact of car size increases.

The share of global car manufacturing located in China has grown substantially

The car market is highly globalised: in most countries, consumers can buy cars from all major original equipment manufacturers (OEMs), even though different carmakers have typically focused on different markets and powertrains. Nearly all the cars sold worldwide today are manufactured by carmakers with headquarters in either the European Union, the United States, Japan, China or Korea, and are manufactured in those countries or regions. In 2008, the majority of global car production took place in Europe (25% of global car output), North America (25%), Japan (20%) and Korea (7%), all of which are home to major incumbent OEMs. Back then, China accounted for just 10% of global production, but by 2017, cars assembled in China made up nearly one-third of global production, and even more by 2024.

OEMs headquartered in the European Union – such as Volkswagen (VW), Stellantis, or Mercedes – are responsible for more than two-thirds of sales in the EU market. However, this only represents part of their global market footprint – other markets represented more than half of sales by EU-headquartered OEMs in 2024. The Chinese market alone made up about one-quarter of their global sales that year, both through exports and through cars produced in China under joint ventures (JVs) with Chinese OEMs. The North American market is the third-largest for EU OEMs, representing 20% of their global sales. In contrast, for electric car sales, EU OEMs are more reliant on their domestic market. In 2024, about 65% of EU OEMs' electric car sales were within Europe; the remainder were split in equal parts between the North American and Chinese markets.

Figure 1.3 Car sales share by location of original equipment manufacturer headquarters, location of sale and powertrain, 2024



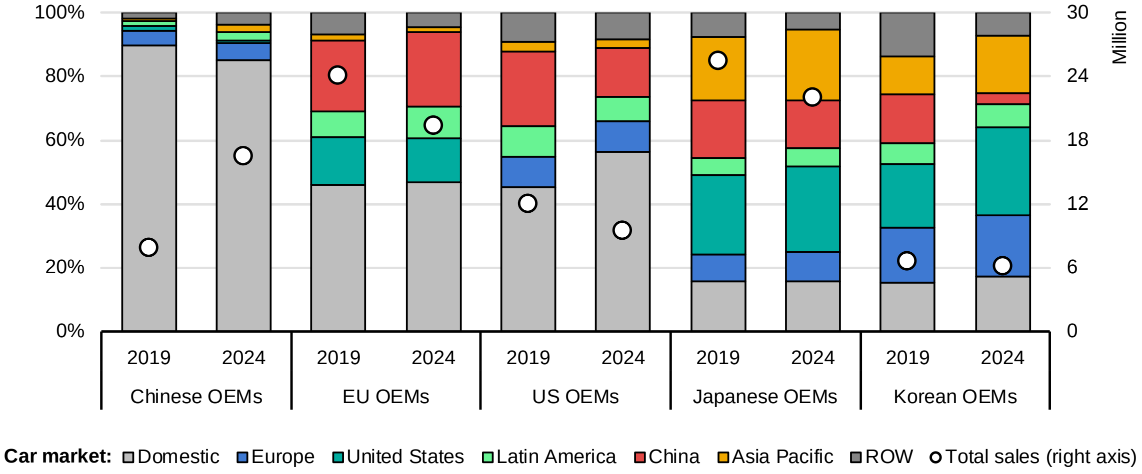
Notes: ROW = Rest of World; OEM = original equipment manufacturer. OEM headquarters location is shown on the left of the Sankey diagram and sales location on the right. Chinese joint ventures with foreign manufacturers are not considered as Chinese OEMs in this graph. Conventional cars include non-plug-in hybrid electric and internal combustion engine cars.
Sources: IEA analysis based on Marklines and EV Volumes.

OEMs headquartered in China have so far sold both conventional ICE and electric cars primarily within their domestic market. This is gradually changing, however, as Chinese car exports to Europe, Russia and to EMDEs have been growing steadily. In 2024, more than one-quarter of ICE sales from Chinese OEMs were in overseas markets, up from around 10% in 2019. The share of overseas markets in total Chinese electric car sales is less pronounced, due to the slower electrification rates of overseas markets compared to the Chinese market. Yet

China is the largest electric car exporter globally, with more than 1.2 million cars exported in 2024, representing over 10% of total Chinese electric car sales.

OEMs headquartered in the United States, such as General Motors and Ford, are heavily reliant on the domestic market due to a combination of structural, strategic and historical factors. Unlike their European and Asian counterparts, which expanded their global footprints in the 1980s and 1990s, US firms primarily focus on the North American market (which accounted for more than 70% of their 2024 sales), particularly through the production of high-margin pick-up trucks and SUVs tailored to North American consumer preferences and US regulatory definitions. Japanese, Korean and European carmakers entered the North American market decades ago, setting up local production facilities and sustaining large market shares ever since. By 2024, US-based carmakers accounted for one-third of conventional ICE car sales in their domestic market,[3] whereas Japanese and Korean firms accounted for almost half. In contrast, the domestic market accounted for more than half of all sales of electric cars produced by US OEMs. Tesla accounts for most domestic sales, and – thanks to its early market entry and overseas assembly plants – has also secured significant market shares in China (35% of Tesla's sales) and Europe (20%), although these sales have come under pressure in recent months.

Figure 1.4 **Original equipment manufacturers' global sales share by car market and total sales, 2019 and 2024**



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Notes: ROW = Rest of World; OEMs = original equipment manufacturers. Both 2019 and 2024 values are based on OEM headquarters location as of 2024. For sales in China, Chinese joint ventures with foreign manufacturers are considered as belonging to foreign OEMs in this figure. Europe is considered to be the EU OEMs' domestic car market. In this figure, the Asia Pacific region excludes China, Korea and Japan.

Sources: IEA analysis based on Marklines.

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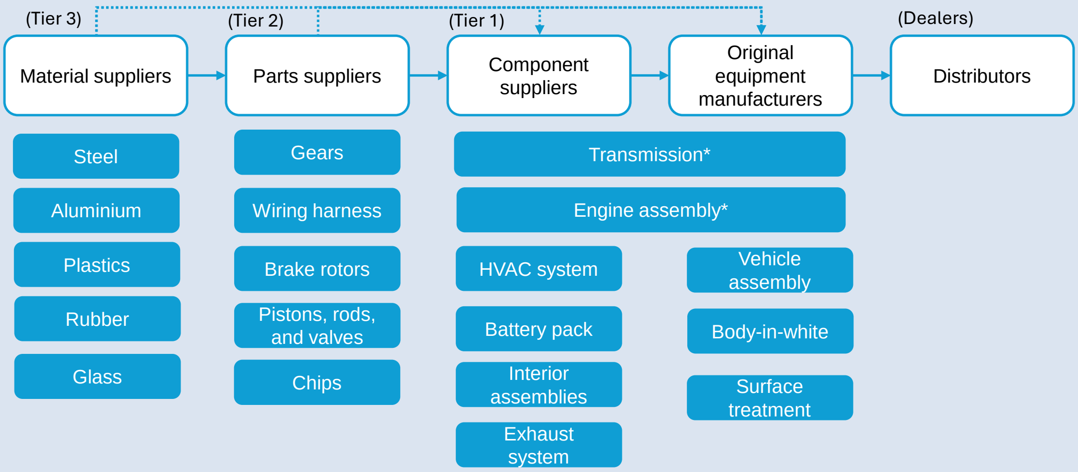
[3] This excludes US brands or subsidiaries of foreign OEM groups. For example, over 1 million ICE cars were sold in the United States by US brands under the Stellantis group (Chrysler, Dodge, Jeep, Ram) in 2024.

OEMs from Japan have a towering presence in global car markets, in particular for ICE and hybrid cars, and rely on overseas sales given the relatively small size of their domestic market. Japanese OEMs supply their domestic market almost entirely, but this only represented a 15% share of their global sales in 2024, almost unchanged from a share of just under 20% 10 years ago. Similarly, **OEMs from Korea** also rely on overseas car markets, although their global sales volumes are much smaller. Despite active engagement in electric car R&D, electric car sales from Japanese and Korean automakers are still much lower than their ICE and hybrid car sales, and many of their electric car sales are overseas.

Industry structure and key inputs

OEMs have a key role in the car industry, but there are many more actors. Originally, many car manufacturers were highly vertically integrated – they owned and managed the production of upstream components. Over time, however, there has been a gradual trend towards specialisation, i.e. outsourcing component manufacturing to external suppliers. Today, OEMs are mostly responsible for the design, assembly and marketing of vehicles, but they also manufacture some key components. Individual company set-ups and strategies vary of course, but typically the ICE (or electric motor in the case of electric vehicles) and the body-in-white (i.e. the assembled car frame before painting) are commonly produced by OEMs themselves. Some components are manufactured either by OEMs or Tier 1 suppliers, such as the transmission systems. The key benefit of outsourcing to suppliers is that it enables larger economies of scale, with suppliers producing components and parts for more clients. OEMs and suppliers are often highly connected and develop products in conjunction.

Indicative structure of the car industry



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Notes: HVAC = heating, ventilation and air conditioning. The list of components is not exhaustive. Components marked with * are manufactured either by Tier 1 suppliers or OEMs directly.

Suppliers to OEMs can broadly be categorised into two groups, component suppliers (Tier 1 suppliers) and parts suppliers (Tier 2 suppliers). Component suppliers usually produce entire vehicle subsystems – for example, the exhaust systems or the interior assemblies – and deliver them to the OEMs. These tend to be very large companies that are often also involved in R&D and design. Parts suppliers, meanwhile, focus on the production of individual parts. Their main clients are the component suppliers. Parts suppliers tend to be smaller and are typically less involved in product development and more focused on the manufacturing of specific parts.

Further upstream in the value chain is the manufacturing of materials, of which vehicles require a significant amount. By weight, steel is the most common material, typically accounting for around 60% of the weight of a car, followed by various plastics (20%) and aluminium (10%). Materials producers can either sell directly to OEMs (for example for the body-in-white production) or to the suppliers of parts and components. For some components, collaboration between the materials and the car industry has been very important; it led to the development, for example, of very high-strength steel that is suitable for automotive applications, which helped decrease the material intensity of the vehicle.

Traditional production centres have not recovered from the pandemic

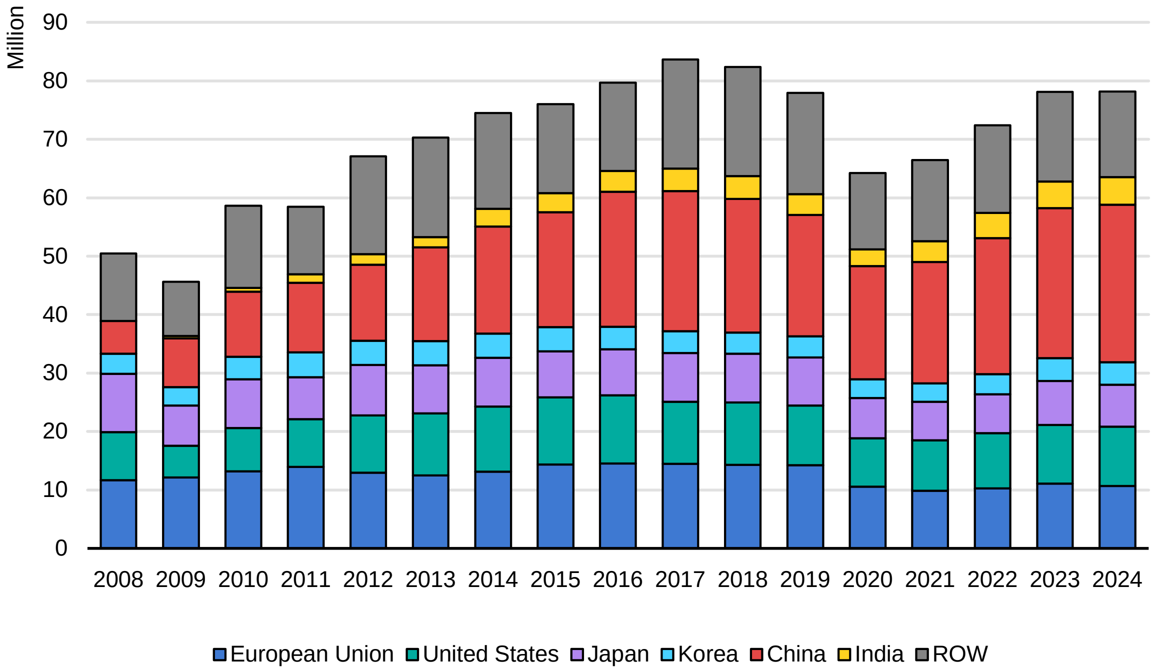
Global car production reached its highest level to date in 2017, at 84 million cars. In the following years, weaker sales in China were the main lever that slowly pushed down global car production to roughly 80 million in 2019. Global car output fell even more sharply to less than 65 million during the pandemic and resulting economic crisis. By 2023, global car production had returned to 2019 levels, but the recovery was uneven across major production centres.

China’s car output reached a historic record high of 27 million in 2024, 30% above pre-pandemic levels. Similarly, albeit starting from a lower basis, India saw its car output grow by 30% compared to 2019 to reach almost 5 million, thanks to soaring domestic sales. Sales in the United States in 2024 were more than 5% lower than in 2019, but US car output remained unchanged due to lower imports.

The car industry in the European Union has not yet returned to pre-pandemic output levels. EU output was particularly affected by the shortage in semiconductors in the aftermath of the pandemic. In addition, EU OEMs have shifted their focus towards high profit margin models in recent years by increasing sales of SUVs and models with upmarket trims. In Germany, for example, this strategy – combined with the growing adoption of electric cars – led to a 25% increase in the average car purchase price in nominal terms between 2019 and

2024, while inflation over the same period stood at around 20% over the same period of time. High car prices and supply chain disruptions, as well as other macroeconomic factors, all impacted demand and production in the region. In 2024, EU car output stood 25% below 2019 levels, while EU sales were 20% lower.

Figure 1.5 Global car production by region, 2008-2024



IEA. CC BY 4.0.

Note: ROW = Rest of World.
Source: IEA analysis based on Marklines.

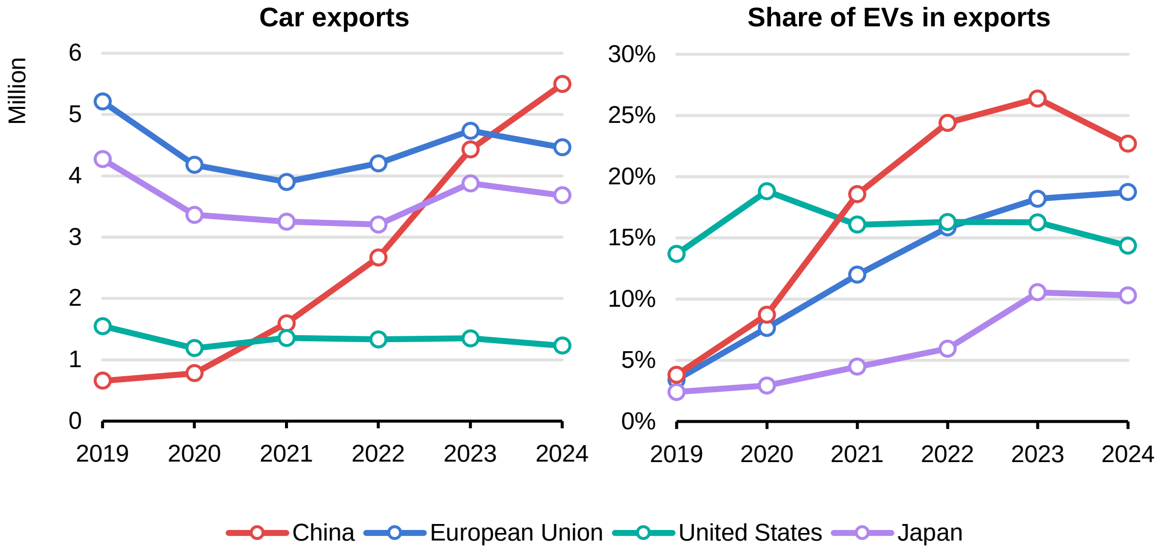
A similar trend was observed in Japan, where production in 2024 fell short of pre-pandemic levels by about 1 million cars. This production downturn was driven in equal parts by dwindling domestic sales and lower car exports, which represent half of the country's car output. Sluggish demand in Europe and North America triggered by the pandemic was the largest contributor to the fall in Japanese car exports and, therefore, to overall output. In contrast, in Korea, car production was 5% higher than before the pandemic, thanks to increasing exports outweighing decreasing domestic sales.

A large share of new cars is traded worldwide

Car manufacturers operate in a global market, underpinned by international trade. Major car markets are also major car-producing regions, with large manufacturing capacities that serve both domestic and international markets. At the same time, countries that are adjacent to major car markets and that benefit from low energy and labour costs – which can provide a competitive edge in car manufacturing – often attract OEMs looking to establish assembly plants overseas. These assembly plants can then serve the domestic market and export cars to other demand centres at lower costs. Examples of such low-cost manufacturing hubs include Mexico, where car production serves the US market, or Türkiye, which serves the rest of Europe. This, combined with significant production capacity in countries including China and Japan, has helped keep the share of global car production that is traded high since the early 2000s.

In 2024, trade involving the world's four largest car-producing regions (China, the European Union, Japan and the United States) accounted for about 30% of global car production, a share that has been stable since before the pandemic. As electrification makes inroads in both major and emerging car markets, and given that demand centres are not always located in the same place as EV manufacturing hubs, electric cars are accounting for an increasing share of global car exports. In 2024, electric cars represented more than 15% of global car trade in units, up from less than 4% in 2019.

Figure 1.6 **Total car exports and share of electric cars in exports per region, 2019-2024**



IEA. CC BY 4.0.

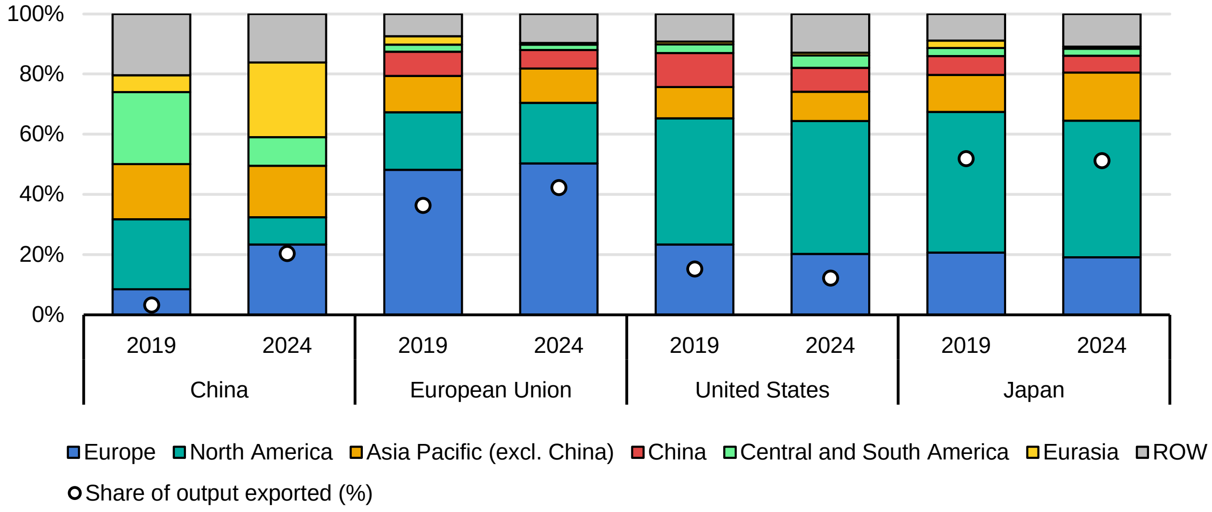
Sources: IEA analysis based on GACC, Eurostat, USITC, JAMA and CAAM.

China is now the world's largest car exporter

China is increasingly relying on exports to use its existing car manufacturing capacity to its full extent. Car exports have been steadily increasing, reaching 20% of domestic car output in 2024, up from about 3% in 2019. As a result, China overtook Japan as the world's largest exporting country in 2023, and then overtook the European Union in 2024, with more than 5 million cars exported. Destination markets for Chinese-made cars have significantly diversified in the past 5 years. While Europe remains a key destination (with the region as a whole accounting for almost 25% of China’s total exports), Russia (18%), the Middle East, Mexico and Southeast Asia are seeing surging car imports from China. In Russia, as incumbent automakers stopped selling cars after Russia’s full-scale invasion of Ukraine in 2022, Chinese carmakers filled the gap. In 2024, Russia imported nearly 1 million Chinese-made cars, becoming the world’s largest importer of Chinese cars.

Since 2019, electric cars have increasingly contributed to China’s car exports. In 2024, close to one in four cars exported by China was electric, of which 75% were battery electric cars. The general expectation is that the share of electric cars in Chinese exports is likely to increase further in the short-term as emerging electric car markets continue to grow, and Chinese OEMs’ fleet of roll-on/roll-off (Ro-Ro) car-carrier ships expands.

Figure 1.7 Destination market shares of major car-exporting regions, 2019 and 2024



IEA. CC BY 4.0.

Notes: ROW = Rest of World. Internal car trade between EU member states is excluded.
Sources: IEA analysis based on GACC, Eurostat, USITC, JAMA and CAAM.

The **European Union** has long been a net exporter of cars, generating a trade surplus revenue of close to USD 90 billion in 2024. While EU car exports have fallen by 15% since 2019, the share of exports in total car production has grown to reach more than 40% in 2024, reflecting dwindling car sales in the region since 2019. In 2024, the United Kingdom (28% of EU car exports), the United States (17%), Türkiye (13%) and China (6%) were the main destination markets for EU-made cars. Due to the high share of premium models in exports, the United States was responsible for the largest share in value terms. Overall exports from the

European Union accounted for more than 4.5 million cars in 2024, a 6% contraction from the year before. Electric cars represent an increasing share of EU car exports, reaching almost one-fifth in 2024, with other European countries (i.e. non-EU member states) and the United States being the largest importers of EU-made electric cars.

In the **United States**, car exports have remained steady at less than 1.5 million cars over the past 5 years, representing less than 15% of US car output. Exports from the United States have long been primarily destined for Canada (representing over 40% of the total), Europe (almost 20%) and Mexico (10%).

Among the major car-producing countries, production in **Japan** and **Korea** relies the most on exports. In 2024, half of Japan's car output was destined for overseas markets, a share that has remained unchanged since 2019. Over the past 5 years, just under half of Japanese car exports were shipped to North America, mostly to the United States. Europe, Australia and New Zealand were also important destination markets for Japanese exports. Similarly, in 2024, exports from Korea accounted for more than two-thirds of the 3.8 million cars produced in the country, higher than the 60% share observed 5 years earlier. An increasing share of these exports goes to North America, which remains by far the largest destination market for Korean-made cars. In 2024, cars shipped to North America grew more than 50% from 2019 to reach nearly 1.7 million units.

The growth of Japanese cars in the United States during the 1970s

When consumer preferences change and established domestic manufacturers are unable to meet them, new market-entrants – including those from abroad – have an opportunity to gain market share. The growing share of Japanese car imports into the United States in the 1970s is one example.

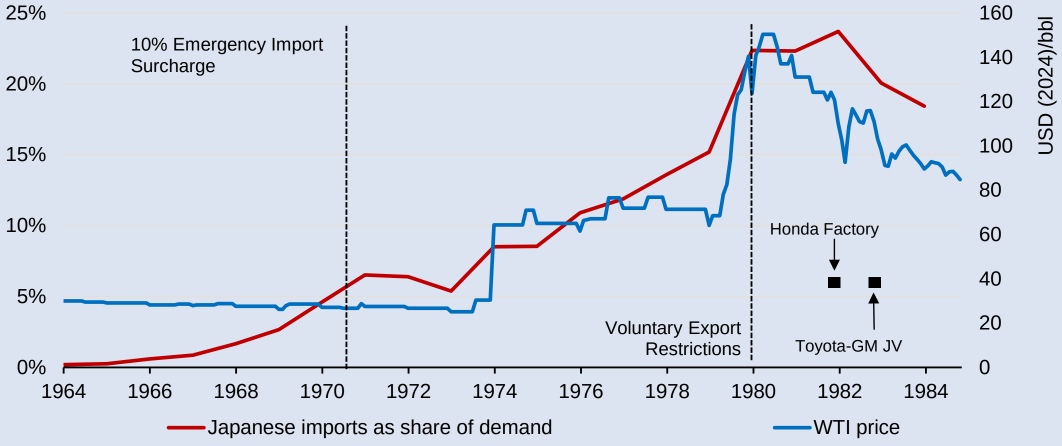
In the late 1950s and early 1960s, Japanese carmakers began increasing their exports, backed by an expansion of manufacturing capacity, a favourable exchange rate and a supportive national industrial strategy. In 1964, Japanese imports accounted for less than 0.5% of car sales in the United States; by 1971, they accounted for 6.5%. In that year, a temporary 10% tariff was added on Japanese imports and followed by a readjustment of exchange rates, which together led to a stagnation in growth until the 1974 oil crisis.

As oil prices increased rapidly in 1974 and the US economy stagnated, Japanese cars gained popularity thanks to their lower price tags and better fuel economy than the cars being produced by the "Big Three" US carmakers of the time (General Motors (GM), Ford and Chrysler). In 1975, the fuel consumption of cars sold by Toyota, Nissan and Honda was 40% lower than that of cars from the Big Three US carmakers – and imported cars were also 14% cheaper than those produced domestically. An important reason for this is that Japanese automakers were technologically superior: they had developed "lean manufacturing" techniques which guaranteed lower costs and higher quality compared to the older manufacturing systems employed by US carmakers at the time.

The affordability and superior energy efficiency led to a surge in imports of cars from Japan. US carmakers were slow to adapt their vehicle offering and technology to cater for the higher oil price environment, leading to losses of over USD 6 billion across the Big Three by 1980. In 1980, more than one in five cars sold in the United States was imported from Japan, and Japan accounted for nearly two-thirds of imported cars. In response, the US government negotiated a "voluntary export restriction" with the Japanese government, effectively setting a quota of cars that could be imported to the United States. This measure remained in place until 1994, and coincided with a real term increase in the price of new cars in the United States.

Japanese carmakers have built manufacturing capacity in the United States since the 1980s. The first Honda factory began operations in 1982, and, in 1984, the landmark NUMMI plant – a joint venture between GM and Toyota – was set up. The investments of Japanese OEMs led to technology transfer, as US carmakers started to adopt some of the new manufacturing techniques pioneered by Japanese carmakers, and improved their productivity and quality over the following decade. The fuel economy of domestically made cars also improved by over 10% from 1980 to 1990, closing the gap with imported cars. To this day, Japanese OEMs account for around one-third of cars produced in the United States.

Japanese car imports in the United States, oil price and political milestones, 1964-1984

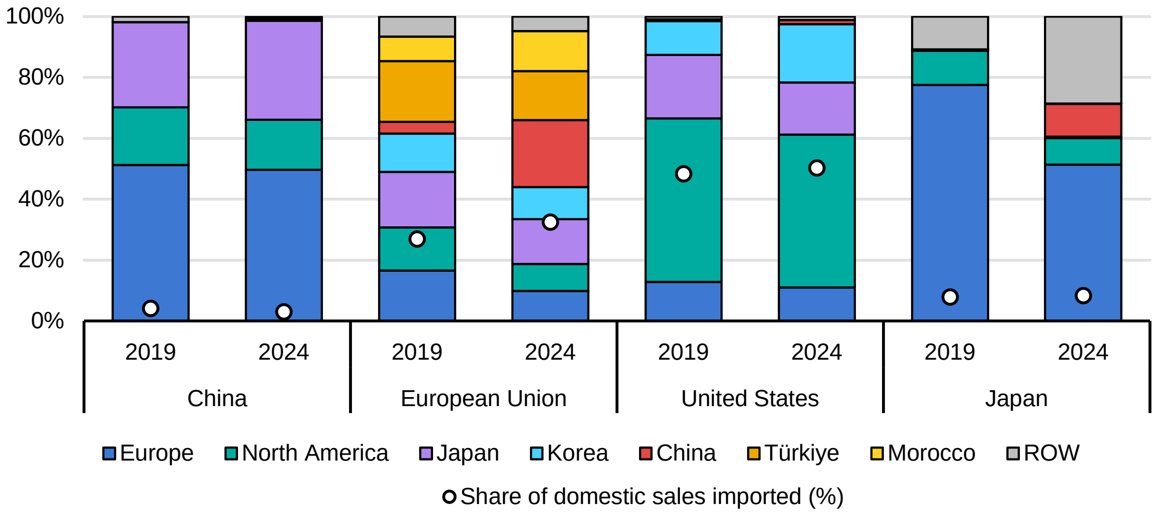


Notes: JV = joint venture. WTI = West Texas Intermediate. Real oil prices are derived using the Consumer Price Index (CPI).
Sources: IEA analysis based on USITC (1985), FRED (2025).

European and American car markets are more reliant on imports than other major car production centres

In spite of the **European Union** being a net car exporter, imports accounted for about one-third of EU domestic sales in 2024. Car imports from China have grown rapidly in recent years, increasing over fivefold from 2019 to 2024. By 2024, they accounted for more than 20% of all cars imported into the European Union. Most of this growth was in electric cars, following the opening of a Tesla factory in Shanghai, the release of affordable Chinese electric car models, and a number of EU OEMs offshoring production to China. This rapid increase in imports triggered an anti-subsidy investigation by the European Commission, which led to the introduction in 2024 of OEM-specific countervailing duties ranging from 8-35% for battery electric cars imported from China, on top of the pre-existing 10% tariff on car imports to the European Union.

Figure 1.8 Origin of car imports by region, 2019 and 2024



IEA. CC BY 4.0.

Notes: ROW = Rest of World. EU car imports exclude internal trade between EU member states. In this figure, Europe excludes Türkiye.
Sources: IEA analysis based on Marklines, GACC, Eurostat, USITC and JAMA.

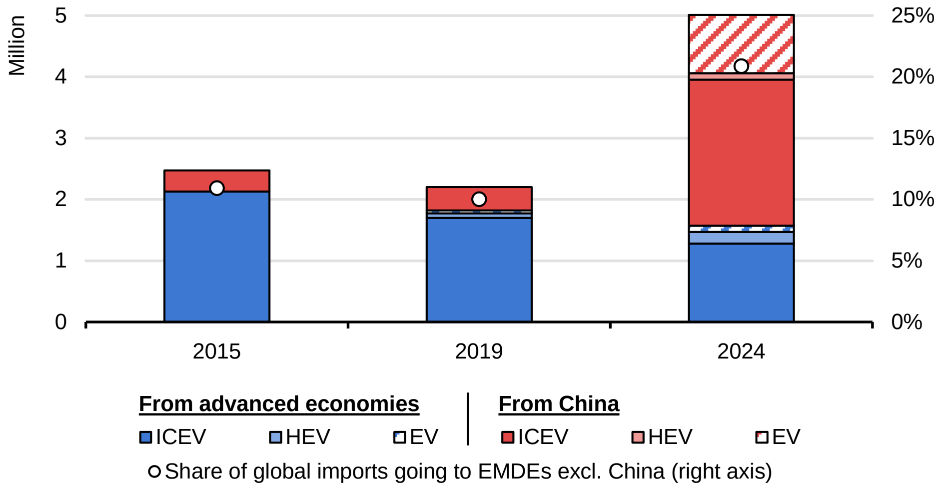
Battery electric car imports from China remained somewhat stable in absolute terms between 2023 and 2024, but their share in total imports from China has steadily declined over the same period. In the first four months of 2025, battery electric models accounted for half of car imports from China, down from nearly 75% in 2023. With new import duties applying only to battery electric models, plug-in hybrid electric cars have been gaining traction in EU imports from China since 2024. In the first four months of 2025, PHEVs made up nearly one-fifth of EU car imports from China, compared to roughly 5% 2 years earlier. Exports of conventional cars (ICE cars and HEVs) from China to the European Union have also grown significantly in recent years, increasing by over 50% in 2024. Between

January and April 2025, conventional cars represented one-third of imports, up from around one-fifth in 2023. However, due to the EU CO_2 emissions standard requiring 100% emissions reductions from new car sales by 2035, growth in non-zero-emission car imports from China is expected to wane in the midterm.

Japan and Korea are also significant car trade partners of the European Union, together making up about one-quarter of EU car imports. Meanwhile, EU OEMs rely on overseas manufacturing hubs to benefit from cheaper energy and labour costs in neighbouring countries like Türkiye (where over 15% of EU car imports are produced) and Morocco (less than 15%), and other more remote production centres like Mexico and South Africa (around 5% each).

In the **United States**, imports account for half of all car sales. There has been little change in the origin of these imports over the years, with Mexico being the country's largest source of imports, thanks to US carmakers' assembly plants operating in the country, supported by the United States-Mexico-Canada Agreement (USMCA) free trade agreement. In 2024, cars made in Mexico accounted for more than one-third of all car imports to the United States. Another one-third came from Korea and Japan, both contributing almost equally, in addition to their US sales from their US-based assembly plants. Similarly to Mexico, Canada produces cars destined for the US market under the USMCA, bringing the share of cars produced elsewhere in North America in US car imports to more than 50%. Europe also contributed to US car imports, although to a lesser extent (10%).

Figure 1.9 **Origin of car imports to emerging markets and developing economies other than China by powertrain, 2015-2024**



IEA. CC BY 4.0.

Notes: ICEV = internal combustion engine vehicle; HEV = hybrid electric vehicle; EV = electric vehicle; EMDEs = emerging markets and developing economies.

Sources: IEA analysis based on GACC, Eurostat, USITC and JAMA.

Advanced economies account for the majority of all cars imported worldwide, but the share of cars imported by EMDEs other than China has been growing since 2020. By 2024, more than one in five car imports worldwide – or 5 million vehicles – was imported by an EMDE, up from around 10% just 5 years earlier. The origin of these imports has been shifting markedly towards China, which was responsible for the majority of the growth. In 2024, almost 70% of cars imported by an EMDE came from China, up from less than 20% in 2019. Two noticeable drivers were behind this trend. First, the 2022 drop in Russian car production triggered the largest car trade flow between China and a single country, representing nearly one-third of Chinese car exports to EMDEs in 2024. Second, Chinese car models are priced competitively against models from leading incumbent carmakers in emerging markets. In Thailand, for example, Chinese ICE cars were the cheapest in 2024, with average prices being 20% lower than those of the second-cheapest option, which were from Japanese brands. Similarly, in 2024 in Brazil, the average Chinese ICE model sold for USD 25 000, just 2% higher than the average price of ICE cars from European brands, which are the market-leaders in the country. The affordability of Chinese cars is not limited to ICE models; electric cars are accounting for an increasing share of Chinese car exports to EMDEs, similarly thanks to their price-competitiveness. In 2024, close to 30% of car exports from China to EMDEs were electric.

The financial performance of the car industry shows mixed fortunes for industry incumbents

Car sales have been declining globally since 2017, but nominal revenues of the 26 largest carmakers in 2024 were around 30% higher than in 2017, reaching USD 2.5 trillion. Average car prices increased during this period, due to increasing sales of cars in higher-price segments (such as SUVs), supply shortages and a larger share of electric car sales, among other factors. When adjusting for inflation,[4] however, revenues peaked in 2018 and remained at a similar level in 2024, despite declining sales volumes. From 2016 to 2024, the Consumer Price Index (CPI) for new motor vehicles increased by 25% in the European Union (lower than the overall CPI increase of 29%), and by 21% in the United States (compared to an overall CPI increase of 31%).

OEMs headquartered in Europe hold the largest share of the global car market by revenue, accounting for around one-third of global revenues in 2024, followed by Japanese OEMs, which accounted for about one-quarter. OEMs from these regions have a global reach and – especially in the case of European OEMs –

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[4] Using regional averages of GDP deflators weighted based on car sales. A GDP deflator measures the change in prices of goods and services across the entire economy.

focus on more premium market segments. Chinese and US OEMs each account for around 18% of the market by revenue.

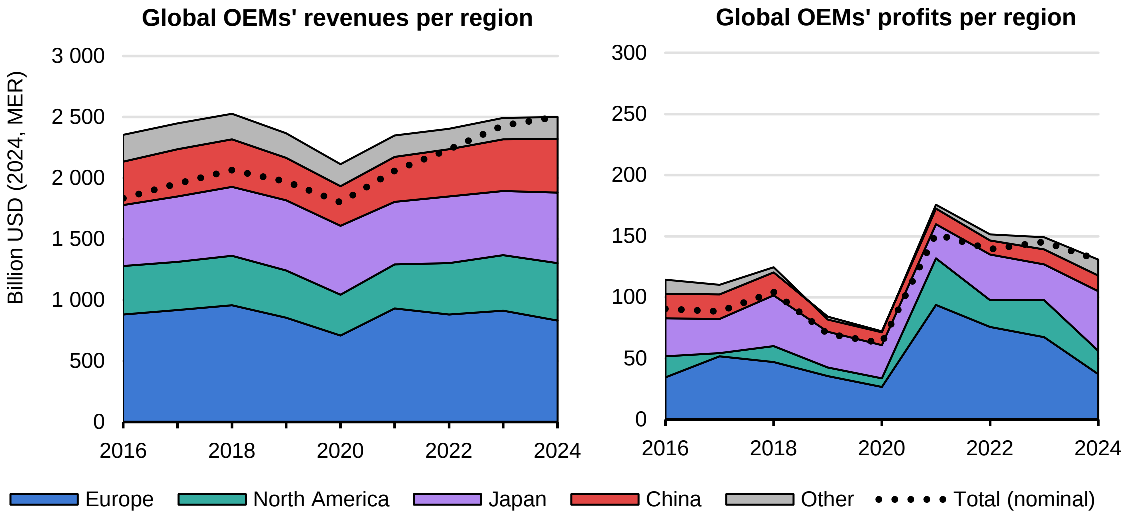
In terms of net profits, global annual profits were around USD 110-125 billion in real terms between 2016 and 2018. Following a weak 2019, profits reached a low of USD 71 billion during the pandemic, and then more than doubled by 2023. This increase was mostly driven by the increased profits of European OEMs, which in 2023 were double those of 2016. North American OEMs experienced losses in at least one year since 2017, and in 2024, they took net profit cuts of 50-70% from their peaks. Chinese OEMs had a wider performance spread. BYD’s profits soared, increasing nearly 12 times from 2021 to 2024, while SAIC reached its profit peak in 2018, and other smaller players experienced net losses.

The most recent data for 2024 shows that revenues were flat in real terms, while profits declined by over 10%. European and North American OEMs were the drivers of this trend, with net profit dropping by 45% and 37%, respectively. Some of the largest decreases came from the two largest European mass-market OEMs, VW and Stellantis, with the profit of the latter falling by over 70%. The decline in profits was mostly due to a decline in sales volumes in North America and China, where European OEMs are struggling to compete on the EV market. At the same time, the profits of Japanese OEMs increased, driven by Toyota's 70% increase in profits.

The year 2024 also saw changes for EV producers, with BYD overtaking Tesla in annual revenues for the first time. Growth in BYD’s revenues has been over 25% every year since 2020, with a peak of 85% in 2022 (when the company already had annual sales worth more than USD 60 billion). Tesla’s revenues were flat in 2024, and its annual growth peak to date was in 2018 (when the annual value of sales was about USD 26 billion). Despite large growth in recent years, annual revenues from BYD and Tesla are still 65-70% smaller than those of OEMs like Toyota or VW.

When considering profitability, i.e. the ratio of profits over revenues, there are some differences across regions and different steps in the supply chain. North American and European automakers saw an average profit margin of 6% over 2021-2024, while that of Chinese OEMs was more than 40% lower. In 2024, however, the profitability of European and North American OEMs declined to levels only slightly higher than those of Chinese companies. Chinese OEMs have a wide spread of performance, with the difference between the best and the worst performers between 15 and 20 percentage points in the past 5 years.

Figure 1.10 Revenues and profits for global original equipment manufacturers, 2016-2024



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Notes: OEM = original equipment manufacturer. Data taken from a sample of the 26 largest automakers with revenues accounting for nearly three-quarters of global sales. China: BYD, Changan, Dongfeng, GAC, Geely, Great Wall, Leapmotor, Li Auto, SAIC, Seres Group. North America: GM, Ford. Europe: BMW Group, Mercedes-Benz, Renault-Nissan Alliance, Stellantis, VW Group. Japan: Honda, Mazda, Mitsubishi, Subaru, Suzuki, Toyota. Other: Tata Group (India), Hyundai (Korea). Chery and FAW (China) are excluded since these are state-owned and there is no financial data reported after 2020. The sales from these companies account for around 80% of the global car market. Numbers are adjusted for inflation to 2024.

Source: IEA analysis based on Bloomberg Terminal.

Automotive suppliers tend to have profit margins that are lower than those experienced by OEMs in advanced economies, partly as a result of strong competition. Chinese automotive suppliers are nearly all related to battery manufacturing and have been leaders in terms of net profit margins, with several companies reaching margins of over 20% in the past 10 years.[5] The average profitability of Chinese suppliers has been lower, at around 6-7% for most years since 2016, although this trend has been broken in the past 2 years to reach more than 10% in 2024. In addition, while North American and European suppliers have not recovered their pre-pandemic profitability, the average profitability of Chinese suppliers has grown, led by CATL, the world's largest battery manufacturer. CATL has experienced unprecedented growth since it first started generating revenues in 2015, becoming a market leader in 2024. The year 2024 was the first in which CATL experienced a decline in total revenues – driven by declining battery prices – after experiencing sixfold growth between 2020 and 2022. CATL's net profit margin has been around or above 10% ever since 2015. This is very high compared to other automotive component suppliers: since 2020, the average profitability of the five largest diversified suppliers by revenue has been around 2.5%. In contrast, among specialised companies (such as those supplying

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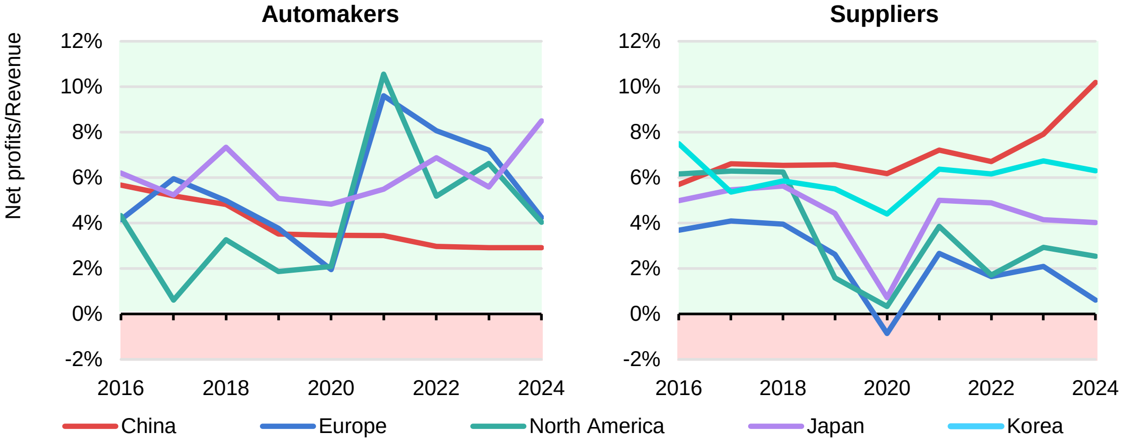
[5] CATL in 2016-2017, Gotion High-tech in 2014-2016 and Eve Energy in 2019-2020.

semiconductors or batteries), some profit margins reached as much as 30%, but there was a much wider spread, with some companies struggling to turn a profit.

Figure 1.11 **Profitability of major automakers and suppliers by region of headquarters, 2016-2024**



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Notes: Data taken from a sample of the largest 26 automakers as in figure 1.10. Suppliers include: Aisin (Japan), BorgWarner (United States), Bosch (Germany), Bridgestone (Japan), Continental (Germany), Denso (Japan), Eve Energy (China), Farasis Energy (China), Forvia (France), Gotion High-tech (China), Hyundai Mobis (Korea), Lear (United States), Magna (Canada), Michelin (France), Samsung (Korea), Valeo (France), Weichai Power (China) and ZF Friedrichshafen (Germany). Figure reflects total revenues, which can include revenues other than from automotive parts.

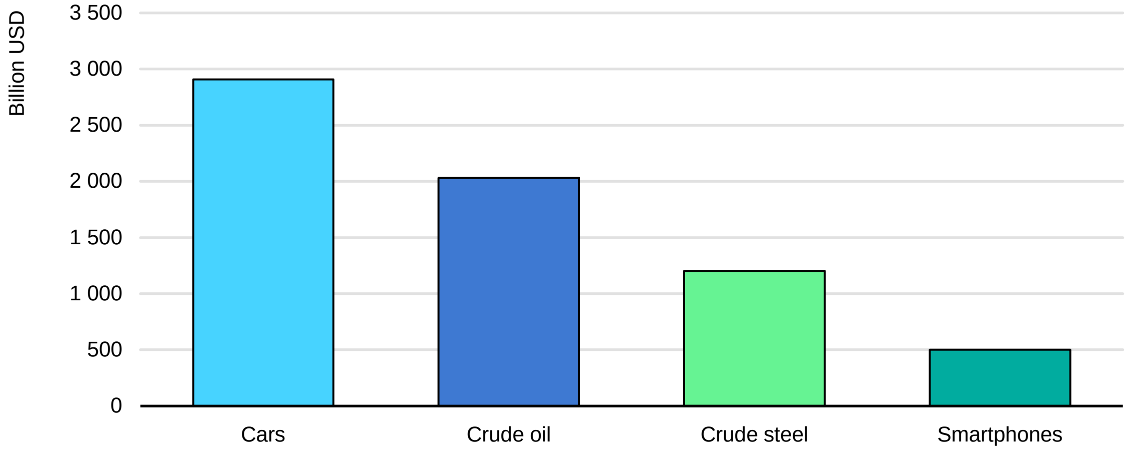
Source: IEA analysis based on Bloomberg Terminal.

1.2 The car industry is an engine of growth

The car market is one of the largest markets for a single product

After housing, transport – particularly the purchase of a car – constitutes one of the single largest expenditures for many households around the world. The global average car price was around USD 35 000 in 2024, but this value varied significantly between countries, from over USD 50 000 in Germany and USD 45 000 in the United States, to around USD 30 000 in China and USD 15 000 in India. With around 80 million cars sold in 2024, and despite more than 80% of the global population not owning a car, this amounts to one of the largest markets for a single product globally, at around USD 2.9 trillion per year. For comparison, the global crude oil market was worth around USD 2 trillion in 2024, and the markets for crude steel and smartphones were around USD 1.2 trillion and USD 500 billion, respectively. Purchases of cars and car parts are equivalent to around 4% of the total spending by households globally.

Figure 1.12 Market size for cars and selected widely used products



Sources: IEA Analysis based on Marklines and S&P Global.

While this vast spending speaks to the economic importance of the car industry, it says little about where or how value is created by the industry. This section explores the various ways in which the car industry is an engine of the global economy, examining different metrics including value addition, job creation and industrial clustering.

How large is the economic value generated by the car industry?

The car industry – including the manufacturing of cars, their components and their parts[6] – is a vital segment of the global economy, accounting for around 6% of gross value added[7] by manufacturing. Given that manufacturing everything in the world, from steel and aluminium to toys and medical supplies, accounts for around 16% of total value added across all sectors of the economy – which is approximately equal to GDP – car manufacturing directly accounted for around 1% of global GDP in 2024. For comparison, the chemical industry accounted for 1.4% of GDP, the global iron and steel industry 0.6%, and the glass industry 0.2%. The industry is concentrated in a few regions; the European Union, Japan, Korea, China and the United States account for around 80% of the value added in global car manufacturing.

Car production stimulates further value addition in other sectors of the economy. For example, around 7% of global steel demand is attributable to the car sector

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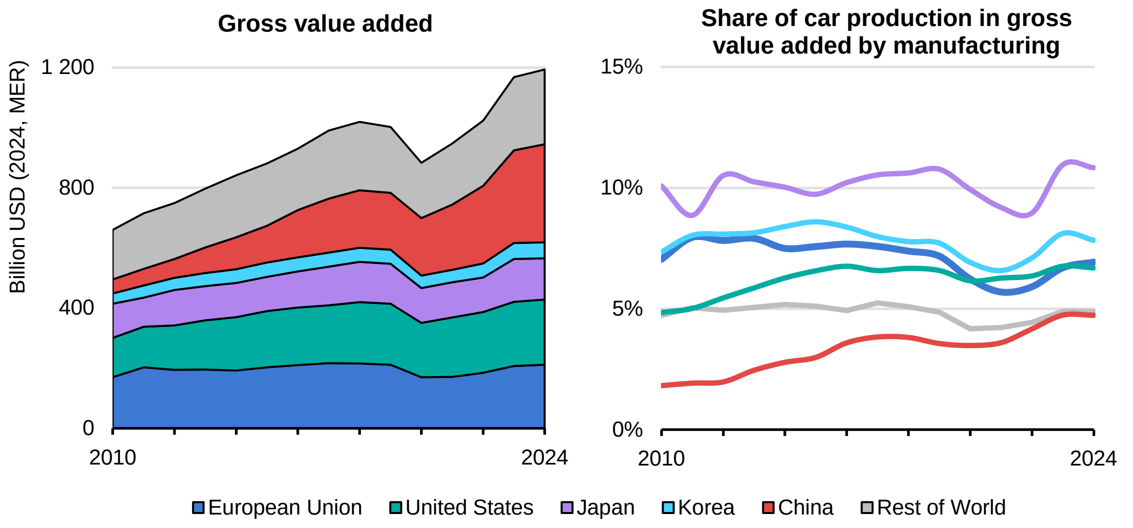
[6] See the box on Estimating economic indicators for the car industry for a description of the methodology used to isolate the car industry from the broader automotive manufacturing industry, which includes other vehicles and equipment besides cars.

[7] Gross value added reflects the value generated by producing goods and services. It is measured as the value of output minus the value of intermediate inputs into production.

(see more on steel and aluminium below). Taking a broader view, in the major car-producing economies listed above, for every dollar of output from the car industry,[8] approximately USD 0.7 of value added is generated in the economy to support production. Combining both the direct and indirect value addition from manufacturing vehicles results in a contribution to global GDP of around 3%.

The car industry had been growing as a share of the manufacturing sector and global GDP in the decade leading up to the pandemic. The importance of the car industry is even greater when considering the wholesale and retail trade and repair of motor vehicles, as well as the other services and inputs required for the final sale of finished vehicles.

Figure 1.13 Gross value added by the car sector



IEA. CC BY 4.0.

Sources: IEA analysis based on Oxford Economics Global Industry Service.

Gross value added by the car industry is generally proportional to the number of vehicles produced, as well as to outputs of car components and parts. The contribution to the economy also depends on the vehicle types (e.g. premium, mass market) and sizes of the cars. The United States, known for producing larger cars with high specifications, has the highest gross value added per car among major car-producing regions – over 40%% higher than the global average. In contrast, China, where smaller, lower-cost cars are more prevalent, sees the lowest value added per vehicle.

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[8] The ‘Motor vehicles, trailers and semi-trailers’ (ISIC Division 29) sector is used as a proxy to derive this figure, in conjunction with Eurostat FIGARO tables (2024 Edition). See the box on “Input-Output tables and Input-Output multipliers – a primer”.

China has registered substantial economic growth from its car industry in recent years, both in absolute terms and as a share of value added by its overall manufacturing sector. The gross value added per car also tripled between 2010 and 2024, reflecting an increase in the average size and specification level of the vehicles produced. Despite this rapid expansion, the car industry still maintains a lower share of manufacturing value added (around 5%) than is seen in other major car-producing countries (such as Japan, at 11%). This reflects the broad-based growth across many segments of China's overall manufacturing sector, and the relatively short time since the inception of the industry in China (in 2010, the car industry accounted for just 2% of China's manufacturing value added, whereas in Japan the share was around 10%).

Estimating economic indicators for the car industry

The International Standard Industrial Classification (ISIC), which was developed by the United Nations to classify economic activities across the world, provides a framework for the organisation of economic data that is comparable across countries. This framework is comparable with other statistical classifications from different regions, such as the Statistical Classification of Economic Activities in the European Community (NACE), which is derived from ISIC.

The NACE code containing car production is NACE Division 29 – manufacture of motor vehicles, trailers and semi-trailers. This division includes vehicles for transporting passengers and freight (including heavy and light vehicles but excluding two- and three-wheelers). It also covers component and parts manufacturing (Tiers 1 and 2) and vehicle assembly. The maintenance and repair of vehicles produced in this division are not included.

In this report, the data presented refers to the entire NACE Division 29, which is referred to as the "automotive industry". Data is also presented specifically on the "car industry", referring to the production of cars, their components and parts, as obtained from various other sources, including regional input-output tables of some countries such as the United States, Japan and Korea.

To estimate gross value added by the car industry we combine detailed bottom-up data on vehicle production and average vehicle prices to estimate the value of car and other vehicle production. The share of production by region and time can be used to split NACE Division 29 into cars and other vehicles. This method has been validated by comparing the results from detailed input-output tables for some countries and years which explicitly distinguish economic activity from car, truck and other vehicle production.

For employees, the separation of ISIC Division 29 into cars and other vehicles is based on national-level data for countries reporting employee data using the North American Industrial Classification System, which differentiates between light-duty vehicle (LDV) and heavy-duty vehicle (HDV) assembly. By comparing this employee data with production, the split of LDV and HDV employees within ISIC Division 29 is estimated, and then LDV employees is split into cars and light commercial vehicles.

ISIC Division 29 includes the manufacture of many vehicle components, including drivetrains, windows, seats and more. It excludes, however, several other important components, notably including batteries (Division 27) and tyres (Division 22). To ensure a fair comparison of labour intensity across ICEVs and EVs (since ICE engines are included in ISIC Division 29 but EV batteries are not), a bottom-up estimate of employment in EV batteries is also included.

The car industry does not operate in isolation. Its inputs are produced by other manufacturing sub-sectors, and its outputs are used all across the economy. In addition to crossing sectoral boundaries in the economy, these inputs and outputs also cross national boundaries through international trade. The car industry is typically a regionally integrated system, with suppliers and customers along the supply chain often located in the same country, or in a country in close proximity. A high degree of regional supply chain integration can be beneficial in reducing costs and improving resilience. Even within a country, the car industry’s supply chain tends to be located in relative proximity to the final car assembly plants (see section below on industrial clusters). This facilitates “just-in-time” delivery, decreases logistics and inventory costs, and enables close collaboration and quality control.

Among the major car-producing countries, more than three-quarters of all economic inputs[9] to the car industry are sourced either domestically or within free trade areas. This includes goods, such as car parts, and services, such as software (see the box on “The growing role of software in shaping the car industry” in Chapter 4). However, there is significant variation in the extent to which each country relies on international trade to source its inputs. In both Japan and China, more than 90% of the value of economic inputs to the car industry come from within the country, followed by the European Union, where around 85% of inputs come from within its single market. The United States has the lowest share of domestically sourced inputs to its production, at around 75%, but the share of local sourcing rises to nearly 85% when including inputs produced in Canada and Mexico, with which the United States has a free trade agreement and special sectoral rules for the automotive sector.

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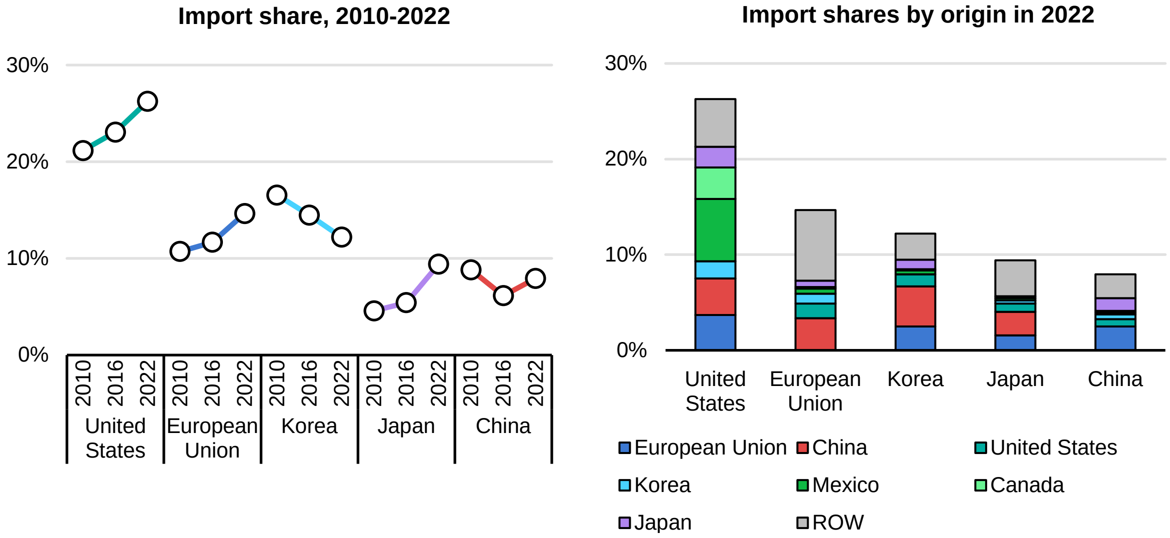
[9] Based on data from 2022.

The supply chains for inputs into vehicle production have become increasingly globalised in recent years, as industry players strive to minimise costs and leverage the specialisation and cost savings that global value chains afford. As a result, the shares of imported intermediate inputs – including components, parts and materials – have been rising steadily since 2010 in the European Union, the United States and Japan. Across all major car-producing regions, car components or parts required for vehicle assembly, such as wiring harnesses or brakes, are the subset of intermediate inputs that are most commonly imported. While the trading relationships that facilitate globalised supply chains are highly beneficial, they are not immune to risks. Increased trade tensions have strained supply chains in recent months. Measures to deal with the resulting uncertainty – whether on-shoring capacity, delaying investments or stockpiling – often come at a cost.

Figure 1.14 Share of imports (by value) in the automotive industry supply chain by origin, 2010-2022



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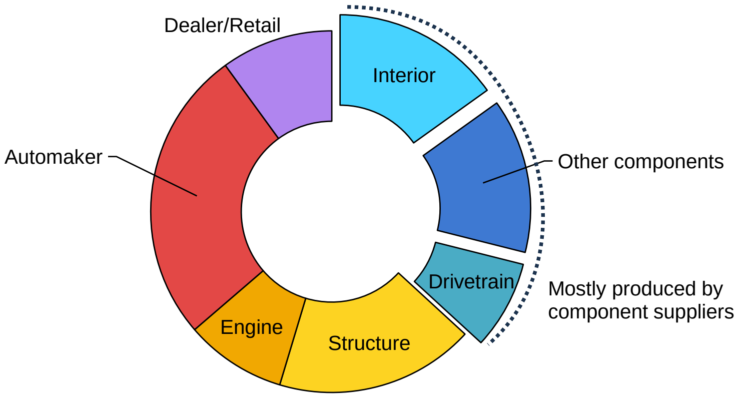
Notes: ROW = Rest of World. The "automotive industry" refers to ISIC Division 29.
Sources: IEA analysis based on Eurostat FIGARO tables (2024 Edition) and Bank of Korea Updated Input-Output Tables.

The share of imported value is not the only metric of interdependence between countries' car and other manufacturing industries. The degree of diversification across imports and domestic suppliers is important, as having a high dependency on a critically important component from a single producer – whether sourced domestically or imported – can severely impact production in the case of any disruption, even if it is a small share of the total cost of the vehicle. The importance of this diversification was highlighted by the global semiconductor shortage in 2021. At the time, demand for semiconductors across all sectors far outweighed supply, and is estimated to have reduced car production by 9.5 million units. The cost of a semiconductor is a fraction of the cost of an entire vehicle, but it is essential for the functioning of various safety features, driver assistance systems and automated driving features.

Irrespective of where a car is produced and the shares of imports used at various steps in its production, more value tends to be generated at the downstream supply chain steps (i.e. closer to the consumer) than it does upstream (i.e. closer to raw material production). While the distribution of value across the supply chain will vary considerably by car type and specification, it is instructive to examine the cost structure of producing an individual vehicle. Taking a small SUV manufactured in the United States as an example, around 55% of the cost (around USD 13 500 in this same example) is associated with OEM operations, which usually include the manufacturing of the vehicle's structure and engine, as well as assembly and painting costs. The manufacture of the main components accounts for around 35%, and distribution costs account for a further 10%. These figures are significantly higher than the costs of the raw materials manufactured by other industries that the car industry consumes: The steel, aluminium, copper and glass contained in a typical car cost around USD 1 400 at average commodity prices, or around 6% of the vehicle retail price considered here.

Figure 1.15 Share of cost for a small internal combustion engine SUV by cost component in the United States



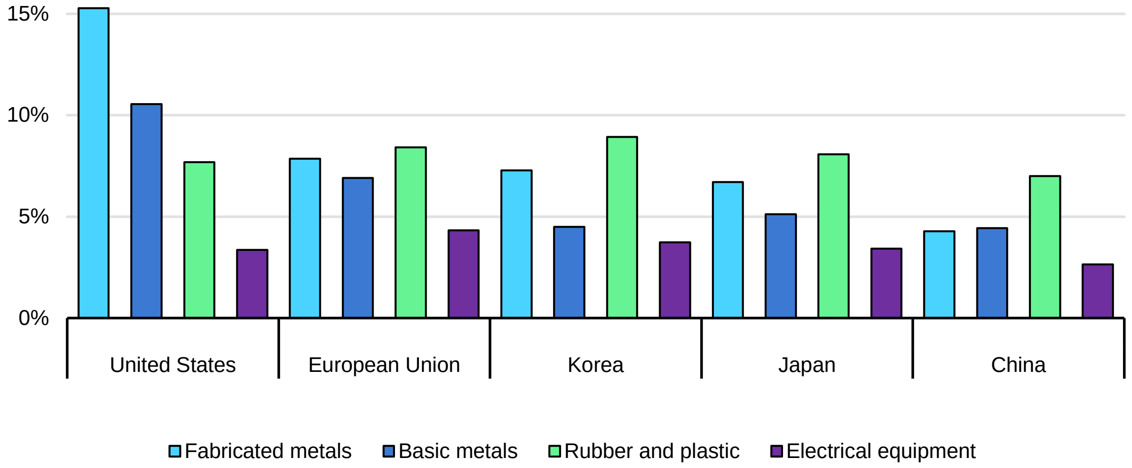
IEA. CC BY 4.0.

Notes: OEM = original equipment manufacturer. Cost shares refer to an internal combustion engine (ICE) car assembled in the United States. Automaker = labour; earnings before interest, taxes, depreciation and amortisation (EBITDA); Structure = chassis, body-in-white (the assembled car frame before painting). Other components = electronics, other non-powertrain-related components.

Sources: IEA analysis based on ICCT, UBS, BNEF, S&P Global Mobility and US Bureau of Labor Statistics.

While the materials contained in cars represent a relatively small fraction of the overall cost, cars – and the car manufacturing industry more broadly – represent a significant part of the total demand for the outputs from upstream industries, such as basic metals, rubber and plastic products, fabricated metals and electrical equipment. Furthermore, car manufacturers tend to be "anchor customers" for manufacturers in these upstream sectors that are located close by, even if this means somewhat higher production costs for the upstream inputs (see section on industrial clusters below). For example, in 2022, the automotive industry in the United States was the destination for around 15% of production of the domestic fabricated metals industry in value terms.[10] Meanwhile, in the European Union and Korea, around 9% of their respective rubber and plastic production was used by their domestic automotive manufacturing industries.

Figure 1.16 **Share of domestic production (by value) that is used by the domestic automotive industry**



Notes: Values are based on data from 2022. Industry names refer to manufacturing industries. Some NACE Rev. 2 product names have been shortened: fabricated metal products, except machinery and equipment (fabricated metals); and rubber and plastic products (rubber and plastic).

Source: IEA analysis based on Eurostat FIGARO tables (2024 Edition).

The car industry is an important source of demand for the steel and aluminium sectors

Steel and aluminium are two of the most widely used materials in car manufacturing, accounting for approximately 60% and 12% of the weight of an average passenger car, respectively. Steel is primarily used in the body and chassis, while aluminium is used across various car components, playing a particularly significant role in the powertrain. Various strategies have been employed to reduce the amounts of these materials required in a given vehicle (see box below), but broader market dynamics mean that in absolute terms, the quantities of steel and aluminium consumed by the car industry continue to rise.

The car industry accounts for an estimated 6% of global steel and 17% of global aluminium demand. These shares are even higher in advanced economies that are among the major car-producing countries. In the European Union, car manufacturing accounts for 12% of steel demand; in Japan, for 14%, and in the United States, 19%. Steel demand for the car industry in the European Union is equivalent to the production capacity of the biggest plants in Italy, France and Poland combined.

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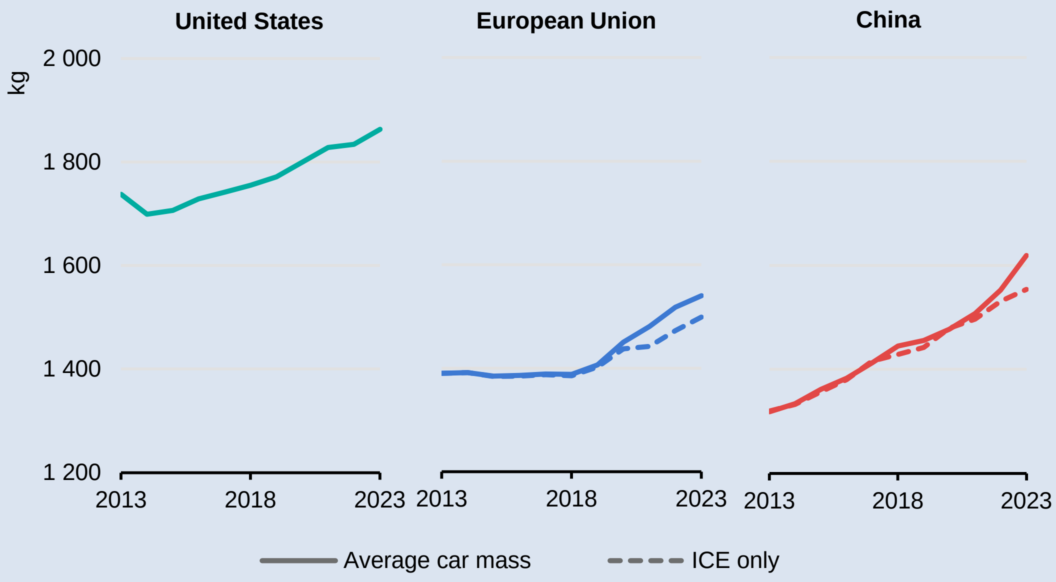
[10] Different industrial classification systems may result in some variation in estimates due differences in statistical boundaries.

Cars are getting heavier despite material substitution efforts

The relative proportions of materials in cars have remained fairly consistent over time, although several improvements have been made to reduce the weight of materials and components while maintaining strength and durability. Examples of these lightweighting efforts include substituting conventional steel for advanced high-strength steel (AHSS) or ultra-high-strength steel (UHSS) grades, replacing steel with plastics and composites in non-structural components, and the substitution of steel for aluminium.

Despite these changes in design, the amount of steel and aluminium used in a vehicle has continued to increase, as has the overall weight of cars on average. The weight of an average European ICE car in 2008 was 1 350 kg, while in 2022 it was 1 490 kg. This increase has been driven by a continuous trend towards larger vehicle segments, with SUVs now accounting for the majority of global sales (see Figure 1.2), as well as an increase in the average size of vehicles within each segment. Vehicle weights vary by region, with cars in the United States (on one end of the spectrum) on average 60% heavier than those sold in Japan, at the other end of the spectrum. In Europe, increased electrification has contributed significantly to average car weight increase since 2019.

Average vehicle mass of new sales, 2013-2023



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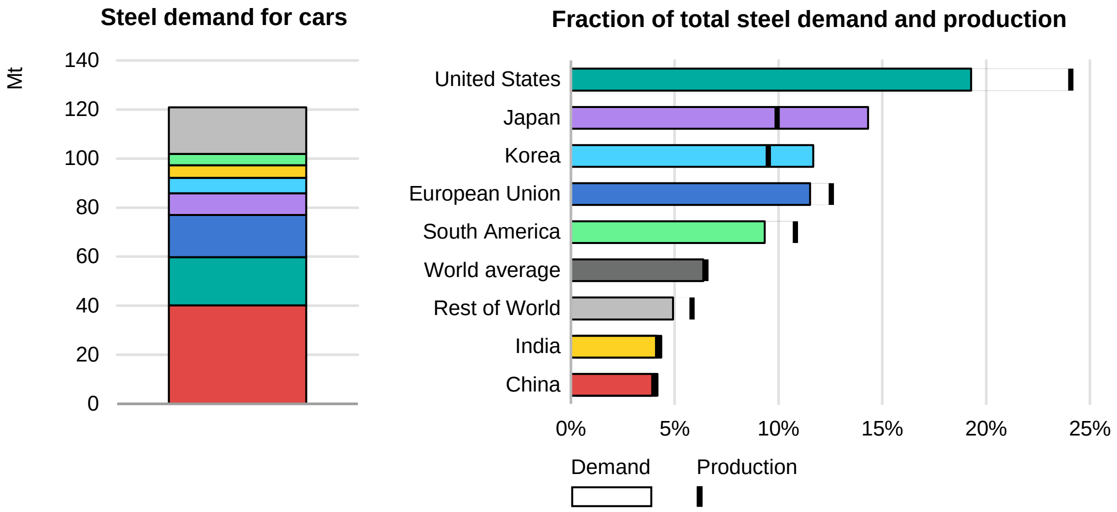
Notes: ICE = internal combustion engine. “ICE only” refers to the average vehicle mass excluding all electric and hybrid vehicles.

Sources: IEA analysis based on S&P Global Mobility, EPA (2024), ICCT (2024) and ICCT (2025), The steel products used in the car industry tend to be of higher quality and higher value than the products demanded by many other applications. The car industry mostly requires galvanised steel – i.e. steel coated with a layer of zinc to protect against corrosion – and high-strength alloys, all with very highly specified standards in terms of metallurgical quality and other physical properties. These steel products command higher-than-average prices. The price of galvanised steel, for example, is typically 20-25% higher that of reinforcing bars, a lower-quality, high-volume product used predominantly in the construction sector.

In the body-in-white of a typical ICE car, only about a third of the steel used is low-strength steel. The remaining two-thirds are higher-performance grades: one-third is high-strength steel, and the other third consists of even higher grades, such as AHSS, UHSS and press-hardened steel. Demand for these high-performance steel products has been driven by stringent safety and fuel efficiency regulations, which in turn have pushed innovation in the steel sector, leading to new manufacturing processes and techniques.

Figure 1.17 Steel demand for car manufacturing, average 2019-2023



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Notes: Total steel demand refers to apparent use of crude steel equivalent. Steel demand for car manufacturing includes steel contained in the vehicle and losses due to manufacturing and semi-manufacturing yields. “Fraction of total steel demand” refers to the share of overall steel demand in a given region that is attributable to car manufacturing (indicated by red dots). The red dashed line represents the global average. “Fraction of total steel production” indicates the proportion of a region’s steel production that is consumed by car manufacturing.

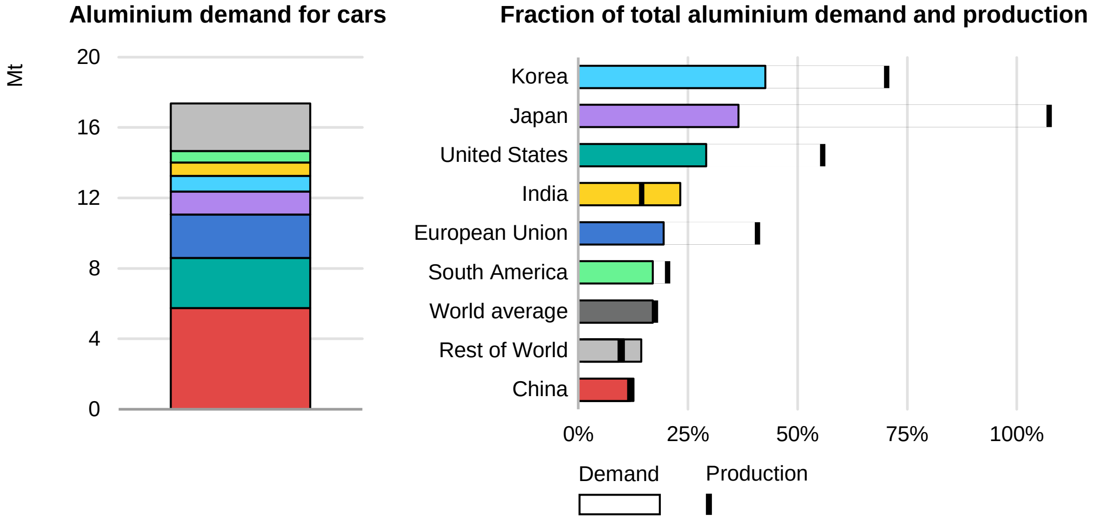
Sources: IEA analysis based on data from World Steel Association; GREET; Cullen at al. (2012), Mapping the Global Flow of Steel: From Steelmaking to End-Use Goods.

In addition, the car industry’s reliance on flat steel products (sheet and coil) influences the structure of steel production in many economies. Flat products, including hot-rolled and cold-rolled sheets, differ from long products such as bars, rods and rails, which are more typical in construction and infrastructure sectors. Flat products are essential for applications where surface quality, precise dimensions and formability are critical, notably in the manufacturing of the car body and external panels. In advanced economies, the steel industry is increasingly oriented towards flat product output to meet automotive demand. Flat products account for around 70% of steel production in the United States and Japan, and approximately 60% in the European Union and other advanced economies. In contrast, flat product shares remain lower in EMDEs, averaging around 50% in China and 45% in India.

The aluminium sector presents a somewhat different picture. Aluminium demand for cars accounts for over 20% of all aluminium demand in most advanced economies, and more than 35% in Japan and Korea. Most advanced economies are major net importers of aluminium, as smelters tend to be located in regions with abundant and inexpensive electricity. The United States, for example, sources much of its aluminium from Canada, and the European Union primarily from Norway and Iceland. The demand for aluminium in the car industry in Japan is higher than total Japanese aluminium production, meaning that the rest needs to be imported.

Unlike steel, the aluminium used in car manufacturing is generally not of higher value than that used in other sectors. Cast aluminium, which is commonly used in vehicles due to its ability to accommodate complex geometries (e.g. in ICE components) and for its heat transfer properties, typically has a higher tolerance for impurities and is often produced with secondary aluminium, and therefore does not command a higher-than-average price. This is not the case for wrought aluminium components used in the body structure and panels, which often use high-grade aluminium alloys.

Figure 1.18 Aluminium demand for car manufacturing, average 2019-2023



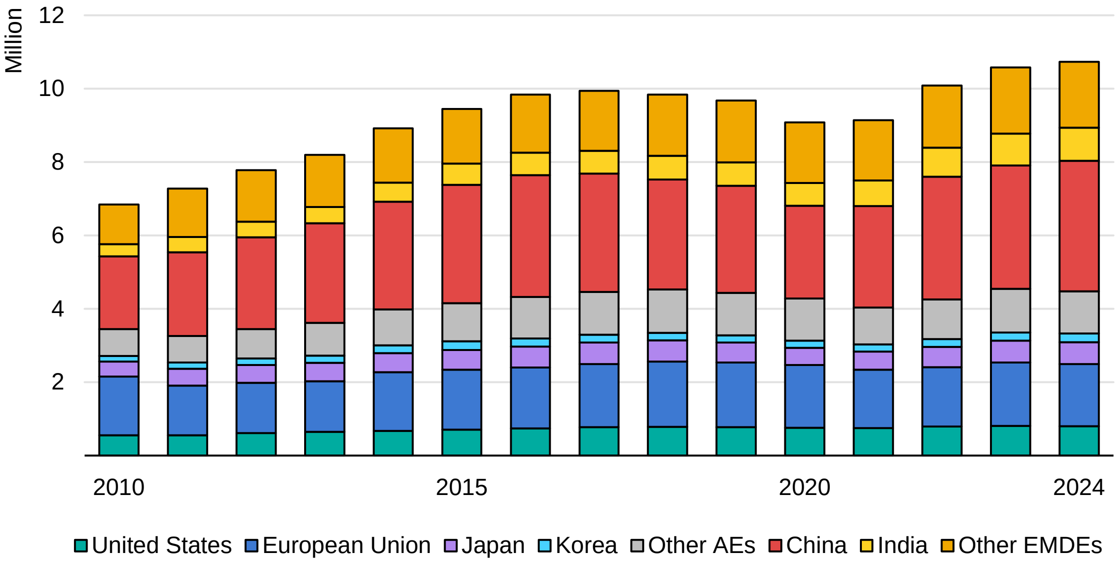
Notes: Aluminium demand for car manufacturing includes aluminium contained in the vehicle and losses due to fabric yields. “Fraction of total aluminium demand” refers to the share of overall aluminium demand in a given region that is attributable to car manufacturing (indicated by red dots). “Fraction of total aluminium production” indicates the proportion of a region’s aluminium production that is consumed by car manufacturing.

Sources: IEA analysis based on data from USGS, IAI, BACI, GREET, Liu et al (2013).

The car industry is a major employer

The sizeable economic activity generated by the car industry requires a large workforce. In 2024, the car manufacturing industry accounted for over 10 million employees globally, including those responsible for assembling vehicles and manufacturing components. Trends in employment levels typically follow car production, but unlike car production, employment reached new heights in 2024, above the pre-pandemic peak in 2017.

Figure 1.19 Car manufacturing employees by region, 2010-2024



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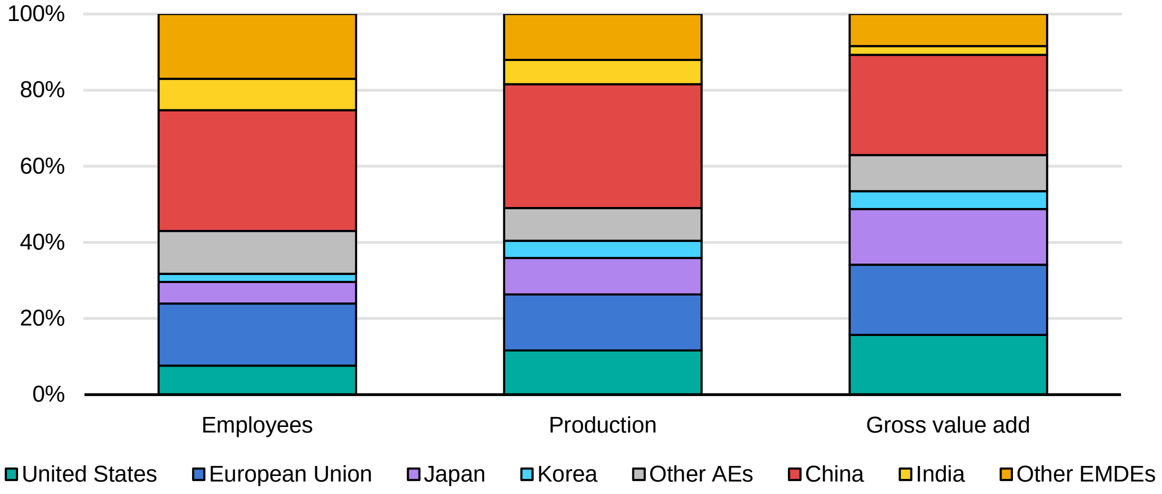
Notes: AEs = advanced economies; EMDEs = emerging markets and developing economies. Employment in “car” manufacturing includes a subset of ISIC Division 29, as well as an estimate of electric vehicle battery manufacturing jobs (from ISIC Division 27) – see “Estimating economic indicators for the car industry” box for details. Figures for 2024 are estimated for some countries.

Sources: IEA analysis based on data from UNIDO INDSTAT, national statistical offices, and Marklines.

The industry’s employment footprint is highest in many of the same regions that account for most value added and car production, especially China (32%) and the European Union (16%). Yet employment is slightly more concentrated in EMDEs than production or gross value added: whereas these economies account for around half of car production, and under 40% of gross value added, they account for nearly 60% of global employees in the sector. This demonstrates that the socio-economic importance of the car industry spreads beyond high-value-added segments in advanced economies, and that its footprint in EMDEs is significant, despite these regions’ lower contribution to global production and value added.

Figure 1.20 **Regional share of car manufacturing employees, production and gross value added, 2023**



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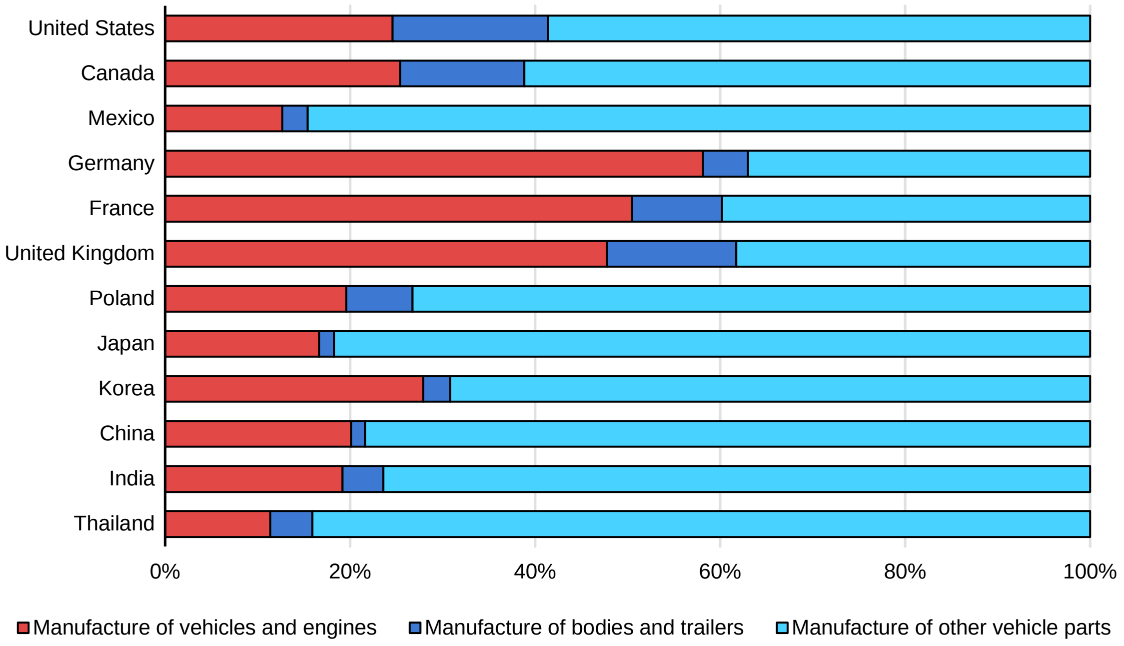
Notes: AEs = advanced economies; EMDEs = emerging markets and developing economies.

Sources: IEA analysis based on data from UNIDO INDSTAT, national statistical offices, Marklines and Oxford Economics Global Industry Service.

As mentioned, the difference between production and gross value added is mostly the result of the greater emphasis on premium market segments in advanced economy production lines. The difference in the global distribution of production and employees, meanwhile, can be explained by two main factors: the greater emphasis on the production of car parts in EMDEs, and differences in automation connected to lower labour costs.

With regard to the first factor, while the manufacturers of car parts account for around half of global gross value added in motor vehicle manufacturing, they account for three-quarters of global jobs in the sector. Jobs in manufacturing vehicle components, which are tradeable and more labour intensive than vehicle assembly, tend to be concentrated in countries which neighbour centres of vehicle assembly and can compete on the basis of lower labour costs, such as Poland, Mexico and Thailand.

Figure 1.21 Subsector share of motor vehicle manufacturing employees by country



IEA. CC BY 4.0.

Notes: All data from 2021, except China from 2023. The three categories shown correspond to ISIC sectors 291, 292 and 293 – see box on "Estimating economic indicators for the car industry" for more details.

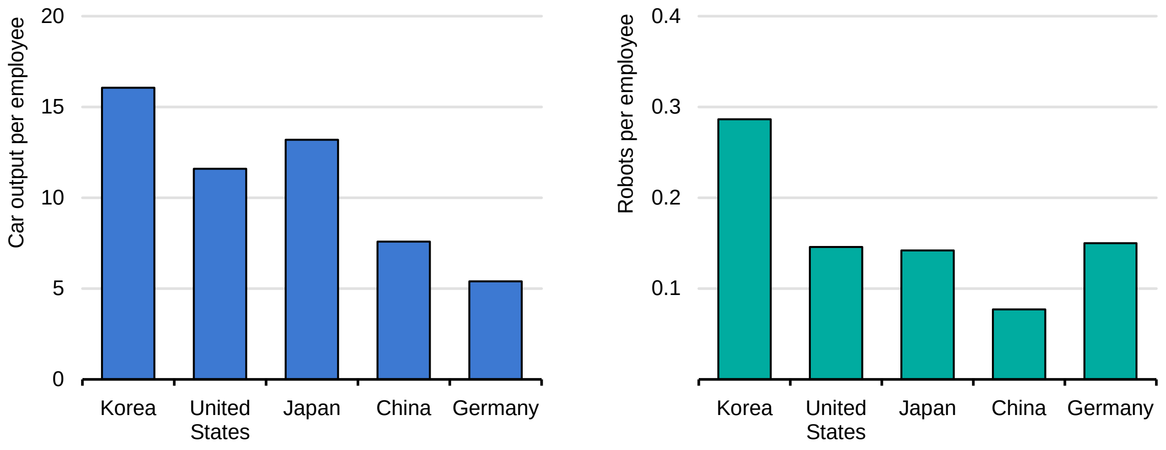
Sources: IEA analysis based on data from UNIDO INDSTAT and China National Bureau of Statistics.

As for the second factor, the distribution of employees differs in line with variations in automation and labour intensity of production. There are many factors that explain the level of automation, but high labour costs – such as in advanced economies – generally serve as a powerful incentive to automate production, especially when it comes to vehicle assembly. Robot density is a useful proxy for the level of automation of the industry: in 2021, Korea had the highest robot density in the automotive industry, with 1 robot for every 3.5 employees, nearly twice as high as in Germany, Japan and the United States (each with over 6.5 employees per robot), and almost 4 times higher than in China (13 employees per robot). China is catching up, however: in both 2022 and 2023, about half of the approximately 135 000 robots installed globally in the automotive sector were installed in China.

Robotisation is contributing to reshaping employment patterns in the industry

While automation reduces the need for lower-skilled and repetitive tasks, it is also creating demand for higher-skilled roles, such as robotics engineers and maintenance technicians. These positions are typically better paid, but they are also fewer in number, potentially resulting in a net reduction in overall employment. This trend could further strengthen with the use of collaborative robots – those able to work alongside humans – and customisable robots, which can change between tasks, improving flexibility. In addition, the integration of artificial intelligence can expand the range and complexity of tasks that robots can perform, further increasing their impact in industrial production. High automation and robotisation of the production process is a viable pathway for countries with higher labour costs to remain competitive on the global market.

Figure 1.22 Car output and robots per employee by country, 2021

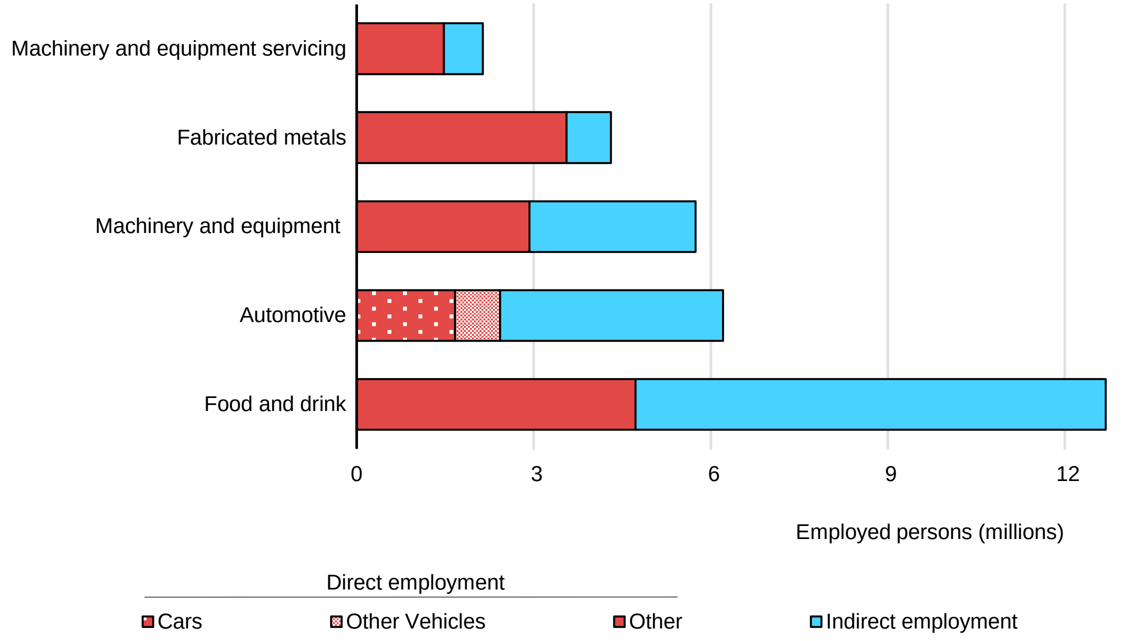


IEA. CC BY 4.0.

Sources: IEA analysis based on data from UNIDO INDSTAT, China National Bureau of Statistics, Statistisches Bundesamt, Marklines and the International Federation of Robotics.

The impact that the car industry has on employment within a region extends far beyond the industry alone to upstream industries such as materials production. Service industries are also required to facilitate production, such as financial services and transportation. Along the supply chain, employment can be distinguished as direct (i.e. required for the core activities of an industry) and indirect (required in the upstream activities that supply inputs into production). For example, in the car industry, a job in a car assembly plant would be considered direct employment, whereas a job in a steel mill that produces steel used to create a chassis would be considered indirect employment.

Figure 1.23 Manufacturing industries with the largest direct and indirect employment in the European Union



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Notes: Data from 2022. Industry names refer to manufacturing industries, unless otherwise specified. Some NACE Rev. 2 product names have been shortened: repair and installation services of machinery and equipment (machinery and equipment servicing); fabricated metal products, except machinery and equipment (fabricated metals); machinery and equipment n.e.c. (machinery and equipment); motor vehicles, trailers and semi-trailers (automotive); food, beverages and tobacco products (food and drink). “Employment” totals presented in this figure differ slightly from “employee” totals in preceding figures, as employment totals also account for the self-employed.

Sources: IEA analysis based on Eurostat FIGARO tables (2024 Edition), Eurostat, UNIDO INDSTAT and ILO.

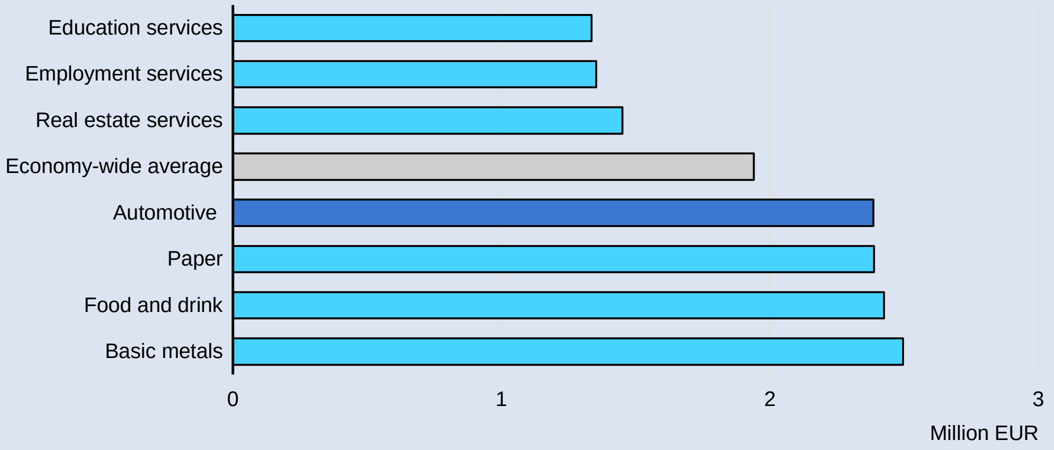
For example, in the European Union, the automotive industry directly supported around 2.4 million jobs in 2022, and over 6 million jobs when including jobs in upstream industries that supply products to the automotive industry for use in production. Similarly, in 2023, the automotive industry in Japan supported almost 900 000 employees, which grows to around 1.4 million employees when including materials and equipment supply. Across the European Union, the automotive industry has one of the highest ratios of indirect to direct jobs, as it produces finished products and requires inputs from across the economy. This trend is also observed in the United States, with car manufacturing featuring some of highest employment multipliers. Finally, in the European Union, the wholesale and retail trade of motor vehicles directly employs almost 3.8 million people, further highlighting the importance of the industry to employment.

Input-output tables and input-output multipliers – a primer

Input-output tables are a statistical tool that provide detailed information about the supply and use of products in an economy. Generally, they form part of a country or region's national accounts, complementing other economic indicators such as national income, expenditure and production aggregates. An important element of input-output tables is that all production and use is accounted for, and the total supply of a product is equal to its total demand.

Goods and services within an economy fall under two "use" definitions: intermediate use, when a product is used in a production process, and final use, when the product is "consumed". Input-output tables can be used to identify the largest inputs into the production process of a particular product, or determine whether a product is purchased by governments, used for capital formation, purchased by households, or exported.

Value of production required in the economy to satisfy EUR 1 million of final demand



IEA. CC BY 4.0.

Notes: Values in 2022 EUR. Industry names refer to manufacturing industries, unless otherwise specified. Some NACE Rev. 2 product names have been shortened: motor vehicles, trailers and semi-trailers (automotive); paper and paper products (paper); and food, beverages and tobacco products (food and drink).
Source: IEA analysis based on Eurostat FIGARO tables (2024 Edition).

One powerful application of input-output analysis is the use of "multipliers". These are based on the relationships between products and industries, and can be used to determine the total value of production, across all parts of the economy, that is required to produce the final demand for a product. For example, in 2022 in the European Union, on average, for each EUR 1 million of final demand for motor vehicles, EUR 2.4 million of production is required across domestic industries to support motor vehicle production. This allows for an understanding of the ripple effect that production has on the entire economy.

This methodology can be extended to undertake employment analysis, as demonstrated in Figure 1.23. When employment by industry is known, it can be used with production multipliers to estimate the number of employees or jobs (direct and indirect) that are supported by production to meet final demand from a specific industry. This takes into account all the jobs in the upstream supply chain. Caution should be applied in using these multipliers to estimate changes to the number of jobs supported given a change in demand for the output of the industry.

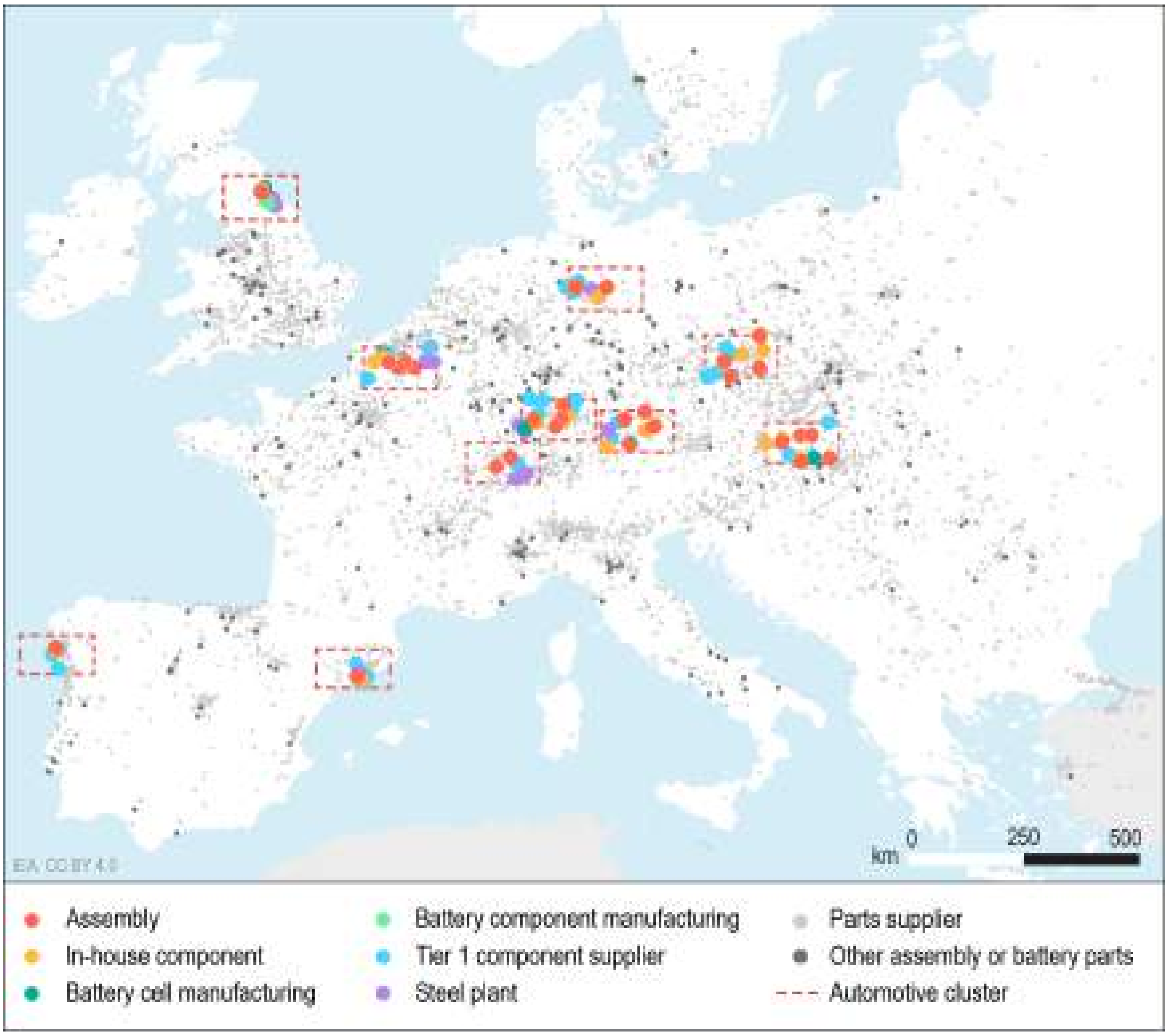
Car industries often form the core of industrial clusters

Regions with strong car industries tend to operate as clusters in which supplier factories are located alongside those of parts manufacturers and material producers. This is because close co-ordination between automakers and a wide network of specialised suppliers is essential to keep costs low. Such production ecosystems also facilitate the rapid exchange of complex, often tacit, knowledge, especially during vehicle development phases where design, engineering and manufacturing decisions must be tightly aligned. Clusters also allow companies to respond quickly to operational challenges and market shifts, enhancing overall productivity and reducing logistical risks. In addition, clusters create strong regional labour markets with pools of industry-specific skills. Over time, educational institutions and training programmes in these regions adapt to serve the needs of the automotive sector, creating a feedback loop between industrial activity and human capital development. This concentration of talent and capability attracts further private investment, strengthening the region's global competitiveness. The globalisation of supply chains has led to many production centres being outsourced to the most competitive regions, but the car industry has remained rooted in regional production systems. Vehicle assembly and parts production often remain close to major end markets, to be able to rapidly respond to fluctuating demand and to minimise costs of logistics.

For example, in Europe, 40% of the continent's car production capacity is located in 10 clusters, each with an area of 120 km by 220 km, and each home to a production capacity of at least half a million cars per year. Many of these clusters are formed around national champions.

In the United States, clustering is less prominent, given that it covers a larger area without national borders, and the manufacturing footprint is instead located along a north-south corridor stretching from Michigan to Alabama. Within this corridor are several automotive clusters scattered around the major global manufacturing regions, some of which have operated for over a century, such as in the Detroit area. The 10 largest clusters – most of which lie within this corridor – account for 60% of the country's total manufacturing capacity. The two main exceptions are the cluster in California, home to Tesla’s largest manufacturing plant in the United States, and the clusters in Texas, home to factories belonging to Tesla, GM, and Toyota.

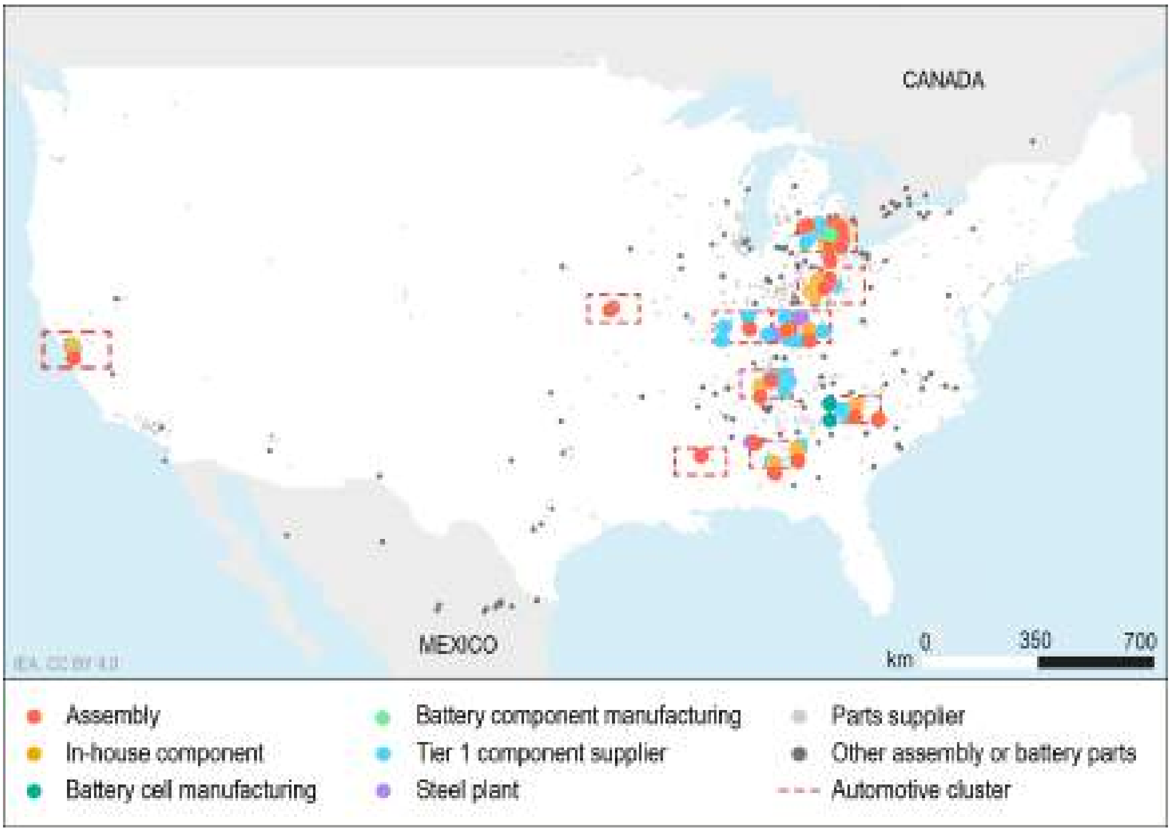
Figure 1.24 Ten largest European automotive manufacturing clusters



Notes: Automotive clusters are defined as areas with a production capacity of at least 500 000 units per year in 2024. “In-house component” represents the manufacturing by original equipment manufacturers for engines, traction motors and transmission. “Parts suppliers” include the following components: body parts, chassis parts, climate control, driveline parts, electric and electronic parts, electric and internal combustion engine powertrain, exterior parts, AD/ADAS/telematics and interior parts. Battery pack assembly and recycling are excluded from the analysis. “Battery component manufacturing” accounts for cathode and anode active materials only. Geotagging of battery cell and component plant locations was performed using the plant and company names, country, and – for battery cell facilities – the city, based on installations as of end-2023. See the annex for a full list of automakers and suppliers used for this analysis.

Sources: IEA analysis based on data from Marklines, Global Energy Monitor and Benchmark Mineral Intelligence.

Figure 1.25 **Ten largest automotive manufacturing clusters in the United States**



Notes: Automotive clusters are defined as areas with a production capacity of at least 500 000 units per year in 2024. See notes in Figure 1.24.

Sources: IEA analysis based on data from Marklines, Global Energy Monitor and Benchmark Mineral Intelligence.

On the following pages, we present data on three car production clusters, each spanning an area of 26 400 km^2: Nagoya (Japan), Shanghai (China), and Detroit (United States). These clusters are home to several car assembly plants as well as a several Tier 1 supplier facilities and several Tier 2 factories. In most cases, at least four steel production plants are located in the area, although these plants may additionally serve customers outside the cluster. However, while Detroit and Nagoya each have one battery factory, the Shanghai cluster has significantly more, and also contains significant facilities for the production of battery components. Overall, the Shanghai cluster is home to 64 battery and battery component factories with a production capacity of about 200 GWh, representing over 5% of the global total.

Table 1.1 Summary of statistics for selected car industry clusters

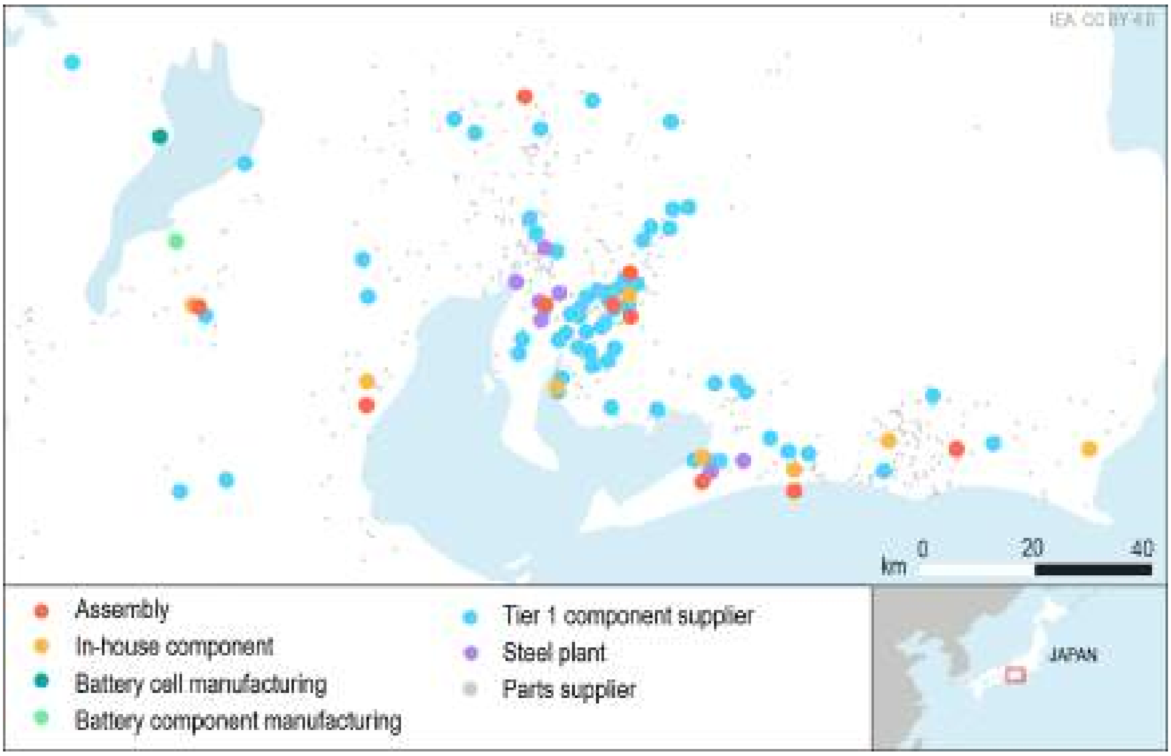
	Number of suppliers	Number of OEMs	Prod. capacity (millions)	Number of assembly plants	Battery production plants	Battery components plants
Nagoya	571	7	3.2	11	1 (2 GWh)	1 (3 GWh)
Shanghai	2 023	12	3.7	11	26 (195 GWh)	38 (255 GWh)
Detroit	347	3	2.2	9	1 (10 GWh)	1 (3 GWh)

Notes: "Suppliers" refers to automotive suppliers with headquarters in each cluster. OEMs: refers to original equipment manufacturers operating within the cluster. Prod. capacity: estimate of yearly production capacity for the car assembly plants. Battery components plants account for cathode and anode active materials only. Geotagging of battery cell and component plant locations was performed using the plant and company names, country, and, for battery cell facilities, the city, based on installations as of end-2023.

Source: IEA analysis based on Marklines.

Clusters offer many operational advantages, but they also pose risks, notably for suppliers that are geographically bound to the carmakers, as any change in car assembly volumes has direct implications for these suppliers. Such suppliers are unlikely to be able to competitively produce products for factories located outside the cluster in more remote geographies. Moreover, the geographical concentration of the automotive sector means that any potential downturn would be disproportionately felt in some regions, as would the socio-economic consequences.

Figure 1.26 Zoom-in on the automotive cluster in Nagoya, Japan

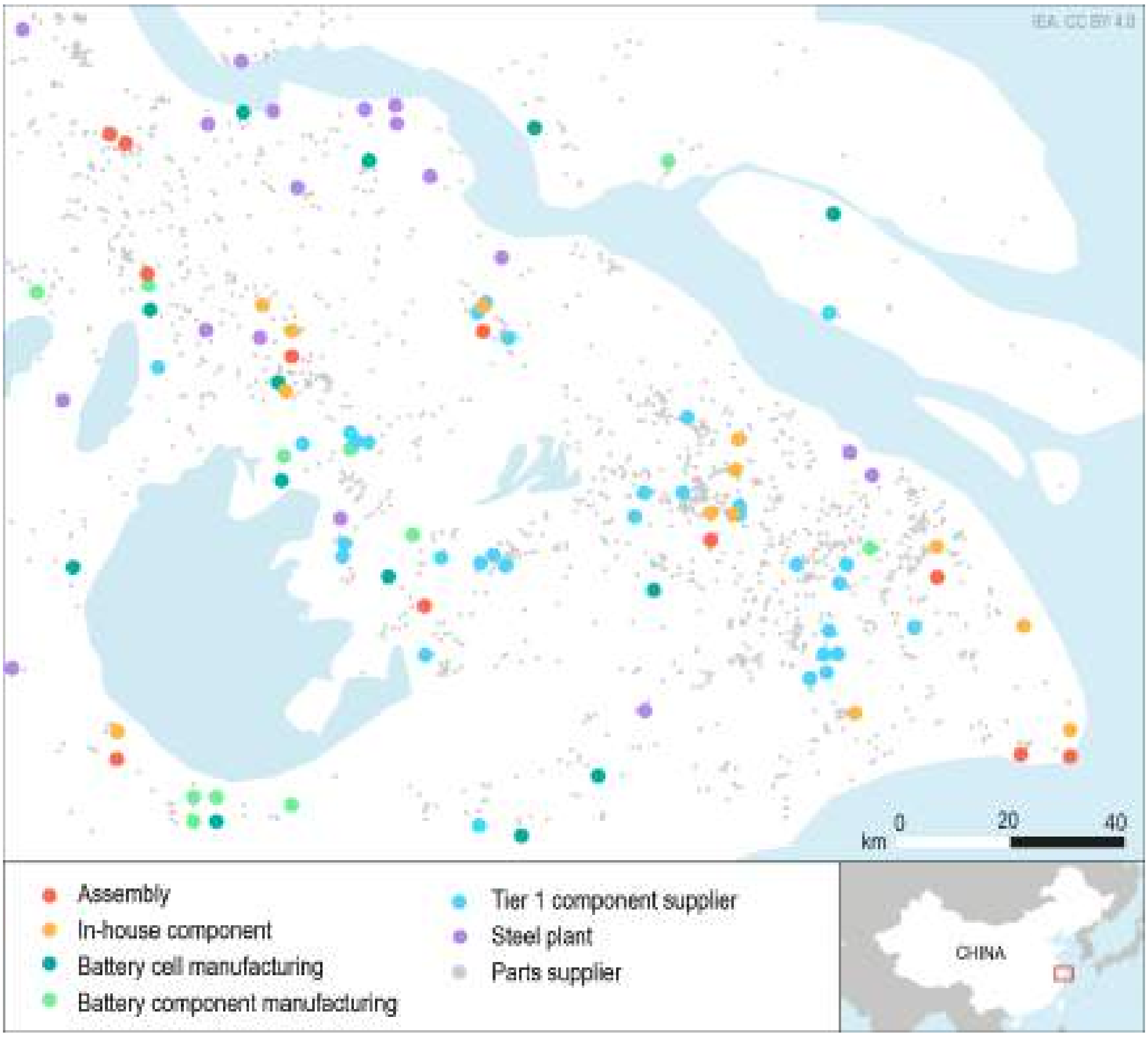


IEA. CC BY 4.0.

Note: See notes in Figure 1.24

Sources: IEA analysis based on data from Marklines, Global Energy Monitor and Benchmark Mineral Intelligence.

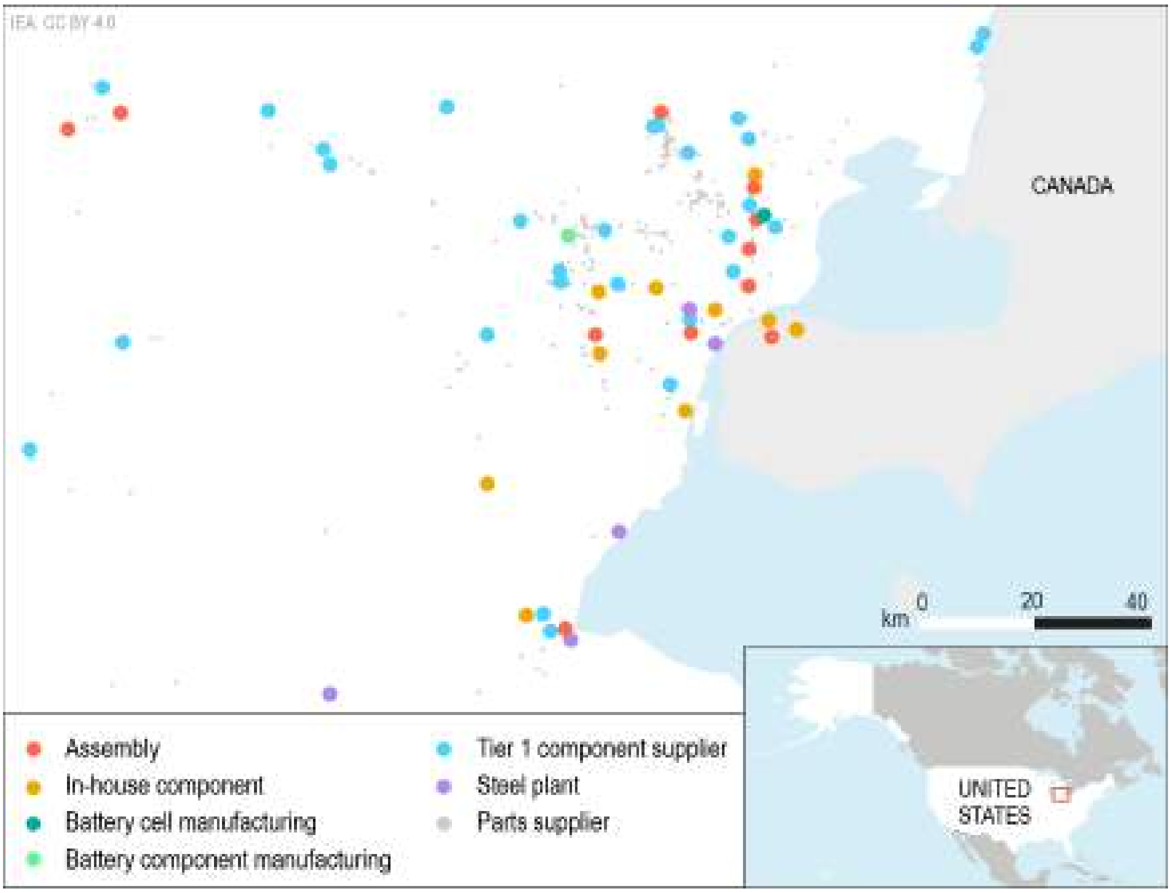
Figure 1.27 Zoom-in on the automotive cluster in Shanghai, China



IEA. CC BY 4.0.

Note: See notes in Figure 1.24
Sources: IEA analysis based on data from Marklines, Global Energy Monitor and Benchmark Mineral Intelligence.

Figure 1.28 Zoom-in on the automotive cluster in Detroit, United States



IEA. CC BY 4.0.

Note: See notes in Figure 1.24
Sources: IEA analysis based on data from Marklines, Global Energy Monitor and Benchmark Mineral Intelligence.

Chapter 2. The importance of the growth in EV sales for the car industry

Highlights

- In 2024, more than one-fifth of all cars sold globally were electric. Policies remain key to growth in many regions, although falling prices make affordability an increasingly important driver. In China, two-thirds of battery electric cars sold in 2024 were cheaper than internal combustion engine (ICE) equivalents. In other major markets like Europe and North America, electric cars remain more expensive on average. But prices have been falling in many emerging economies on the back of affordable Chinese imports; in Southeast Asia, this helped push the share of electric car sales to 9% in 2024, almost double the share in 2023.
- For the same output power, an electric drive is about 60% cheaper, nearly 3 times lighter and generally requires less space than a comparable ICE powertrain. The costs of storage are vastly different: while the fuel tank of an ICE car costs around USD 200, a battery costs around USD 6 500 on average. The value of materials used in a battery electric car is up to 60% higher than in an ICE car, due to the critical mineral content. Demand for refined battery minerals, the supply of which tends to be concentrated in China, is set to keep growing, especially for lithium, for which electric cars already account for over 50% of global demand.
- Around a decade ago, several major automakers already had electrification strategies, but approaches differed. Chinese automakers and Tesla were particularly successful at quickly reaching economies of scale for electric cars. Before 2020, only 6 battery electric models had reached the production threshold of 50 000 units per year – 3 were Chinese models, 2 were Tesla models, and 1 was the Nissan Leaf.
- While incumbent original equipment manufacturers (OEMs) initially focused on nickel-based batteries because of their superior energy density, Chinese manufacturers succeeded in advancing lithium iron phosphate (LFP) chemistries, which rely less on critical minerals and are therefore cheaper. By 2024, all OEMs either sold or planned to sell cars with LFP batteries, though China maintains a near-monopoly on the technology.
- The automotive industry spent around 5% of its revenues on R&D in 2015-2023. Although Chinese OEMs on average invested significantly less, spending only 2% of revenues on R&D in 2016, investment has risen in recent years and accounted for 5% of their revenues in 2024.

Introduction

Electric cars are getting closer to mass-market adoption. While early deployment was driven by policy action and public spending, to reach widespread uptake, electric cars will need to compete with conventional cars on price – with significant implications for carmakers. This Chapter highlights some of the key policies that have supported electric car deployment over the past few decades and presents the latest data on electric car affordability, in order to provide a context for the ongoing changes in the car industry. It then focuses on the differences between electric and conventional cars and the impact for car and battery manufacturers in terms of inputs required. Finally, it analyses how different car manufacturers – both industry incumbents and new market-entrants – have implemented different strategies for electrification.

2.1 Electric cars are getting closer to mass-market uptake

Policy support has underpinned the recent electrification of cars

For decades, policy makers have passed legislation supporting road transport electrification as a way to address various policy priorities, including energy security (by reducing reliance on oil), climate change, air pollution and industrial competitiveness. Policies have targeted both the demand-side and the supply-side, although to varying degrees in different countries. The main policy drivers that have spurred the adoption of electric cars across major car markets have been increasingly stringent new vehicle fuel economy and/or CO_2 emissions standards – especially those that require a certain level of zero-emission vehicle (ZEV) sales, and financial incentives for purchasing electric cars and for building out public and private charging infrastructure. Industrial policies have also supported electric car manufacturing in different countries, as well as strengthening the broader supply chain, including the manufacturing of batteries and their components.

In **Norway**, consistent policy direction over many years has supported deployment such that it is now the country with the highest share of electric cars in the total car stock, and a 100% share of zero-emission cars in new sales is targeted for 2025. Fiscal incentives were put in place as early as 1990. These include VAT and import duty exemptions for electric cars, along with other benefits such as free parking and reduced road tolls. At the same time, the country increased taxes for fossil fuelled-vehicles. In 2017, Norway passed the "charging right" law, giving residents of apartment buildings the right to request the installation of a personal charging point.

In 2024, electric cars reached almost half of total car sales in **China**. China has taken a comprehensive approach to electric vehicles (EVs), with the government setting targets for EV production and deployment, while placing particular emphasis on their role in industrial development since 2001. The introduction of the dual credit policy promoted the manufacturing of ZEVs as a way to meet both the new energy vehicle targets and fuel efficiency targets. The government used a range of incentives to spur demand, including purchase subsidies, tax exemptions, as well as support for the build out of charging infrastructure. Some localities also offered vehicle registration plate incentives to promote demand. Electric car sales in China have become increasingly market-driven and not just driven by policy alone, thanks to their increasing affordability. In fact, the 2025 sales target laid out in the New Energy Vehicle Industrial Development Plan for 2021-2035 was met in 2022, which coincided with NEV purchase subsidies ending after that year.

In addition to increasing EV manufacturing, the Made in China 2025 initiative (published in 2015) set goals for innovative and efficient manufacturing and supply chain integration, including domestic content targets for core components and materials. Demand-side support for EV deployment was also tied to industrial strategy: from 2015-2019, under conditions set by the Ministry of Industry and Information Technology (MIIT), EV makers had to use batteries from suppliers included on the "white list" (which excluded many top Japanese and Korean battery makers) to be eligible for new energy vehicle (NEV) subsidies. In 2016 the National Plan for Mineral Resources was published, identifying battery metals as "important minerals", and encouraging domestic production and international collaboration with resource-rich countries. As a result, Chinese companies have become major players across the EV supply chain, from mining to EV manufacturing.

In the **European Union**, support for EVs has been driven mainly by energy security and climate change priorities. Policy mechanisms have focused on financial incentives, alongside regulations on charging infrastructure deployment and CO_2 emissions reductions. While various EU initiatives have highlighted the importance of securing reliable access to raw materials and developing an "innovative, competitive and sustainable battery value chain" in Europe, the EU battery supply chain remains heavily reliant on imports. To address this, and to deliver on the Green Deal Industrial Plan, the European Union adopted the Net-Zero Industry Act in 2023 to scale up manufacturing of clean technologies, including batteries. Demand-side policies (including purchase subsidies provided by individual countries) have served to boost the sales of electric cars in the region to around 20% of total car sales, with the shape of the adoption curve closely reflecting the step function of the EU CO_2 targets. The CO_2 standards target a 55% emissions reduction for new cars in 2030 (compared to 2021) and a 100% CO_2 emission reduction from 2035 onwards. In 2023, the European Union also adopted the Alternative Fuels Infrastructure Regulation, which included mandatory targets for the deployment of charging infrastructure.

Support for EVs in the **United States** began after the 1970s oil crisis and following the adoption of the Clean Air Act, acknowledging the role EVs can play in both reducing dependency on oil and in reducing air pollution. Support has included R&D funding, vehicle fuel economy and emissions standards, tax credits and federal funding to support deployment of charging infrastructure. States – especially California – have also adopted policies to promote the adoption of EVs, including zero-emissions vehicle sales mandates. The US government has also promoted innovation to reduce the need for critical minerals in the production of clean energy technologies, while the 2022 Inflation Reduction Act (IRA) introduced supply chain-related eligibility criteria for EV tax credits. However, changes in US administration and corresponding priorities over the years have meant that policies – particularly fuel economy standards and financial incentives – have changed as well. In 2024, light-duty vehicle emissions standards were finalised that would require over 50% of car sales in 2030 to be electric. However, in January 2025, Executive Order 14154 directed a reconsideration of fuel economy standards, a termination of state emissions waivers[11], elimination of subsidies for EVs and a review of the NEVI Formula Program. Congress and the relevant government agencies have since been following this direction.

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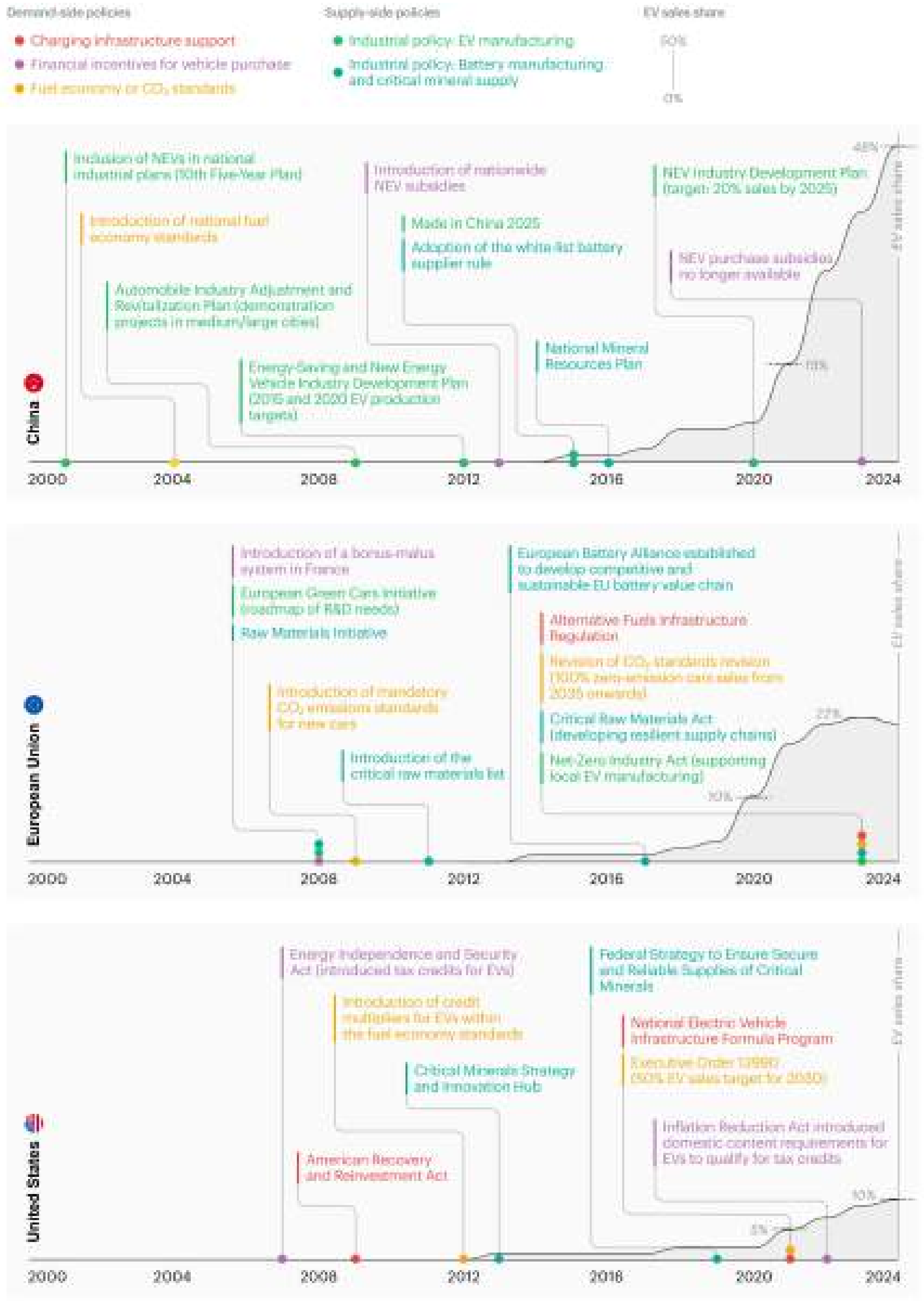
[11] Such as the waiver of pre-emption granted to California in December 2024 for their Advanced Clean Cars II regulation.

Figure 2.1 Overview of key policies supporting the electric car industry in major markets, 2000-2024



Notes: NEV = new energy vehicle; EV = electric vehicle.

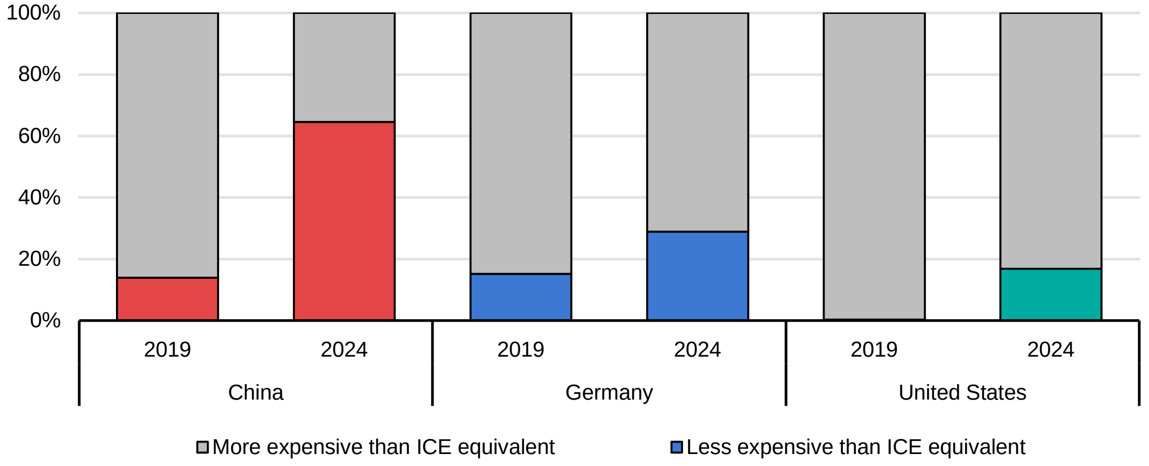
Policies in **Japan** have focused on supporting "electrified" vehicles, which include hybrid, plug-in hybrid, battery electric and fuel cell electric vehicles (FCEVs), with the government supporting R&D of these vehicle technologies as a way to reduce dependency on oil and local air pollution. In addition, Japan's 2020 Green Growth Strategy listed EVs and their batteries as one of the key areas for industrial growth. Similarly, **Korea's** policy frameworks to support EVs have also focused on industrial development and addressing climate change and public health. For example, in 2017 Korea set targets for electric car and charging infrastructure deployment. And in 2021, Korea enacted the Framework Act on Carbon Neutrality and Green Growth, which called for formulating and implementing a policy for phasing out the sale and operation of ICE vehicles.

Affordability is the key to unlock market-driven growth

Like many technological transitions, the early adoption of electric cars has been supported by policy and public spending. For uptake to continue and further accelerate, however, the new technology must be able to compete with the incumbent technology on price. For electric cars, there are two important milestones:

- **Total cost of ownership (TCO) parity with ICE cars**. The higher efficiency and lower maintenance costs of electric cars can make up for their higher upfront purchase price through reduced operating costs. The speed at which TCO parity is reached depends on the price difference between gasoline fuel and electricity, as well as the purchase price gap between ICE and electric models. As described in the Global EV Outlook 2024, TCO parity had already been reached in 2019 in key markets like Europe and China.
- **Purchase price parity with ICE cars**. Electric cars require fewer parts because their powertrains are significantly simpler than those of ICE cars, but their powertrains cost more to produce when compared to equivalent ICE cars, due to the additional cost of the battery. Provided that battery manufacturing costs continue to decline, electric cars could be both cheaper to operate and to purchase. Purchase price parity is even more instrumental to mass-market adoption than TCO parity, as upfront expenses are typically the dominant factor in car-buying decisions for private consumers.

Figure 2.2 **Share of battery electric car sales that are more or less expensive than conventional equivalents in selected markets, 2019 and 2024**



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Notes: ICE = internal combustion engine. Price data is adjusted for inflation. Price of electric cars in data has been increased by 10% to adjust for the registration tax exemption in China. The share of battery electric cars cheaper than their conventional equivalents is calculated as the number of car sales priced lower than the sales-weighted average price of the ICE car in their segment category.

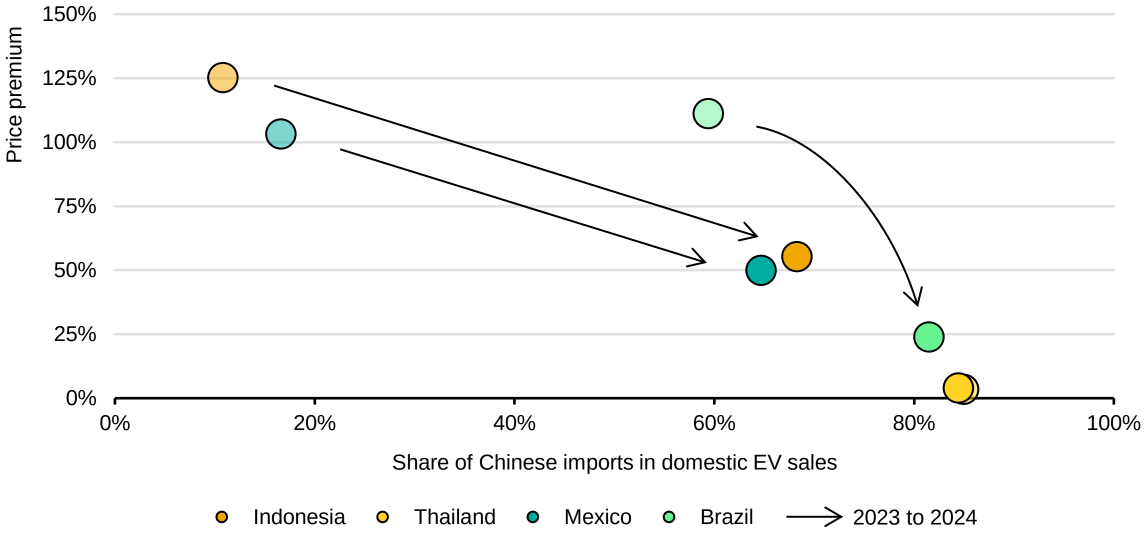
Sources: IEA analysis based on data from S&P Global Mobility and IEA (2025), Global EV Outlook.

As these milestones are achieved in more markets, electric cars may become the powertrain of choice for a growing number of consumers. In **China**, battery manufacturing cost reductions, a high degree of vertical integration of EV supply chains and fierce competition between EV makers have led to purchase price parity in most car segments. In 2024, two out of every three battery electric cars sold in China were cheaper at the point of purchase than the average ICE car in their segment, even when excluding registration tax exemptions. The average purchase price of battery electric cars is more than 15% lower than that of conventional cars, even without purchase incentives. Government spending played a crucial role in the early days of car market electrification but has been decreasing over time. EV purchase subsidies were phased out in China in 2023, and in 2024, we estimate that Chinese government support amounted to under USD 3 000 per EV (due to the purchase tax waiver), less than half the level in 2019. However, competition in the Chinese EV market and low profit margins have recently raised concerns over the health of the industry and long-term market stability. Major price cuts by market leader BYD triggered rapid market consolidation, and the number of EV brands declined for the first time in 2024. In response, the China Association of Automobile Manufacturers (CAAM) and MIIT called for car makers to move away from offering heavy discounts in order to sell large volumes, and instead to work towards competing on value for customers, and encouraging technological innovation. This strategy aims to strengthen the domestic electric car industry at the same time as boosting its competitiveness at the global level.

In the **European Union** and the **United States,** progress on affordability has been slower, in part due to differences in the vehicle specifications demanded by consumers compared to China, meaning that financial support and other regulatory frameworks still have a role to play in supporting further car market electrification. In spite of the electric car offers in these markets being dominated by more expensive, higher-end models, the share of electric cars in all car sales has continued to grow in recent years.

In **emerging markets and developing economies (EMDEs) outside of China,** affordably priced electric cars from China are driving up sales shares of electric cars. In 2024, the share of electric cars in total car sales grew in markets such as Brazil, Mexico, Indonesia and Thailand. In Brazil, for example, a recent surge in Chinese imports meant the purchase price gap between battery electric cars and their conventional equivalents decreased steeply, from more than 100% in 2023 to about 25% in 2024. In Mexico, the price premium for battery electric cars fell to around 50%. In Thailand, battery electric cars were priced almost on par with their ICE counterparts. As a result, electric car sales shares in EMDEs across Asia, Latin America and Africa almost doubled in 2024, reaching 4%.

Figure 2.3 Battery electric car price premium over conventional cars versus share of Chinese imports in domestic electric car sales in selected emerging markets, 2023-2024



IEA. CC BY 4.0.

Notes: EV = electric vehicle. Price data is adjusted for inflation. The price premium shows the relative price difference between an average battery electric car and an average conventional internal combustion engine car.

Sources: IEA analysis based on data from S&P Global Mobility and EV Volumes.

In EMDEs including China, plug-in hybrid electric vehicles (PHEVs) have carved out a distinct position in global EV markets. PHEV sales have grown consistently over recent years, and in 2024 they accounted for nearly 40% of global electric car sales. Nevertheless, adoption rates vary markedly: in 2024, 75% of global PHEV sales were in China, while sales plummeted in other major markets, in part due to their increasing purchase price and the lack of affordable models in OEMs' line-ups outside China, and in part because subsidies for PHEVs are being phased out.

The role of sustainable fuels in the outlook for the car industry

This report focuses on the implications of the increasing sales of electric cars for the global car industry, to provide insights for stakeholders in government and industry into ways to enhance the competitiveness of EV manufacturing. However, from the view of key policy goals such as reducing oil import dependency and mitigating climate change, electric and fuel cell vehicles are not the only options.

Sustainably produced biofuels and synthetic fuels can also meet a number of policy priorities for the road transport sector, even if reducing air pollution with such fuels relies on the additional use of catalytic converters. These fuels have the significant advantage of being drop-in fuels, meaning that they can be used directly to reduce CO_2 emissions of the existing vehicle fleet, whereas it takes time for sales of zero-emission vehicles to translate into a significant vehicle stock. The extent to which liquid fuels can support emissions reduction depends on their emissions over the lifecycle of the fuel supply chain, and therefore requires accurate accounting for these emissions. There is significant uncertainty around the emissions impacts of land-use change associated with biofuels production, in particular indirect land-use change, which is a major source of disagreement on GHG accounting methods.

Biofuels are currently the most developed alternative to fossil fuels in transport, and they are already a viable option in several parts of the world today. In 2024, an estimated 2.5 EJ of biofuels was used to fuel cars. There are limits to their scalability, however, both in terms of the availability of sustainable bioenergy and competition with other sectors. To reach high levels of deployment, substantial efforts would be needed to expand and diversify sustainable biomass feedstock supplies, commercialise new processing technologies and harmonise sustainability frameworks to address concerns related to large-scale deployment.

Synthetic low-emissions fuels are another option; they can be produced using biogenic CO_2 (which has the same limits to sustainability as biofuels), or by using CO_2 from direct air capture and electrolytic hydrogen produced from renewables, for example. Such fuels are currently very expensive: direct air capture, in particular, is a significantly more expensive source of the required CO_2 feedstock, being anywhere from 3 to almost 70 times as expensive as concentrated streams of CO_2, such as those resulting from ethanol production. The lowest production cost associated with synthetic fuels – using concentrated CO_2 streams – is estimated to be around USD 400/bbl today and would remain above USD 250/bbl even with high levels of deployment. However, there is potential for further cost reductions in the 2030s and beyond, which could support the use of such fuels, especially in countries with limited domestic renewable energy potential.

Sustainable liquid fuels are particularly attractive for the hardest-to-electrify end-uses that have a relatively high willingness to pay, such as aviation, and so there could be competition for the limited sustainable biomass potential. The production of synthetic kerosene via the Fischer-Tropsch process can result in a synthetic gasoline by-product, which could be used in ICE, hybrid or plug-in hybrid vehicles.

While some governments have pledged to reach 100% sales of cars that produce zero GHGs at the tailpipe, others that instead consider the emissions impacts across the full fuel pathway (i.e. “well-to-wheel” emissions) are keeping the option open for sustainable liquid fuels to play a role in decarbonising road transport, including for cars. For example, Brazil has adopted legislation that promotes the expanded use of biofuels as a means to reduce emissions from transport. The EU CO_2 regulation aims to maintain technology neutrality, which could allow cars running exclusively on CO_2-neutral fuels to contribute to the emissions target. The Japanese government has set a target that all new car sales from 2035 will have electrified powertrains (electric, fuel cell or hybrid vehicles). The limitations on availability and cost mentioned above mean that most benefit from such fuels would result from being used in combination with highly efficient cars, such as hybrids. The difficulty will lie in ensuring that only truly CO_2-neutral fuels are used in combustion engines, supported by well-to-wheel assessments that include the impact of land-use change.

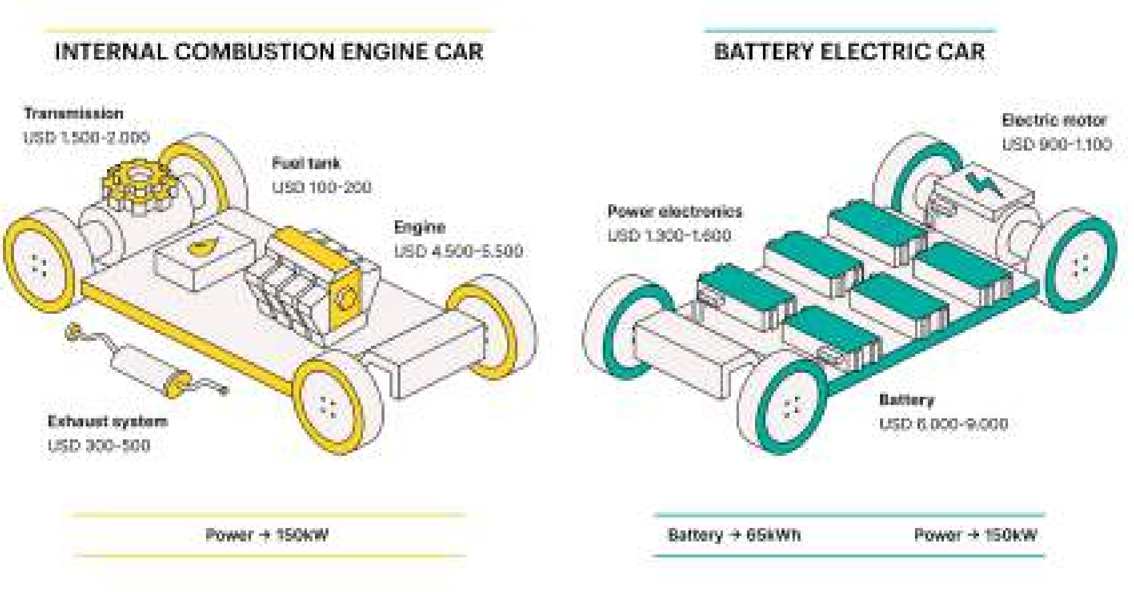
2.2 How different is EV manufacturing from the production of conventional cars?

The rise of electric cars is reshaping parts of the automotive supply chain. This section explores the raw materials required for battery electric and ICE cars, including critical minerals. It then goes on to outline automakers’ strategies for electrification and steps to develop supply chains for securing batteries and their raw materials, as well as investment and R&D trends among incumbent OEMs and new market-entrants.

The structural differences between electric and conventional cars centre on the powertrain

The main difference between a battery electric vehicle (BEV) and internal combustion engine vehicle (ICEV) lies in the powertrain. In an ICEV, motive power is delivered via an ICE through a gearbox, and energy is stored in a fuel tank. In a BEV, motive power is delivered by an electric drive, consisting of an electric motor, its power electronics control and a reducer. Energy is stored in a battery, which also requires power electronics for charging from the grid and for powering the low-voltage ancillary systems of the vehicle.

Figure 2.4 Differences in powertrain structure and cost between internal combustion engine and battery electric cars



IEA. CC BY 4.0.

Notes: Electric motor refers to the electric machine plus the reducer, power electronics to the inverter, DC-DC converters, on-board charging, junction box and high voltage cables, and battery refers to the battery pack including the battery management system. The location of the power electronics can vary significantly across different models, either being centralised in a dedicated unit for functional integration or distributed in functional units across the powertrain. Battery price refers to battery pack, including the battery management system. A 65-kWh battery pack represents the global sales-weighted average for battery electric cars in 2024. In internal combustion engine cars, transmission refers to the gearbox and drivetrain.

Sources: IEA analysis based on ICCT, UBS, BNEF, S&P Global Mobility and US Bureau of Labor Statistics.

Converting electricity into kinetic energy through an electric drive is more energy-efficient and simpler in design than converting fuel chemical energy into kinetic energy via an engine. Along with their superior energy efficiency, the electric motor and its power electronics feature high specific and volumetric power densities in comparison to ICEs, making them easy to integrate in vehicle powertrain systems. Additionally, electric motors can operate on a very wide speed range, requiring only a simple mechanical reducer to deliver power from the motor to the wheels. ICE cars are also equipped with complex exhaust after-treatment systems which are needed to comply with pollutant emission standards, especially in advanced economies, resulting in additional powertrain complexity and manufacturing costs when compared to electric drives. As a result, the electric drive can be smaller, simpler in design and more cost-effective than an ICE powertrain system (including the engine, the engine cooling system, the exhaust after-treatment system and the gearbox). For the same output power, an electric drive costs about 60% less, is almost three times lighter and generally takes less space than a comparable ICE powertrain system.

Storing energy, on the other hand, is much more cost-effective in an ICE car using a fuel tank than in a battery electric car through a battery. While a fuel tank only costs around USD 200, the battery accounts for the majority of powertrain costs (around USD 6 500 on average globally).

Another important difference is in the number of individual components needed. EVs have simpler vehicle architecture and up to 80% fewer moving parts. This has two consequences. First, fewer parts are needed from parts suppliers (Tier 2) than for ICEVs. Second, fewer parts could mean that less labour is needed to assemble these parts in OEMs' or component suppliers' factories.

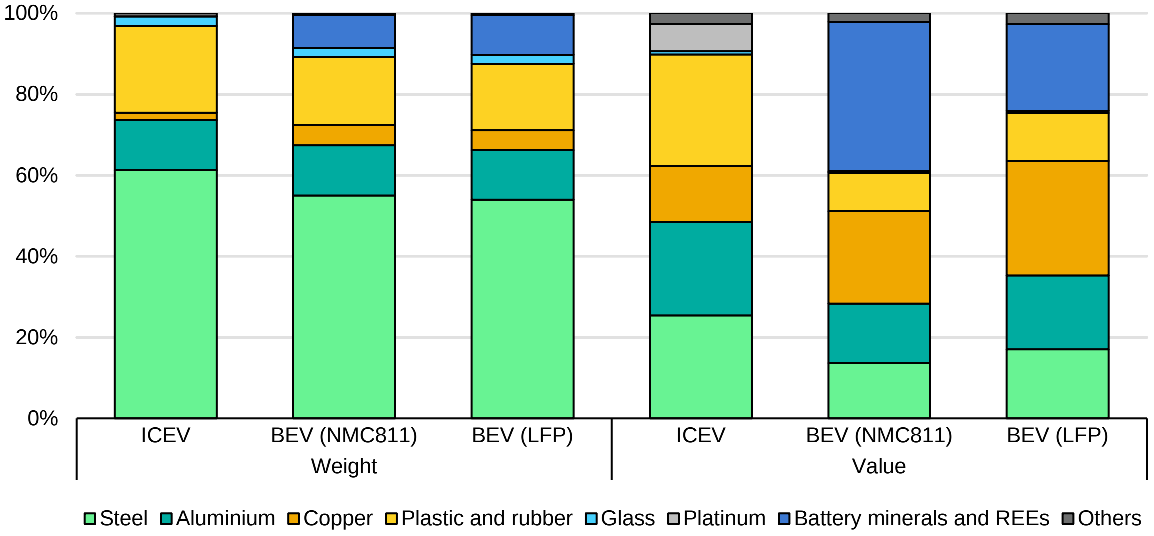
Recent evidence and modelling from the United States suggests that shifting from the production of ICEVs to BEVs does not necessarily decrease employment – it actually increases employment in the short term as factories are set up. In the longer term, once production processes are optimised, whether or not BEVs will have a higher or lower labour intensity is still uncertain. For the time-being, it is reasonable to assume equivalent labour intensity.

Electric cars require different inputs

The technical differences between electric cars and ICE cars mean that different inputs are needed for their production. Battery electric cars are typically 20-30% heavier than ICE cars, mostly due to the added weight of the battery. However, most of the vehicle's weight – whether ICEV or BEV – is made up of bulk materials such as steel, aluminium, plastic and rubber. Steel alone typically accounts for more than half of the total weight. Battery materials and copper represent around 15% of the total weight in battery electric cars.

From a value perspective, the share of steel is much lower than in weight terms, accounting for less than 30% of the value of an ICE and just over 15% of a battery electric car, and the share of aluminium is broadly similar. Critical minerals – particularly copper, battery minerals and rare earth elements – account for about half of the value of materials contained in a battery electric car. Copper is also used in ICE cars, accounting for less than 15% of their materials value. Platinum is the only critical mineral that is required in ICE cars but not in battery electric cars, as it is used in the catalytic converter. Although only small quantities are used, its high price means that it accounts for over 5% of the total material value of an ICE car.

Figure 2.5 Share of materials in an internal combustion engine and battery electric car by weight and value



IEA. CC BY 4.0.

Notes: ICEV = internal combustion engine vehicle; BEV = battery electric vehicle; LFP = lithium iron phosphate; NMC811 = lithium nickel cobalt manganese oxide 811 ($LiNi_{0.8}Co_{0.1}Mn_{0.1}O_2$); REEs = rare earth elements. Vehicle here refers specifically to cars. The value shares refer to raw but refined material inputs, such as refined critical minerals not yet processed into battery components, or crude steel prior to conversion into advanced grades like ultra-high-strength steel. Battery minerals exclude copper contained in batteries, which is grouped together with the copper used in the vehicle. “Others” includes ceramic materials, chromium, carbon fibres, wood, zinc and lead.

Sources: IEA analysis based on data from Argonne National Laboratory (GREET), International Copper Association, Bloomberg.

Steel and aluminium account for the bulk of the vehicle weight, and while overall demand for these materials is comparable for electric and ICE cars, their distribution differs. Electric cars typically use higher shares of aluminium, and also tend to use a higher share of advanced high-strength steel (AHSS) than ICE cars, despite the cost, for three main reasons. First, lightweighting is more important for electric cars than for ICE cars, as lighter vehicles can travel longer distances,[12] all else being equal. Second, some aluminium is required for the battery, and some steel components in ICE cars are not needed in electric cars. Third, electric car production often makes use of gigacasting, a process designed to replace assemblies of up to 100 parts, often with a single aluminium cast, thereby reducing complexity and costs, particularly in greenfield investments. However, overall costs of gigacasting are still likely to be higher than for equivalent stamped steel components due to the higher cost of aluminium.

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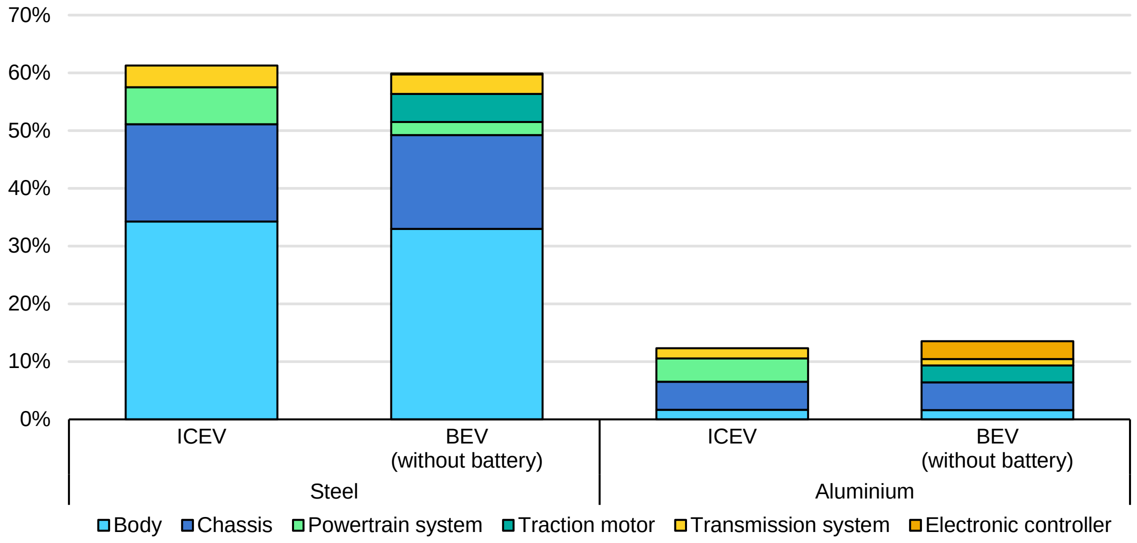
[12] This is also true of ICE cars, where lightweighting is used to offset the increased weight due to fuel economy improvement measures.

Figure 2.6 Average steel and aluminium shares (by weight) for internal combustion engine and battery electric cars across different vehicle components



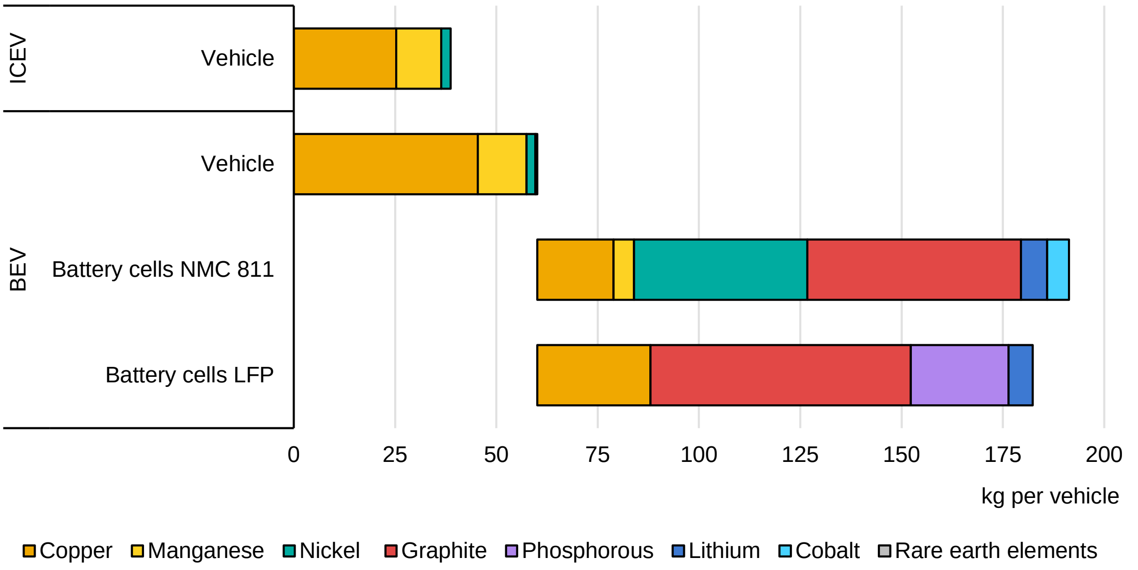
IEA. CC BY 4.0.

Notes: ICEV = internal combustion engine vehicle; BEV = battery electric vehicle. Vehicle here refers specifically to cars. Shares can vary significantly between models.
Source: IEA analysis based on data from Argonne National Laboratory (GREET).

The largest difference between the materials needed for a battery electric or ICE car lies in the battery, which requires minerals such as lithium, nickel, cobalt, manganese, phosphorous and graphite, which are very different to the materials traditionally used by the car industry. This shift has important implications for car supply chains, increasing reliance on a different set of critical minerals. In addition, the type and quantity of minerals required vary considerably depending on the battery chemistry.

Electric cars also require almost three times more copper, used for their batteries and additional electronics, and rare earth elements such as neodymium and dysprosium, which are essential for high-efficiency electric motors, even though only small quantities are required. Overall, the average battery electric car contains about five times the critical minerals content of a similar ICE car.

Figure 2.7 **Battery electric and internal combustion engine car critical mineral demand**



IEA. CC BY 4.0.

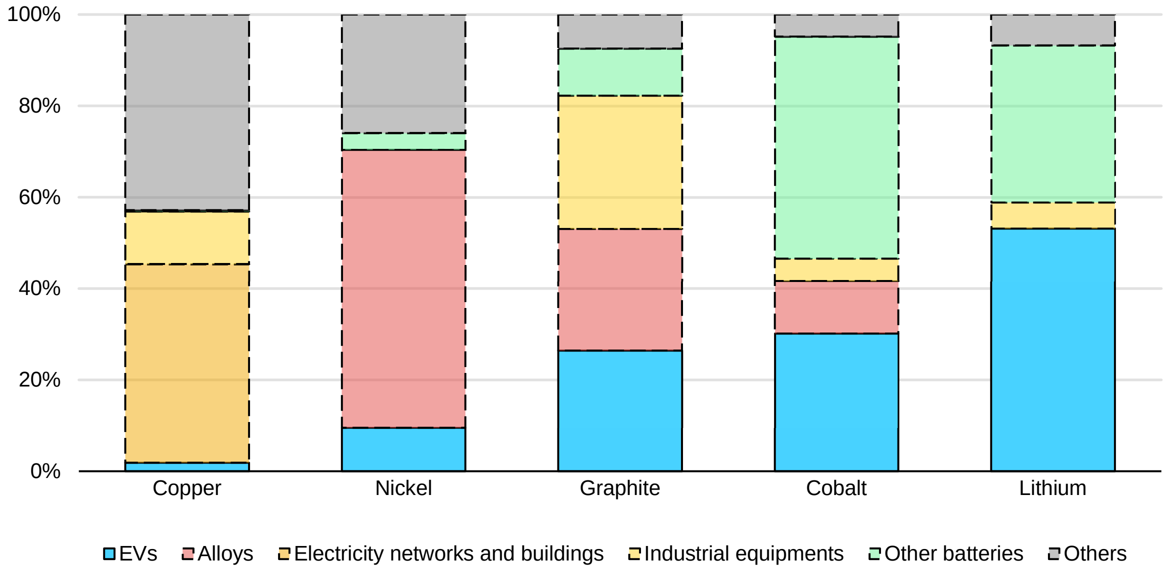
Notes: BEV = battery electric vehicle; ICEV = internal combustion engine vehicle; LFP = lithium iron phosphate; NMC811 = lithium nickel cobalt manganese oxide 811 ($LiNi_{0.8}Co_{0.1}Mn_{0.1}O_2$). Vehicle refers to an average-sized car, with a battery size of 65 kWh, about the same size as the 2024 sales-weighted global average. Battery refers to minerals used in the battery cells. The copper used at the battery pack level, including cables and the battery management system, is grouped under vehicle. Nickel and manganese listed under vehicle refer to the nickel and manganese used in the steel. Bulk materials such as iron and aluminium are excluded from the analysis.

Sources: IEA analysis based on data from IEA (2025), Global Critical Minerals Outlook, Argonne National Laboratory (GREET), International Copper Association.

Electric cars are already the main driver of lithium demand growth, accounting for over 50% of total demand (Figure 2.8). However, they represent a significantly smaller share of global demand for other key materials such as cobalt (30%), copper (2%), graphite (just over 25%), and nickel (10%). For copper, graphite, and nickel, this is largely due to the maturity and scale of these commodity markets, but electric cars are becoming an increasingly important source of demand for graphite and nickel. Electric cars are also the fastest-growing source of copper demand, but their impact on the overall copper market remains limited.

In 2024, global lithium demand amounted to around 200 kt, which is more than 15 times smaller than demand for nickel, over 20 times smaller than demand for graphite, and 130 times smaller than copper demand. Other important applications for these minerals are electricity networks and buildings (copper), industrial equipment (graphite), and stainless-steel production (nickel). Demand for cobalt is at a similar level to demand for lithium, and remains largely driven by portable electronics, which mostly uses cobalt-intensive battery chemistries such as lithium cobalt oxide. Beyond volume, the quality of materials also plays a key role. Battery applications require high-purity material grades, which differ significantly from the grades used in traditional sectors such as stainless-steel production (nickel) or as conductors and refractory materials (graphite).

Figure 2.8 Global share of selected critical mineral demand for electric vehicles and other applications, 2024



IEA. CC BY 4.0.

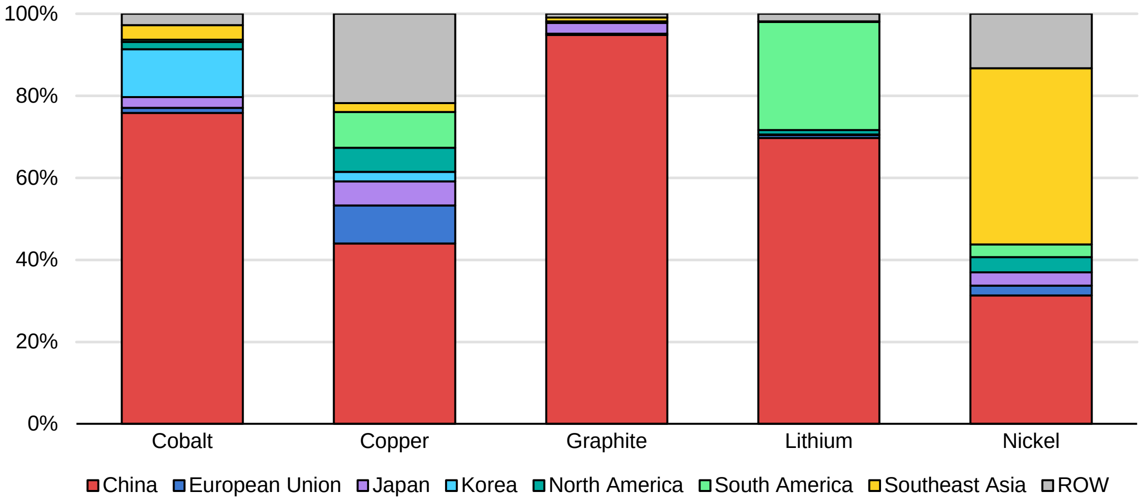
Notes: EVs = electric vehicles. Alloys include stainless-steel. Other batteries include battery storage and other applications such as portable electronics.

Source: IEA analysis based on data from IEA (2025), Global Critical Minerals Outlook.

Refining minerals to the purity levels and form (e.g. sulphates) required for battery production is a critical step, and China plays a dominant role in this segment, particularly for battery-relevant materials. It accounts for 70% of lithium and almost 80% of cobalt refining, and over 90% of graphite processing. While China's share of global nickel refining is lower (around 30%), Chinese companies have been key drivers of the rapid expansion of nickel production and refining capacity in Indonesia – now the world's largest supplier of the mineral. Copper refining is more diversified than that of other battery-related minerals, though China remains the largest producer, accounting for about 45% of global supply.

Demand for battery minerals is expected to continue growing rapidly as electric car uptake advances, with increases for different minerals ranging between 20% and over 100% between 2024 and 2030. At the same time, the share of EVs in total demand rises across all critical minerals, reaching more than 70% for lithium, for which demand is driven by rising EV sales.

Figure 2.9 Geographical concentration of selected refined critical minerals supply, 2024



IEA. CC BY 4.0.

Notes: ROW = Rest of World. Supply refers to the refined minerals (all applications).
Source: IEA analysis based on data from IEA (2025), Global Critical Minerals Outlook.

Not all demand will be met through mining, as recycling is already a significant source of supply for well-established minerals such as copper, and it is expected to play a growing role for other minerals over time. However, the rapid expansion of the battery sector, combined with the time lag between battery manufacturing and end-of-life, will constrain the near-term availability of recyclable materials. End-of-life EV and storage batteries are expected to account for only one-third of recyclable feedstock by 2030 and even less in the interim, with manufacturing scraps making up the rest. It will take approximately a decade for end-of-life batteries to become the primary source of recycled material, with manufacturing scraps being the primary source until then.

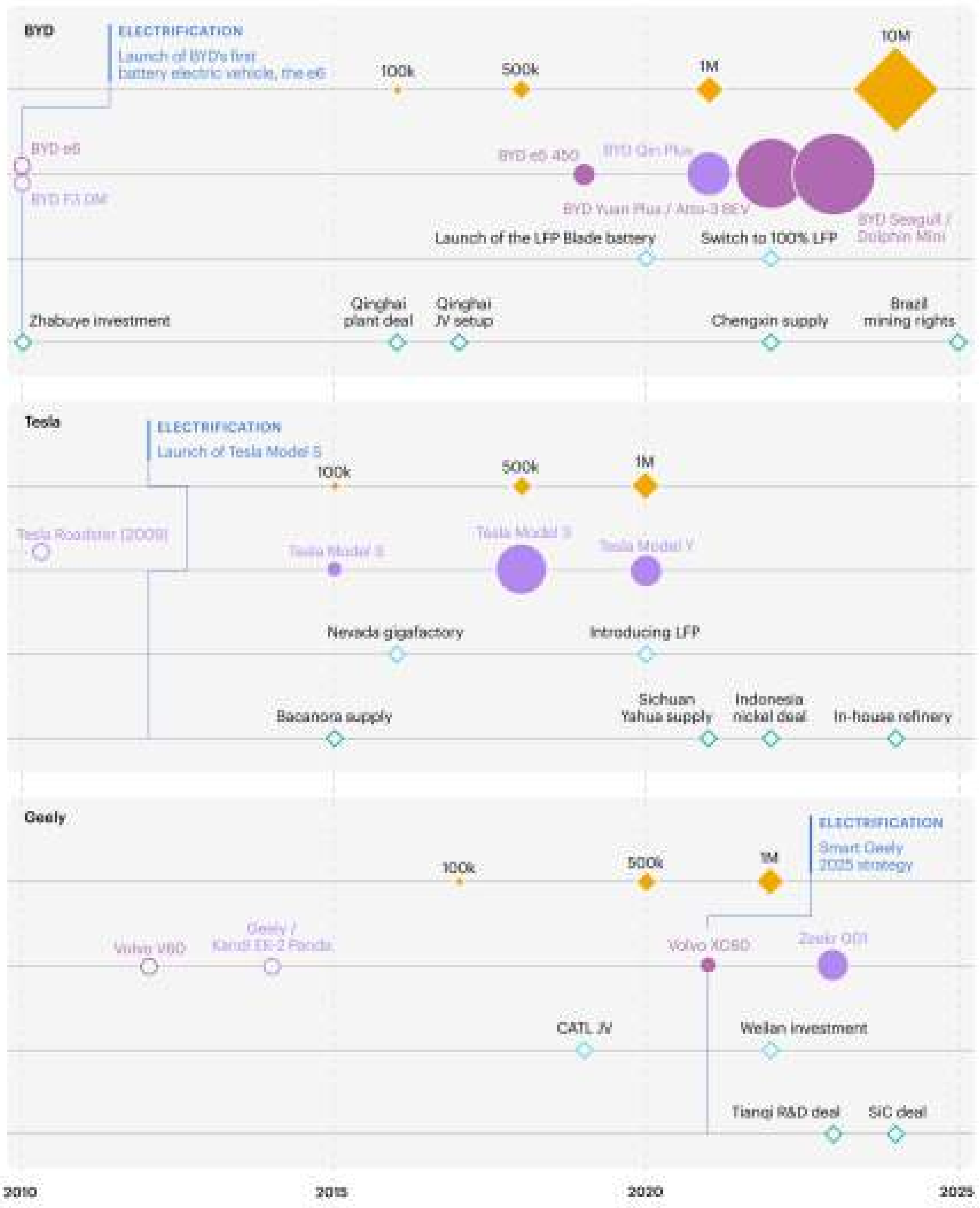
Corporate strategies for electrification

All major carmakers have responded to policies supporting electric cars and, by 2017, some of the world's biggest carmakers – Toyota, Volkswagen (VW) and General Motors (GM) – had already published an electrification strategy. Different companies have adopted different strategies for the electrification of their line-up, depending on their exposure to different markets, their customer base and their visions of technological development. While all companies essentially started with a blank sheet in the late 2000s, some carmakers have been more successful than others in developing and producing this new technology. Chinese carmakers, partially thanks to a conducive policy environment, and Tesla, thanks to several innovative car features, have been much more successful in the mass production of electric cars than incumbent OEMs. In this section we outline four key reasons that help explain the different outcomes of various car makers.

Figure 2.10 Timeline of corporate strategies, 2012-2024

This infographic tracks the evolution of corporate strategies for electrification and electric car sales from some of the world's biggest carmakers and pure-play electric car manufacturers.

IEA. CC BY 4.0.



IEA. CC BY 4.0.

Notes: JV = joint venture; NMC = lithium nickel manganese cobalt oxide; LFP = lithium-ion phosphate; SiC = silicon carbide. The Wuling Hongguang Mini is manufactured by the SAIC-GM-Wuling joint venture.
Sources: IEA analysis based on Marklines and Bloomberg Terminal.

Early move to mass manufacturing

When looking at the earliest electric car models entering the market, there is very little difference between incumbent automakers and new market-entrants. The very earliest models are the Tesla Roadster from 2008 and the Nissan Leaf from 2010. BYD started selling its first electric car in 2010, and by 2013 nearly all major automakers had at least one electric car model in their line-up. In many cases, however, the electric cars being produced were "compliance" vehicles to meet policy requirements (e.g. California's zero-emissions vehicles mandate) and not designed to appeal to a large number of customers. Tesla distinguished itself by bringing to market models whose technical characteristics were highly appreciated by consumers beyond California.

Chinese automakers and Tesla were particularly successful at rapidly reaching economies of scale for their electric cars: Chinese carmakers had access to a very large domestic market, while Tesla focused on producing a limited number of models that it sold globally. Before 2020, only 6 battery electric models had reached the production threshold of 50 000 units per year. Of these, three were Chinese models (by BYD and BAIC), two were by Tesla (Model 3 and Model S), and only one was by an incumbent manufacturer – the Nissan Leaf. When including plug-in hybrids, Toyota's Prius also reached mass-manufacturing levels early on. As the Chinese electric car market started to increase rapidly after the pandemic, the divergence between Chinese automakers and incumbents further widened. By 2024, 36 models were produced in more than 100 000 units per year – 29 of these were from Chinese carmakers (and 2 were Tesla models). This rapid move towards mass manufacturing has granted Chinese carmakers (and Tesla) greater experience in manufacturing electric cars, more purchasing power, and economies of scale – all of which has cut costs and provided a competitive edge against incumbents, which have instead mostly produced electric cars in small volumes, despite designing many different electric models.

Battery technology and chemistry choices

A key difference between most incumbent OEMs and Chinese players has been in their strategies relating to battery chemistries. Most incumbent OEMs have focused heavily on nickel-based chemistries because of their superior energy density, despite their higher cost and greater critical mineral requirements compared to lithium iron phosphate (LFP) batteries. Chinese OEMs, on the other hand, have taken a more diversified approach by developing both technologies. In 2019, the energy density and general performance of LFP meant that it was generally considered to be unsuitable for the types of high-end vehicles being sold and planned by incumbent automakers in advanced economies. In contrast, Chinese carmakers were installing LFP batteries in cheaper vehicles designed for urban use, for which affordability was more important than range. In 2019, no major incumbent OEM sold electric cars with LFP batteries, while Chinese OEMs were selling about a quarter of their electric cars using this chemistry, mostly for small battery electric cars or for PHEVs. By 2021, developments in cell-to-pack technology had significantly increased the value proposition of LFP batteries. Tesla was quick to integrate this technology in its line-up, and by 2021 nearly a quarter of its sales were using LFP, while virtually no incumbent OEM was selling vehicles with this technology (except GM through its Chinese joint venture). By 2024, the advantages of LFP had led all OEMs to start selling or planning to sell vehicles equipped with this technology. However, by then, nearly all the LFP supply chain was based in China, and Chinese companies had gained several years' advantage on the development of the technology.

There is evidence that Chinese carmakers have faster development time for their models – i.e. less time is needed to go from concept to production compared to incumbents from advanced economies. There are various reasons for this, but one key implication is that Chinese carmakers have been able to better adapt to the very rapid development of battery technology, which is in stark contrast to the slow, incremental improvement that has characterised ICE development over the past decades.

Following a dual-chemistry approach – i.e. using LFP and NMC batteries – has proved to be a winning strategy for carmakers, given that LFP ended up improving much more rapidly than NMC, thereby favouring carmakers who hedged their bets. BYD provides an example of a dynamic and diversified strategy on different battery chemistries – its expertise in both NMC and LFP has enabled the company to rapidly pivot from one to the other in response to the latest innovations. Their first consumer-facing electric car model, the E6, released in early-2010 and equipped with LFP batteries, sold around 400 units in 2011. However, in 2013, they also started selling some cars with NMC chemistries. In 2020, BYD developed their version of the cell-to-pack technology using LFP blade batteries, and while LFP only accounted for one-quarter of their sales that year (up from 8% in 2019), they decided to discontinue development on NMC chemistries altogether to focus on LFP. In 2021, LFP accounted for about 80% of batteries used by BYD, a share that increased to over 95% in 2022. In 2024, BYD sold over 4 million electric cars, all powered by LFP batteries.

Strategies to secure battery and mineral supply

Strong links between carmakers, battery makers, and raw material suppliers are essential to ensure smooth operations and reduce the risks associated with volatile critical mineral markets. Three broad strategies have been used by carmakers to develop such links:

1. Direct involvement with miners – carmakers have directly invested in raw material operations to guarantee access to output, or signed long-term offtake agreements for critical minerals supplies, both of which increase security of supply at competitive prices.
2. Direct involvement in battery production – carmakers have also invested in in-house battery production, enabling a greater level of vertical integration. This, however, requires expertise in battery manufacturing, which carries some risk and requires significant investments for traditional carmakers.
3. Co-operation with battery makers – joint ventures or long-term agreements with battery makers have enabled carmakers to guarantee access to batteries at competitive prices and to the latest battery technologies. The battery makers, in-turn, engaged with battery components and raw material suppliers.

By 2024, most OEMs had adopted at least one of these strategies for securing batteries and critical raw materials. However, companies that started working on such agreements early on gained an advantage, as there often is a significant delay between the agreement and actual output. For example, validating material quality from new suppliers can take 1-2 years before integration into battery production lines, and batteries intended for automotive applications must undergo rigorous approval procedures, such as Production Part Approval, which can take up to a year.

BYD was an early mover, adopting a strategy of direct involvement with mineral suppliers while producing batteries in-house. They bought a stake of nearly 20% of a Chinese lithium mine in 2010, and then set up agreements with other Chinese lithium suppliers in 2016 and 2017. In the 2020s, BYD continued with this strategy and expanded the scope of their investments to Brazil and more locations in China.

VW has had a similar approach to access raw materials, but has prioritised long-term agreements over equity stakes – VW signed agreements for lithium with a Chinese supplier in 2019 and a co-operation with Vulcan energy as of 2021; for nickel, it signed agreements with companies in Indonesia and Canada. Similarly, other incumbent OEMs only really started engaging with upstream suppliers around 2020, thus far later than the early movers. However, in the next 5 years, as agreements and investments made at the turn of decade start to deliver results, this gap should narrow.

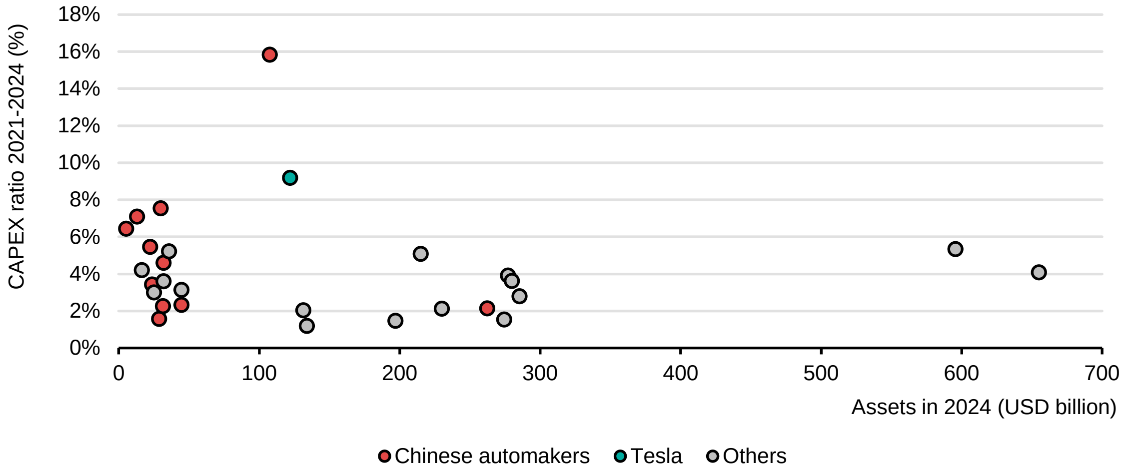
Close co-operation with battery makers has also been a recipe for success, with Tesla being a prime example. As early as 2009, Tesla partnered with Panasonic – already a well-established battery maker – for the design and production of the battery cells of its vehicles. This partnership proved fundamental to rapidly setting up a large-scale battery manufacturing operation (the largest at the time) in parallel to scaling up vehicle production. Tesla was also relatively quick to secure suppliers, for example by signing long-term agreements with Glencore in 2018. Toyota took a similar approach, and partnered with Panasonic as early as 2012 to power its hybrid and plug-in hybrid vehicles. Toyota was also involved in lithium projects through its subsidiary Toyota Tsusho Corporation as early as 2010. Similar partnerships were also an important part of European carmakers' strategies. Renault partnered with LG Energy Solution (LGES) in 2012, and BMW signed a supply contract worth EUR 4 billion with CATL in 2018. This further increased to EUR 7.3 billion in 2019, and BMW also participated in the investment to develop the CATL battery factory in Erfurt, Germany. The ties between CATL and VW are also growing stronger – VW sourced over 30% of its batteries from CATL in 2024, and in the same year, certified CATL's test and validation centre in Germany.

Other European and North American incumbent OEMs have also entered into or announced partnerships and joint ventures with established battery makers more recently – such as the joint venture between Stellantis and CATL in Europe announced in 2024, or between GM and LGES, announced in 2019. Hyundai formed a joint venture with LGES for battery production both in Indonesia and in the United States. However, this delay in partnering and collaborating with established battery makers has put them at a disadvantage compared to the early movers.

Investment and R&D trends

Incumbent OEMs from Europe, Japan and the United States account for almost 80% of capital expenditure (CAPEX) in the car industry. These companies have extensive assets (mostly factories) that require constant CAPEX for maintenance and upgrades, and most of these factories are dedicated to ICE technologies. The propensity to invest is often measured by the CAPEX-to-assets ratio (the CAPEX ratio). Over the past 4 years, this ratio ranged from an average of 3.5% for European carmakers to 4.7% for Chinese carmakers. While large carmakers worldwide generally maintain relatively low CAPEX ratios, new entrants focused on electric cars have recorded much higher ratios as they renew or expand production capacity and invest in R&D. This approach is typical of newcomers aiming to gain market share. Moreover, new entrants concentrate nearly exclusively on the electric powertrain, whereas incumbents spread investments across their extensive ICE manufacturing asset base. In 2016, BYD invested 3.9% of the value of its assets in CAPEX. Between 2021 and 2023 – when the company focused solely on EVs – its CAPEX ratio rose to 12–20%. In 2023, BYD's CAPEX was 30% lower than Toyota's, despite selling roughly one-third the number of cars. Similarly, Tesla peaked at a 12% CAPEX ratio in 2017 and in most years since has maintained a ratio two to three times higher than the industry average, with all investments targeting electric cars. Smaller Chinese companies that are still rapidly expanding have not surpassed 10% in the past 5 years. A similar trend exists among automotive suppliers; for example, CATL's annual investments exceeded 8% of its total assets from 2015 to 2022, peaking at 18% in 2015.

Figure 2.11 Automakers' average capital expenditure in relation to total assets, 2021-2024



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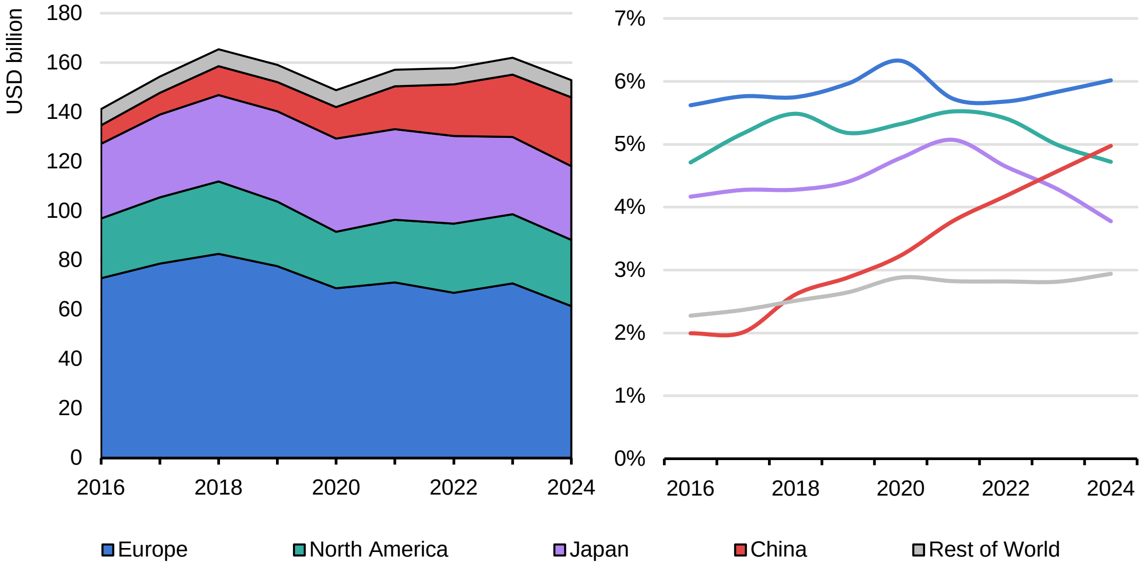
Notes: CAPEX ratio refers to the CAPEX as a share of total assets. Data taken from a sample of the largest 26 automakers listed in the annex.

Source: IEA analysis based on Bloomberg Terminal.

The higher propensity to invest is also reflected through R&D expenditure as a share of revenue. Incumbent carmakers have traditionally invested significantly in R&D – the automotive industry overall spent around 5% of its revenues on R&D in 2015-2023. Over the past 9 years, OEMs from Japan, Europe and the United States have spent almost USD 1.2 trillion on R&D, compared to only around USD 130 billion by those from China. Before 2022, the share of R&D expenditure by Chinese companies was lower than for incumbents elsewhere in the world, but it has been rising significantly. BYD has an R&D expenditure as a share of revenues (around 6%) that is comparable to those of German OEMs, on the high-end of the spectrum, while smaller innovative Chinese carmakers have higher shares, largely due to their relatively smaller scale. On the other hand, older, state-owned Chinese carmakers such as BIAC and SAIC still only invest 2-3% of revenues in R&D. Component suppliers from advanced economies have also been spending more on R&D than Chinese battery makers. However, a key difference is that while incumbent suppliers and carmakers conduct R&D on multiple vehicle components and powertrains, Chinese battery makers focus on a single component, and innovative Chinese companies mostly focus on electric cars.

Figure 2.12 R&D expenditure by location of company's headquarters, and as a share of revenue, 2016-2024



IEA. CC BY 4.0.

Notes: Data taken from a sample of the largest 26 automakers and 19 component suppliers, as listed in the annex. Numbers are adjusted for inflation to 2024.

Source: IEA analysis based on Bloomberg Terminal.

Carmakers are also funding a large share of their spending with debt. The debt-to-equity ratio for companies outside of China has been around 50% higher than for those in China – with higher debt ratios normally found for North American automakers. High debt ratios have the benefit of lower average cost of capital (since debt has lower rates than equity), but also increase the cash flow used for interest payments, and could affect future cost of capital if they reach levels that impact the perceived creditworthiness of the company – a risk that Chinese carmakers are not facing with the same intensity. This can also be explained by evidence found regarding below-market rate loans received by some Chinese carmakers, which may have facilitated investments by Chinese players.

Lastly, incumbent OEMs have re-invested smaller shares of their revenues in growing their operations compared to new market-entrants and Chinese carmakers. From 2021 to 2024, incumbent OEMs returned nearly twice as much to shareholders as a percentage of net profits – through dividends and stock buybacks – compared to Chinese OEMs. The propensity to return profits to shareholders is healthy for an industry in a steady state, however, during this transition phase, it may have weakened the ability of these companies to invest in new technologies and equipment. On the other hand, Chinese OEMs have re-invested a much larger share of their resources and have focused them mostly on electrification, thus helping to explain their success in the transition towards electrification and their expanding market share.

Chapter 3. Present and future prospects of electric car manufacturing

Highlights

- New market-entrants focusing on electric car production are expanding rapidly. Pure-play electric car makers, especially those from China and US-based Tesla, are capturing a growing share of sales; some 45% of global electric car sales in 2024 are from pure-play electric car makers, compared to 35% in 2019.
- The growth in electric car sales affects both car makers and automotive suppliers, especially those producing powertrains and related components. The automotive supplier market is worth about USD 1.3 trillion, equivalent to over 40% of the global car market. For all components except batteries, companies from advanced economies dominate the market, but for battery-related components, Chinese firms control around 85% or more of global manufacturing capacity.
- The value added to the economy by the manufacturing of electric cars differs from that of internal combustion engine (ICE) cars primarily with regards to the value related to the powertrain, especially the battery. In regions with supply chains for ICE and electric cars, like Japan and China, the difference in value addition is negligible. In the European Union, however, the difference is large – for ICE cars, over 90% of the engines and parts are produced domestically, compared to just over 40% for batteries and electric car parts. The difference is less pronounced in the United States, which imports both engines and batteries, albeit from different regions.
- Regions without a battery industry see lower economic value addition, as the battery accounts for around one-quarter of the value of an electric car. Yet most of the economic value of a car comes from assembly and production of non-powertrain components; even in regions where all battery components are imported, the majority of the value is retained. Striking a balance between cost-effective production through imports and domestic value creation is crucial.
- Available manufacturing capacity for electric cars varies by region, but there is the ample opportunity to retool existing conventional car production capacity. Based on manufacturers’ announcements, production capacity for batteries and key components is set to rise by 40-190% to 2030 relative to today. Despite an increase in the geographic diversity of battery cell production, for most cell components, at least 85% of capacity is expected to remain in China in 2030.

Introduction

As electric car uptake progresses, it is having a profound impact on where car manufacturing is undertaken and, crucially, where value is created. This chapter takes a closer look at the supply chain for electric cars to examine how value is being created in different markets and at different steps of the supply chain. It analyses the effects of imports on value creation and the prospects for different countries seeking to boost the competitiveness of their domestic industries.

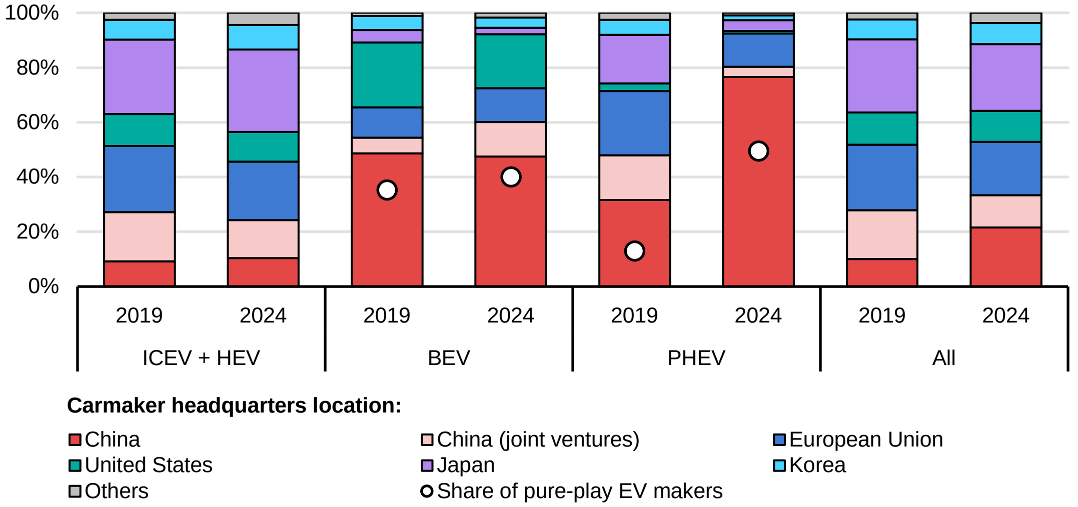
3.1 Assessing the impact of electric car manufacturing

New manufacturers are capturing a large share of electric car sales

Many of the largest European and North American ICE carmakers in operation today were founded in the early 20th century, while their Japanese and Korean counterparts began operations towards the mid-20th century. Modern electric vehicle (EV) manufacturing has a much shorter history. The very first mass-market electric cars were developed in the early 2010s by long-established, incumbent carmakers (such as the Chevrolet Volt, Nissan Leaf or Renault Zoe), but they were quickly followed by new market-entrants, such as Tesla, offering disruptive models compared to what had previously been offered.

Two broad categories of car makers can be distinguished to understand the dynamics of the car industry. One category is that of the **incumbents**, which include all major, long-established automotive groups, which primarily retail ICE cars. In 2024, this original equipment manufacturer (OEM) category captured around 90% of the global car market but only 55% of the electric car market. The other category is that of **new market-entrants**, which includes companies that primarily focus on EV manufacturing. The emergence of these new EV makers on the market has been uneven across regions. In the United States, Tesla is known as the first pure-play EV maker, falling under the new market-entrant category. It is also considered to be the only major pure-play EV manufacturer today that is not from China. First established in 2003, Tesla started to ramp up production in 2015, with its annual production exceeding 50 000 electric cars, and eventually reached full-year profitability in 2019. Tesla was soon followed by a wide range of new EV makers from China, such as BYD Auto (created in 2003), NIO (2014), Xpeng Motors (2014), Li Auto (2015), and Leapmotor (2015), as well as from other new entrants from the United States such as Rivian (2009), Lucid (2021), and Slate (2022). Other new companies from different countries also entered the market, such as Viet Nam’s Vinfast (2017), or Türkiye’s Togg (2018).

Figure 3.1 Global car sales shares by powertrain and carmaker headquarters, 2019 and 2024



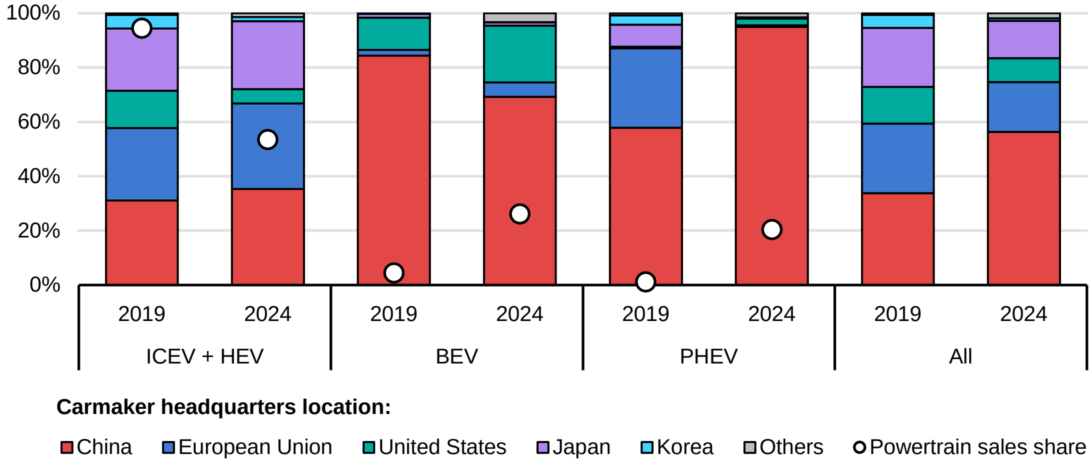
IEA. CC BY 4.0.

Notes: ICEV = internal combustion engine vehicle; HEV = hybrid electric vehicle; BEV = battery electric vehicle; PHEV = plug-in hybrid electric vehicle. Pure-play EV makers include Aiways, BYD Auto, Evergrande, Fisker, Geely NECV Group, Jemmell New Energy, Leap Motor, Li Auto, Lucid Motors, Neta Auto, NIO, Rivian, Seres Group, Tesla, Togg, VinFast, Xiaomi, Xiaopeng, and Yudo Auto.
Sources: IEA analysis based on Marklines and EV Volumes.

The increasing electrification rate of major car markets is challenging long-held tenets in the industry. While incumbent OEMs maintain their dominant position in conventional ICE car sales, new market-entrants are rapidly capturing an increasing share of the growing electric car market. Recent growth in electric car sales has benefited pure-play EV makers from China and US-based Tesla, and to a lesser extent the pure-play EV brands launched by incumbent OEMs (GAC Aion, Geely Polestar, etc). The former saw their share of the global battery electric car market grow steadily to 40% in 2024, up from an already high basis of 35% in 2019. This trend was even starker in the plug-in hybrid electric vehicle (PHEV) market, where new market-entrants captured half of 2024 global sales, up from roughly 15% in 2019. While Chinese OEMs are leaders in their home PHEV market, European carmakers have the largest share of PHEV sales outside China, and accounted for half of such sales in 2024 – albeit representing less than 15% of global PHEV sales.

In the Chinese market, entirely home-grown Chinese carmakers are now challenging the market share of foreign carmakers operating through joint ventures (JVs) with other Chinese OEMs. While the market share of JVs has dwindled since the pandemic, car sales from Chinese carmakers have grown steadily to reach 14 million in 2024, doubling from pre-pandemic levels to make up almost 60% of the market. This growth was primarily driven by soaring electric car sales; two-thirds of cars sold by Chinese carmakers in 2024 were electric, up from less than 15% in 2019. Additionally, pure-play EV makers have been capturing a growing share of the Chinese electric car market. By 2024, Chinese pure-play EV makers and Tesla accounted for more than half of electric car sales in China, up from less than 30% 5 years earlier. Over the same period, foreign carmakers with JVs in China have maintained their dominant position in the country's market for ICE cars, while losing ground to Chinese OEMs in the market for electric cars. Overall, 2.5 times more electric vehicles were produced in China than elsewhere in the world.

Figure 3.2 **Car sales shares by powertrain and carmaker headquarters location in China, 2019 and 2024**



IEA. CC BY 4.0.

Notes: ICEV = internal combustion engine vehicle; BEV = battery electric vehicle; PHEV = plug-in hybrid electric vehicle; HEV = non-plug-in hybrid electric vehicle. Chinese Joint Ventures with foreign manufacturers are not considered as Chinese original equipment manufacturers (OEMs) but as belonging to foreign OEMs.

Sources: IEA analysis based on Marklines and EV Volumes.

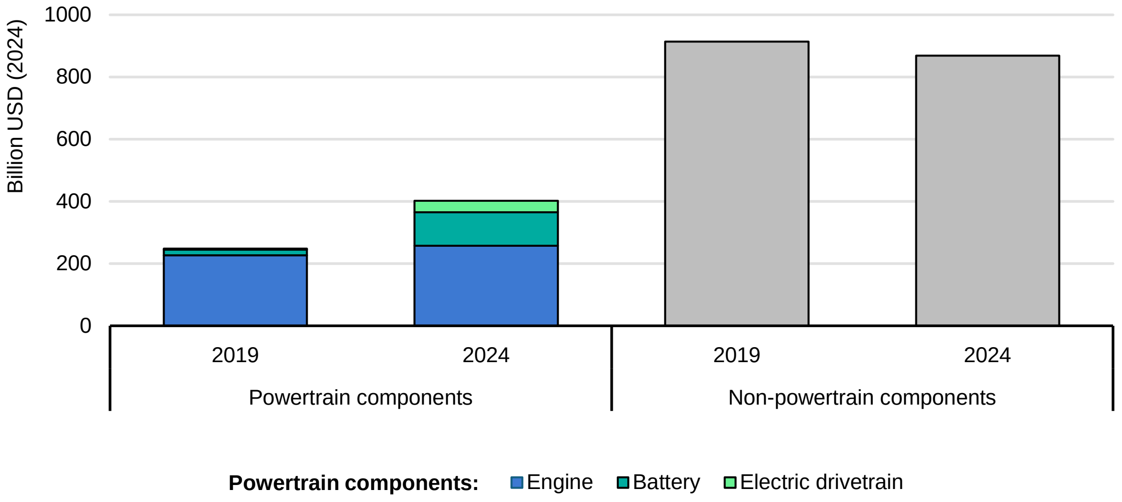
The electrification of cars also affects automotive suppliers

Countries that are home to incumbent OEMs are also home to some of the largest producers of automotive components and parts suppliers, for whom the changes underway in the car industry have significant impacts (see the box on Industry structure and key inputs in Chapter 1 for an overview of parts and components).

For the purposes of the analysis in this report, three broad categories of components are defined: ICE-related components (i.e. the engine, exhaust and transmission systems), battery electric-related components (electric drivetrain and battery), and non-powertrain components. While suppliers for components in the first two categories are directly affected by the ongoing transition towards electric cars, suppliers of components unrelated to the powertrain are not.

The global market size of the automotive supplier sector was about USD 1.3 trillion in 2024, which is equivalent to more than 40% of the global market size of cars. Over two-thirds of the automotive supplier market is for non-powertrain related components,[13] around 20% is for ICE-specific components,[14] and the remaining 10% is for EV-specific components.[15] This 1:2 ratio between EV- and ICE-specific components is higher than the 1:4 ratio in car sales for 2024 because the average cost of an electric powertrain is higher than for the average ICE powertrain. The market for EV-specific components has grown nearly seven times since 2019, but this is slower than growth in overall electric car sales because battery costs have declined over the same period, despite increases in average battery size. Although ICE car sales have declined 18% since 2019, the value of the global ICE market still grew by almost 15% due to increasing global average engine power.

Figure 3.3 Estimated market size of car components, 2019 and 2024



IEA. CC BY 4.0.

Notes: The market size for car component suppliers was derived from McKinsey and Deloitte for the year 2022. This value has been scaled to 2019 and 2024 taking into account global electric and internal combustion car sales, average battery size and average engine (and electric motor) power. Battery, engine and e-drivetrain manufacturing costs are calculated using unit cost (USD/kWh and USD/kW) from BNEF and ICCT studies.
Sources: IEA analysis based on McKinsey, Deloitte, ICCT, S&P Global Mobility, Marklines, EV Volumes and BNEF.

Suppliers headquartered in advanced economies typically hold very large market shares for a variety of components and parts. Some companies have specialised in the manufacturing of few components (e.g. France's Michelin for tyres), but the largest suppliers by revenue all manufacture several components and parts. For example, Bosch (Germany), ZF Friedrichshafen (Germany), Hyundai Mobis (Korea), Continental (Germany), Magna (Canada) and Aisin (Japan) have some

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[13] Interiors, electronics, wheels and tires, infotainment, steering, chassis, suspension.
[14] Transmission, combustion engine, exhaust system, fuel system.
[15] Electric drive, batteries, sensors.

of the widest portfolios of products and all have annual revenues of more than USD 30 billion each, which is comparable to the revenues of Mazda Motor Corporation. For both ICE-specific components and non-powertrain components, suppliers from Korea, Japan, North America and Europe account for over half of the global market, and in some cases for more than 90%. Larger suppliers tend to have a global presence; for example, a supplier like Magna has 142 manufacturing plants in North America, 100 in Europe and 69 in China. Chinese suppliers for these ICE components are significantly smaller and mostly cater for the domestic market; they are included in the “other” category within the data that is available. One exception is the production of airbags, for which a Chinese company (Ningbo Joyson Electronic Corp.) took over a Japanese manufacturer in 2017.

Although almost all major car-component manufacturers remain headquartered outside China, over the past decade China has become a leading global exporter of car parts.[16] China moved from a balanced trade position in 2014 – when its imports equalled its exports – to having a substantial surplus today, on par with levels seen in Japan and the European Union, which have traditionally had a trade surplus in car parts.

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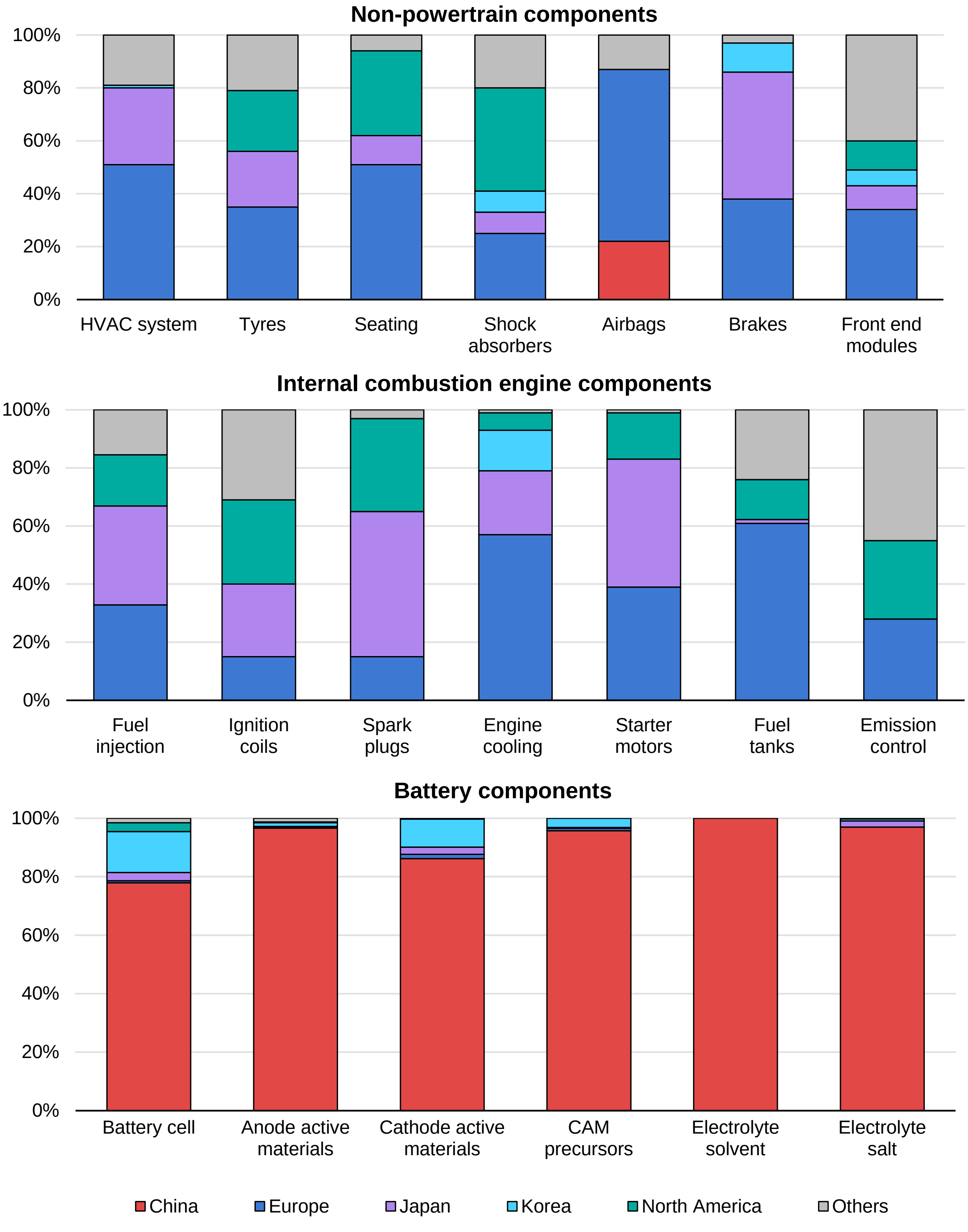
[16] Defined as HS code 8708: Parts and accessories of the motor vehicles of headings 8701 to 8705.

Figure 3.4 Global market or manufacturing capacity share of selected car components, by company headquarters, today



Notes: CAM = Cathode active material; HVAC = heating, ventilation, and air conditioning. Regional allocation is based on company headquarters. Non-powertrain and ICE refer to market share (2023) for the largest suppliers of each component. Battery cells and components refer to manufacturing capacity share (2024). Battery data as end of April 2025. See Annex A for full assumptions and costs used.

Sources: IEA analysis based on Bloomberg, Benchmark Mineral Intelligence and Bloomberg New Energy Finance.

When it comes to battery electric vehicle (BEV)-specific components, the reverse is true: Chinese battery manufacturers command around 80% of global (lithium-ion) battery cell manufacturing capacity, led by CATL and BYD. Korean companies, including LG Energy Solution, account for nearly 15%, while Japanese firms such as Panasonic represent about 3%. A similar pattern emerges further upstream in the battery supply chain, where Chinese firms account for between 85% and 100% of production capacity for key components. European manufacturers are virtually absent from the landscape of BEV-specific components, while North American firms hold only modest shares. The North American presence is largely due to Tesla’s role in battery cell manufacturing.

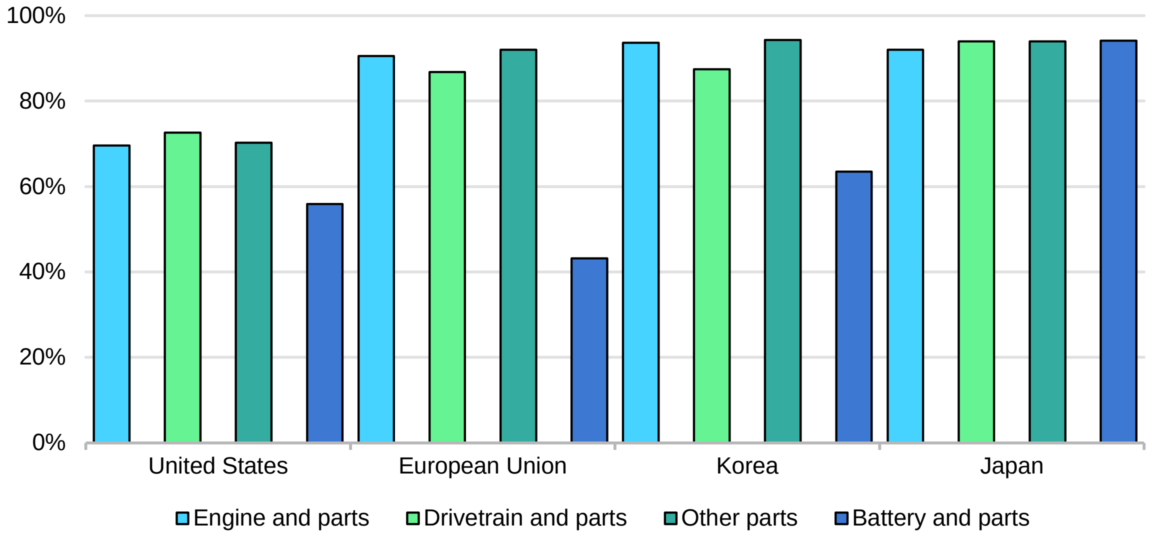
Electric motors, another key powertrain component of battery electric cars, are either produced or designed in-house by automakers such as BYD and Tesla, or sourced from Tier 1 electric drive suppliers directly or through joint ventures. European and Japanese companies are leading the Tier 1 electric drive supply sector, with major players including Nidec Corporation, Bosch, Continental AG, and Magneti Marelli.

The shift towards electrification is posing a significant challenge to automotive suppliers of powertrain components from advanced economies, which lead the market for components that are ICE-specific, but not for components that are electric car-specific. At the same time, the value of powertrain-related components is far smaller than the value of non-powertrain components, and suppliers from advanced economies have a very strong position in the market for the latter – those suppliers are therefore not likely to be affected by a shift in production towards electric cars.

Value addition is lower in regions without a battery industry

Value addition from the manufacturing of electric cars differs from the manufacturing of ICE cars only for the portion of value that is related to the powertrain and its components. The powertrain accounts for around a quarter of the price of the car for ICE cars and one-third for battery electric cars. Therefore, the main difference in terms of value addition between electric cars and ICE cars depends on the share of components related to the powertrain that are sourced domestically, with the battery being the most important component. In regions where both an ICE and battery electric car supply chain are present, the difference in value addition between the two types of cars is negligible – as is the case for countries like Japan and China.

Figure 3.5 Domestic share of car components sales for selected regions, 2024



IEA. CC BY 4.0.

Notes: The domestic share of the value only represents the direct value and not the indirect value. For example, the domestic share of engine and parts industry represents domestic share the engine block and its key parts such as pistons, crankshafts, etc. It does not include the inputs that go into manufacturing these parts such as materials and other spare parts. The estimate for the domestic share of material has been separately estimated.

Sources: IEA analysis based on data from UBS; ICCT; US IO table; SK IO table; Japan IO table; EU PRODCOMM

This is not the case for other major car manufacturing regions. In the European Union, over 90% of the engines for ICE cars are sourced domestically, while for batteries for battery electric cars, this figure is a little over 40%. As such, while for every dollar spent on an engine, around USD 0.90 stays within the European Union, for every dollar spent on a battery, only around USD 0.40 remains in the region and the rest goes towards imports. In the United States, the difference between engines and batteries is not as pronounced, since both are imported, although from different regions – most engines and engine components are sourced from within North America, while batteries and their components come from China and other Asian countries. Despite these differences, electric cars produced in countries without a developed battery supply chain still contribute significantly to value addition, since the powertrain does not account for the majority of the overall value of a car (see below). Nevertheless, developing a domestic battery industry can ensure that the difference in value addition between electric cars and ICE cars can be reduced to zero.

The effect of imports of electric cars and their components on domestic value creation

Importing vehicle components reduces the share of a vehicle's value produced domestically, but may enhance the overall competitiveness of the domestic car industry if such imports significantly reduce production costs. Striking the right balance between cost-competitiveness and domestic value creation is therefore essential. Even vertically integrated ICE manufacturers, such as those based in Japan, import on average almost 10% of their intermediate inputs, underlining that full self-sufficiency is rare, even among established players.

Imports of critical minerals or cathode and anode active materials represent a relatively small (about 4% each) share of the overall car value, meaning that importing these inputs still allows countries to capture most of the economic value associated with electric car production domestically. In contrast, batteries, together with battery components, account for about one-quarter of the vehicle value. Importing finished cars that are fully produced overseas results in about 90% of the vehicle value being generated abroad. The remaining 10% is attributable to distribution and retail activities.

Other import-export combinations are also possible. For instance, if the battery pack (and the cells therein) produced in country A are exported to country B, where it is integrated into a car that is then exported back to country A, the latter would not retain the value associated with vehicle assembly and the production of non-battery components (nearly 65%),[17] but it would retain the value from battery cell and pack manufacturing (around 26% if components and minerals are sourced domestically, or around 18% if they are imported), along with the value generated from retail activities. A similar pattern applies to imports of other powertrain or non-powertrain components – for example, importing the electric motor and power electronics of the EV powertrain would reduce the value produced domestically by 5%-10%.

Overall, if sourcing battery minerals and components domestically results in significantly higher production costs, it may be more strategic to prioritise strengthening the competitiveness of higher-value segments – such as battery and EV production – in the short term, while supporting supply chain diversification to strengthen the resilience of the EV supply chain over the medium term, which remains important under a supply chain security lens. Moreover, as battery prices continue to decline, the value share of the powertrain is set to decrease, further pointing to the importance of vehicle assembly and the production of non-powertrain components for value creation.

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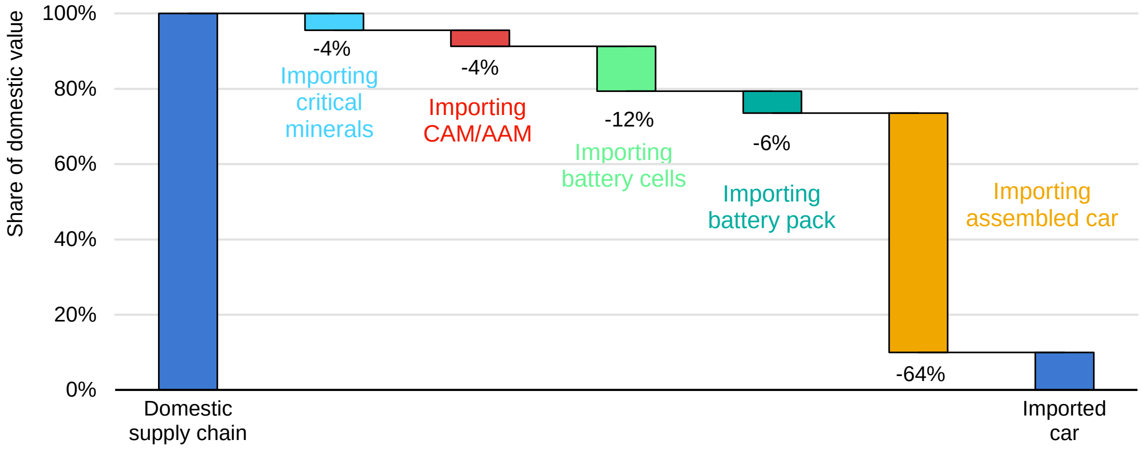
[17] This assumes that non-battery components are also produced abroad.

Figure 3.6 **Global average share of battery electric car value captured by domestic production for different import scenarios, 2024**



Notes: CAM = Cathode active material; AAM = Anode active material. Lithium nickel cobalt manganese oxide 811 (NMC811) and artificial graphite are considered as CAM and AAM, respectively. Domestic supply chain refers to a hypothetical case where every single component of the electric car is produced domestically – automakers typically import at least 10% of their components. The electric car value refers to its final price, which here is assumed to be around USD 30 000. The battery pack size is assumed to be almost 75 kWh. Each percentage associated with the battery supply chain reflects the share of an electric car's value that is imported for a specific step of the supply chain. Therefore, the percentages reported are additive in case a downstream product which used upstream components produced abroad is imported. For example, importing a battery cell using components and critical minerals not produced domestically would lead to a net loss of 20% (12%+4%+4%) of the electric's car value. Critical minerals accounts for the cathode and anode materials as well as rare earth elements for the electric motor, but excludes copper. For instance, importing a battery pack implies that the battery cells, CAM, AAM, and critical minerals were produced abroad. Importing the assembled car assumes that the vehicle's components (motor, power electronics, etc.) are produced abroad. See Annex A for full assumptions and costs used.

Sources: IEA analysis based on data from IEA (2025), Global EV Outlook, Bloomberg, BNEF.

3.2 Future prospects for electric car manufacturing

The future location of car manufacturing centres will depend on a range of different aspects, including demand expectations, the relative industrial competitiveness of different regions, and industrial and trade policy developments that affect the car industry. The introduction or increase of tariffs in the recent past may potentially alter some longstanding approaches of the industry. Nonetheless, current data on manufacturing capacity and existing expansion plans for car and battery supply chains can provide insights into the future direction of the industry.

Electric car demand is unlikely to outpace supply, but existing capacity needs repurposing

Global car manufacturing nameplate capacity stood at more than 150 million units per year at the end of 2024, with China accounting for 40% of the global total and Europe and North America each constituting 15%. Electric car production is significantly more concentrated: As of 2024, driven by unparalleled growth in domestic EV sales and production, China accounts for nearly three-quarters of global EV manufacturing capacity, at around 20 million units per year. Europe and North America follow, with roughly 15% and 10% of the world's total, respectively.

In the car industry, as in many other industries, maintaining a high rate of capacity utilisation is important to achieve profitable operations. Where domestic demand declines, carmakers typically look for ways to use their existing manufacturing to supply demand abroad, i.e. by increasing exports. If profitable export opportunities are not available, carmakers tend to reduce their production capacity, i.e. by closing down factories.

In **Europe**, the average utilisation rate fell from 70% in 2019 to under 60% in 2024, as European sales and exports declined. As a result, several EU carmakers, like Volkswagen (VW) and Stellantis, carried out layoffs.

In **China**, according to national statistics, utilisation stood around 77% in 2019, but the average utilisation of Chinese car manufacturing capacity dropped to under 72% in the first quarter of 2025. There is uncertainty around this figure, however; international datasets and recent public discussions suggest that utilisation rates might be lower, at around 50% of Chinese overall car production capacity. Capacity-utilisation rates are also uneven across powertrains. The surge in electric car sales since 2019 has come with high capacity-utilisation rates for some electric carmakers (even close to 100% in some cases), while the resulting low ICE sales lowered that of conventional car manufacturing capacities. The result of the latter is that ICE car exports from China ramped up during this period.

In **North America,** utilisation rates are higher. In the United States, the capacity-utilisation rate is close to 80% for cars, a level higher than before the pandemic, due to reduced car imports and one major assembly plant closure. In Mexico, the car industry recovered from the pandemic even more rapidly, thanks to domestic sales and increasing exports to the United States. Recent data indicates that, in Mexico, the automotive industry was recorded operating at up to 95% capacity utilisation in 2024. In Canada, meanwhile, car production had begun to decline even before the pandemic. Since 2016, production by US carmakers in Canada – including brands later acquired by Stellantis – has steadily declined. This trend, compounded by the pandemic, drove the country's car output to a record low capacity-utilisation rate of just above 50% in 2021. Since then, the car industry has recovered, though at a slower rate than in other North American countries. In 2024, Canada's car output fell again back to 2022 production levels, suggesting a drop in capacity utilisation as a result.

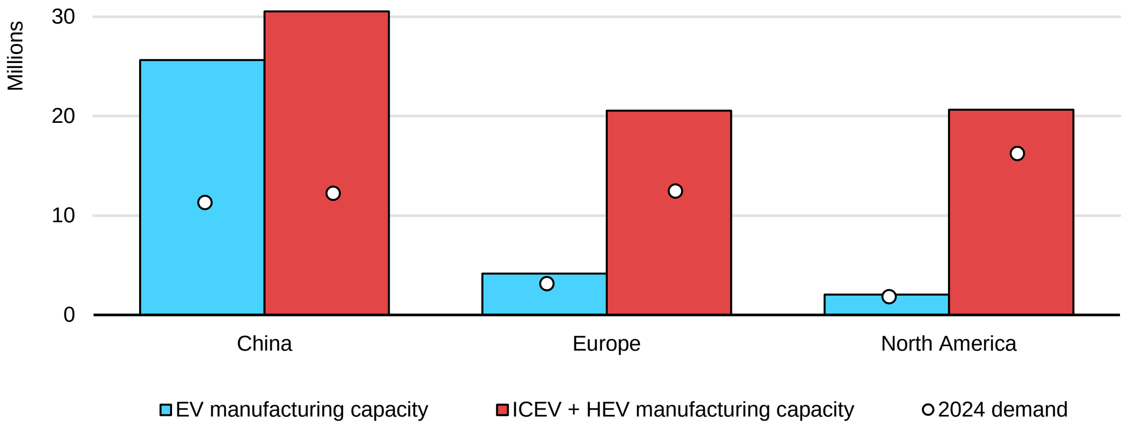
Available manufacturing capacity for electric cars differs by region. For example, in China, electric car manufacturing capacity today is more than double what is needed to meet domestic demand. In contrast, in Europe, such capacity is just

30% higher than domestic demand, and in North America, just 10% higher than demand. In these regions, meeting future demand growth for electric cars by domestic production would therefore require more EV-specific manufacturing capacity.

This does not, however, mean that new factories need to be built. The available manufacturing capacity offers the opportunity for retooling and repurposing to adjust to demand for different powertrains. Repurposing car factories to accommodate electric cars can be undertaken without necessarily stopping conventional car production: the VW Zwickau plant in 2019 is one recent example. Retooling, meanwhile, can take around 1 year (as was the case for Stellantis Mirafiori plant in the same year), meaning that relatively little lead time is needed to adjust to rising electric car demand.

Additional electric car manufacturing capacity is currently being built (see next section), but, in view of the above considerations, is not a key determinant in defining future trade and production patterns for electric cars. Trade policy and relative competitiveness are likely to play a much stronger role.

Figure 3.7 **Car manufacturing capacity of major car-producing regions and demand by powertrain in 2024**



IEA. CC BY 4.0.

Notes: HEV = hybrid electric vehicle; ICEV = internal combustion engine vehicle; EV = electric vehicle. Overall car manufacturing capacity by region is derived from Marklines' assembly plant dataset. EV manufacturing capacity is determined by using electric car production numbers divided by the overall car manufacturing utilisation rate.

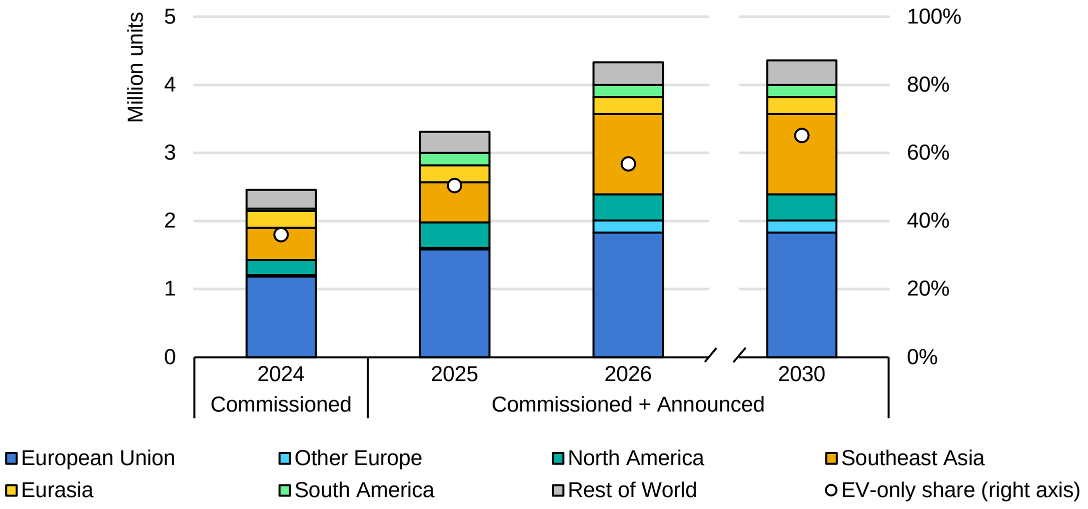
Source: IEA analysis based on Marklines and EV Volumes.

Chinese carmakers are expanding their overseas manufacturing footprint

Chinese OEMs are increasingly looking abroad to capture a larger share of the global electric car market but, in 2024, a wave of new tariffs made key markets harder to access. The European Union introduced OEM-specific countervailing duties on battery electric cars imported from China, while the United States and Canada imposed tariffs exceeding 100%, with more increases being considered in the United States for 2025. Mexico ended its EV tariff exemption for countries without a free trade agreement, and Brazil began gradually increasing tariffs from 10% to 35% by 2026.

Information on expansion plans of the car industry is typically more limited and harder to access than for other energy-related technologies, but it is well-established that these additional export costs have prompted Chinese OEMs to establish new overseas manufacturing capacities. The plants being planned are likely intended to both directly supply local markets (like BYD’s plant in Brazil) and produce EVs for exports (such as from BYD’s plant in Türkiye for exports to the European Union), thereby reducing exposure to tariffs targeting imports from China.

Figure 3.8 Commissioned and committed announcements for overseas electric vehicle manufacturing capacity of Chinese carmakers by region, 2024-2030



IEA. CC BY 4.0.

Notes: EV = electric vehicle. Manufacturing capacity refers to plants producing EVs, either exclusively or alongside internal combustion engine vehicles without specifying the EV share. The EV-only share is calculated as the share of EV-only commissioned and announced assembly plants in total manufacturing capacity shown. Volvo brand commitments to reach a 50% and 90% EV share in its 2025 and 2030 sales, respectively, are treated as EV-only manufacturing capacity and are therefore accounted for in the EV-only share. Both full-process manufacturing and knocked-down (in which pre-manufactured components are imported and assembled) types of assembly plants are considered. Announcements refer to committed investments only.

Source: IEA analysis based on IEA (2025), Global EV Outlook.

Most of the overseas production capacity owned by Chinese OEMs today is in the European Union, primarily through Volvo Cars’ assembly plants, which produced more than 170 000 electric cars in 2024. By 2026, when including both EV-only assembly plants and dual EV/ICE assembly plants, overseas manufacturing capacity owned by Chinese OEMs is expected to almost double compared to 2024 levels, to reach over 4.3 million vehicles per year. Europe and Southeast Asia are likely to remain the primary locations of these new assembly plants, with almost half of the total Chinese overseas manufacturing capacity being located in Europe by 2026.

The global manufacturing reach of Chinese OEMs is not limited to electric car-making. In particular, after incumbent OEMs left Russia following Russia's full-scale invasion of Ukraine, many Chinese OEMs took over their car assembly plants. This is likely to help Chinese automakers to maintain or increase their presence in the Russian market despite the planned hike in recycling fees (a non-tariff trade measure) for imported vehicles.

Other countries have seen Chinese OEMs setting up car production facilities within their borders over the past decade – such as in Brazil, Iran, Egypt, Pakistan and South Africa. This suggests that while the market share of Chinese OEMs might continue to increase in the coming years, exports from China might decrease.

Despite concentration in the battery supply chain, production can scale with demand

Manufacturing capacity for battery cells – and for key components[18] – is expanding rapidly, and data on expansion plans is more readily available than for car manufacturing. Between 2024 and 2030, such production capacity growth is expected to range between 40% and almost 200% across different segments of the supply chain, based on committed projects (i.e. projects either currently under construction or having reached a final investment decision).[19] Production capacity is expected to be built in a more diverse set of regions, especially in the case of battery cell manufacturing. The share of global battery cell manufacturing capacity located in China is projected to decline from approximately 85% in 2024 to less than 70% by 2030, even as total global capacity more than doubles over the same period. However, for all major battery cell components, at least 85% of global manufacturing capacity is still expected to be in China by 2030, showing limited progress towards supply chain diversification.

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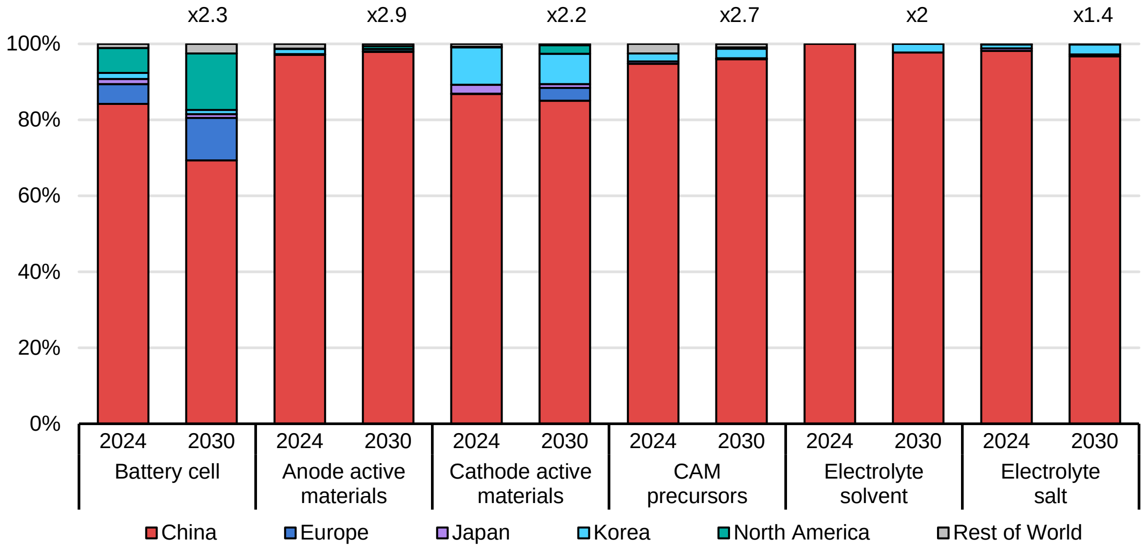
[18] Battery cells are composed of three main constituents – the cathode, anode and electrolyte. The cathode and anode are electrodes whose key component is their active material, which stores lithium ions, while the electrolyte enables their movement between the electrodes. Hundreds to thousands of battery cells are assembled into a battery pack, which also integrates components such as the battery management system, and is then installed in the vehicle.

[19] This analysis does not account for market risks and dynamics that could lead to the cancellation or failure of some existing or planned projects, which may, in turn, affect the actual level of supply chain concentration in the coming years.

Figure 3.9 Share of existing and committed nameplate manufacturing capacity for lithium-ion battery cells and components by region, 2024 and 2030



IEA. CC BY 4.0.

Notes: CAM = cathode active material. Region indicates the location of the production plant. 2030 capacity refers to the sum of the installed capacity (2024) and the committed manufacturing capacity by 2030. Committed refers to plants that have reached a final investment decision and are starting or have already started construction works. All manufacturing plant expansions announced for completion by 2027 are considered as committed. The “x” on top of the 2030 bars indicates how much larger manufacturing capacity in 2030 is compared to 2024 for each step of the supply chain. Data as of end of April 2025.

Sources: IEA analysis based on Bloomberg, Benchmark Mineral Intelligence and Bloomberg New Energy Finance.

It is important to note that the existence of manufacturing capacity alone does not guarantee supply chain security, as not all production capacity is the same – quality and chemistry differ and so not every component factory can serve any factory producing battery cells. For example, China holds nearly all global manufacturing capacity for lithium iron phosphate (LFP) batteries and CAM, which is a cheaper chemistry that is important for producing affordable electric cars. While production capacity outside China is starting to be announced, for example by Ford in the United States, adapting to a sustained supply disruption would require time to upgrade or repurpose existing capacity, or to re-engineer vehicles such that new sales can accommodate the supply available.

Of course, there is an additional competitiveness consideration, as production costs in China are much lower than elsewhere and so any potential disruption would affect both the ability to produce and the costs. Although countries outside China had sufficient production capacity for both battery cells and CAM to meet their domestic demand in 2024, China remained a major exporter, largely due to its lower production costs. Nonetheless, supply security is becoming an increasing concern in the automotive industry, driven by risks linked to Chinese export controls, which could slow or hinder knowledge transfer from Chinese companies to companies abroad, and jeopardise access to batteries and battery components outside China.

Given the geographical profile of production capacity and of electric car demand, trade of various elements across the battery supply chain is likely to expand by 2030. Exports are likely to come primarily from China, because of the size of its industry and its competitive costs, but Korea also looks set to continue being an important supplier, especially for upstream components.

China's export controls bring supply chain risks for batteries and electric vehicles to the fore

Chinese export controls have emerged as an important supply chain risk for lithium-ion batteries and electric vehicles. These measures exacerbate existing geographical concentration: China accounts for between 60% and nearly 100% of each step of the battery manufacturing supply chain and nearly 95% of permanent magnets used in EV electric motors globally.

Since late 2023, China has progressively tightened export control measures:

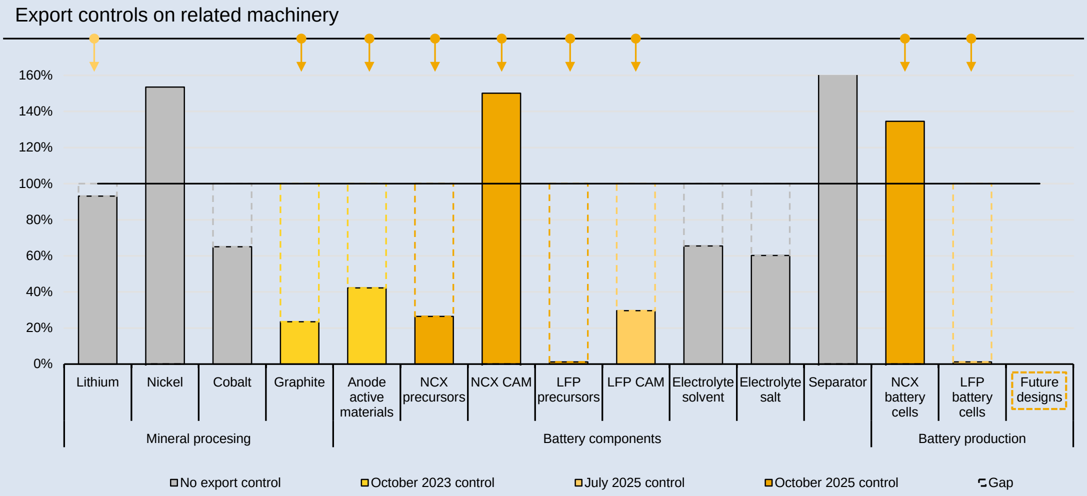
- October 2023: Controls on high-purity synthetic and natural graphite threaten battery anode supply, for which China holds over 90% market share. These were tightened further in December 2024 for exports to the United States.
- April 2025: Limits on key rare earth elements and permanent magnets. This led to a sharp decline in export volumes in April and May, with many carmakers in the United States, Europe, and elsewhere forced to cut production rates temporarily.
- July 2025: Fourth-generation LFP technology and lithium processing added to restricted export lists, hindering efforts to diversify LFP production and scale low-cost EV batteries production outside of China.
- October 2025: Expanded restrictions cover cathode active materials and their precursors, anode materials, LFP components, advanced chemistries under development (such as solid-state and lithium-rich manganese), and production equipment, amplifying supply concentration risks. These measures were later paused for one year following the latest trade agreement with the United States.

These measures affect all important steps of battery supply chains, with anode active material, cathode materials precursors, and LFP cathode and batteries being the most vulnerable steps, given there are only few options for diversification. Disruption of these supplies could severely limit the ability of the rest of the world to produce batteries.

The latest export controls also apply to manufacturing technologies rather than solely to finished products. China is home to some of the most advanced battery making equipment, especially for LFP technologies. Access to the latest machinery needed for production of LFP batteries and components could speed up the uptake of this technology outside of China – the implementation of these controls could stifle technology and knowledge transfer.

The extent to which export controls will be enforced remains uncertain, but they introduce an additional risk. In addition, the application process requires companies to submit detailed information on production facilities using controlled materials and technologies, which comes with significant insights into global supply chains.

Share of battery demand outside China that could be met without supply from China, 2024



Notes: NCX includes lithium nickel cobalt manganese oxide (NMC) and lithium nickel cobalt aluminium oxide (NCA); LFP = Lithium iron phosphate; CAM = cathode active material. 100% refers to global demand excluding China. The export controls announced in October 2025 are currently temporarily suspended. Full bars refer to production facilities located outside of China, with production assumed to be raised to 85% of nameplate capacity. Arrows indicate the battery components or systems for which export controls apply to the associated production machinery. Export controls on lithium processing refers specifically to lithium processing technologies. Future designs refer specifically to batteries with an energy density greater than 300 Wh/kg and lithium-rich manganese-based chemistry. The NCX cells affected by export control are those with an energy density greater than 300 Wh/kg. All facilities able to produce graphite anode suitable for battery applications are included within the scope of global anode manufacturing capacity.

Sources: IEA analysis based on data from EV Volumes, Benchmark Mineral Intelligence, and BNEF.

Chapter 4. Pathways to global EV cost-competitiveness

Highlights

- The gap in competitiveness in electric car manufacturing between new market-entrants located in China and incumbents in other countries has grown in the past 5 years. Battery electric car production costs are over 30% lower in China than in advanced economies, and around a third of the difference can be attributed to the battery. However, a similar production cost gap exists for conventional cars.
- Battery cell prices are, on average, over 30% lower in China than in Europe and over 20% lower than in the United States. Reducing the manufacturing cost gap is possible – half is due to efficiency and automation, and 30% to access to low-cost supplies of critical minerals and battery components.
- Energy costs have only a small impact – between 1% and 4% depending on the region and powertrain -- on the direct cost of car manufacturing including parts and assembly. However, they can be twice as high for battery electric as for conventional cars in countries with above-average energy prices. In upstream industries like steel production, energy accounts for 25% of costs, on average.
- The differences in purchase prices for battery electric and conventional cars in different regions are larger than the differences in direct manufacturing costs between regions, partly due to manufacturers' pricing strategies, profit margins, and subsidies, and partly due to model variation within a segment. In China, profit margins have been reduced by competition, especially for electric cars.
- Chinese carmakers are very cost-competitive, but incumbent manufacturers can build on their strengths in the global premium market and in emerging economies, where future growth is concentrated. Nevertheless, boosting competitiveness in electric car production will remain a priority for incumbent carmakers aiming to maintain a share of this market.
- Chinese carmakers have a significant technological advantage, but others could catch up by setting the right priorities for their comparatively high R&D budgets. Relying on yet-to-be-developed battery technologies to boost competitiveness is risky, however, and does not replace the need to champion current technologies, such as by collaborating with today's technology leaders. Innovation in power electronics will also be crucial, especially to support the trend towards higher-voltage models, and to reduce dependency on rare earth elements for electric motors and counter the risk of supply chain bottlenecks.

Introduction

Not every country, nor every manufacturer, is able to produce electric cars at a cost that is comparable to that of internal combustion engine (ICE) cars today. For electric cars, Chinese automakers currently have a competitive edge over the manufacturing operations of many incumbent manufacturers elsewhere, and so governments and industry in many countries are currently working to meet the challenge of electrification at competitive costs. The first part of this chapter quantifies and compares the production costs of manufacturing electric cars in different regions today, identifying the main factors that are contributing to cost gaps in terms of technology and industrial base. It then goes on to review the key drivers of competitiveness, with an eye on opportunities for incumbent manufacturers to reduce the cost-competitiveness gap along the supply chain, and to capitalise on their market presence and legacy of technology innovation.

4.1 Quantifying the competitiveness gap

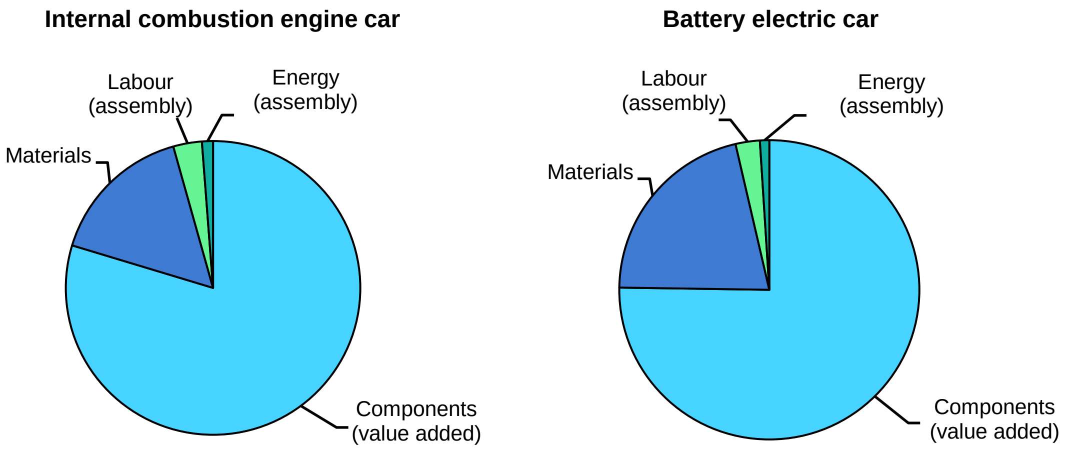
The different approaches taken by governments around the world, and by incumbent original equipment manufacturers (OEMs) and new market-entrants, have resulted in a significant difference in the price of electric cars in China compared to the rest of the world. The pre-tax difference in price for electric cars exists for two reasons – differences in cost of production, and differences in the ratio between the cost of production and retail price.

Differences in production cost are primarily driven by battery costs

The cost of producing a car can be divided into two broad parts: the indirect manufacturing costs, which include annualised capital expenditure (CAPEX), R&D expenses and all costs associated with company administration and marketing; and the direct manufacturing costs, which include labour, energy, material and component costs. While it is possible to quantify direct manufacturing costs based on available literature and teardown reports, indirect manufacturing costs are company specific and commercially sensitive. As a point of reference, the US National Highway Traffic Safety Administration applies a retail price equivalent factor of 1.5 in its Corporate Average Fuel Economy standards – indicating that indirect manufacturing costs generally represent one-third of the final vehicle retail price.

The production costs of a car can vary significantly depending on its size, features and market segment positioning. In this analysis, cost estimates are based on the average base-model car in the small SUV segment (which accounts for almost a third of the global market).

Figure 4.1 **Share of direct manufacturing costs for small SUV by cost-component in China, 2024**



IEA. CC BY 4.0.

Notes: Internal combustion engine car based on an 80-kW engine; battery electric car based on a 150-kW electric drivetrain and a 75-kWh battery.

Sources: IEA analysis based on ICCT, UBS, BNEF, S&P Global Mobility and US Bureau of Labor Statistics.

For both battery electric and ICE cars, at least 75% of the direct manufacturing cost comes from components (excluding materials). Materials account for just over 15% of the cost for ICE cars and just over 20% for battery electric cars, which have up to USD 1 300[20] worth of additional material costs, primarily due to battery minerals and increased copper needs. Direct labour and energy costs incurred during assembly account for the remaining 5% of manufacturing costs, with few differences between powertrains. Therefore, while energy and labour assembly costs vary significantly across regions, their impact on direct manufacturing costs does not lead to significant differences between ICE and battery electric car production costs. In addition, car assembly is only the final step of the car supply chain – to better understand the production cost structure across regions, it is necessary to take into account the cost breakdown by components.

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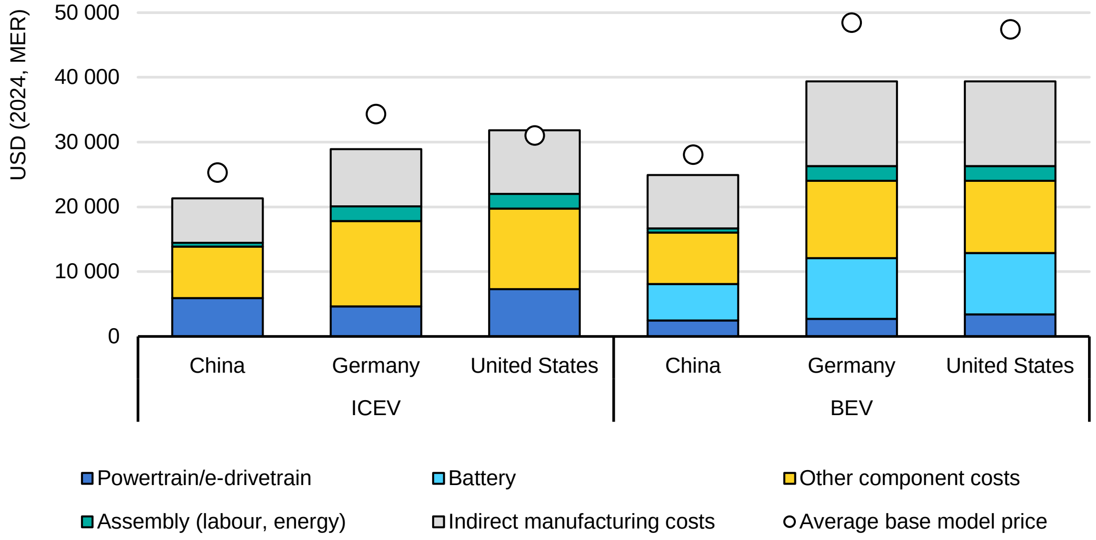
[20] This assumes NMC811 as battery chemistry and it reflects the difference in material costs between ICE and BEV technologies across all materials.

Figure 4.2 **Bottom-up price estimates of a small SUV and sales-weighted average base-model prices in selected countries, 2024**

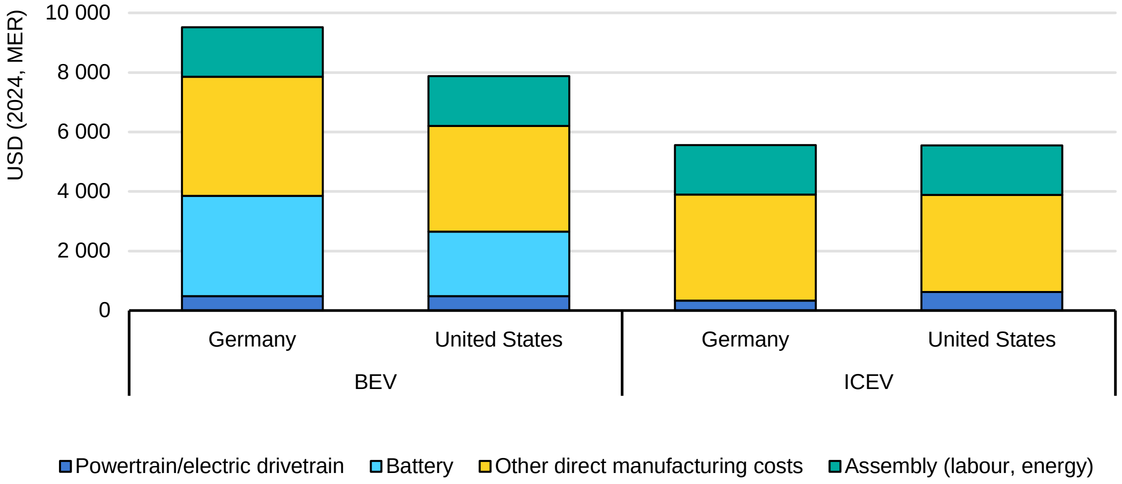


Notes: ICEV = internal combustion engine vehicle; BEV = battery electric vehicle. Across all countries shown, the sales-weighted average base-model specifications of a small SUV are considered, for both ICEV and BEV. The resulting average battery sizes are around 60 kWh, 68 kWh and 77 kWh for China, Germany and the United States, respectively. For the electric powertrain, the following power levels have been considered: 173 kW, 154 kW and 196 kW, respectively. ICE rated power levels are 129 kW, 93 kW and 146 kW, respectively. “Other direct manufacturing costs” include chassis, body-in-white, exterior, interior and electronic equipment. “Indirect manufacturing costs” include R&D, sales, general and administration expenses, profit and dealer’s margin. In this analysis, we assume that these represent a constant 33% of total manufacturing costs across all selected countries and powertrains.

Sources: IEA analysis based on ICCT, UBS, BNEF, S&P Global Mobility and US Bureau of Labor Statistics.

For ICE cars, the share of powertrain costs in the estimated retail car price ranges from 15% to just under 30%. For battery electric cars, however, this share goes up to one-third – with the battery alone accounting for nearly 25% of final retail price and the electric drive (including power electronics) for the remainder. Assembly costs, including labour and energy, account for around 5% of the estimated retail car price in Europe and the United States, while in China they account for about 2%. Differences in manufacturing costs across regions also reflect regional vehicle specifications, such as average power and battery size. For example, ICE cars in the small SUV segment in the United States have more than 50% higher power than those sold in Germany, and battery electric small SUVs have an almost 30% higher average battery capacity in the United States than in China.

Figure 4.3 **Additional direct manufacturing costs compared to costs in China for a small SUV by country and by powertrain, 2024**



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Notes: BEV = battery electric vehicle; ICEV = internal combustion engine vehicle. In all countries analysed, BEVs are based on a 150-kW electric drivetrain and feature a 75-kWh battery. ICEVs are powered by an 80-kW engine. “Other direct manufacturing costs” include chassis, body-in-white, exterior, interior and electronic equipment.

Sources: IEA analysis based on ICCT, UBS, BNEF, S&P Global Mobility and US Bureau of Labor Statistics.

For a car with the same technical specifications (i.e. for battery size and rated power), the direct manufacturing costs in China are around one-third lower than in western Europe and in the United States, and the relative difference is only slightly higher for battery electric cars than for ICE cars. Assembly costs and non-powertrain related costs account for nearly all of the difference in direct manufacturing costs for ICE cars, primarily because both categories of costs are reduced by the lower cost of labour and high manufacturing efficiency in China.

For battery electric cars, the manufacturing cost gap with China is almost USD 2 500 higher than for ICE cars in the United States and USD 4 000 higher in Germany. The cost of powertrain components is the main technology-related reason behind the cost advantage of producing battery electric cars in China. In the example of the small SUV, nearly 40% of the difference in direct manufacturing costs can be attributed to the difference in cost of the electric powertrain, including the battery.

Battery cell prices are, on average, more than 30% lower in China than in Europe and more than 20% lower than in the United States. For a 75-kWh battery,[21] this alone translates to a cost difference of between USD 2 000 and USD 3 500 for an average SUV with an on-road range of about 400 km. Other powertrain

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[21] 75 kWh is about the global average for battery electric SUVs in 2024.

components, specifically the electric motor and power electronics, also tend to cost less in China, but only account for a small share (around 5%) of the cost difference.

Differences in the cost of non-powertrain components also play a significant role in the direct manufacturing cost gap between regions. In the case of the small battery electric SUV, direct labour costs related to assembly account for less than 20% of the cost gap, although lower labour costs in China also contribute to lower costs for components. More than 40% of the cost gap with China can be attributed to non-powertrain related components, such as interior sub-assemblies, exterior, body and chassis components.

When comparing the sales-weighted average prices of base models (i.e. with the cheapest trim level) with our bottom-up price estimates, some differences can be observed due to the heterogeneity of models within a specific car segment and available features that cannot be captured with this bottom-up assessment. Assumptions on indirect manufacturing costs may also help explain these differences. The share of indirect manufacturing costs in final car retail price could be higher as a result of different OEM pricing strategies, corporate efficiency levels and R&D spending across carmakers and powertrain types. However, when looking at some specific popular small SUV models, such as the petrol-fuelled Volkswagen (VW) T-Roc (marketed at USD 29 000 in 2024 in Germany), or the electric BYD Song Plus (USD 24 000 in 2024 in China), the gap between our bottom-up price estimates and their actual retail prices narrows.

Energy costs play a role in the car industry supply chain

The impact of energy costs on the assembly of a car is relatively small, as car assembly itself is not energy-intensive. However, energy costs accumulate at each step of the supply chain, from material production to the manufacturing of parts and components.

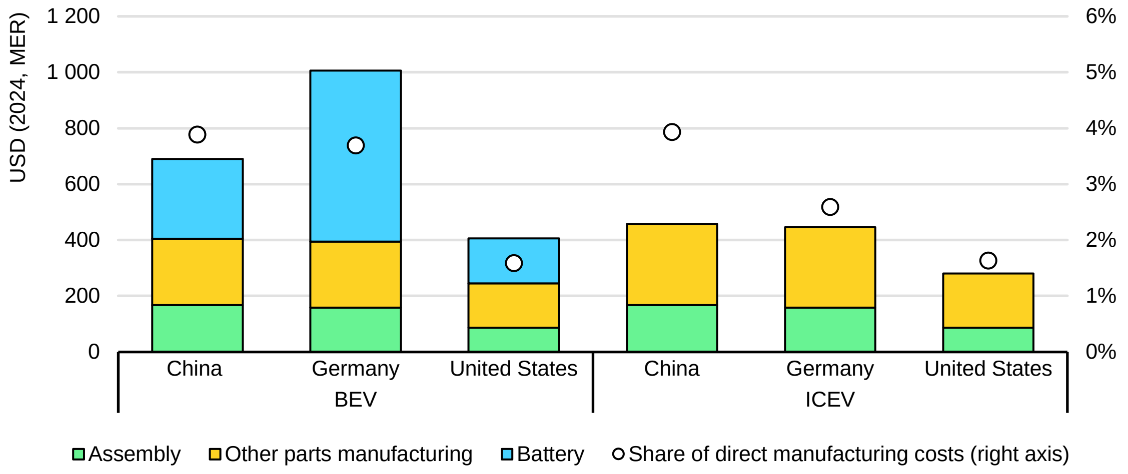
Information on the differences in energy use by factories across regions is limited, but, according to GREET, the energy needed to assemble a car and to produce the materials used in the car is less than 85 GJ for a small ICE SUV, and 90 GJ for a comparable battery electric SUV. These values are representative of cars produced in the United States. Around 70% of the energy demand is required to produce the materials needed in a car, about 20% is needed for parts manufacturing, and the remaining 10% for assembly.

To illustrate the impact of this energy requirement on energy costs in different regions, it is instructive to focus on energy requirements for assembly and parts manufacturing, since upstream materials could be produced in locations with more favourable energy pricing (especially for aluminium) compared to the location where the cars are produced. For ICE cars, energy costs account for around

USD 400 per car, or roughly 3% of the direct manufacturing costs. While the United States experiences the lowest energy costs, it is estimated that China and Germany experience similar costs per car since Germany's higher energy prices are counterbalanced by higher industrial energy efficiency, as suggested by energy efficiency indicators.

For battery electric cars, energy costs for manufacturing range between 50% and over 100% more than for ICEVs, but the share of energy in direct vehicle manufacturing costs remains similar in China and the United States whether for an ICE or battery electric car. In contrast, in Germany, this share is about 40% higher for a battery electric car than an ICE car. In a country like Germany, with higher-than-global-average energy prices, the energy costs of producing a battery electric car and its components could reach USD 1 000 if all battery materials were produced domestically, whereas they are typically imported today.

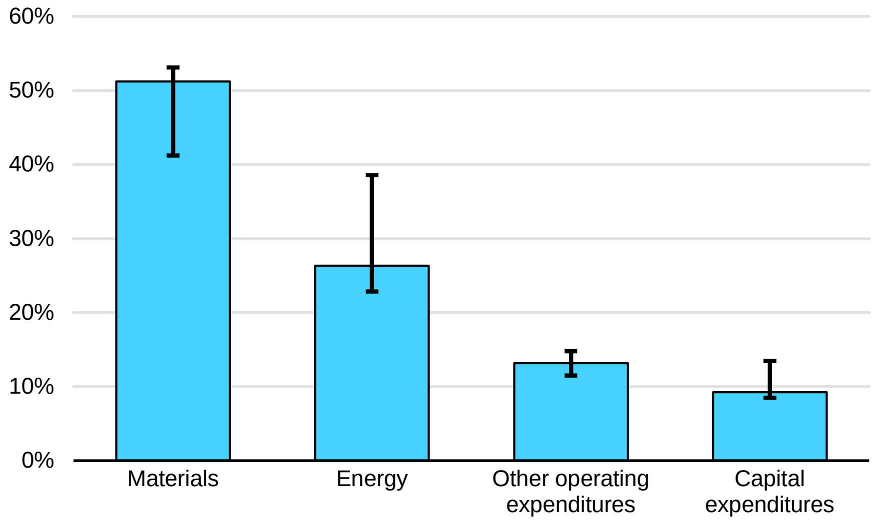
Figure 4.4 Estimated energy costs for producing a small SUV by supply chain step and as a share of direct manufacturing costs by powertrain in selected countries, 2024



Notes: BEV = battery electric vehicle; ICEV = internal combustion engine vehicle. The BEV is assumed to have a 75-kWh battery. The energy consumption for battery production refers to the 2024 world average battery chemistry and it assumes the same manufacturing efficiency across regions.
Source: IEA analysis based on GREET.

The bulk of energy costs related to car manufacturing are associated with the production of the materials that are being used. Here, energy prices make all the difference when it comes to competitiveness – taking the example of steel production, energy accounts for one-quarter of production costs on average, although this share can be up to 40% in regions with higher energy prices. Reining in energy costs is therefore particularly important for upstream industries, more than for direct car manufacturing.

Figure 4.5 Share of costs in steel production and regional variation, 2024

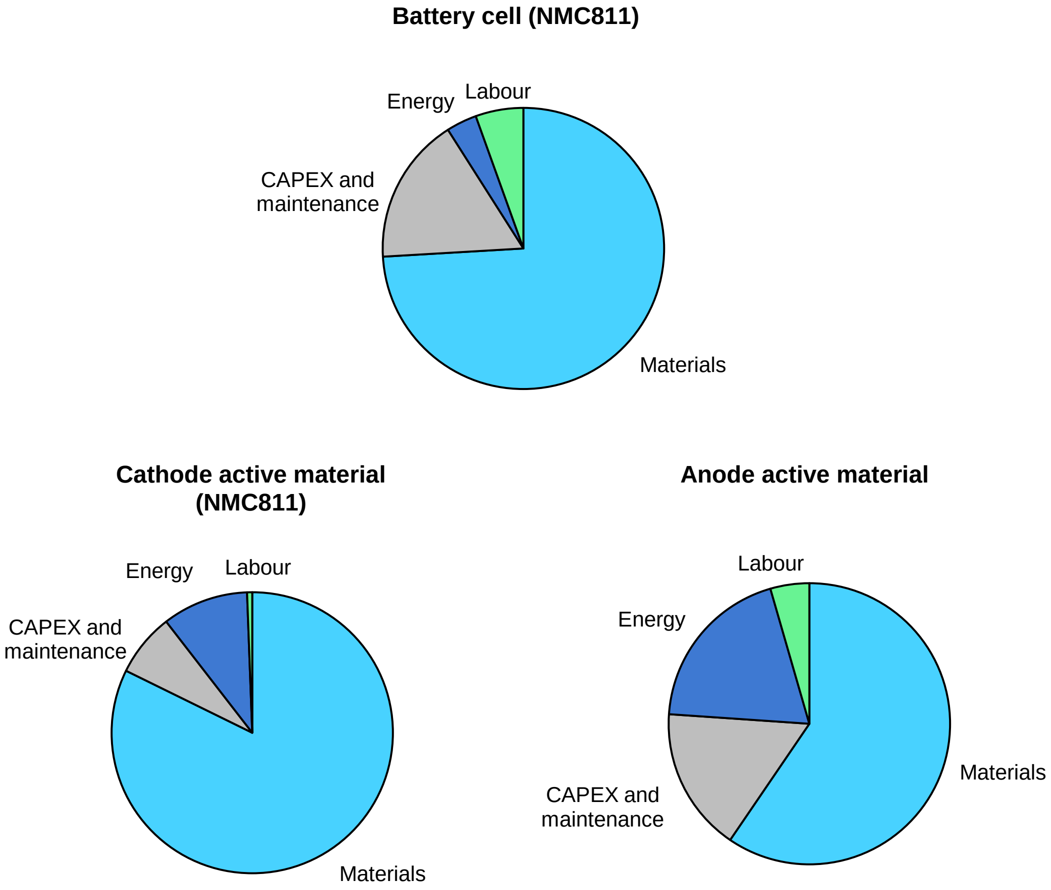


IEA. CC BY 4.0.

Notes: Solid bars show world average for blast furnace – basic oxygen furnace production assuming no scrap input; error bars show regional variation. Materials refers to the non-energy input materials to steel production, mostly iron ore.

Just as for car manufacturing, energy costs for battery manufacturing are especially impactful in upstream steps of the supply chain. Taking the example of a battery cell produced in China, energy only accounts for around 4% of the production costs. This share increases to 10% and 20% for cathode and anode active material production, respectively. Measured on a per kWh level, energy cost differences between Europe and the United States for all steps of the battery supply chain alone could account for about USD 5/kWh (or between 5% and 10% of total manufacturing cost) if similar manufacturing efficiencies are assumed. Low energy prices can therefore provide a competitive advantage, even though they are not the key determinants of production costs for battery manufacturing.

Figure 4.6 Share of levelised cost of production for battery cells, anodes and cathodes in China, 2024



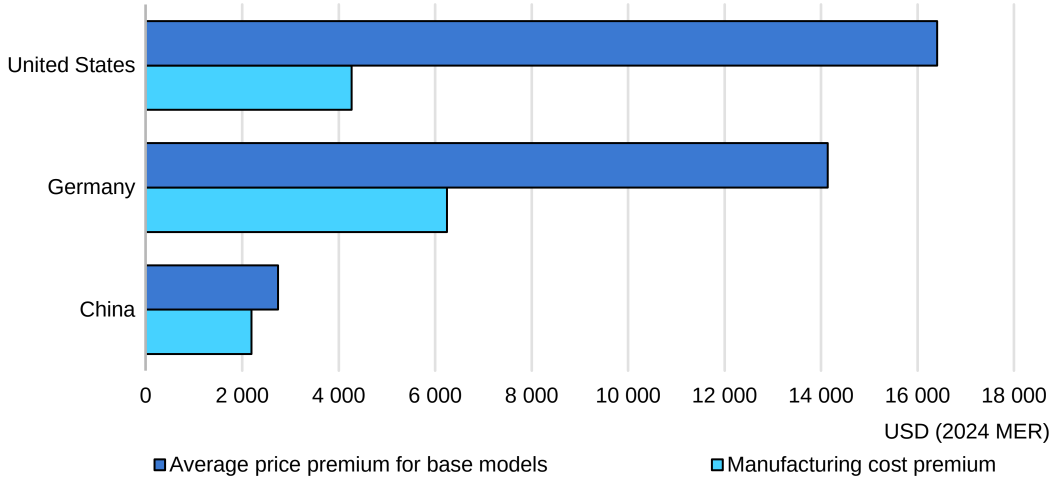
Notes: Material spot prices are considered for this figure, which excludes preferential pricing accessible to major battery manufacturers thanks to vertical integration and larger bargaining power. Energy prices reflect the energy prices for the overall industrial sector in China. Components refer to cathode and anode active materials purchased as inputs for battery cell production, for which indirect manufacturing costs such as administrative, retail, and R&D costs, and profit margins were considered. These costs are excluded from the levelised cost of production shown for individual production steps in the associated pie charts, such as cathode active material synthesis or battery cell manufacturing, therefore reflecting direct manufacturing costs. Please see Annex A for full assumptions and costs used.

Sources: IEA analysis based on GREET; BNEF; IEA (2024), Energy Technology Perspectives.

Higher costs and different pricing strategies lead to big differences in car prices

The differences in the cost of production across regions and across powertrains are smaller than the differences in purchase prices. The difference in direct manufacturing costs between an average ICE small SUV model and its battery electric counterpart is around USD 2 200 in China, while the difference in purchase prices is around USD 2 700. In Germany, however, these premiums are significantly higher and reach USD 6 200 and about USD 14 000, respectively.

Figure 4.7 Direct manufacturing cost premium and purchase price premium for an average battery electric small SUV model compared to its average conventional counterpart in selected countries, 2024



Notes: Across all countries shown, the sales-weighted average base-model specifications of a small SUV are considered, for both ICEV and BEV. The resulting average battery sizes are around 60 kWh, 68 kWh and 77 kWh for China, Germany and the United States, respectively. For the electric powertrain, the following power levels have been considered: 173 kW, 154 kW and 196 kW, respectively. Internal combustion engine rated power levels are 129 kW, 93 kW and 146 kW, respectively.

Sources: IEA analysis based on ICCT, UBS, BNEF, S&P Global Mobility and US Bureau of Labor Statistics.

There are numerous reasons that could explain why the ratio between purchase price and manufacturing cost premiums is lower in China, but it is difficult to ascertain their relative weight as the pricing strategies of carmakers may differ. Four potential explanatory factors are outlined below:

- **Pricing strategies** for electric cars can differ across OEMs. Carmakers producing both ICE and electric models may transfer earnings made from profitable ICE sales to R&D and manufacturing investment for developing and producing electric cars. As such, the actual overhead expenditures resulting from electric car manufacturing are not entirely carried by electric car sales but also by ICE sales, further lowering electric car prices compared to other OEMs.
- **Profit margins** in the Chinese car market are lower than in advanced economies (see Chapter 1), especially for electric cars. The Chinese market for electric cars is extremely competitive, with over 50 active companies, and so prices are continuously declining.
- **Subsidies to carmakers** could be another explanation. The European Commission has identified evidence that electric cars produced in China have benefited from sizeable subsidies in the form of preferential access to land or below-market rate loans, which can contribute to lower capital expenditure requirements for carmakers producing in China.

- **Heterogeneity within a segment** could also help explain these differences. For example, in early-adoption markets like Europe and the United States, battery electric SUVs are, on average, positioned towards the higher end of the market targeting consumers that are less price-sensitive, while ICE SUVs tend to target mass-market consumers. On the other hand, in the more mature Chinese electric vehicle (EV) market, ICE and electric cars generally feature comparable trim levels and specifications, reducing the bias in segment-level comparison.

4.2 Key ingredients of competitiveness

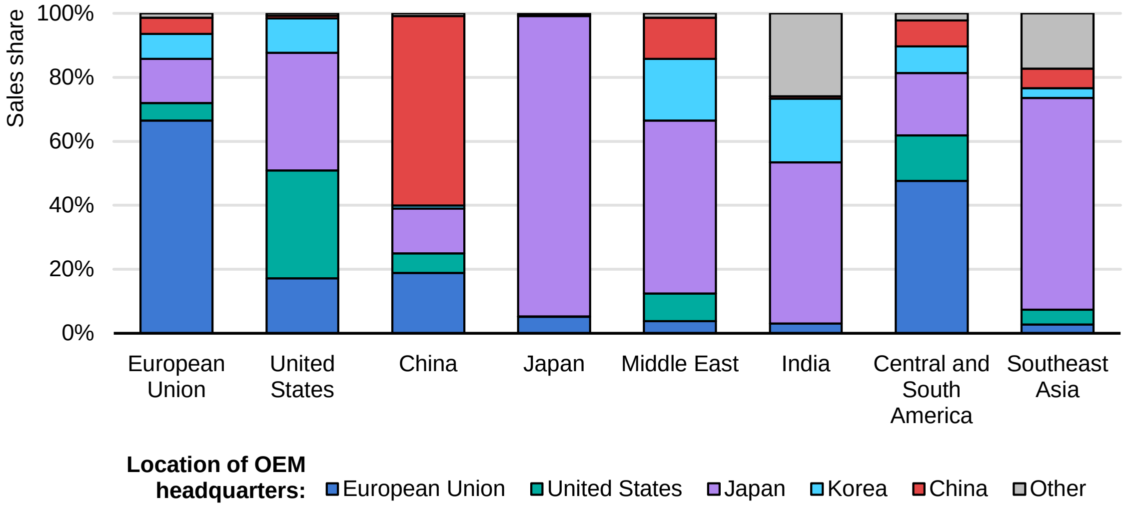
The gap in cost-competitiveness in electric car manufacturing between new market-entrants producing in China and incumbent carmakers in other countries has widened over the past 5 years as a result of decisions taken by both industry players and governments. However, the car industry is primarily based on technology and industrial capacity, and does not rely on natural endowments. This means that the future of the industry remains open to new possibilities, and countries aiming to compete in the market for electric car technology and manufacturing still have opportunities to do so. Incumbent manufacturers, in particular, can build on their global presence, strength in certain car segments and decades at the forefront of technological innovation. This section explores the key elements for increasing competitiveness in electric car manufacturing and identifies priority actions for bridging the current competitiveness gap.

Capturing growing opportunities in emerging markets

Over decades of operations, incumbent OEMs have expanded their sales networks across the world. This has been vital to their growth, especially for Japanese OEMs since the Japanese car market peaked in 1990. In 2024, new car sales in Japan were about 25% lower than in 1990; and even though new car sales in the European Union peaked more recently, sales in 2024 were about 10% lower than in 1990.

European and Japanese OEMs, in particular, have very high market shares in emerging markets and developing economies (EMDEs). This results from an early entry in those markets, which has provided the time to develop extensive retail networks and to build brand awareness. Japanese carmakers command two-thirds of the market in Southeast Asia, and over half the market in the Middle East and India, while European carmakers have nearly a 50% market share in Central and South America.

Figure 4.8 New car sales share by region and location of original equipment manufacturer headquarters, 2024



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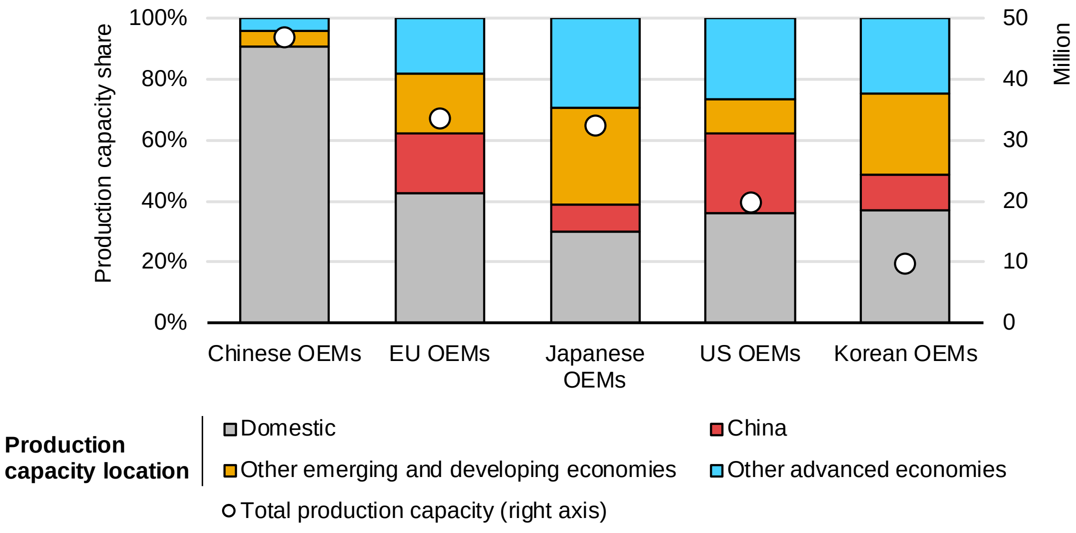
Notes: OEM = original equipment manufacturer. Chinese joint ventures with foreign manufacturers are not considered as Chinese OEMs in this figure.

Source: IEA analysis based on data from Marklines.

Most new cars sold in these markets are produced in local factories that were first established decades ago, often focusing on existing vehicle models tailored to the needs of the market. Incumbent OEMs with a long history in EMDEs continue to have a significant manufacturing footprint in these regions: European, Japanese and Korean OEMs have 20-30% of their production capacity located in EMDEs other than China, while Chinese OEMs have just 5%. However, the sales in these EMDEs account for a smaller share of output (see Figure 1.4), since some of the production capacity is used to produce cars destined for exports to advanced economies.

Around 85% of the growth in car sales since the 2008 financial crisis has come from China, with the remaining 15% shared between other EMDEs and advanced economies, making China by far the most important growth market in this period. However, these shares are likely to change over time once the Chinese car market starts to saturate and as other EMDEs reach levels of economic development that are typically associated with a rapid increase in motorisation. It is likely that ICE cars will be a key technology in EMDEs other than China during the next years to come; in 2024, the share of EVs in total car sales was less than 5%.

Figure 4.9 **Shares of production capacity in different regions by location of carmaker's headquarters, 2024**



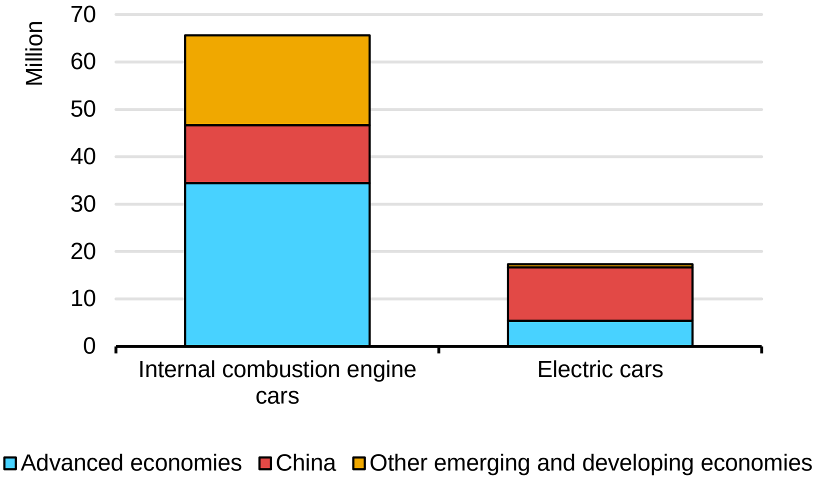
Notes: OEM = original equipment manufacturer. Chinese joint ventures (JVs) with overseas manufacturers are not considered as Chinese OEMs in this graph. In JV-operated assembly plants, production capacity is equally divided among stakeholders.

Source: IEA analysis based on data from Marklines.

The global presence of incumbent OEMs puts them in a strong position to tap into these growth opportunities; Chinese OEMs sell 85% of their cars domestically and their global presence is still limited compared to incumbent manufacturers. In EMDEs other than China, incumbent OEMs from advanced economies accounted for 75% of ICE cars sales in 2024, whereas Chinese OEMs accounted for over half of the electric car sales in these markets.

Faster progress towards electrification in EMDEs other than China is possible; climate goals (as illustrated in IEA decarbonisation pathways) can be one reason, of course, but the uptake of electric instead of ICE cars can also improve air quality and cut oil import bills, both of which are pressing policy priorities for governments in EMDEs. The falling prices of electric cars produced by Chinese manufacturers also make them an increasingly attractive choice for consumers (Chapter 2), which could lead to accelerated adoption. Nevertheless, OEMs with a strong manufacturing foothold in EMDEs outside of China are likely to enjoy continued revenues from these markets, which they could use to support the investments required to bridge the gap with Chinese OEMs. Yet this advantage is not immutable, as manufacturing capacity can be built relatively quickly; for example, the VinFast manufacturing facility in Viet Nam was built in less than 1 year, while the first Chinese car factory in Brazil was built in under 3 years.

Figure 4.10 Car sales in different economies by powertrain, 2024

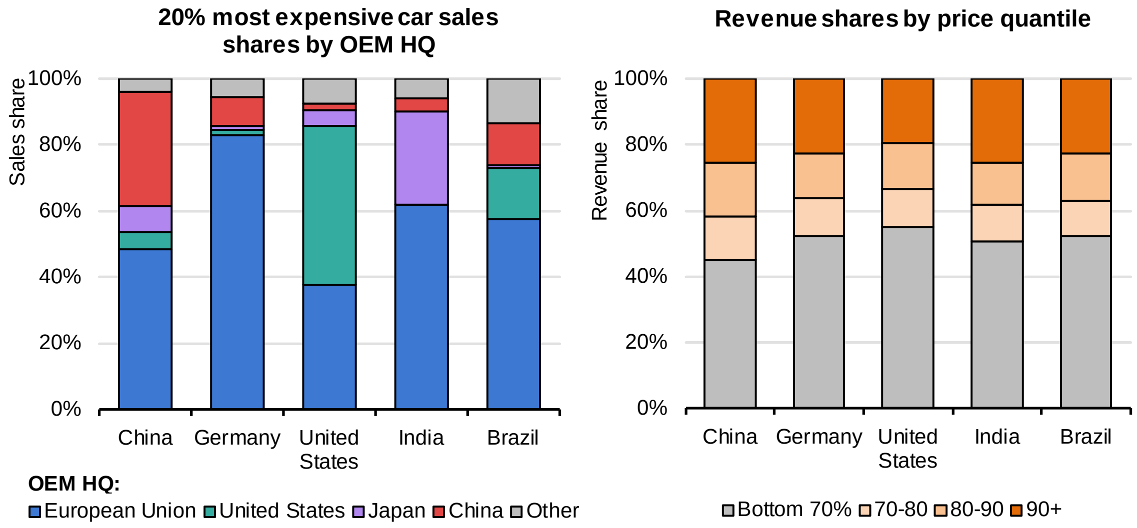


Sources: IEA analysis based on Marklines and EV Volumes

Controlling high-revenue, premium segments

Long-established car manufacturers typically have strong brand identities, and several have a solid foothold in the premium and luxury market segments in particular. Sales of cars with prices in the top quintile (used here as a proxy for the premium market) account for more than one-third of revenues in advanced economies like Germany and the United States. In EMDEs including China, the share is closer to 40% of revenues, reflecting the larger price difference between mass-market vehicles and premium vehicles in EMDEs. In addition to generating higher revenues per vehicle sale, premium segments tend to have higher profit margins for OEMs, as customers are more willing to pay higher prices. Profit margins for premium brands like Porsche are above 15%, while for mass-market brands like the Volkswagen (VW) Group's core brands, they are around 5%. When looking at the market share for premium segments, incumbent OEMs still retain most of the market, including in China.

Figure 4.11 Sales share by location of original equipment manufacturer headquarters for the most expensive 20% of sales by region (left) and revenue share by price quantile (right) per region, 2024

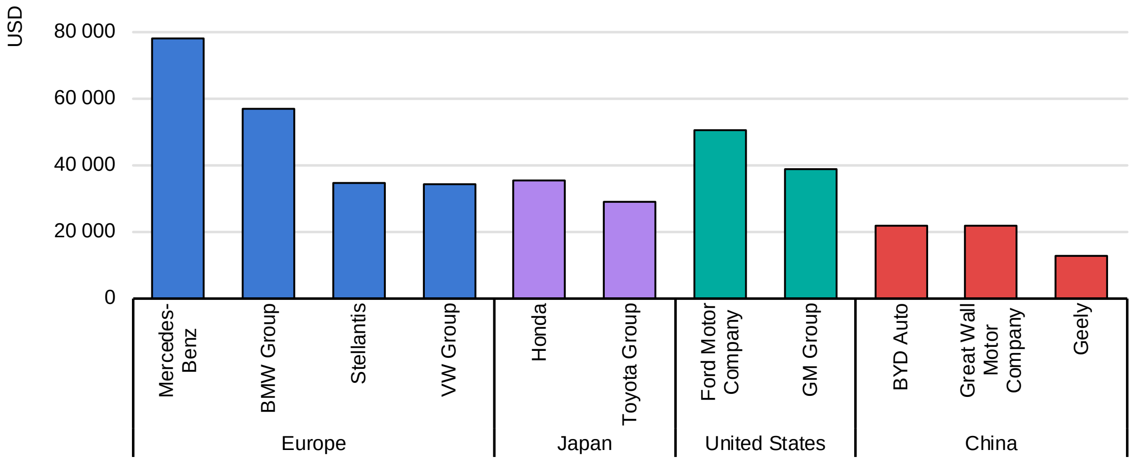


IEA. CC BY 4.0.

Note: OEM HQ = Original equipment manufacturer headquarters.
Source: IEA analysis based on data from S&P.

This means that for each car sold by incumbent OEMs, they receive higher revenues. On the high end, Mercedes-Benz reaches revenues of nearly USD 80 000 for each vehicle sold, and BMW USD 57 000. Mass-market manufacturers like VW and Toyota achieve average revenues of around USD 32 000. In contrast, Chinese OEMs see much lower revenues at around USD 13 000 for Geely, and around USD 22 000 for BYD or Great Wall Motor. The differences in revenue per car sold largely result from two factors – the share of premium vehicles sold globally, and the exposure to markets with higher or lower average prices. In 2024, the average price of a car sold in China was about 30% lower than that of a car sold in Germany or in the United States. The strong exposure of Chinese companies to their home market is therefore a disadvantage from a revenue perspective.

Figure 4.12 Revenue per vehicle sale for selected automakers, 2024



Notes: Total company revenues are scaled down to account only for the share of revenue from car sales (retrieved from Bloomberg Terminal) and they are then divided by their global car sales. Cars sold through joint ventures are allocated according to the equity share of each joint venture.

Source: IEA analysis based on Marklines and Bloomberg Terminal.

The premium car market has higher barriers to entry, as legacy and brand identity play a stronger role in driving consumer choices compared with the mass market, where affordability is a primary concern. While even the premium market may be subject to change – as exemplified by Tesla's rapid ascent in the premium market – it is likely that the existing brands from incumbent OEMs will be relatively more resilient to competition within this segment, at least in the medium term. The availability of this highly profitable revenue stream provides a strong advantage to incumbent automakers, particularly European ones, since they can use the income from this business to invest further in electric cars and bridge the existing competitiveness gap.

Seizing opportunities across the battery supply chain

The battery is a key cost-component of an electric car, and in China, the costs of battery production are far lower than in other regions. More advanced battery designs and faster innovation cycles are among the key advantages enhancing the competitiveness of Chinese companies in the electric car market. This section assesses the factors that explain the cost-competitiveness of the Chinese battery industry in comparison to other regions.

Mastery of manufacturing, battery chemistry and supply chains is key for the battery market of today

Batteries are complex systems whose performance depends not only on the materials used but also on their precise combination and interactions, and whose final characteristics are shaped by hundreds of parameters, including manufacturing processes and battery chemistry.

Manufacturing know-how

One of the key explanatory factors behind the success of lithium-ion batteries is their modularity. This has enabled rapid scaling and a sharp decline in costs, with EV battery prices dropping by over 75% between 2015 and 2024. During this period, leading battery manufacturers from China, Korea and Japan, such as CATL, BYD, LG Energy Solution, Panasonic, SK Innovation and Samsung SDI, have developed extensive manufacturing expertise, solidifying their global leadership in the sector.

Among the three largest EV battery markets, China has far outpaced the United States and Europe in battery (cell) production, accounting for about 75% of the EV batteries ever produced globally. The resulting manufacturing know-how has supported the rise of giant manufacturers such as CATL and BYD.

Up until 2018, cumulative EV battery production in the United States was similar to in China, and EV batteries were even slightly cheaper in the United States. In the same year, some of the most advanced battery manufacturing was undertaken in the United States, mostly thanks to the partnership between Tesla and Japan’s Panasonic, which was then operating the largest battery factory in the world. Back then, the major battery makers of today were accelerating production in China but had not yet emerged as global leaders. Just 6 years later, however, the difference in scale of EV demand and production between China and the rest of the world had expanded significantly, meaning that by 2024, factories in China had cumulatively produced over six times more batteries than factories in the United States, and ten times more than factories located in Europe.

Manufacturing expertise and availability of an experienced and specialised workforce – particularly production line workers, battery engineers and managers with large-scale manufacturing experience – are required for optimised production processes. This is a key driver of manufacturing efficiency,[22] leading to low manufacturing scraps and limited unplanned production line downtime. The higher

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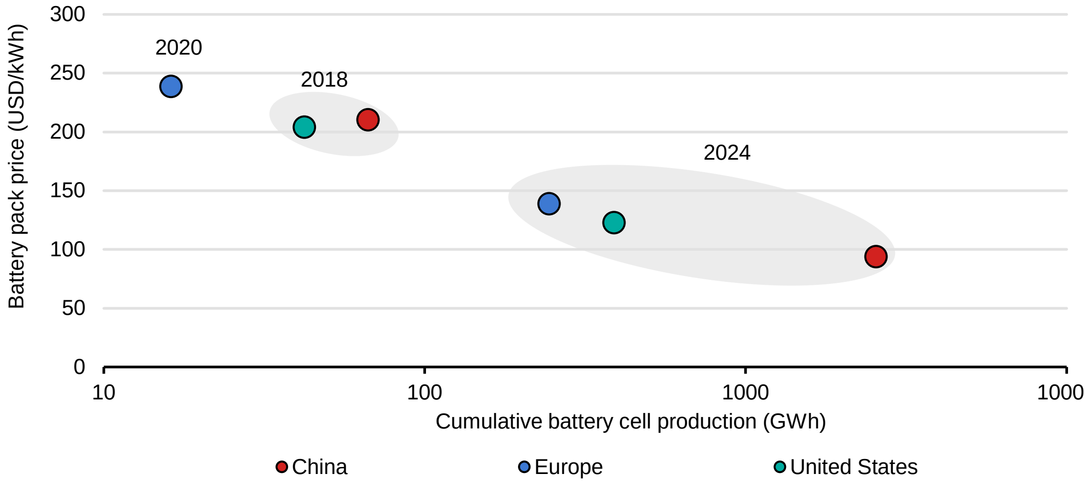
[22] Manufacturing efficiencies refer to the proportion of batteries produced that meet quality standards once commercial-scale production is reached.

production volumes in China have translated into a significant advantage in manufacturing know-how and expertise compared to other regions, as well as accelerating innovation.

Battery manufacturing requires extremely high production speed and quality standards. The number of batteries produced on a single production line (of comparable footprint) varies greatly depending on the level of automation and production speed, with more outputs being achieved in factories equipped with the latest advances in battery manufacturing technologies. A state-of-the-art gigafactory of 50 GWh capacity can produce up to 10 million (cylindrical) or hundreds of thousands (prismatic) EV battery cells per day,[23] with well above 90% of them meeting the stringent quality standards required for automotive applications.[24] Developing a competitive battery manufacturing industry is no easy task, requiring industry-specific knowledge and skills, as well as investment in advanced equipment to reach economies of scale.

Figure 4.13 Battery price and cumulative production by different countries or regions, 2018-2024



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Notes: Cumulative battery production refers to electric vehicle (EV) and battery storage applications. Battery prices by region refer to the average battery pack price in a given region, including locally produced batteries and imports across EVs and battery storage applications. EV and battery stockpiling and production scraps are excluded from the analysis.
Sources: IEA analysis based on data from BNEF, BMI and EV Volumes.

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[23] Assuming an average plant utilisation factor of 85% over the year, a cell voltage of 4 volts, and a cell capacity of 60 ampere hours (prismatic) and 3 ampere hours (cylindrical).

[24] <10 defective cells per million. An EV battery pack of 65 kWh requires between a few hundred (prismatic) to several thousand (cylindrical) battery cells depending on their size and chemistry.

The key role of battery manufacturing equipment providers

Access to the latest manufacturing technology and competitively priced equipment plays a crucial role in de-risking and accelerating battery production scale-up, while also enabling manufacturers to achieve high (>90%) manufacturing efficiency.

Manufacturing equipment providers have developed alongside the historic and current leaders in battery and component production, all headquartered in China, Korea, or Japan. Leading suppliers such as Wuxi Lead Intelligent Equipment (China), People & Technology Inc. (Korea), and Hitachi High-Tech (Japan) have closely collaborated with major battery manufacturers in their home countries – including CATL and BYD (China), LG Energy Solution, SK Innovation and Samsung (Korea), and Panasonic and PPES (Japan). These partnerships have secured large and growing markets both domestically and internationally. Asian companies now account for 95% of global manufacturing capacity, including over 90% of installed battery cell production capacity in the European Union and more than 60% in the United States.

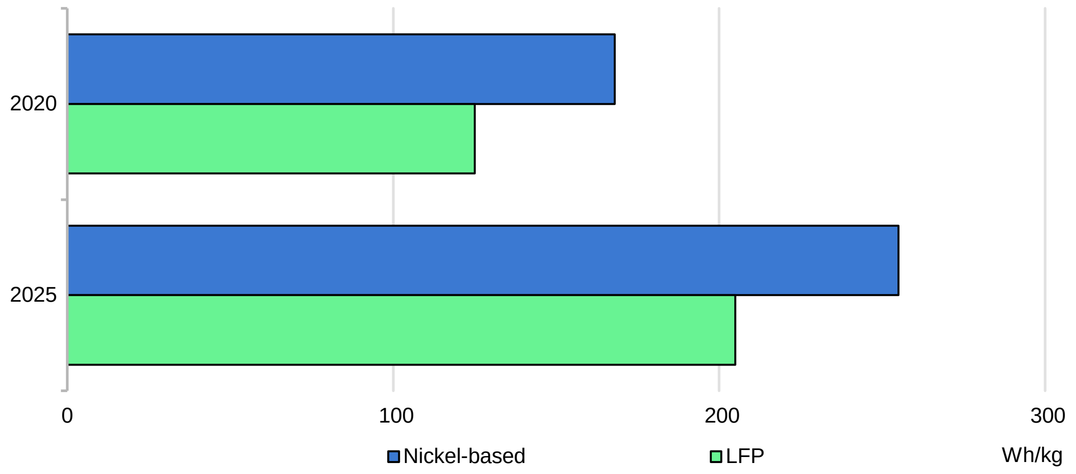
Chinese and Korean equipment providers currently lead the market, with companies like Wuxi Lead and People & Technology setting benchmarks in automation and mass manufacturing. China's larger battery production base has given its equipment manufacturers a competitive edge both in terms of technology development and in terms of costs, enabling them to offer lower prices and shorter lead times. This contributes to explaining about 40% of the difference in CAPEX requirements between building a battery factory in China versus one in Europe or the United States. In addition, close collaboration with leading battery producers such as CATL and BYD has further supported faster innovation cycles. For companies operating outside of China, the proposed expansion of Chinese export controls to certain battery manufacturing equipment could limit access to these machines, particularly the latest-generation technologies if ever enacted.

Other equipment providers for lithium-ion battery manufacturing exist, such as COMAU, Mondragon Assembly, Digatrom Power electronics, Dürr and Grob in Europe. However, the absence of large domestic battery producers and the lack of investment by battery manufacturers in co-developing machinery with European equipment suppliers have largely constrained their growth, leading many to specialise in smaller segments of the production process – such as prototyping equipment, cell testing or battery pack assembly – or to remain significantly smaller than their Asian competitors.

Battery chemistry

Among today's main battery chemistries – lithium nickel cobalt manganese oxide (NMC) and lithium iron phosphate (LFP) – NMC (and similar chemistries like lithium nickel cobalt aluminium oxide (NCA)) has historically led the electric car battery market thanks to its higher energy density,[25] enabling longer electric ranges. However, over the past 5 years, LFP batteries have gained significant traction in China, capturing about three-quarters of its EV market in 2024. LFP batteries have three major advantages when compared to NMC batteries: lower reliance on critical minerals, lower production cost, and longer lifetimes. LFP relies on only one traditional critical mineral, lithium, while NMC requires lithium, nickel, manganese and cobalt. The reduced critical mineral need is the major driver of the lower cost of LFP batteries, which today are almost 30% cheaper per kilowatt-hour (kWh).

Figure 4.14 Lithium-ion battery pack energy density by chemistry, 2020-2025



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Notes: LFP = lithium iron phosphate; Nickel-based includes all lithium nickel cobalt oxide (NMC) types, lithium nickel cobalt aluminium oxide (NCA), and lithium nickel manganese cobalt aluminium oxide (NMCA). Data for 2020 refers to the NCA and LFP versions of Tesla Model 3. Data for 2025 refers to CATL's Shenxing PLUS battery for LFP and CATL's Qilin battery for the Nickel-based.

Despite these advantages, LFP batteries were initially considered unfit for the electric car market because of their lower energy density, which reduces the vehicle range. In 2020, the battery pack of a Tesla Model 3 had an energy density of almost 170 Wh/kg when using lithium nickel cobalt aluminium (NCA), a similar chemistry to NMC – 35% more than the Tesla Model 3 equipped with CATL LFP batteries in the same year, which had an energy density of just 125 Wh/kg at the pack level.

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[25] "Energy density" is used here as a general term referring to the amount of energy stored per unit of mass or volume. It can be divided into two specific metrics: specific energy (Wh/kg) and energy density (Wh/L). While the term is often used – albeit imprecisely – to refer specifically to specific energy, this simplified nomenclature is retained here for improved readability.

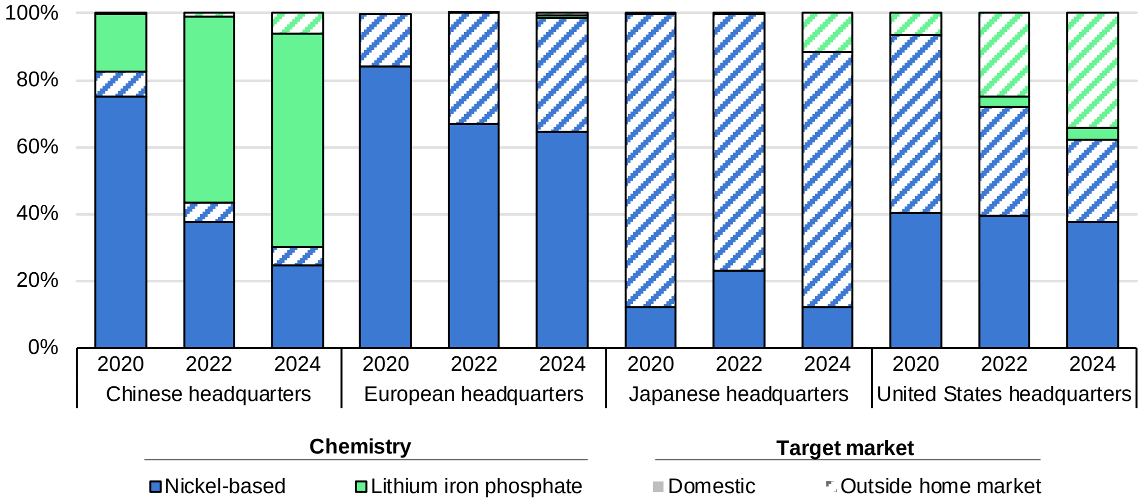
This has changed rapidly in the past 5 years, thanks to innovations such as cell-to-pack and cell-to-chassis designs and increased compaction density through the fourth generation of LFP active material, although processing technologies for the latter are now subject to proposed export restrictions by the Chinese government. The latest generation of LFP materials – the production of which is led by Chinese companies such as Fulin Precision Machining, Hunan Yuneng, and Changzhou Liyuan – enabled commercial LFP battery packs to reach an energy density of up to 205 Wh/kg, over 20% higher than the 2020 Tesla Model 3 using NCA batteries. These innovations have been driven by sustained Chinese investment in this battery chemistry in recent decades, despite LFP having been first discovered in the United States in 1997 and the first LFP production plant having been established in Canada in 2006.

NMC batteries also benefit from cell-to-pack and cell-to-chassis technologies and continue to offer higher energy densities, reaching up to 255 Wh/kg for the battery pack, nearly 25% higher than LFP. However, the energy density reached by LFP batteries now comfortably meets the performance needs of most electric cars, making their lower cost a big advantage as major carmakers seek to reach mass markets. In 2024, LFP batteries became for the first time the single most-employed battery chemistry in the EV industry worldwide, reaching nearly half of the market.

LFP batteries are still primarily used in China – just over 10% of EV sales used this chemistry in Europe in 2024, and an even lower share in the United States. However, LFP batteries are already widely adopted in EMDEs, especially where Chinese electric car imports are prevalent: in Southeast Asia, Brazil and India, the share of electric cars sold using LFP batteries reached more than 50% in 2024. China maintains near-total dominance over LFP battery production, though recent investments by Korean and Japanese manufacturers could introduce some diversification, including through production in Europe and the United States. Nonetheless, carmakers outside of China are increasingly considering LFP batteries as a way of reducing production costs, and some have already adopted it extensively, though typically for vehicles sold outside advanced economies. However, export controls on LFP technology, related production equipment, and associated know-how – particularly for the latest generation – may contribute to keeping this technology in the hands of Chinese companies, potentially constraining the rapidly growing adoption of LFP globally and the diversification of its supply.

Although the United States remains one of the markets with a smaller uptake of LFP, US OEMs used LFP in about 40% of their vehicles in 2024, second only to Chinese OEMs. This was largely driven by Tesla, which mostly sold LFP-equipped vehicles in China, but also accounted for over 60% of the LFP-equipped car sales in the United States, and almost half in the European Union. General Motors (GM) and Ford also incorporated LFP batteries into their lineups, with GM primarily using them for vehicles sold in China, while Ford deployed them mostly in the United States (70%) and Europe (20%). Japanese automakers, particularly Toyota, also adopted LFP batteries in 2024, though all its LFP-equipped EVs were sold in China. European OEMs are still almost exclusively using NMC chemistries, but their interest in LFP technology is growing rapidly as competitive pressure intensifies.

Figure 4.15 Share of electric car lithium-ion battery sales by chemistry and automaker headquarters, 2020-2024



Notes: Nickel-based includes all lithium nickel cobalt oxide (NMC) types, lithium nickel cobalt aluminium oxide (NCA), and lithium nickel manganese cobalt aluminium oxide (NMCA). Lithium iron phosphate (LFP) includes LFP and lithium manganese iron phosphate (LMFP). Battery chemistry sales share is based on the battery capacity of electric vehicles produced by companies headquartered in the different country or region. Full colours represent sales in the country or region where the automaker is headquartered, while hatching represents sales in a country other than where the automaker headquarters are located. The latter includes vehicles produced in the country or region where the automaker is headquartered and exported, as well as vehicles produced in another country and used domestically or exported (except for exports towards the country or region where the automaker is headquartered). Electric vehicle and battery stockpiling are excluded from the analysis.

Sources: IEA analysis based on data from EV Volumes and China Automotive Battery Industry Innovation Alliance.

Technology know-how

The recent uptick in LFP batteries – driven by innovations such as cell-to-pack and cell-to-chassis technologies – is just one example of the potential to optimise established lithium-ion battery technologies.

The pace of innovation has accelerated in the past few years, predominantly led by Chinese companies such as CATL and BYD. Fast-charging capacity, for example, has skyrocketed since 2023, enabled by advances in multi-gradient layered graphite anode designs, in particular. The first company to announce this achievement was CATL, in 2023, and they continue to improve the technology. BYD likely used a similar strategy to achieve similar charging capabilities, which they have also coupled with a dedicated charging platform that includes megawatt chargers and a 1 000 V architecture enabled by high-voltage power chips and all-liquid-cooling systems – a reminder of the importance of system optimisation.

Another recent example is the lithium manganese rich NMC batteries (LMR-NMC) developed by LG Energy Solution in collaboration with GM, and planned for commercial production by 2028. These feature higher lithium and manganese content than standard NMC batteries, reducing material costs while maintaining high energy density. However, LMR-NMC batteries typically suffer from poor durability and rapid performance degradation, suggesting that their development has required significant system-level optimisation to mitigate these drawbacks.

The combination of different battery technologies can also offer opportunities to further fine-tune performance, for example combining LFP and NMC batteries in the same pack, as presented by CATL at the end of 2024. Established lithium-ion technologies can also be coupled with emerging ones – such as sodium-ion or "anode-less" batteries. The latter can deliver extremely high energy density and, therefore, range, but typically suffer from low durability. Companies like CATL address this by combining established NMC or LFP cells for regular use with anode-less cells activated only for extended range, enabling electric ranges up to more than 1 000 km when needed. Such hybrid systems require sophisticated management of charge and discharge cycles, underscoring the need for expertise not only in battery chemistry but also in power electronics, software, thermal management and safety systems to optimise overall pack performance. Battery designs are also evolving and are no longer limited to the battery pack, with some producers expanding their scope by designing entire vehicle chassis that enable greater system control and integration.

Lithium-ion battery technology is rapidly progressing, largely driven by continual improvements from established Asian battery manufacturers. As a result, the barrier to entry for new players is becoming increasingly high.

Battery supply chain

Access to lower-cost critical minerals and battery components is important for competitiveness in today's battery markets, as components and materials can account for up to 75% of total battery cell production costs. Between the end of 2021 and 2022, a surge in critical mineral prices (for example, lithium prices increased by over 150% in 1 year), due to high demand and limited supply, caused the first-ever recorded increase in lithium-ion battery cell prices (+7%). Since then, however, battery metal prices have declined sharply, and by the end of 2024 they reached levels that were about as low as in 2015, despite global battery demand expanding roughly tenfold over the same period. The volatility of critical mineral markets is a source of concern for battery makers and carmakers alike, and therefore investments in upstream supply are commonly used to mitigate risks related to price volatility. In advanced economies, this has mostly taken the form of equity stakes in mining projects overseas or long-term purchase agreements.

In China, the critical mineral industry is well established, and all steps of the supply chain are present domestically. This has been developed over the years under the co-ordination of the national government, which made the industry a national priority. The ability to access a large, co-ordinated and well-supplied market gives battery producers in China a comparative advantage. Vertical integration, economies of scale and bargaining power mean that very large purchase orders by major producers in China can command lower prices from mineral suppliers. In addition, leading Chinese battery producers have reportedly accessed below-market prices for critical minerals, in particular lithium. This was supported by the acquisition of lithium mines, with recent reports indicating government backing.

The pathway to competitiveness in different regions

Manufacturing efficiency, chemistry choice, and vertical integration or access to preferential supply chains are the major factors explaining regional differences in battery production costs today, and they are also key to closing the gaps.

Battery production in the European Union is at a critical juncture

Battery production in the European Union operates at a smaller scale than in China, with a mix of experienced Asian manufacturers, such as LG Energy Solutions in Poland, and newer factories set up by European players, which are now ramping up. Today, most batteries made in Europe import anode and cathode materials from Asia. In 2024, the average price premium for batteries in Europe, including cheaper imported batteries, was almost 50% compared to battery prices in China.

The European Union's key advantage is its position as a global leader in the automotive sector, with a large and growing EV market that serves as a demand centre attracting battery manufacturers. Achieving cost-competitiveness in local battery production is therefore a priority for strengthening the competitiveness of the European EV industry. This is likely to require investments from – and collaboration with – established Asian battery producers. In the short term, at least, it is likely to require imported battery components, due to limited manufacturing capacity and higher production costs in Europe. However, once battery production becomes competitive, it could attract upstream suppliers, strengthening supply chain security over the medium term.

For battery factories, it can take more than 5 years from starting operations to being able to operate at close to nominal capacity. New battery makers tend to need more time than established players with proven manufacturing expertise and management capabilities for advanced battery production. However, the lack of an experienced workforce and limited supply chains for battery-making equipment and components means that even experienced players in Europe require longer timeframes to scale up production, and are operating at sub-optimal rates compared to factories located in Asia. All of this results in a significantly lower average manufacturing efficiency in Europe compared to China.

In the European Union, the estimated average production cost of an entirely domestically produced NMC battery – including locally produced cathode and anode active materials (CAM and AAM) – is about USD 90/kWh, a premium of almost 70% compared to the same battery made in China. Closing the production cost gap between the European Union and China is feasible, and developing an integrated domestic supply chain is a crucial part of the long-term solution. However, a stepwise approach that balances cost efficiency with supply chain security will be required in the short term.

The first step towards bridging this gap lies in mastering battery production and achieving a production efficiency that is comparable with established manufacturers, such as those from China; this alone could halve the cost gap. Europe is home to world-leading industries and has an established and deep manufacturing base and engineering know-how, so there is no particular reason why this could not be achieved. It will require increasing and sustaining production levels, greater use of automation and digitalisation tools to hone manufacturing processes, and support to build the necessary skills and know-how in the workforce. Experience is essential to achieving high production efficiency, so production must continue to ramp up.

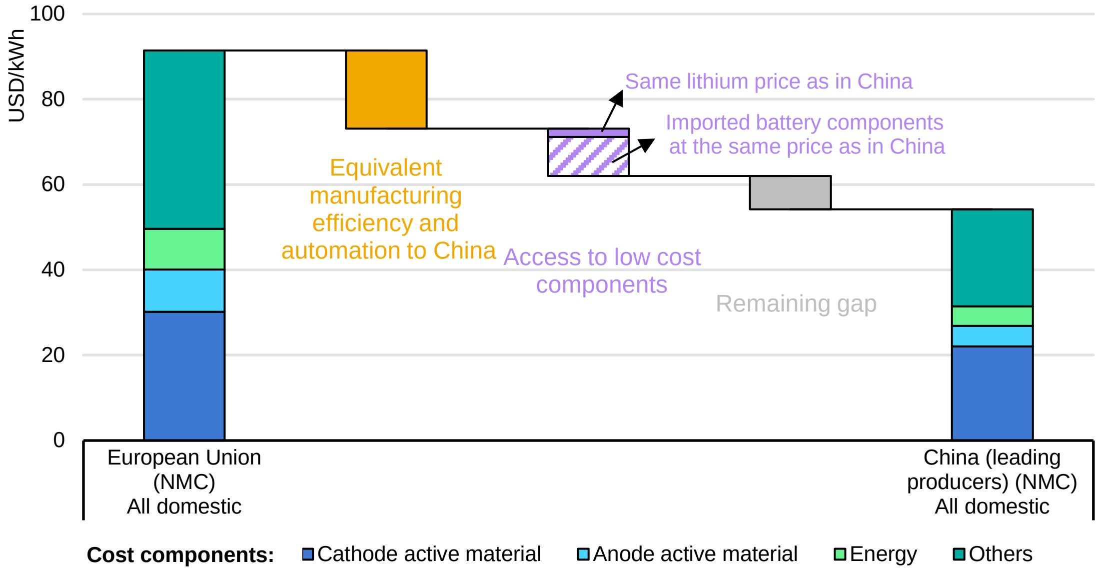
Investments from incumbent battery manufacturers – primarily Chinese, Korean or Japanese – are already driving manufacturing capacity growth worldwide, including in the European Union, and are likely to be essential to achieve competitiveness in the short term. Partnerships, collaboration and joint ventures, in particular, can leverage the economies of scale and supply chain advantages of established battery producers, while also de-risking investments and facilitating knowledge transfer for developing a larger, specialised local workforce. Knowledge transfer can take place via joint ventures with European companies or though non-equity-based models, such as licensing arrangements, which facilitate knowledge transfer without requiring ownership stakes.

Access to preferential critical mineral prices, particularly lower lithium prices, at levels comparable to those secured by major Chinese battery producers, would further reduce the EU premium by about 5 percentage points. This could be achieved through long-term contracts and equity investments in mines across the world. The main requirement for such a framework is certainty on sustained future demand, meaning that a stable policy environment is crucial. Governments could further support this type of agreement by establishing international co-operation agreements with countries that are home to mineral supplies. For example, the partnerships developed under the European Commission’s Global Gateway for the development of sustainable supply chains of critical minerals are a step in the right direction.

Even with access to lower critical mineral prices and high manufacturing efficiency, the premium between China and the European Union would, however, remain at about 30%. This is partially due to the higher costs incurred in the production of CAM and AAM in Europe, related to both CAPEX and energy costs (Figure 4.6). This gap could be reduced in three ways. Firstly, by prioritising locations for CAM and AAM production in Europe where energy costs are low (such as in the Nordic countries). Secondly, by developing component production facilities in neighbouring countries with access to lower energy and CAPEX costs; and thirdly, by continuing to import these components from the global market, for which collaboration with China, Korea and Japan will be important.

If producers are also able to access battery components at the same price as in China, the EU premium could be cut to less than 15%. At this level, the advantages of being located in the European Union – such as proximity to its large demand centres and stable legal and political frameworks – may outweigh the remaining cost difference. This would position the region as not only a major battery market but also a competitive battery producer, laying the foundations for a globally competitive EV industry.

Figure 4.16 Estimated direct costs of fully domestic lithium-ion battery cell production in the European Union and China, and key drivers to reduce the cost gap



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Notes: USD (2024). Production costs refer to the estimated average direct manufacturing cost in the European Union if key battery components (cathode and anode active materials) were produced domestically (left) and the estimated production cost of leading Chinese manufacturers in China (right). Production costs refer to batteries using lithium nickel cobalt manganese oxide (NMC) 811 as cathode active material (CAM) and synthetic graphite as anode active material (AAM). CAM and AAM are inputs of the cell production cost and include indirect manufacturing costs such as administrative, retail, and R&D costs, and profit margins. “Others” include capital and maintenance costs, labour, other materials (such as electrolyte, current collectors, and casing), CO_2 cost, and manufacturing inefficiencies. Yield increases and automation refers to production cost in the European Union at the same manufacturing efficiency and labour intensity as in China. Energy prices reflect the energy prices for the overall industrial sector. Imported battery components refer to imports of CAM and AAM, specifically. Please see Annex A for full assumptions and costs used.

Sources: IEA analysis based on data from IEA (2024) Energy Technology Perspectives, BNEF and CRU.

Chemistry choices also play a critical role in the competitiveness of the battery industry. In China, LFP battery production costs are more than 20% lower than NMC battery production costs, due to reduced reliance on expensive minerals. It is estimated that today, manufacturing LFP cells in the European Union would cost over USD 75/kWh, or 90% more than leading producers in China, if all components were produced domestically. However, by applying the steps outlined above, production costs could fall to close to USD 50/kWh.

The implications of such a cost decline would be very large for mass-market vehicles. For example, the cost of a battery for a medium car priced at around USD 25 000[26] would be reduced from over USD 5 000 (for an optimised NMC battery produced in the European Union) to less than USD 4 000 – meaning the battery would account for only about 15% of the vehicle price. A transition to higher shares of LFP batteries would be highly beneficial in terms of competitiveness in the mass market, and could support supply chain diversification if expertise in LFP production (today almost a monopoly of Chinese producers) diversifies, or if collaboration with leading Chinese producers is strengthened, including through Chinese investments overseas.

Transitioning to higher shares of LFP batteries does not mean, however, that the development or use of NMC batteries in Europe should be halted. Higher-energy-density NMC batteries will remain advantageous for applications requiring longer ranges (such as in premium vehicles) or operation in cold climates, where LFP technology is typically less effective. Having a dual chemistry approach would serve both the mass market and high-end market segments, while preserving technology flexibility for future innovations.

Battery production in the United States has strong potential but there may be limits ahead

Thanks to more extensive production experience and lower energy prices, the production cost premium for a fully domestically produced NMC battery in the United States is lower than in the European Union, but still stands at about 50% compared to production in China. Improvements in manufacturing efficiency and securing lower critical mineral prices could reduce this by almost 30 percentage points. The remaining gap could be offset by Inflation Reduction Act (IRA) tax credits, which were mostly retained under the latest bill. However, insufficient availability of CAM and AAM manufacturing projects will likely require continued imports of battery components in the short term, the final price of which will depend on import and export tariffs, potentially undermining the competitiveness of the industry.

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[26] The Citroën C3, equipped with a 45 kWh battery pack, is used as a representative medium-sized battery electric vehicle for the European mass market.

This outlook could improve over the course of the 2030s if the United States strengthens support for domestic CAM and AAM production and attracts the necessary investments. However, policy uncertainty may also decrease the pace of investments or increase production costs, widening the competitiveness gap. A challenge for the industry is the decrease in battery demand stemming from reduced electric car sales due to the phase-out of the USD 7 500 tax credits. This could mean factories run below the production levels needed for profitability, which, together with perceptions of policy uncertainty, could lead to significant investment cancellations.

Korea and Japan are silent battery leaders

Korea and Japan are already major players in the global battery industry, home to specialised suppliers and key battery makers with comparable manufacturing efficiencies to Chinese producers, giving them an advantage compared to Europe and the United States. Higher CAPEX for battery, CAM and AMM manufacturing plants and higher labour costs, however, mean that production in China is likely to remain less expensive. However, the production cost premium in Japan and Korea could be as low as 10% if battery components can be sourced or produced at prices similar to those in China. Recent policy action is helping to meet this aim. For example, the Japanese government approved a fund of up to USD 2.4 billion to support EV battery investments in September 2024, and in 2023 developed an initiative to subsidise up to half the cost of mine development for lithium and other critical minerals. In the meantime, the Korean government pledged USD 38 billion to shore up battery components and critical minerals while also building lithium reserves. A unique strength of Korean and Japanese manufacturers is their global manufacturing footprint, with production sites located domestically and in China, Europe and the United States. This means they are likely to remain key actors in the global battery industry.

Relying on disruptive innovation to reach competitiveness is risky

Innovations have the potential to disrupt the competitive landscape by introducing new battery technologies that provide a step-change in performance compared to existing batteries produced by established players. While this is indeed possible, relying on technologies that are yet to be developed in order to gain competitiveness comes with significant risks.

Solid-state batteries (Technology readiness level [TRL] 6) could increase battery cell energy density by more than 50% compared with conventional lithium-ion technologies, potentially giving a significant competitive advantage to whichever company first develops them. European, Japanese and American OEMs are investing in this technology, either through collaborations with start-ups (such as the partnership between Stellantis and Factorial Energy), or through in-house development (such as Toyota's). Chinese producers are also investing in this technology, such as BYD, which plans to roll out its first EV using all-solid-state batteries as early as 2027. Even once solid-state battery technology is fully developed, reaching mass manufacturing would take years, as production processes will need to be refined over time to eventually reach the levels of efficiency currently achieved by lithium-ion batteries. In addition, its energy density advantage at the cell level may be partially offset by challenges related to integration into EV battery packs. New supply chains would also have to be developed, such as for battery-grade lithium sulphide used in the production of sulphide-based solid electrolytes, while still relying on key minerals such as lithium, nickel and cobalt. Solid-state batteries may even require more lithium than conventional lithium-ion batteries. Chinese companies may therefore retain an advantage, thanks to the strength of their domestic supply chain. The recent Chinese export controls targeting high-energy density cells could put at risk the use of this technology outside China, if it is developed there first and export restrictions are enforced.

Sodium-ion batteries (TRL 8) bring the promise of reducing the use of critical minerals and lowering costs, and are often cited as a pathway to diversify the battery supply chain away from dependence on Chinese manufacturers. These batteries are already produced today, with the first EV models using them hitting the market in late 2023 in China. The year 2025 is expected to be a promising one for this technology: It started with the second generation of HiNa and CATL sodium-ion batteries being presented, with CATL also announcing a dedicated sodium-ion battery brand. Nevertheless, sodium-ion batteries still pose challenges, and many of their advantages are often misinterpreted. For example, 95% of existing manufacturing capacity and about 85% of the announced manufacturing capacity by 2030 uses (or plans to use) layered oxides as main battery chemistries, which have a similar nickel intensity compared to mid-nickel NMC lithium-ion batteries, meaning sodium-ion batteries are not devoid of critical minerals. In terms of cost, recent analyses indicate that sodium-ion batteries will require either increased energy density or more favourable operating conditions – particularly higher lithium prices – to compete with LFP batteries on a price per kWh basis. Virtually all large-scale (>100 MWh of nameplate production capacity) sodium-ion battery production plants were in China in 2024, and on the basis of announcements, nearly 95% of capacity in 2030 would still be in China. It is therefore unlikely that regions outside China will be able to gain an edge thanks to sodium-ion batteries.

Lithium-sulphur batteries (TRL 5), which can deliver increased gravimetric energy density (Wh/kg) and the substitution of some critical minerals, have recently gained momentum, particularly in the United States. However, they have so far attracted significantly lower levels of investment, remain at an earlier stage of development, and may still require up to a decade of further R&D, given the number of unresolved technical challenges. These include improving volumetric energy density (Wh/L), enhancing durability, and addressing safety concerns related to the use of lithium metal anodes.

In the meantime, the pace of innovation in lithium-ion technologies – driven in particular by Chinese battery manufacturers such as CATL and BYD – has been remarkable and shows no sign of slowing down. Advances in manufacturing, cell formats, pack designs, ultra-fast charging, “no degradation”, and ultra-energy dense batteries, among other innovations, are already shaping market dynamics. The continued evolution of lithium-ion technologies raises the bar for emerging alternatives, which may struggle to gain a foothold if they reach the market too late or fail to offer a clear and cost-effective advantage.

Securing supplies for electric motors and power electronics

Beyond the battery, two other key technologies for electric vehicles are the **electric motor** – which converts the electricity generated by the battery into mechanical energy to power the vehicle – and the **power electronics** (e.g. direct current (DC)/DC converters and inverters). These manage electrical power flows, convert DC power into AC (alternating current) power required by the motor, and control the motor.

Electric motors

Thanks to the high efficiency of their batteries, electric motor and power electronics, battery electric cars have a significantly higher powertrain efficiency than their ICE-based counterparts. ICE cars typically have a tank-to-wheel efficiency of 15-35% depending on driving conditions, meaning that up to 35% of the fuel energy eventually powers the car. Full hybridisation enables powertrain efficiency to reach up to 40% in urban driving conditions thanks to regenerative braking. In contrast, battery electric cars demonstrate a plug-to-wheel efficiency typically ranging from 70-90%.

AC motors have been historically preferred over their DC counterparts in EV powertrains. The two key components of an electric motor are the rotor and the stator, which are typically made of electrical steel (iron alloy based on silicon instead of carbon), copper windings and – for certain types of rotors – rare earth element-based magnets. Several electric motor designs are used in the EV industry today; some of the most common ones are listed below:

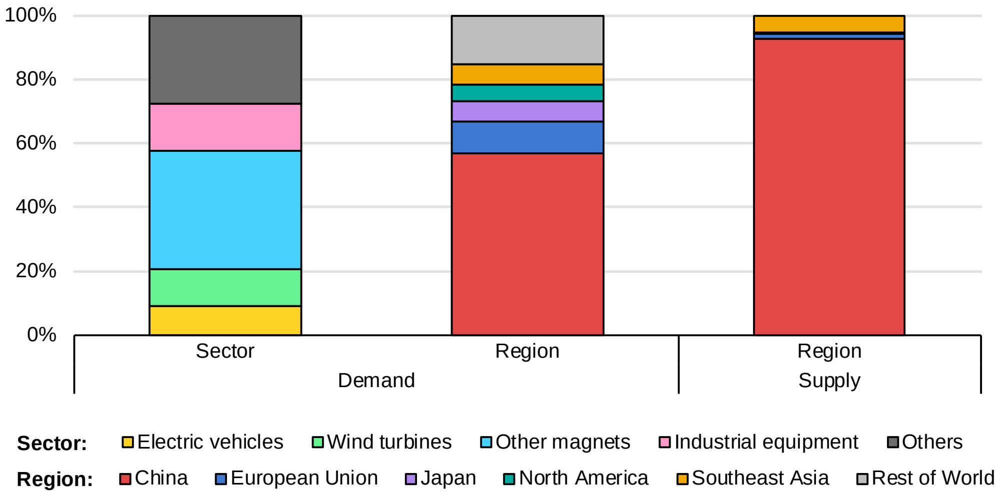
- **Permanent magnet synchronous motors (PMSMs):** These motors use rare earth-based permanent magnets in the rotor and copper windings in the steel-based stator. PMSM is the most common electric motor design today due to its high efficiency at both rated power and partial load, superior power density and generator mode capacities. However, PMSMs are heavily reliant on rare earth elements (REEs). The use of REE-based permanent magnets increases manufacturing costs and exposes the PMSM supply chain to geopolitical and economic risks, given the regional concentration of REE extraction and refining. As of 2024, China accounted for over 90% of global production of REE-based permanent magnets.

- **AC induction motor:** Also known as asynchronous motors, AC induction motors use copper or aluminium windings in the rotor and are propelled using electromagnetic induction. AC induction motors do not use REEs and are generally more cost-competitive, but they typically offer lower efficiency, power density, and control precision compared to motors with permanent magnet-based rotors.
- **Wound rotor synchronous motor:** Like asynchronous motors, the rotors of these motors contain copper windings, but unlike them, these windings are actively powered with a DC current. This requires a supply of electrical power to the rotor, which adds design complexity and wear parts that require maintenance. While not as compact or efficient as PMSMs, they are REE-free, more efficient than AC induction motors, easier to control, and generally more cost-competitive.

PMSMs dominate current EV designs due to their high efficiency and torque density, which makes them compact. Some carmakers combine electric motor types to balance performance and cost. For example, Tesla employs a dual-motor strategy, using a PMSM in the front and an induction motor in the rear to improve traction, handling and overall vehicle flexibility. Some automakers, such as Tesla and BYD, design their own electric motors, and BYD also manufacture them in-house. Most electric motors are produced by European and Japanese companies, including Nidec Corporation, Bosch, Continental AG, and Siemens.

There is no significant structural technology difference or cost gap in electric motor production between Chinese manufacturers and those elsewhere, and motors account for only around 5% of the manufacturing cost of a battery electric car. However, Chinese carmakers and motor suppliers benefit from more secure access to the REEs used for PMSMs, which are the preferred technology choice. In April 2025, following the introduction of higher tariffs by the United States, China – which is responsible for over 90% of global REE refining – announced that it would implement export controls on REEs, impacting the auto industry worldwide. This underscores the potential vulnerability of electric motor supply chains outside of China, particularly since it is not the first time that export restrictions for rare earths have been implemented.

Figure 4.17 **Demand for selected rare earth elements by sector and region, and supply by region, 2024**



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Notes: Rare earth elements here specifically refer to magnet materials (neodymium, praseodymium, dysprosium and terbium). Supply refers to the refined minerals (all applications).
Source: IEA analysis based on data from IEA (2025), Global Critical Minerals Outlook.

To combat this vulnerability, electric motor producers outside China would need to diversify their supply chains and advance alternative motor designs that reduce or eliminate the need for REEs. One approach under development is the substitution of REEs in permanent magnets, for example through ferrite, which is already used in mid-power motors in hybrid electric vehicles (HEVs). This is being explored by companies such as Tesla, and by Niron, with investors including Volvo, Stellantis and GM. Another avenue for R&D lies in improving the efficiency of REE-free motor technologies, including induction, wound rotor, and synchronous reluctance motors, which are developed by companies such as Renault and Mitsubishi Electric.

Power electronics

Electric motors require AC input power, but the battery only supplies DC power. Electricity from the battery therefore needs to pass through DC/DC converters (to boost or reduce voltage), as well as an inverter (to convert DC current into AC current) before powering the electric motor. These components typically rely on power semiconductors used as switches to process and convert the electrical power flows. Several power semiconductor technologies are used in modern power electronics:

- **Silicon (Si) Insulated Gate Bipolar Transistors (IGBT)** are the most common technology used in EV powertrains to date because of their technological maturity and unmatched cost-competitiveness, but have a slower switching frequency yielding lower efficiency in comparison with more advanced semiconductor technologies.

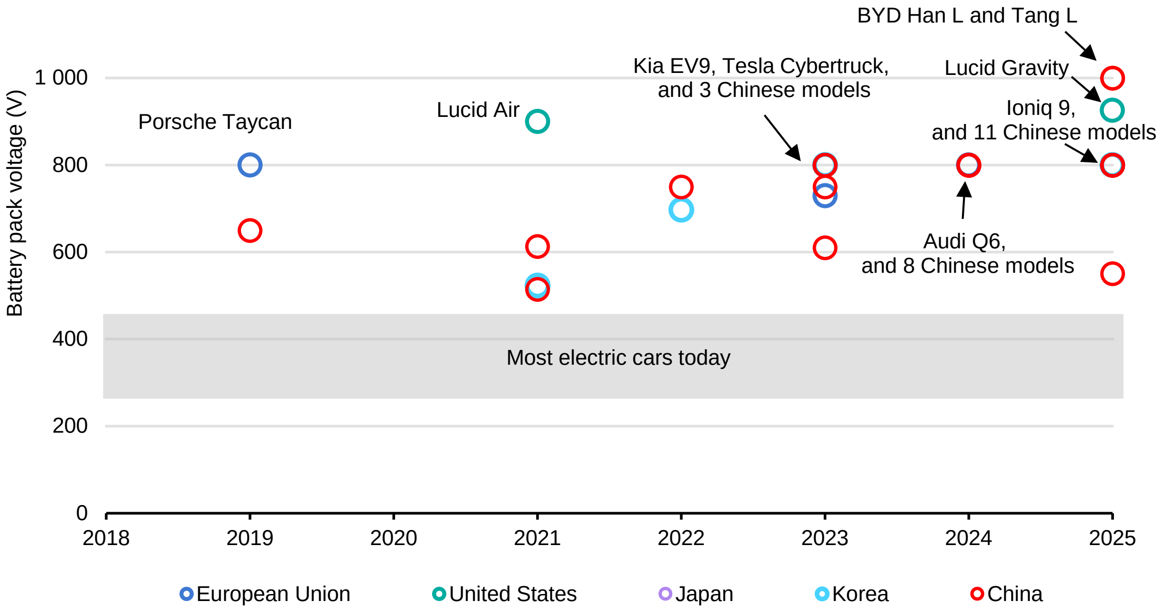
- **Silicon Carbide (SiC) Metal-Oxide-Semiconductor field-effect transistors (MOSFET)** are the second most-used semiconductor technology in EV power electronics. They have higher manufacturing costs but faster switching performances than IGBTs, resulting in higher efficiency. They are particularly well-suited for high-voltage powertrain architectures (e.g. 800 V) typically used in premium electric car models and heavy-duty applications, though not limited to these applications.
- **Gallium Nitride (GaN) high-electron-mobility transistors (HEMTs):** are a nascent semiconductor technology that feature ultra-fast switching performances enabling even higher efficiency levels. However, GaN-based semiconductors are still an emerging and low-scale technology, making them less cost-competitive than their silicon-based counterparts.

Power electronics designs also differ in their level of functional integration. A power electronics combination module (PECM), such as BYD's 8-in-1 power electronics architecture, can integrate multiple functions into one single unit. This approach improves power electronics packaging efficiency, enables shared thermal management across components, and optimises manufacturing costs through system simplification.

Most electric cars today operate ~400 V electric powertrain architectures, for which power electronics components are widely available. However, the transition towards high-voltage electric vehicle systems is accelerating. The first 800 V "high-voltage" production vehicle was the Porsche Taycan, introduced in 2019, in which about 20% of the battery could be recharged in just 5 minutes. By 2021, more models from both incumbent and Chinese carmakers started to adopt similar architectures. In March 2025, BYD set a new benchmark with its Super-e platform, using a 1 000 V architecture. This leap was made possible by the use of next-generation batteries, megawatt chargers, high-voltage silicon carbide power semiconductors, and all-liquid-cooling systems, enabling nearly 60% of the battery to be recharged in just 5 minutes, equal to about 400 km of range.

EVs equipped with high-voltage battery packs continue to be developed outside of China, with notable examples including the Lucid Air, Kia EV9, and Tesla Cybertruck. However, all non-Chinese high-voltage models target the premium segment, with prices typically ranging from USD 55 000 to USD 100 000. While Chinese automakers also offer premium high-voltage models, they have introduced several models priced between USD 15 000 and 35 000, making ultra-fast charging more accessible to mass-market consumers.

Figure 4.18 Voltage range of selected electric vehicles by company headquarters, 2018-2025



IEA. CC BY 4.0.

Notes: The same vehicle model may be offered with different battery packs featuring different voltage levels. For the purpose of this figure, if a model is available with a high-voltage system (>450 V), it is classified as such. Models for which battery pack voltage levels have not been publicly disclosed are excluded.

Sources: IEA analysis based on data from EV Volumes and Marklines.

European, American and Japanese companies such as Infineon Technologies, STMicroelectronics, Wolfspeed, ON Semiconductor, Coherent, and ROHM Semiconductor lead in the design and manufacturing of power semiconductors. All these companies design and produce power modules, and most have in-house production capacity for SiC power semiconductors, which are gaining importance in the EV sector.

The shift towards higher-voltage platforms and the associated transition from IGBT to SiC MOSFET, combined with increasing functional integration, are set to shape the EV semiconductor market in the coming years. In 2023, while Si IGBTs accounted for the largest share of the global battery electric vehicle (BEV) inverter market, SiC-based power modules captured the remaining 30% of the market, and this share is set to grow based on the most recent EV model developments. This trend could give a competitive advantage to certain Tier 1 suppliers, with the five largest Tier 1 suppliers in the growing SiC market accounting for more than 90% of the global market share in 2024. Most of these companies were headquartered in Europe, United States and Japan. In China, EV makers are either supplying their SiC power modules internally, like BYD, or – for OEMs with lower supply chain integration levels – using Tier 1 suppliers from overseas.

Semiconductors used in the automotive industry are not limited to power electronics in the form of inverters, DC/DC converters or on-board chargers. Across all types of powertrain, chips are also needed in low-voltage and low-power applications like powertrain control units, electronic control units for infotainment devices and interior devices (doors, HVAC, lights, etc), and advanced driver assistance systems (such as anti-lock braking, speed control, lane-keeping assistance, etc). Partnerships with advanced chip designers will be increasingly important, but securing a stable and resilient chip supply chain remains critical for the automotive sector, as highlighted by the serious impact of the chip shortages experienced during the pandemic.

The growing role of software in shaping the car industry

While traditionally characterised by a focus on hardware, the car industry has seen the role of software and power electronics grow rapidly over the past decade, with these technologies now as crucial as mechanical engineering. Modern vehicles contain hundreds of millions of lines of code – over ten times more than modern cell phone operating systems and more than twice that of Windows 10.

Software development in the automotive sector supports a wide range of functions, many of which depend on dedicated hardware, such as sensors for advanced driver assistance systems, the use of which is expanding across the industry. Software enhances vehicle control by operating core systems such as the powertrain, braking and steering; assists drivers with features like cruise control, emergency braking, and parking assistance; and – in the case of electric cars – manages the battery to optimise performance, safety and longevity. Software also plays a key role in improving driver comfort, enabling in-vehicle infotainment and more efficient management of heating and cooling systems. As connectivity and digital functionality expand, the demand for robust cybersecurity is also becoming a key priority in automotive software development.

The rising importance of software in the automotive sector is leading investments and demanding different skills. Some market observers suggest that the market for automotive software will grow at three times the rate of the broader automotive market to 2030, and electric and software engineers are playing an increasingly central role alongside traditional mechanical engineering. The growing integration of software into vehicles initially led to expectations that manufacturers could command higher sticker prices, reflecting the added value for drivers. However, increasing competition is making software development a necessity for remaining competitive, rather than a source of additional profit.

This shift is most evident in the industry's transition toward software-defined vehicles, in which software determines vehicle functionality, while hardware remains relatively fixed. Features and performance can be enhanced over time through over-the-air updates in which software and firmware upgrades are delivered via wireless connectivity, without requiring a visit to a dealership or service centre.

Software development requires a fundamentally different approach compared with traditional automotive engineering, creating an advantage for newer entrants that are structured around this model, as well as for incumbent manufacturers that can successfully adapt to it. While conventional vehicle development typically defines specifications early in the design process, software development relies on iterative cycles – introducing a set of features early on, followed by multiple rounds of updates for bug fixes and additional functionality.

Automakers are adopting a range of strategies to strengthen their software capabilities. Companies such as Tesla, GM, XPeng, and BYD emphasise in-house development, while others have established dedicated software subsidiaries, such as ECARX (Geely). Some companies are pursuing multiple approaches. For example, VW initially established a dedicated subsidiary, CARIAD, but has more recently shifted towards a software-focused joint venture with Rivian, while Toyota developed its own on-vehicle operating system, Arene, alongside a long-term collaboration with Aurora.

Autonomous driving is another important area of development, driven by advancements in artificial intelligence (AI), sensor technology, and on-board computational power. Mercedes became the first automaker to receive certification for level 3 autonomous driving in the United States, in which all aspects of driving can be automated, but the driver must remain available to take control if prompted to do so, and the first models are now available in California and Nevada. Meanwhile, BYD has begun incorporating its level 2 autonomous driving “God’s Eye” system into low-cost EV models, while Tesla continues to pursue level 3 and level 4 autonomy, but is limited to level 2 at present.

Competition in the field of software-defined vehicles and autonomous driving is intensifying, with all major automakers investing in auto software and no clear regional disparity. Companies across the United States, Europe and China are all advancing toward similar technological goals. However, the development of next-generation automotive software platforms is unlikely to follow a linear path, as highlighted by Ford’s recent decision to abandon its “fully networked vehicle” project. The success or failure of automakers’ strategies for software architecture will be a key factor shaping their competitiveness and market appeal in the years ahead.

Prioritising electrification in innovation efforts

Keeping up with the technological frontier is of key importance for any firm in the highly competitive car industry. While most incumbent manufacturers from advanced economies have spent many years at the forefront of technology development in the industry, they have been falling behind on technologies related to electric cars.

Car technologies developed over decades

Incumbent car manufacturers have long legacies, in some cases dating back to the invention of the car itself. The first patented ICE vehicle was attributed in 1886 to Karl Benz, a co-founder of Mercedes-Benz. The mass production of motor vehicles began with Henry Ford's Model T in 1908, while contemporary "lean manufacturing" techniques were pioneered by Toyota in the middle of the twentieth century.

Over the decades, industry incumbents have continuously developed all aspects of vehicle technologies, from aerodynamics to vehicle dynamics, engine performance and exhaust emission controls, with intense R&D activity resulting in a dominance of technology and processes. These companies have traditionally invested a larger share of revenue in R&D than companies in most other industrial sectors (see Chapter 2).

One way to gauge the outcomes of R&D is by analysing International Patent Families (IPFs[27,28], referred to as "patents" hereafter) for a given technology by the country of inventor(s). From 1980 to 2001, Europe, the United States and Japan were responsible for 90% of all patents in technologies related to conventional cars. Europe was the leader, accounting for nearly half of all patents over the same period. In the early 2000s, patenting activities in the automotive sector also started to pick up in China and in Korea, but in 2021, Europe, the United States and Japan still accounted for 70% of all patents – indicating a dominance in innovation related to conventional cars.

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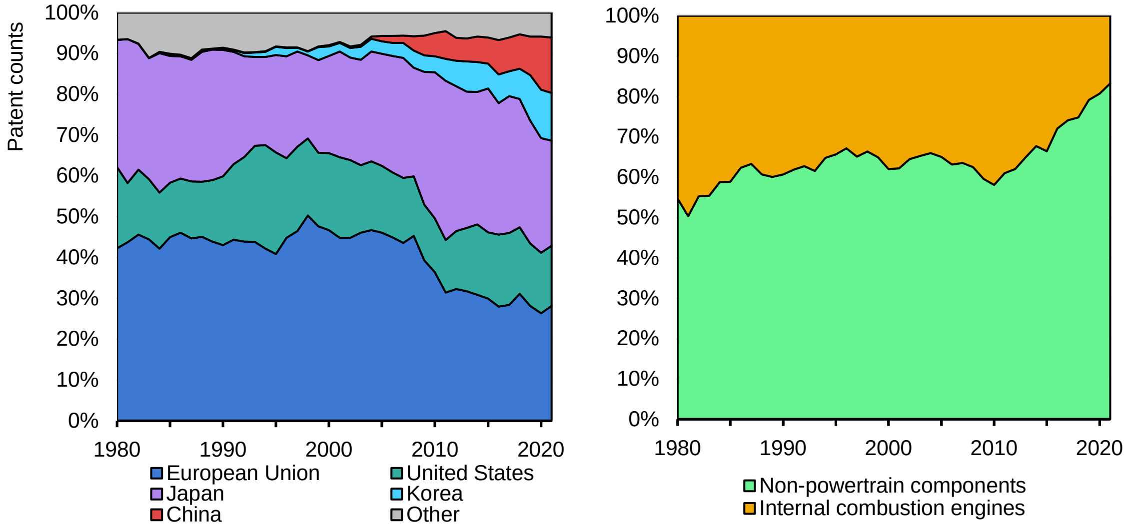
[27] A proxy for a distinct invention, corresponding to a set of patent applications protected in at least two IP jurisdictions, thus ensuring that low-value patents are not included in the counts.

[28] Each patent application is counted according to the fraction of the inventors from a given country (e.g. an application with two inventors living in France and one in Canada would be a patent count of two-thirds for France and one-third for Canada).

Figure 4.19 Share of patent counts relating to conventional car technologies by region and component, 1980-2021



Notes: Conventional car technologies defined in the European Patent Office (EPO) report Patents and self-driving vehicles, and includes the following Cooperative Patent Classifications (CPCs): B60R, B62D, B60K, F02D, B60W, F02M, F02B, F01N, B60J, B60T, B60N, B60G, B60Q, F02F, B60H, F02P, F02N, F16D48, B60B, B60C, B60D, H01T. Internal combustion includes the following CPCs: F02B, F02M, F02D, F01N, F02F, F02P, F02N.

Source: IEA analysis based on PATSTAT patents database.

Since 2010, the number and share of patents related to ICEs have declined as global innovation efforts have refocused on EVs. Until 2010, around 40% of the patents were directly attributable to technologies related to the ICE, while the rest applied to the myriad other technologies that are needed to manufacture a car. In contrast, in 2021 less than 20% of patents related to conventional vehicles were related to the ICE, while the remainder were related to technologies that do not form part of the powertrain. This goes to show that traditional car-manufacturing countries retain a healthy innovation environment for vehicle technologies that are not limited to ICEs.

China has become a locus for electric car-related patent filings, especially for battery technologies

Patenting activity related to EVs was very low until the mid-2000s, but had increased ninefold by 2011 compared to in the 2000-2005 period. Japan accounted for over half of these filings, demonstrating the country's early focus on the development of this technology. From 2015, however, China started to become the global centre for EV innovation and had more than trebled its yearly patenting by 2021.[29] In 2021, 50% more patents on EVs were filed in China than in Europe and the United States combined. Over two-thirds of the patents related

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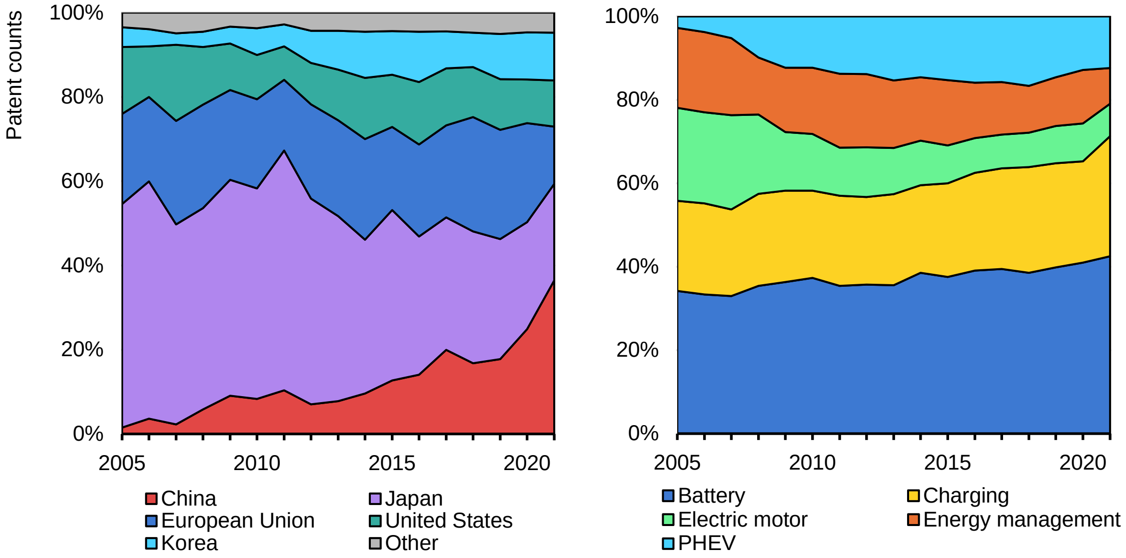
[29] The last year with reliable data for this dataset.

to EVs target innovation in battery and charging technologies (both in terms of charging stations and on-board charging power electronics), while technologies relevant to electric motors and energy management account for around 20% of patents, and the remainder is targeted at plug-in hybrid vehicles.

Figure 4.20 Patenting activity in electric mobility by region, 2000-2021

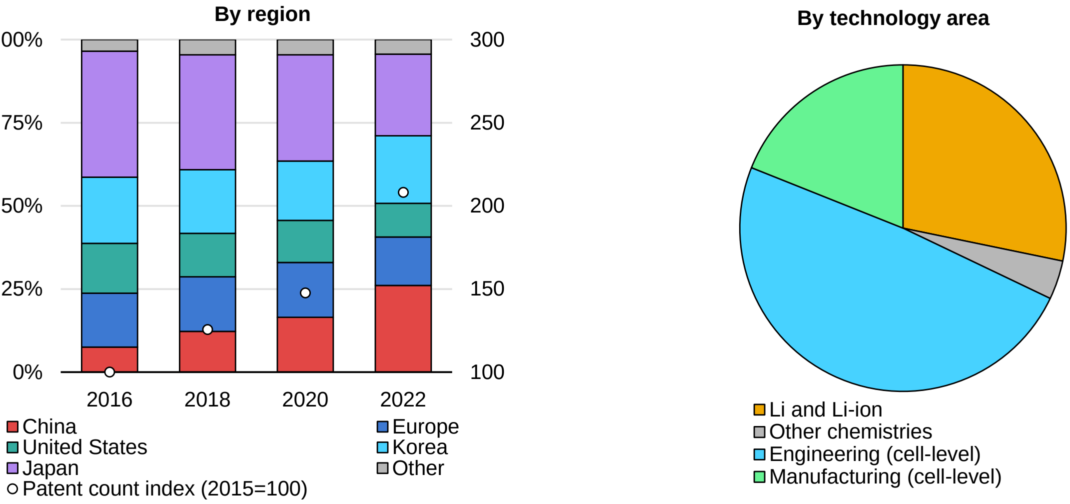


Notes: PHEV = plug-in hybrid electric vehicle. Electric mobility patents are defined as a subset of the Y02T category including the following codes: Y02T 90/167, Y02T 90/14, Y02T 90/12, Y02T 10/92, Y02T 10/64, Y02T 10/70, Y02T 10/7072, Y02T 10/72.
Source: IEA analysis based on PATSTAT patents database.

Battery-related patenting activity has rapidly increased in China, more than doubling between 2016 and 2022. More than one-fifth of patents relating to battery technologies from this period were filed by inventors located in China. Japan and Korea together account for nearly half, which demonstrates the strength of their innovation systems, thanks in part to several leading battery makers being located there.

Importantly, innovation in battery technology is not just about developing advanced chemistries and formulations in the lab. Although innovations related to chemistries account for about one-third of all patents, the majority of innovations focus on engineering and manufacturing technologies for batteries, indicating that mastering this technology is an industrial challenge more than a scientific one. Advanced chemistries beyond lithium-ion, while holding a lot of promise, account for less than 5% of total patenting activity (although this may be partially explained by the early stages of development of these technologies).

Figure 4.21 Patenting activity for batteries by region and technology, 2016-2022



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Notes: In comparison to PATSTAT data, the EPO dataset used here has a smaller time lag in filling applications and is more precise on technologies. However, it is only available for specific technologies.
Source: IEA analysis on EPO data on batteries technologies.

Prioritising R&D for electric cars could accelerate innovation even without extra spending

While Chinese automakers have built up a significant technological advantage over the past 5 years or so, technology can be transferred across borders, and there is no reason why other regions could not reach the technological frontier by prioritising their R&D budgets accordingly. Automakers and Tier 1 suppliers outside China currently account for the vast majority of private sector R&D spending in the car industry (see Investment and R&D trends in Chapter 2). It may therefore be possible to close the technological gap even without increasing spending, but rather through refocusing R&D activity in line with individual company strategy. While this might not be easily accomplished in a short period of time, it could be achievable in the medium term.

Chapter 5. Policy and strategic actions

Highlights

- As global electric car markets grow, countries that are home to car manufacturing operations are faced with the challenging task of ensuring that the industry retains its domestic footprint and international revenues, or even expands downstream to become a larger supplier of final products that add more value to the economy. Among other factors, uncertainty about the pace of electrification and the cost gap with Chinese production mean most countries face tough choices as they pursue near- and long-term strategies to boost industrial competitiveness.
- Where the car industry aims at pursuing electrification strategies, there are public and private sector actions that can help to close cost gaps and ensure competitiveness. These actions cover five key areas: ensuring sufficient demand and capital to unlock economies of scale and “learning-by-doing”; scaling up battery manufacturing and the skills to support it; selecting the most competitive battery chemistries and innovating the next generations; securing dependable critical minerals supplies; and minimising energy costs for manufacturers.
- Each country and region has its own strengths and priorities, and national circumstances vary. But there are five main archetypes that can help explain how differences can inform distinct strategies: regaining ground internationally (e.g. European Union, United Kingdom); sharpening EV advantages (e.g. Japan, Korea); playing to domestic strengths (e.g. Canada, Mexico, United States); investing for balanced growth (e.g. Thailand, Indonesia, Morocco, Brazil, South Africa, Türkiye); seizing new opportunities (e.g. Egypt, Viet Nam, Chile, Nigeria).
- Several of the archetype countries have the opportunity to build on extensive existing capabilities in internal combustion engine (ICE) car assembly and supply chains. Existing industrial clusters and know-how represent a competitive advantage, as well as a source of revenue from ICE vehicle sales as electric car markets ramp up. However, there will also be new opportunities for countries with fast-growing car markets, low energy costs and access to critical minerals. In all cases, it will not be possible in the medium term to stay competitive in a dynamic global market without effective international partnerships.
- Decisions about the future of the car industry must be responsive to fast-evolving conditions, which is a challenge in a sector where it takes years from the initial design of a new car model to its market introduction. Establishing data-driven metrics for tracking progress and early course-correction will be essential to monitor emerging risks and opportunities.

Introduction

The car industries of different parts of the world have distinct characteristics that will shape their responses to this moment of strategic uncertainty. Levels of vertical integration vary, as do the extents of integration with other regions. In some countries, car manufacturers and components and materials suppliers have adapted and integrated to serve a domestic market, one that they have played a role in shaping over many decades. In other countries, the car industry has traditionally been more reliant on imports and exports of finished and semi-finished products, and its companies are more likely to operate factories overseas. In addition, some countries without a strong tradition of manufacturing in many parts of the supply chain are now aiming to secure a foothold that would enable them to supply growing domestic markets and open up the option of exports.

Regardless of the starting point, there is increasing recognition among stakeholders that revenues from ICE cars are challenged by the growing market uptake of electric cars. A transition is already underway in certain countries and market segments, but the timing of any broader market uptake towards largely electrified fleets remains uncertain. Indeed, ICE vehicles are likely to remain dominant in certain market segments and countries for many years to come, yet the interplay between conventional and electric cars is set to play an increasing role in the industry’s financial health over the next decades. Strategic planning must now account for the possibility that revenues from electric cars are set to pull ahead between now and mid-century, posing a challenge for transition planning for many incumbent manufacturers and countries that are home to their operations.

The pace of market uptake of electric cars is dependent on factors including government policy, electric car prices, energy prices and technology and infrastructure availability, which vary between countries – different countries have different circumstances, and so priorities for the near to medium term may differ. However, for both industry incumbents and the new market-entrants that wish to challenge them, the effectiveness of their capital investments in the electric car value chain will influence the extent of the market segments and regions in which they are able to participate.

Today, the car industries of traditional car-producing regions face strategic choices that have been brought into focus by the recent market developments described in this report. The considerable asset value that many companies have built up in the ICE car value chain over many decades has made it harder to prioritise electric cars in their long-term strategy. For new market-entrants, the absence of such a legacy presented an opportunity to fully prioritise electrification in their long-term planning. A divergence in the competitiveness of China and other regions in battery and car manufacturing has emerged over the past 15 years and, more recently, it has become clear that the competitiveness of Chinese firms is also rooted in a lower profit threshold and shorter model-planning cycles than their overseas rivals. The technological know-how of Chinese firms and their critical mineral supply chains are now hard to sidestep for any company seeking to make competitively-priced electric cars this decade. As exports of Chinese ICE and electric cars have rapidly expanded and are gaining larger market shares, including through electric car sales in other emerging markets and developing economies, the sales of cars from incumbent original equipment manufacturers (OEMs) are further challenged.

There are many uncertainties in the outlooks for ICE and electric cars on a 10-year horizon, but the strategic decisions taken today in traditional car-making regions will determine their options to compete for market share at home and abroad, not least in view of the long planning cycles involved for developing new vehicle models. These are not easy decisions: there are no obvious, low-risk strategies for capital allocation for most firms, and yet insufficient or delayed investments due to uncertainty could lead to a loss of competitiveness. More broadly, this could threaten government objectives relating to economic growth and jobs, as well as air pollution and climate change.

Governments can take action to address these challenges, but choices are not straightforward – not only because of aforementioned uncertainties, but also because actions must be co-ordinated between decision makers in the areas of environmental regulation, tax policy, regional development, industrial and trade policy, innovation spending and electricity market regulation. Nonetheless, there is a growing realisation that there is a narrowing window of opportunity for doing so.

This chapter outlines some of the main overarching elements of such a policy package and how they might differ depending on the nature of a country's existing car industry. Of course, governments cannot act alone, which means that the policy recommendations in this chapter are aimed at key decision makers in governments working together with their counterparts in the relevant corporate sectors and with labour representatives.

Strategic policy questions being asked by governments in 2025

In the IEA's discussions with governments in recent months, we have heard several key questions that are at front of policy makers' minds. While the answers they settle on will vary across different national and regional contexts, the questions cover some common themes, and an illustrative list is provided here:

- At what share of imports of components, batteries or cars do risks to supply chain resilience and economic security become unacceptable?
- What are the trade-offs between maintaining ambitious deployment targets for electric cars that mean investment risks must be taken for factory conversions and technology choices, versus relying for longer on the existing assets of incumbent ICE producers?
- Is it possible to develop domestic battery and electric car production value chains that can be internationally competitive in the 2030s while ensuring that prices are affordable?
- How many value chain steps – from mining to vehicle assembly – must be located domestically (or among valued trading partners) to ensure resilience?
- Is there a single factor, such as energy prices, that could be key to shoring up the full supply chain, from steel and aluminium to batteries and car assembly?
- If public resources are used to support battery manufacturing, would it be better to support lithium nickel manganese cobalt oxide (NMC), lithium iron phosphate (LFP) or other battery chemistries?
- What are the risks and potential benefits of securing manufacturing competitiveness through partnerships with the leading and most experienced battery and electric car manufacturers from overseas?
- What car industry investments will have the biggest impact on maintaining employment in the related sectors of metals, chemicals and components?
- Should domestic companies be supported to establish plants abroad – especially in emerging markets – to prioritise exports, or to focus on the home market?

This chapter cannot answer all these questions precisely – there remain many unknowns in most markets. However, it lays out a set of key priorities to be considered in different regions.

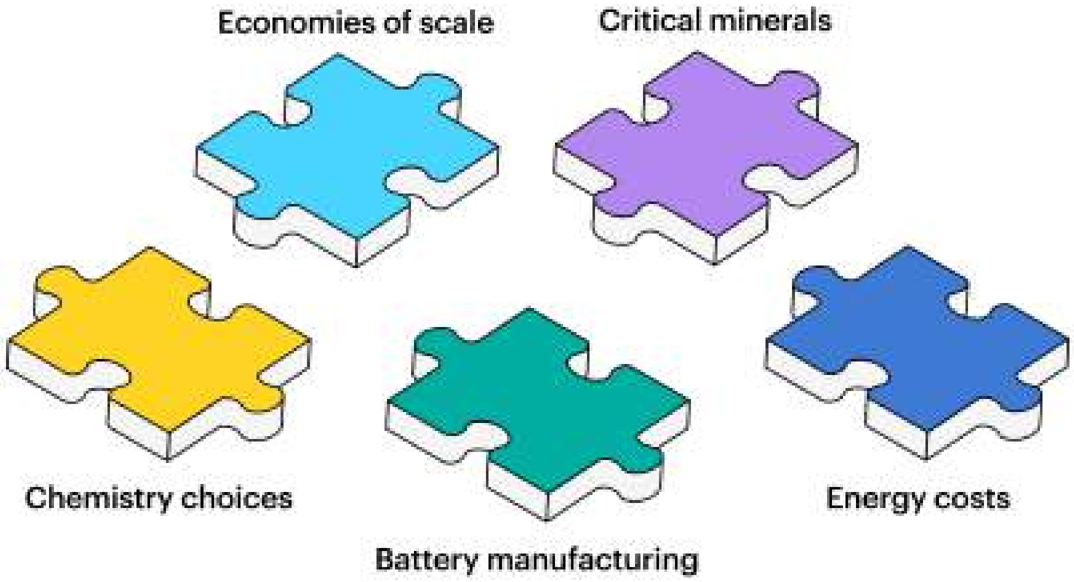
5.1 The competitiveness toolbox

This chapter is relevant to all countries that seek to host a competitive car industry in the 2030s – whether serving mainly the domestic market, producing for exports or manufacturing overseas – but which face strategic risks in key car market segments. In relation to electric car manufacturing, many of the risks relate to achieving price parity, which has two dimensions:

- the price gap between domestic production and imports, notably those from China.
- the price gap between electric car prices and what consumers are willing to pay, which is today represented by an ICE benchmark in most countries outside China.

The goals of related policy and strategy decisions in the car industry today focus on narrowing these two price gaps.[30] While IEA analysis shows that there is no single approach that will be able to fully bridge the gap in any country, there are several ways in which costs can be reduced in the short, medium and long term. Of course, it is essential to think about competitiveness in dynamic terms: there is no reason to believe that today's most cost-competitive producers will not continue to innovate and find means of improving their own competitive positions in the coming years. The set of different approaches should therefore be understood as a "toolbox" from which a package of policies will need to be assembled.

Figure 5.1. The toolbox of strategic priorities for reducing price gaps in the car industry



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Reaching economies of scale and learning-by-doing

Economies of scale and learning-by-doing are two powerful and proven industrial effects that can be expected to drive down costs as manufacturing scales up. For example, they are widely considered to be responsible for most of the cost declines for solar PV in the past two decades, with more impact than those resulting from important innovations in the underlying cell design. Unless demand and investment conditions enable car manufacturers to produce electric cars at scales of similar magnitude to ICE cars, they will have a lower chance of achieving

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[30] One exception is the strategy of developing new services for car drivers that can command a premium price, such as autonomous driving. However, this exception is not covered in detail in this chapter as the underlying vehicle remains subject to the same competitiveness principles.

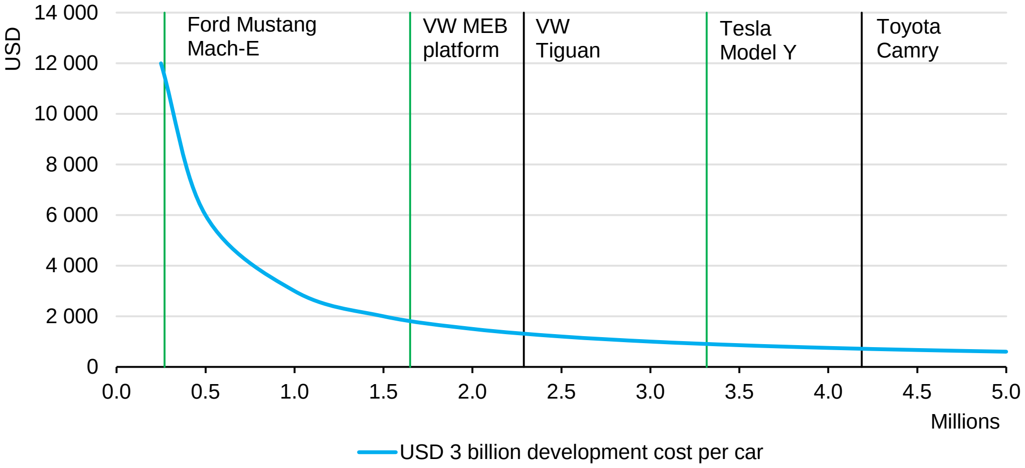
competitiveness. This is of particular importance for car assembly and battery production, but also other mass-produced components.

Economies of scale refer to the savings that can be made by spreading capital and fixed operational costs across a larger number of units of output. For plants where manufactured goods are produced on uniform production lines, economies of scale are generated by fixed costs and variable costs that scale more gradually than the increase in production capacity, including:

- R&D, testing and advertising expenses for a new model
- Infrastructure, including car-carrying trucks, barges and ports
- Management and supervisory staff
- Land and permitting
- Investments in automation
- Contracting for raw materials and offtakers
- Office utilities
- Costs of capital.

The costs to develop a new car model and set up a factory for its production vary widely between models. Exact values are commercially sensitive, but publicly available estimates range from USD 1 billion to USD 6 billion to develop a new model. To increase economies of scale, some carmakers develop “platforms” that can produce several models with only limited variations between them. For mass-market vehicles, it is typical to sell over 2 million vehicles for each model (or “platform”) over the course of 5 years. This is, however, not always the case for electric models, which can result in much higher development costs per vehicle if production runs are lower. For example, if development costs were USD 3 billion this would translate into USD 2 000 per vehicle if 1.5 million are sold in total, but USD 6 000 per vehicle if just half a million are sold.

Figure 5.2. Variation in development costs per car for different levels of production of a model



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Notes: Green lines show battery electric model platforms. Assumes fixed costs of USD 3 billion for all new models, shared equally across all output. Ford Mustang Mach-E (2020-2024), VW MEB platform (2019-2024) [Q4-etron, Q5-etron, Born, Tavascan, Enyaq, Elroq, ID.3/4/5/6/7, ID.Buzz], VW Tiguan (2019-2024), Tesla Model Y (2020-2024), Toyota Camry (2017-2024) [XV70 version].

Learning-by-doing is the process in which manufacturing is actively improved by the people who are engaged in its operation, such as by reducing waste in the production process or running conveyor belts at a higher speed. It includes any incremental technical innovations to a product design or substantial innovations in manufacturing processes that address constraints on production speed or sources of interruption. Much of China’s competitiveness in battery and electric car manufacturing has been accumulated through learning-by-doing as firms manufactured more units and, in parallel, innovated new ways to make their processes more reliable and competitive with those of their rivals. While the outcome of learning-by-doing is uncertain and depends on how easily knowledge is shared within a sector, its magnitude is related to scale: you do not start learning-by-doing until you start doing, and the more you do, the more you learn.

At a national or regional level, significant economies of scale can result from integration and more efficient use of shared resources. An industrial cluster can share infrastructure and operational costs, including those relating to utilities, whether they are onsite or secured via power purchase agreements (PPAs). As an industrial cluster scales up, it attracts suppliers and offtakers that wish to co-locate, reducing transport costs for materials and transaction costs for contracts. Dialogue between co-located firms – or those in regional proximity – can reduce risks related to customer preferences and help guide R&D efforts towards the needs of clients. However, this must be balanced against the possibility that interdependence reduces firms’ resilience to shocks that affect the local ecosystem.

Salient example: economies of scale in China's electric car manufacturing expansion

Between 2015 and 2024, China's electric car market grew from 200 000 sales per year to 11 million. This was largely the result of a policy environment that, despite several overhauls, gave a clear signal that market growth would be supported by national and provincial governments. Carmakers wishing to sell into this market as it scaled up could build ever-larger factories with minimal risk of exceeding market demand, as long as their products remained competitive. The strong incentives to scale up to large plant sizes encouraged the development of regional industrial clusters for batteries and components, as well as reducing costs through learning-by-doing. Today, the biggest EV factories in China can make over 1 million cars per year, compared with 0.1 to 0.6 million cars for typical plants outside China, most of which do not currently operate near full capacity.

The need for Chinese carmakers to expand quickly and secure market share also influenced company strategies. Given that not all firms would be able to service only the most profitable premium segments to cover the higher upfront costs of electric cars, carmakers had to work out how to compete for the custom of mass-market consumers. Due to the lower margins in the cheaper car segments, it was essential for them to develop lower-cost designs and manufacturing methods, and turn them into mass-market products with huge volumes of sales per model.

There are important lessons from China's experience of creating a large and dependable market through demand-led measures, which spurred economies of scale and learning-by-doing, making it a formidable global competitor. However, it would be a mistake to ignore some downsides of China's approach to driving cost reductions through cut-throat competition between firms and between their host provinces, which provide low-cost finance to local champions. One downside has been a high bankruptcy rate, which is a drag on the benefits of such policies to taxpayers. Since 2018, 400 of 500 new Chinese EV companies have reportedly gone bust.

Actions for government

To create a dependable market environment for investment in larger total production volumes and more integrated supply chains, governments can:

- Build a domestic market for electric cars by setting clear and ambitious deployment targets, along with various supportive measures, including legal instruments.
- Increase domestic consumer demand for electric cars through measures such as fuel economy or emissions standards, consumer grants, tax incentives, fuel taxes

and electricity tariffs, differential vehicle registration taxes, differential road and parking pricing, and investment in charging infrastructure.

- Reduce costs associated with first-of-a-kind manufacturing investment risks to drive more private capital into large production plants. Instruments can include junior or concessional debt, financial guarantees and tax incentives. Performance-based elements, such as delayed payback schedules if output milestones are achieved, can encourage competitiveness.
- Support overseas investment by domestic firms via export credit agencies and counter-guarantees.

Actions for industry

- Develop strategies for producing and selling mass-market vehicles that can compete with compact ICE options and cheap electric car imports.
- Work closely with suppliers on multi-year roadmaps to help co-ordinate investments through the supply chain and provide as much offtake certainty as possible.
- ICE carmakers should ensure that revenues from the market segments and countries that are most resistant to change can help fund the transition to long-term electric car competitiveness.

Scaling up battery manufacturing and related skills

The battery is the most valuable part of an electric car, and an important component of hybrid cars. In the EV supply chain, battery manufacturers capture a large amount of the cashflow. If batteries are imported, a big part of the retail value of cars in a market flows out of the country. Sudden jumps in battery prices or supply disruptions can lead to reduced vehicle availability – as occurred with semiconductors for cars in 2021 – and negatively impact consumer perceptions. In addition, batteries play other vital roles in the energy system, including ensuring electricity grid reliability, a task for which many grid operators would prefer to have batteries produced locally to known security standards.

However, as described in Chapter 4, establishing a competitive local battery manufacturing sector is highly challenging. Due to discrepancies between countries in terms of minerals endowment and energy prices, the task tends to become harder with every step upstream in the value chain towards energy-intensive raw materials processing that a company or government wishes to integrate within its domestic sector. However, the review of battery cost components in this report indicates that much of the price gap between domestic production and Chinese imports could be closed, even in relatively high-cost regions such as Europe and Japan. To do so will require best-in-class performance across a range of factors, including automation, access to minerals and economies of scale. While this is challenging, the car industries of Europe and Japan have been operating best-in-class supply chains for many decades.

Some recent experiences with trying to establish cutting-edge battery manufacturing have demonstrated that steep learning curves must be scaled when the location does not have an existing foothold in the market. By contrast, the main Chinese, Korean, and Japanese battery manufacturers have already had many years to develop specific technical and managerial skills for increasing yield, reducing defects and responding to underperformance.

New market-entrants face several inevitable hurdles when scaling up in a new location. These include their lack of operational experience and the absence of experienced equipment suppliers and troubleshooters nearby. It can take 5 or more years to reach nominal production capacity in new battery production facilities. Until companies reach steady-state growth, equipment and component suppliers do not have enough certainty of demand to establish local bases. This puts any newcomer at an immediate disadvantage, albeit one that is surmountable with patient capital and strategic planning. Northvolt, for example, ran out of working capital before it could learn from its initial experiences.

In the medium to long term, battery manufacturing competitiveness will derive from innovation, much of which is already underway within the leading companies. Continual innovation – driven by competition and slender margins – will doubtless improve factory productivity in the coming years, in ways that may be unanticipated today. Countries with competitive battery manufacturing will be those with companies operating at the forefront of artificial intelligence-led process control, conveyor speed optimisation and precision robotics, among other things. Targeted government support for these types of technological projects, which have not traditionally been considered within the scope of industrial research, can help confer an advantage. Worker mobility can also be a motor of manufacturing innovation, as operators and technicians are conduits for ideas when they move between factories and firms. While there are some structural barriers to worker mobility in China, competition and turnover among companies in its battery and car industries can result in high levels of personnel movements in pursuit of new opportunities. Ensuring that experienced staff have suitable incentives to join new ventures should be considered as a part of innovation policy in this area.

Salient example: Teething problems turn to disaster for Northvolt

While it is not representative of all battery manufacturing experiences, the experience of Northvolt, as a new entrant in Europe, is instructive. Established in 2015 to build large-scale EV battery factories and demonstrate the feasibility of gigafactory production in Europe, the company filed for bankruptcy in March 2025 after failing to scale up operations in Sweden and Germany as planned. Between 2017 and the end of 2024, it raised nearly USD 5 billion of equity and almost USD 25 billion in debt, grants and other forms of finance, including about USD 8 billion in public funding. This funding came from 9 corporate partners, 7 governments, 6 pension funds and 19 other investors.

Northvolt's plan was to become a producer of cathode active material, electrodes, battery cells, and battery energy storage systems, all with high standards for sourcing and clean energy inputs. It successfully began production in 2022 in Sweden and reached significantly less than 1 GWh of lithium NMC cell output by 2024. It had raised funds to help expand its 16 GWh plant in Sweden, and to open plants in Canada, Germany and Poland. It also signed PPAs for renewable electricity for its factories. However, the pace of scale-up repeatedly slowed due to unanticipated problems with yield, quality and technical integration of the plant. This led to the cancellation of contracts with major European OEMs and the depletion of financial reserves.

One factor – not the only one – that affected Northvolt's ability to scale up as planned relates to its relationships with suppliers of machine tools. These were Asian firms and global market leaders, but they were not integrated into the local industrial ecosystem to the same extent as for their domestic operations. In the case of certain critical items of machinery, they were not on hand to troubleshoot problems that arose. Northvolt's story is by no means a lesson about the infeasibility of producing batteries in Europe – there are many plants already operating successfully – but it provides insights into the importance of involving experienced partners, ensuring local expertise, planning expansion carefully, and having contingencies for unexpected delays during several years of commissioning.

Actions for government

To support the growth of a competitive domestic battery manufacturing sector, governments can:

- Use government resources – such as investment tax incentives and financial guarantees – to help new manufacturers to steadily climb the learning curve in their first years of operation. If support is to be linked to output, allow a grace period before penalties for underperformance kick in. Where there are clear criteria and processes for their eventual phase-out, trade policies may help support the early stages of domestic investment and competitiveness in an emerging sector, though the economic efficiency of such measures depends on their design.
- Support and guide the private sector's efforts to forge domestic manufacturing joint ventures or licensing deals with leading overseas makers and align them with

government priorities. While this can be a delicate issue, and the approach must be tailored to national situations, disparities in experience and expertise mean that many governments may need to balance market access against long term know-how gains (in the form of faster production scale-up and access to the latest technologies) and taxpayer value. Intellectual property, integration into regional value chains, use of cutting-edge technology and staff training will need to be considered.

- Encourage the domestic establishment of suppliers of machine tools for large-scale battery manufacturing. Ensure that any public funds are directed to projects that share their scale-up experiences with government funders as they proceed, and that commit to training a local workforce of technical experts in installation and maintenance.
- To share scale-up risks, develop partnerships with key trading partners who either have more experience of battery manufacturing or are embarking on a similar trajectory. For example, long-term outcomes are likely to be best served by co-operating with neighbours in a region, despite short-term incentives to compete for battery-related investments.
- Invest in programmes, including car industry reskilling initiatives, that train workers for battery production skills. Where possible, facilitate the movement of staff between similar facilities and limit the barriers to worker mobility.
- Carve out funds within innovation programmes to be dedicated to the technology required for cutting-edge battery manufacturing, including automation, flexibility, quality control and speed of throughput.

Actions for industry

- Plan for longer battery factory commissioning periods than best-case-scenarios and secure a capital buffer to cover such eventualities.
- Deepen relationships with machine tool suppliers within regional clusters, and others in the value chain, to conduct joint R&D and ensure rapid and expert troubleshooting in case of unforeseen challenges.
- Help workers to gain experience in similar factories elsewhere – such as those operated by joint venture partners – as part of professional exchanges.
- Work on metrics for demonstrating supply chain resilience and show how they are contributing to improvements over time.

Adopting the most competitive battery chemistries

In battery and electric car manufacturing, scale-up risks are compounded by the possibility that the chosen battery chemistry could be made uncompetitive by the technological advances of competitors or the choices of customers. While it appears highly unlikely that there will be a single winning chemistry for all future electric cars, the size of the market that a given chemistry can address can change quickly. This consideration has become more pronounced with the emergence of lithium iron phosphate (LFP) chemistry as the leading technology in Chinese electric cars, conferring a significant cost benefit without an equal performance disadvantage. As described in Chapter 4, in early 2025, China placed export controls on the latest generation of LFP cathode production process equipment, a technology for which Chinese companies now hold the intellectual property despite LFP being first identified in North America in 1997. While construction of LFP production plants overseas by Chinese firms appears to be proceeding, the costs for entering the LFP business outside China have been significantly raised. At the same time, imported compact Chinese electric car models that contain LFP batteries carry very attractive prices for consumers in many countries who are looking for an affordable electric car. These prices are typically not achievable with other battery chemistries and manufacturing costs outside of China.

As the markets for electric cars grow in major car-producing economies, competition for sales share will increasingly focus on more affordable car models for mass-market consumers. The car industries of these countries will need a two-pronged strategy: first, a supply of batteries that can keep car costs affordable must be secured in the near term, whether domestically or from overseas; and, second, longer-term investments in next-generation battery developments to build competitiveness into the next decade.

A primary reason that both parts of the strategy are required is the importance of customer relationships and manufacturing know-how in the EV battery sector. Battery chemistries that are not yet in serial production – such as solid-state batteries – are unlikely to supply more than a small fraction of car sales in any region in less than 5-7 years from now. This time horizon is equivalent to the car model-planning cycles for major OEMs (outside China), who already know which models they will be making in 2030, if not precise volumes. The need to accommodate new types of batteries in this schedule of car model-planning slows the speed with which they can scale up. In the meantime, the manufacturers of existing lithium-ion battery types will be gaining an ever-greater competitive edge in supply chain integration and operational capabilities as several million additional electric car sales are added each year. These factors will only make it harder for a new manufacturer with a new battery chemistry in the 2030s to disrupt the market and become a major global player.

For firms, ownership of cutting-edge intellectual property can be compared with countries' possession of critical mineral resources. In both cases, firms and governments alike must decide where in the value chain for intellectual property or critical minerals they wish to stand. In both cases, the value of investments can be quickly eroded by innovation in battery chemistries. However, in the case of intellectual property, innovators that can continually tailor new battery chemistries to customer needs can create new and long-lasting economic opportunities from anywhere in the world.

As described in the IEA report The State of Energy Innovation, there are cathode, anode and electrolyte designs at different stages of development today that can potentially avoid minerals with highly concentrated supply chains or further improve performance. Some partnerships between battery makers and OEMs have already communicated the late 2020s as a target for starting serial production of energy-dense solid-state batteries for electric cars. The potential benefits of new chemistries in terms of additional range, improved safety, reliance on abundant materials, recyclability or, in some cases, costs, are potentially large and mean that the sector will remain dynamic, but competition with established chemistries will remain fierce.

Salient example: how LFP batteries got their big break far from home

The story of LFP cathodes illustrates how battery innovation is not only about the invention of new technologies but also about their competitive integration into a dynamic supply chain. The LFP cathode was first identified in 1997 by researchers in the United States, and further developed in Canada and the United States through the early 2000s to overcome its initially low electrical conductivity. Today, it represents around three-quarters of the Chinese EV battery market, double its share in 2020. Its more than 10% share in 2024 in the European Union was more than twice that of the previous year. However, this does not mean that its inventors have profited from this eventual success.

The first tonne of LFP was made in Canada in 2001, where a commercial plant started operation in 2006 using a solid-state process. A subsequent cathode factory was opened in Canada in 2012 with support from the Canadian government, using German hydrothermal technology. However, the LFP produced provided insufficient electric ranges for North American electric carmakers, who preferred the higher energy density NMC chemistries. Due to tight control of LFP intellectual property, its rate of improvement slowed as scale-up stalled.

Chinese firms invested in further scale-up under a more favourable intellectual property agreement for domestic LFP production and use. They were attracted by its lower costs and avoidance of vulnerable cobalt and nickel supply chains. Today, nearly all global production is in China, where manufacturers have achieved a globally dominant market position through extensive expertise and refinement of the solid-state process. In the meantime, other Chinese-led innovations, such as new cell formats, cell-to-pack and cell-to-body configurations, have supported the rise of LFP in EV applications, and together with advances in LFP chemistry, have led to an estimated 65% increase in LFP EV battery pack energy density between 2020 and 2025.

The Chinese government implemented export controls on advanced LFP cathode materials in July 2025, and announced further restrictions in October 2025 (which were subsequentially postponed). The absence of producers of high-energy density LFP cathodes outside China means that the uptake of this technology elsewhere is at risk.

Actions for government

To foster battery manufacturing and innovation that drives competitiveness and affordability, governments can:

- Work with the private sector on business environments for manufacturing today's cost-competitive chemistries close to car assembly centres, while maximising domestic learning.
- Use grants, loans, equity and prizes to continue to advance next-generation technologies, and link funding to their manufacturability, for example by making it contingent on partnerships between innovators and producers.
- Where there is an agreed need and insufficient private capital available, consider supporting the establishment of pilot facilities that can replicate the manufacturing of different battery cell types, thereby generating insights for firms to select or scale up chemistries that are not already made domestically.
- Incentivise battery and battery component manufacturers that are active in the country to invest in R&D facilities and projects in the same region, in co-operation with other domestic firms where appropriate.

Actions for industry

- Develop business cases that support licensing and partnerships with leading producers of cost-competitive batteries.
- Evaluate the present value of past investments in more expensive chemistries and whether they are likely to struggle when the production lines come online.
- Ramp up testing and partnerships for next-generation chemistries in line with OEM electric car model-planning cycles.

Securing dependable supply chains for critical minerals

As described in this report, most countries have an opportunity to become competitive manufacturers in important parts of the car industry, from components to assembly. Manufacturing can be geographically mobile, driven by innovation, experience, supply chain integration and cost control. The key exception to this is upstream – critical minerals and essential bulk metals are not evenly distributed and are typically energy intensive to process. Today, their supplies are highly concentrated among a small number of countries. In 2025, shortages of rare earth magnets for vehicle motors and other components disrupted car production at some plants in Europe, India and elsewhere, after China applied export restrictions. In the case of critical minerals, which are a small factor in total car costs, ensuring reliable supplies for continual industrial operations can be more important than securing the lowest prices.

Despite reasonable goals to eliminate dependencies on suppliers that are apt to wield market power in this way, for most car markets around the world this will take many years, if it is possible at all. The interim period, as diversified supply chains are built up, will be crucial for determining long-term competitiveness.

Any policy or strategy for narrowing the price gap for electric car production must have a strong component relating to the security and availability of critical minerals supplies. This especially concerns lithium and copper, and also, depending on the chemistries pursued, cobalt, nickel and manganese. Some regions will have the ability to develop their own mineral production, for example by extracting lithium from geothermal brines, but scaling up these resources will take time and may never cover the full demand of the domestic market. Therefore, each government and company will need their own near-term and medium-term strategies. In the near term, the strategy should focus on ensuring that critical mineral supplies are not a constraint on their overall car industry planning. To secure battery and mineral supplies, OEMs have already developed several different approaches (see Strategies to secure battery and mineral supply in Chapter 2). In the medium to long term, the strategy will focus more on technological and regulatory developments that can increase local minerals supplies, reduce demand via changes in battery chemistry and electric motor design, or increase recycling. Integrated into such strategies will be requirements relating to the environmental and social impacts of mining and processing.

Building up a recycling sector will be an integral part of many governments' critical mineral strategies for batteries and rare earth metals for other car components, but it is neither straightforward nor a panacea. As described in the IEA report EV Battery Supply Chain Sustainability, while battery recycling is important for the longer term, it will not be able to make a significant contribution to meeting battery demand this decade. Today, most recyclable material comes from factory scrap, not used batteries, and even with government support, hosting recycling plants in places that could benefit from alterative supplies of critical mineral resources will take time to put in place.

Salient example: The EU Global Gateway supports investments in partner countries to help them achieve the highest standards

Launched in 2021, the EU Global Gateway initiative recognises that the European Union will continue to rely on imports of certain goods, including for clean energy applications, but that EU demand for these goods comes at the risk of environmental and social harm in exporting countries. To help resolve this tension, the European Union will mobilise up to EUR 300 billion (USD 350 billion) for projects that support its partners to develop sustainable and high-quality digital, climate and energy and transport infrastructures and strengthen health, education and research systems, taking into account their needs as well as the European Union's own interests. The aim is to invest in projects that can be delivered with high standards, good governance and transparency, while ensuring financial sustainability.

Among 138 projects begun to date under the initiative, several relate to critical minerals. These include value chain development for lithium in Argentina, and for lithium and copper in Chile; capacity building in Central Asia; a partnership with the Democratic Republic of Congo for an electricity interconnector project to support a mining region; development of a bauxite mine and refinery in Ghana; a partnership with Kazakhstan; a partnership with Namibia; and a roadmap with Zambia. Most of these multi-year projects are currently in the planning phase.

In addition, in 2024 the European Commission adopted a regulation on a framework for ensuring a secure and sustainable supply of critical raw materials. Under this framework, it invited applications for strategic projects in third countries and listed 13 selected projects in June 2025. Of these, 11 relate to battery minerals and 2 to rare earth elements. The projects are located in Brazil, Canada, Greenland, Kazakhstan, Madagascar, Malawi, Norway, Serbia, South Africa, Ukraine, the United Kingdom and Zambia. They will need funding support for their implementation.

Actions for government

To ensure that critical mineral supplies do not become a constraint for competitive electric car manufacturing, governments can:

- Co-operate with critical mineral producing and processing countries to support supply chain diversification goals and facilitate access to battery minerals at competitive prices. This could include facilitating foreign direct investment by companies in producer countries, for example by underwriting offtake contracts or offering export credit instruments.
- Support R&D and investment for scaling up alternative or domestic sources such as geothermal lithium and recycled content. To support recycling, these strategies can be backed with regulations on end-of-life battery options. These actions should be integrated into wider strategies for critical minerals based on realistic assessments of the contributions of these sources to total domestic supply chain resilience, as well as contingency planning.
- Incentivise the production of smaller cars, which require smaller batteries and therefore fewer critical mineral inputs. Car weight taxes are a measure that has been adopted in countries such as France and Norway.

Actions for industry

- Work with suppliers on multi-year roadmaps to help co-ordinate investments and streamline material testing.

- Work with suppliers in public-private partnerships to develop dependable standards for social and environmental considerations that reduce investment risk.
- Dedicate R&D budgets to innovative battery chemistries and electric motors that require fewer critical mineral inputs, including via joint ventures and partnerships.

Minimising energy costs

As described in Chapter 4, energy costs accumulate at each step of the supply chain, from material production to the manufacturing of parts and components. When excluding energy for material production, the energy costs for producing an electric car are 30-60% higher than for an equivalent ICE car, and the energy intensity of the battery-making process accounts for nearly all of the difference. The threefold difference in energy prices between Germany and the United States demonstrates how energy prices can influence siting decisions for new manufacturing plants.

However, guaranteeing cheaper energy for all manufacturing steps is not an effective way to close price gaps. Firstly, even in Germany, energy costs represent less than 4% of electric car production costs, while the difference in production costs between Germany and China is around 60%. Secondly, much of the benefit would be gained by directing public resources to securing cheaper energy prices for a small number of energy-intensive steps. These steps include steel production, aluminium smelting and making battery electrode active materials.

Regions that import most of their fossil fuels face a particular challenge to continuing to attract investment in all parts of the car industry value chain. At the same time, the twin trends of renewable electricity cost declines and electrification of industrial processes – including direct or indirect electrification of steelmaking, and innovations around dry electrode processing (for battery-making) – present opportunities for cost control and product differentiation on environmental criteria.

Salient example: Power purchase agreements as a means of reducing energy price volatility and costs for heavy industry

Governments including the European Commission are taking steps to help heavy industrial electricity users to sign competitive PPAs in future and penalise more carbon-intensive suppliers. So-called hybrid PPAs are also emerging as a means of contracting for stable electricity supplies from solar PV or wind energy paired with energy storage.

Partly inspired by shutdowns of energy-intensive plants in Europe due to high and volatile energy prices in 2022, the European Commission recommended that Member States should remove any unjustified administrative or market barriers to corporate purchase agreements of renewable energy. It followed this with a regulation in 2023 that requires Member States to facilitate PPAs as part of wider electricity market arrangements, and allows guarantee schemes to be created to reduce PPA risks.

The result of such measures could be more examples of PPAs in the battery sector, following those signed by Umicore in 2022 and 2023 for wind power to run plants in Belgium and Poland for cathode active materials production, metals recycling and research.

Actions for government

To help minimise the impact of energy costs on car manufacturing, governments can:

- Focus on where energy costs matter the most, in particular emerging industries such as those producing battery components, rather than blanket subsidised tariffs.
- Structure electricity markets so that large users have access to cost benefits and lower price volatilities for renewable and nuclear power in the medium term.

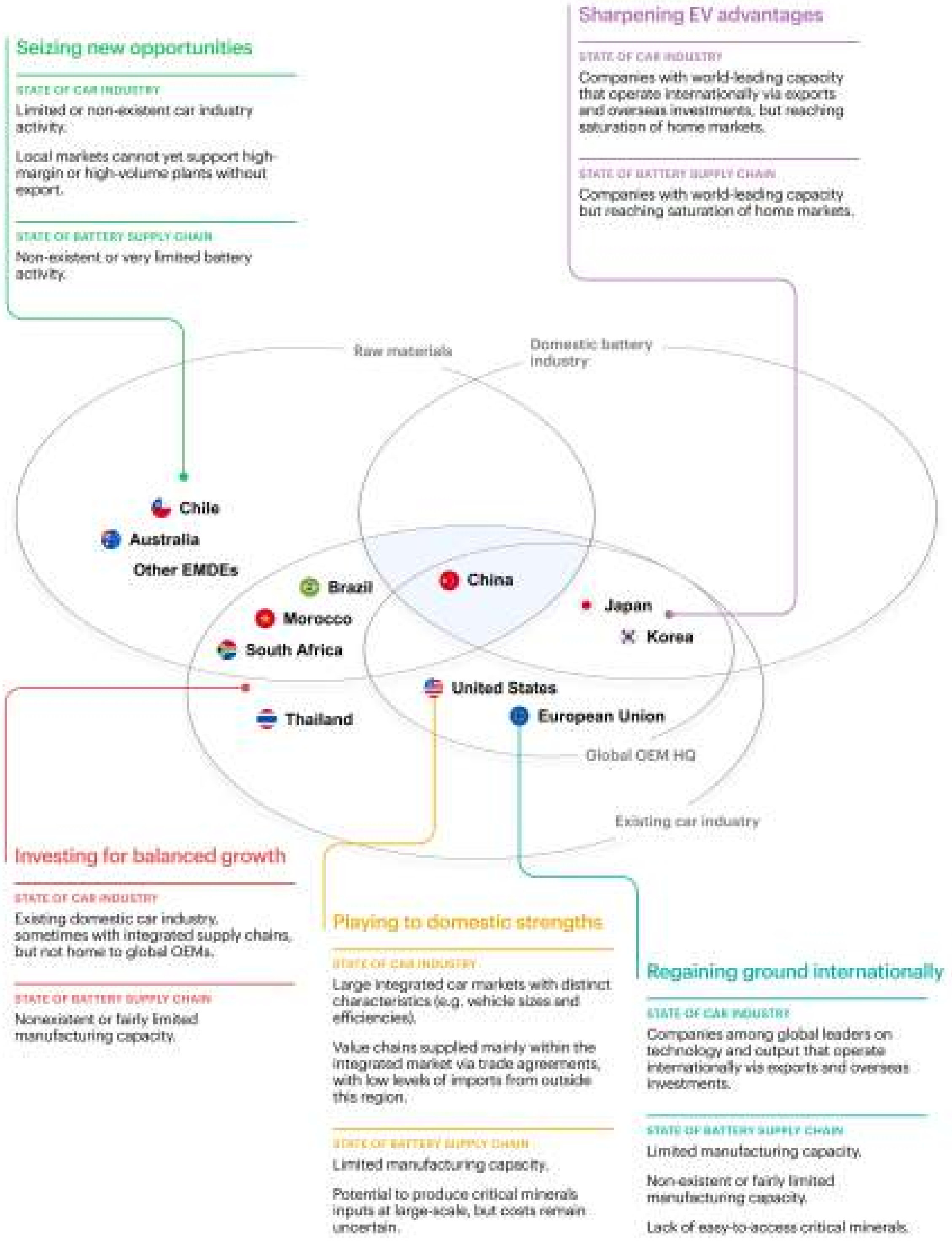
Actions for industry

- Standardise appropriate PPA arrangements with operators of renewables and storage.
- Develop and incentivise more efficient production processes in the supply chain.

5.2 Tailoring tools to the strengths of five strategic archetypes

All countries' car industries face different combinations of market conditions, industrial strengths, trade relationships and resource endowments. The number of dimensions along which they differ are too numerous to illustrate with a simple matrix. However, to facilitate understanding of policy options for different national contexts, we have developed five broad archetypes that characterise the challenges confronting the car industries of several major economies.

Figure 5.3. Archetypes representing strategic concerns for national car industries or major corporate players



Seizing new opportunities

STATE OF CAR INDUSTRY

Limited or non-existent car industry activity.

Local markets cannot yet support high-margin or high-volume plants without export.

STATE OF BATTERY SUPPLY CHAIN

Non-existent or very limited battery activity.

Sharpening EV advantages

STATE OF CAR INDUSTRY

Companies with world-leading capacity that operate internationally via exports and overseas investments, but reaching saturation of home markets.

STATE OF BATTERY SUPPLY CHAIN

Companies with world-leading capacity but reaching saturation of home markets.

Investing for balanced growth

STATE OF CAR INDUSTRY

Existing domestic car industry, sometimes with integrated supply chains, but not home to global OEMs.

STATE OF BATTERY SUPPLY CHAIN

Nonexistent or fairly limited manufacturing capacity.

Playing to domestic strengths

STATE OF CAR INDUSTRY

Large integrated car markets with distinct characteristics (e.g. vehicle sizes and efficiencies).

Value chains supplied mainly within the integrated market via trade agreements, with low levels of imports from outside this region.

STATE OF BATTERY SUPPLY CHAIN

Limited manufacturing capacity.

Potential to produce critical minerals inputs at large-scale, but costs remain uncertain.

Regaining ground internationally

STATE OF CAR INDUSTRY

Companies among global leaders on technology and output that operate internationally via exports and overseas investments.

STATE OF BATTERY SUPPLY CHAIN

Limited manufacturing capacity.

Non-existent or fairly limited manufacturing capacity.

Lack of easy-to-access critical minerals.

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The starting point for these considerations is the assertion by governments that they wish to maintain or expand a car industry in the coming decades that either represents a similar domestic footprint and international revenues as today, or, where existing activities are more limited, that grows to become a significant domestic and international supplier of higher value-added products, if not a source of global innovation. Governments are generally willing to extend support to the major companies headquartered or already operating in their regions to help their car industries manage the transition to a market that is led by electrification, if not exclusively defined by it. Some governments also envision new actors – domestic start-ups or foreign investors – playing central roles in keeping their car industries competitive. It is therefore important to also consider the actions that the private sector would need to take to translate the support of governments into a joint public-private outcome.

Each government and major corporate player will need to define a near-term and medium-term approach to the five tools for narrowing price gaps set out in the previous section. However, depending on the market, expertise and geographical context of the country or region, some elements will take higher priority than others, and the precise approaches will differ. This section explores how those priorities might align for the five archetypes identified earlier in the chapter.

Table 5.1 Summary of the strengths and priority actions per archetype

	Economies of scale and "learning-by-doing"	Battery manufacturing	Battery chemistries	Critical minerals	Energy costs
Regaining ground internationally	Top priority	Top priority	Top priority	Key action area	Key action area
Sharpening EV advantages	Top priority	Strength	Strength	Top priority	Key action area
Playing to domestic strengths	Top priority	Top priority	Key action area	Strength	Strength
Investing for balanced growth	Top priority	Top priority	Key action area	Strength/ Key action area	Strength
Seizing new opportunities	Key action area	Top priority	Key action area	Strength	Strength/ Key action area

The importance of metrics for decision-making under uncertainty

This chapter outlines actions that can be taken to address concerns about future car industry competitiveness. Decisions will be made in a dynamic environment in which governments and the private sector must adjust to the actions of others and respond to exogenous factors. This makes data-driven metrics important for early course-correction and policy adjustment, as well as for tracking progress.

Policy and strategy are designed to shape the behaviours of individuals, firms and other actors in society towards preferred outcomes – ideally "win-win" outcomes in the long term. In almost all cases there are trade-offs, including those that consider the balance between existing assets and the promotion of a new technology that is expected to deliver greater economic and environmental benefits in the future. For the car industry, whether enacted policy packages and corporate decisions do indeed balance these trade-offs for the better is something that can be measured and tracked.

Some of the most informative overall signals of success in building or maintaining a resilient and competitive domestic car industry – such as car sales or employment – are lagging indicators, which means that other, earlier indicators are needed to grasp whether strategies are effective at the earliest possible moment. It is therefore not necessary to wait 5 to 10 years for outcomes to be clear before judging progress. Different sets of metrics could be prioritised by a given country or region, depending on its strategic priorities.

Key data-driven indicators of policy success for competitive car industries

Type of indicator	Indicator	Metric	Information
Early (within 2 years)	Final investment decisions in the supply chain	USD or nameplate capacity	Whether the combination of demand, cost factors and regulation support business confidence.
	Balance of investment in the supply chain	Shares of capacity in operation and construction, by value chain step (mineral and material inputs; battery components; battery assembly; vehicle components; vehicle assembly)	Whether the new market and policy environment supports a balanced domestic industry or results in gaps.
	Changes in relative costs between vehicle production with high domestic content and imports	USD per car in successive time periods	Whether the policy measures have reduced or created any production cost gaps that affect competitiveness.

Intermediate (2 to 5-year time horizon)	Factory load factors	Output as a share of nameplate capacity	Whether manufacturers can operate at profitable levels.
	Relative revenues from ICE vs electric cars in the domestic market	Sales multiplied by price	Whether a commercial transition is underway in aggregate.
	Job postings	Change in aggregate job postings in the sector	Whether more jobs are being retained and created.
	Share of domestic production per value chain step	(sales - imports) divided by total sales	Whether domestic producers are maintaining competitiveness.
	Patents filed	International patent family applications in car-related technologies filed by firms headquartered domestically	Whether the combination of market incentives and support policies drive greater innovation effort for long-term competitiveness.
Outcome (5 to 10-year horizon or more)	Frequency of supply chain disruptions	Price volatility per value chain step	Whether efforts to enhance resilience are paying off.
	Employment	Headcount across all car-related segments, by skill level	Whether jobs have been retained and created, and their overall quality improved.
	Corporate revenue	Aggregate EBITDA of domestically headquartered firms	Whether the domestic sector in total grows as it manages the transition.
	Exports of intangible assets	USD received from licensing of intellectual property and consulting	Whether the region is a global leader in the underpinning expertise of the evolving sector.

Note: EBITDA = Earnings before interest, tax, depreciation and amortisation.

Archetype 1: Regaining ground internationally

The car industries of countries in this category face challenges on numerous fronts, but have the experience to overcome them. They hold significant ICE manufacturing operations but are also tightly integrated into global markets, from which they purchase components and to which they export vehicles with high profit margins. Their domestic supply chains are large employers of specialised personnel in sectors from steel to chemicals and components that serve the local automotive sector. They have access to large regional markets covered by harmonised regulation and extensive retail networks, and can rely in the near term on a degree of brand loyalty. However, to reach the level of today's best-in-class globally they will need to achieve excellence in key areas for electric car manufacturing – such as batteries, where they lack capacity – and retool many existing assets. A clear-eyed strategy will also be required to manage critical mineral value chain risks as the market evolves over a 10-to-20-year time horizon, including appropriate international partnerships.

- Examples: European Union, United Kingdom.

Priority actions

Competitiveness for these countries will depend on effective policy support across all five areas of the toolbox. There will be limited room for delays or missteps. To help build upon the legacy of excellence in ICE value chains, and the long-standing relationships built between suppliers and OEMs over decades, public-private partnerships are set to play a major role in the period to 2030. While they currently manufacture most of the electric cars sold in their home markets, attempting to onshore all parts of the value chain could widen the price gaps, notably because of the lack of easy-to-access critical minerals and high energy costs for minerals processing.

The core task will be to create a market environment that can support investment in world-class car plants at large scale, principally through conversion of ICE facilities. **Economies of scale and learning-by-doing** can be ensured through joint commitments of governments and companies to electric car sales targets across the region, backed by regulations. Public finance for reducing price gaps compared to ICE cars – whether through incentives for consumers or for manufacturers – will be important and must be accompanied by programmes that guarantee the completion of an EV charging network across all relevant countries, something that is already well underway.

Given the aim of successfully transitioning an expansive, integrated ICE car-making sector to be fit-for-purpose in an electric car-dominated future, there is a strong argument for linking public funding to the development of electric car models for lower-cost market segments. Road-mapping exercises can help generate consensus around how to keep costs on a downward trajectory.

For major OEMs, there is an opportunity to balance revenues from continued sales of high-quality ICE cars against the remaining costs of electric car development. Maintaining export opportunities to countries making a slower transition to electric car sales is one way of supporting such a strategy. Though diminishing, there will be continued ICE sales at home too, and, in some regions, parts of the car market may continue to be powered by liquid fuels for several decades. It is important to strike an effective balance between continued investment to serve these weakening markets and higher investment to build an equivalent position in electrified drivetrains. While this may be a drag on the profits of the largest OEMs in the near term, it represents a plausible pathway to competitiveness on the other side of a complex transition.

A domestic **battery manufacturing** strategy, such as the one that is already taking shape in Europe, will require patient capital and the development of a network of suppliers, skills and innovation. There is a stepwise logic to proceeding from car assembly to battery cells, cathodes and precursors, while seeking to preserve or initiate production of steel, aluminium and non-battery components. Compared with having higher capacities at the end of the value chain closest to the consumer, there will be fewer benefits from investing in manufacture of cathode or anode active materials if the region does not have the battery cell plants to use them.

Countries in this category will benefit from working together as a common hub for executing this strategy. However, they will not be able to work in isolation from other regions due to considerations relating to **battery chemistries** and **critical minerals**. As shown in Chapter 4, closing price gaps appears feasible only with a transition towards more LFP-based battery production, and that will require well-designed agreements with the leaders in such technologies, which are based overseas. To secure dependable access to critical minerals, alternative sources, recycling and next-generation battery chemistries can all contribute to long-term competitiveness but, in the coming years, resilience will be determined by international partnerships to secure access to processed minerals. Governments can facilitate this by strengthening relationships with producer countries and helping them to improve social and environmental performance, as well as supporting new entrants from countries with attractive resources.

Policies to help manage **energy costs** will play an important role in these countries, where high electricity prices place them at an international disadvantage. In the longer term, targeted tariffs should be avoidable through price reforms, flexible manufacturing operations and the availability of low-cost PPAs. In the near term, some targeted measures may be considered, and could concentrate on the elements of the value chain that pass high energy prices through to customers as a large share of prices, such as mineral processing and electrode active material production. These steps are also often responsible for significant shares of overall EV manufacturing emissions.

Archetype 2: Sharpening EV advantages

Countries in this category have world-leading capacity in both ICE value chains and battery production, as well as international operations. This can balance their saturated home markets and high domestic manufacturing costs while maintaining domestic employment and intellectual property advantages. Maintaining a similar level of industrial activity in markets that shift further towards electric car sales will require a step-change in cost-competitiveness and minimisation of cross-border supply chain risks.

- Examples: Japan, Korea.

Prioirity actions

Maintaining global competitiveness for car industries from these countries is, in large part, a question of staying at the technology frontier, especially in batteries, with a significant presence in markets across the globe. Many of the policy tools required will be the same as those for countries in the "Regaining ground internationally" archetype, with a more strategic focus on **battery manufacturing**, **battery chemistries, critical minerals** and support for overseas investments. Major companies from these countries have extensive strengths in ICE car production that can continue to support revenue around the world and be reinvested in repurposing supply chains for a more electrified future at the same time as managing transition risks. While their home markets are important, they alone are not big enough to support the scale of activity that firms from these regions currently operate, nor do they represent a large, integrated market when combined.

With existing leadership in battery and vehicle innovation and manufacturing at the cutting edge, firms from these countries have an opportunity to be in the driving seat of the transition to a more electrified car industry. However, to do so will require a focus on three strategic issues: continual cost reductions; access to global markets; and staying ahead of the pace of electrification in advanced and emerging economies alike. The greatest challenge facing incumbent firms from these countries is in measuring the speed with which their ICE and hybrid car customers may switch to electric cars or cheaper Chinese ICE cars. To help mitigate this risk while helping firms to build on their strengths in the electric car value chain, governments can engage with their international partners to support their electrification policy goals, for example in countries where their companies have existing investments and market share.

Continued innovation in battery chemistry, battery design and manufacturing can sustain existing advantages in electric car manufacturing. Technological leadership in batteries will attract carmakers from Europe, North America and elsewhere into partnerships and joint ventures for high-performance vehicles. As has been the case in the past decade, such partnerships will help get new chemistries to market before competitors, augment industrial experience and make it harder for others to catch up. If these chemistries can reduce reliance on critical mineral mining and processing, they will offer significant additional value to potential partners. Firms from these countries are already expected to be the first to bring to the mass market a car with a solid-state battery, a product that should be able to command larger profits than mid-market EV batteries with slimmer margins. Innovation policy tools will play an important role, and could include R&D tax incentives, project grants, public-private research programmes and international co-operation on joint projects with strategic partners. The establishment of satellite R&D centres in key markets can be a mutually beneficial means of building local capacity and benefitting from local talent, for example in those emerging and developing economies with which healthy trade relationships are valued.

Archetype 3: Playing to domestic strengths

Countries represented by this archetype have significant opportunities to manage the evolution of their car industries in coming years. The large and distinctive markets served by the car industries in these countries allow them to be somewhat insulated from international competition, but not entirely and not forever. One reason that they are less integrated into global supply chains relates to consumer preferences that have led to high shares of large sports utility vehicles and pickup trucks, which make up a smaller fraction of sales in most other regions. There is also an opportunity to integrate domestic critical mineral and bulk material production at large scale, although costs remain uncertain. Nonetheless, achieving a similarly self-reliant situation as electric car sales rise and ICE sales decline will require co-ordinated investment in many as-yet undeveloped areas, such as minerals processing, battery components and peripherals.

- Examples: Canada, Mexico, United States.

Priority actions

As is the case for the other archetypes considered, elements of all the strategic considerations will be important if these countries wish to maintain the levels of domestic car industry activity that they have historically achieved. However, they currently face fewer concerns about high energy costs and, if their markets are integrated with one another, they can sustain world-class economies of scale in the ICE and electric car value chains. These countries have the potential to leverage continued sales of high-margin, large personal cars to support investments in electrification, allowing the transition to unfold in line with other domestic policy priorities and the speed at which a domestic EV sector can be built up.

However, while a strategy based around high levels of self-reliance and market stability confers many advantages, it brings some notable near-term and longer-term risks. In the near term, it will not be possible to make a rapid transition to fully domestically sourced **critical minerals** or components, including for electronics, motors or **battery manufacturing**. In the longer term, firms and governments may need to work hard to stay at the international technological frontier if they are less exposed to global markets than their peers in other regions. As electrification takes higher shares of total sales in the coming years, the technological leaders will increasingly be capable of producing more affordable and higher performing cars.

Not all these countries are able to meet the critical mineral needs of their car sales today with domestic supplies. While this mainly concerns electric cars, rare earth elements are also essential for modern ICE cars, especially hybrid cars. There are no obvious alternatives in the near term to strong international partnerships that secure supplies of these materials for the domestic industry, whether as processed minerals or in finished components. These countries also have a major opportunity to lead the development of alternative sources of minerals in parallel, including direct lithium extraction from geothermal and oilfield brines, or new mining techniques. Sustained innovation funding, including finance for first-of-a-kind projects, the underwriting of initial offtake contracts, international co-operation and market creation will be important. Existing innovation ecosystems of public and private actors can be expected to respond effectively to such incentives to take risks and compete.

Over the longer term, the key to success will nevertheless lie in international competitiveness and being the best at producing the cars that the domestic market most values. In the context of the current outlook for increasingly affordable and reliable electric cars, with European and Asian manufacturers shaping up to take on Chinese frontrunners, there is little room for complacency. Regardless of the region, maintaining market share in mid-range and cheaper market segments in the 2030s, will most likely depend on competitive manufacturing practices and integrated value chains for EVs. Access to international markets will increasingly be determined by these factors and, in some cases, upstream environmental performance too. Indeed, continued exposure to international markets, even if partial, can help hone competitiveness and support leaner operations. While some cost elements will be harder to control in these countries when compared with Chinese peers, low-cost, long-term contracts for energy inputs will be an advantage, which could also bring inexpensive steel and aluminium supplies.

Archetype 4: Investing for balanced growth

Countries in this category are typically emerging or developing economies that already host sizeable car industry activities – either local factories of multinational firms or homegrown firms that supply domestic consumers – for parts manufacturing and some car assembly, currently mostly focused on conventional powertrains. However, their specialisations tend to be fragmented and without international innovation leadership. Nonetheless, they have resources and economic outlooks that make them attractive places for car industry investment, just as many advanced economies were good locations for ICE vehicle-related investments in the mid-20th century. They are expected to increase their per capita car ownership in the next decade as their economies and populations expand, and represent much of the growth in conventional car sales today and in the medium term (Chapter 1). As ICE vehicles are likely to meet much of the domestic demand, they have an opportunity to maintain employment and investment in both drivetrains, leveraging existing capabilities to grow an electric vehicle supply chain over time. In some cases they also have access to critical minerals.

- Examples: Thailand, Indonesia, Morocco, Brazil, South Africa, Türkiye.

Priority actions

These countries have ambitions to keep their car industries competitive into the 2030s to supply their rapidly growing domestic demand, driven by “first-time buyers”, as well as to strengthen their positions as export hubs. As ICE-related industries will be needed to supply part of their growing domestic markets, and as electrification expands at home and abroad, investments in both drivetrains are likely to make sense in the near term. An ICEV supply chain can help retain value in the national and regional economy and support economic growth. At the same time, a longer-term view compels them to have strategies for electric car manufacturing and deployment opportunities, including **battery manufacturing**.

While some of today’s barriers to electric car adoption – such a lack of charging infrastructure and a strained electricity grid – may persist over the medium term, targeted investments can help to overcome them. Entering parts of the electric car supply chain today by relying in large part on exports can enable these countries to attract investment in the near term, and facilitate a transition to a more complete supply chain in the longer term, as well as a high share of electric cars in the local market. This would avoid some of the risks associated with trying to build a full EV supply chain from scratch at a later stage, a process that can take several years.

With affordable **energy costs** and land and labour rates, these countries are often competitive places to achieve manufacturing **economies of scale**, irrespective of the powertrain. In today’s market environment, operating world-scale facilities is necessary to achieve cost-competitiveness through **economies of scale** and, in time, **learning-by-doing**. Strategic partnerships that build on local capacities and enable access to cutting-edge technologies can provide a competitive edge to countries that decide to follow this route.

Archetype 5: Seizing new opportunities

These countries – typically EMDEs – are expected to expand their economies in coming decades. They are home to a young workforce and have attributes that could make them globally competitive battery and electric carmakers. In most cases, they have only a limited car industry for parts manufacturing, often geared towards exports, but wish to move up the value chain towards car production. While many are endowed with low-cost renewable energy resources, several also already mine battery minerals, or are considering exploiting their critical mineral resources. However, despite the opportunity to contribute to international supply chain diversification, they do not yet have local markets that can support high-margin or high-volume electric car plants without exports.

- Examples: Egypt, Viet Nam, Chile, Nigeria.

Priority actions

The opportunities for these countries to enter the electric car supply chain are very attractive, and could enable greater diversification of electric car value chains globally while promoting sustainable economic growth. They have high potential to offer competitive clean **energy costs** to manufacturers, they often have access to **critical mineral** resources and they have growing labour forces.

However, they are constrained by several factors, which include very limited EV charging availability for cars, low willingness among drivers and governments to pay the upfront costs of electric cars, relatively small and fragmented regional car markets, high costs of capital for infrastructure investments, high levels of friction in the development of new projects, and, in some cases, a lack of existing experience with cutting-edge manufacturing. Nonetheless, compared with ICE cars, the mass-production of standardised electric car components and the less mechanically complex task of electric car assembly lead to lower barriers to entry. The emergence of a domestic Vietnamese EV maker – Vinfast – since 2017, is testament to this possibility.

For long-term competitiveness, strategic partnerships that build on local capacities will be key. Critical mineral extraction and processing projects represent important opportunities to enter the value chain, and there is considerable mutual interest in joint projects with importing countries. However, strategies do not need to be limited to the initial upstream stages of the value chain. Well-designed projects can promote opportunities to expand into adjacent downstream areas. Co-operation with advanced economies can help to manage the investment and offtake risks of investing in large-scale facilities. This can be especially important for gaining commitments that environmental and social standards meet the needs of importers from the outset. Investment risks can be mitigated or shared via measures such as joint ventures, offtake contracts, export credits and counter-guarantees, and capacity building programmes, including worker exchanges.

In the current political climate, concluding such partnerships comes with additional challenges, further elevating the role of governments, including via trade agreements. It should nonetheless be possible to identify many “win-win” cases if there is commitment to supply chain diversification. In such cases, emerging economies will have some leverage to ensure that projects help them to move up the value chain over time. For example, partnerships could include provisions for expanding local renewable electricity supplies and grids, or co-operation in joint innovation centres relating to manufacturing or **battery chemistries**. They could also include pathways towards integrating higher shares of critical minerals and metals – such as steel and aluminium – produced domestically with cutting-edge near-zero emissions technologies.

Annex

Annex A: Key assumptions

Battery components conversion factors

	Active materials Practical specific capacity (mAh/g)	Voltage difference (V)	Intensity (kton/GWh-eq)
LFP	160	3.2	~1.95
NMC111	160	3.7	~1.69
NMC532	170	3.7	~1.59
NMC622	180	3.7	~1.5
NMC811	190	3.7	~1.42
NMC955	200	3.7	~1.35
NCA	185	3.7	~1.46
NMCA	200	3.7	~1.35
LNO	200	3.7	~1.35
LMO	120	4	~2.08
LMNO	150	4.7	~1.42
Graphite	360	0.1	~0.79
Electrolyte			
Electrolyte solvent			~0.29
Electrolyte salt			~0.05

Notes: LFP = Lithium iron phosphate; NMC = lithium nickel cobalt manganese oxide; NCA = lithium nickel cobalt aluminium oxide; mAh = milliampere hour; V = volts; eq = equivalent. Voltage difference refers to voltage difference against lithium. The graphite intensity does not account for the negative to positive ratio. Equivalent refers to the energy that this material can provide when coupled with another reference material (graphite for the cathodes, an average cathode (3.5 V) for graphite). Calculations for the electrolyte conversion factor assume a concentration of 1 molar for the electrolyte salt (LiPF6), 1 gramme of electrolyte (solvent) per ampere hour, and an average cell voltage difference of 3.5 V.

Electric vehicle, battery and battery components global average prices (lithium nickel cobalt manganese oxide [NMC] 811), 2024

	Critical minerals Value	Main source
Material prices (USD/kg)	Yearly average spot prices	BNEF
Material intensity (kg/kWh-eq)	~0.1 (Lithium), ~0.66 (nickel), ~0.08 (cobalt), ~0.08 (manganese)	IEA
Battery critical mineral prices (USD/kWh-eq)	~18	
Electric motor rare earth elements (USD/vehicle)	~66	GREET
	Cathode and anode active materials	
NMC811 (USD/ kWh-eq)	~30	BattMan (BNEF)
Artificial graphite (USD/kWh-eq)	~6	BattMan (BNEF)
	Battery cell	
Average battery cell price for battery electric cars (USD/kWh)	73	BNEF
Electric car battery chemistry share (World)	~47% lithium iron phosphate, ~53% lithium-nickel-cobalt-X	IEA
LFP/NMC cell price ratio	~0.66	BNEF
Estimated NMC811 battery cell price for battery electric cars (USD/kWh)	~87	
	Battery pack	
Average battery pack price for battery electric cars (USD/kWh)	97	BNEF
Estimated NMC811 battery pack price for battery electric cars (USD/kWh)	~110	
	Other inputs	
Vehicle price (USD)	~31 000	S&P
Assumed vehicle dealer profit margin	10%	UBS
Battery size (kWh)	~75	
Negative to positive ratio	1.05	Frith, Lacey, and Ulissi, 2023

Notes: LFP = Lithium iron phosphate; NMC = lithium nickel cobalt manganese oxide; eq = equivalent. Battery critical minerals account for the materials used in the cathode and anode active materials. It excludes copper in the anode current collector, in the battery pack, or in the vehicle, or lithium used in the electrolyte. USD/ kWh-eq refers to the critical mineral or active material requirement for an equivalent kWh of battery. A negative (anode) to positive (cathode) ratio refers to the additional anodes used in the final cell for safety reasons and to account for the unreversible capacity losses during the first battery charge/discharge cycles. The price of lithium nickel cobalt manganese oxide 811 battery cells and packs has been estimated using the global average price for battery electric cars, the 2024 global electric car chemistry share, and the LFP/high-nickel battery pack price ratio (~0.72) as reported by BNEF, which was used also to estimate the LFP/high-nickel battery cell price ratio by subtracting the pack price. Lithium-nickel-cobalt-X refers to all types of NMC and all types of lithium nickel cobalt aluminium oxide (NCA).

Estimated battery cell production cost of fully domestic lithium-ion battery cell production in China and the European Union, 2024

Manufacturing efficiency and automation		
	China	European Union
Manufacturing inefficiencies	5%	15%
Labour intensity (workers per GWh)	35	125
Line operators out of total workforce	75%	75%
Engineers and manager out of total workforce	25%	25%
Indirect manufacturing costs and profit margins (CAM)	~10%	~10%
Indirect manufacturing costs and profit margins (AAM)	~10%	~10%
Material prices		
Lithium (USD/kg)	~55 (~10 USD/kg Li_2CO_3 equivalent)	~70 (~13 USD/kg Li_2CO_3 equivalent)

Notes: CAM = Cathode active material; AAM = anode active material. Fully domestic production refers to cathode and anode active materials as well as battery cell production. Manufacturing inefficiencies refer to the combination of manufacturing scraps and (un)planned production line downtime. Labour intensity relates to level of automation and worker know-how. Indirect manufacturing costs account for administrative, retail and R&D costs. Manufacturing inefficiencies and labour intensity refer to regional or country averages. The cell production cost does not consider indirect manufacturing cost as the associated figure (Figure 4.16) depicts (direct) production cost. The lower lithium prices in China reflect preferential pricing accessible to major Chinese battery manufacturers thanks to vertical integration and greater bargaining power (data from CRU).

Annex B: Automakers and supplier groupings

The sample of the 26 largest automakers used in this report comprises the following companies. From China: BYD, Changan, Dongfeng, GAC, Geely, Great Wall, Leapmotor, Li Auto, SAIC, Seres Group. From North America: GM, Ford. From Europe: BMW Group, Mercedes-Benz, Renault-Nissan Alliance, Stellantis, VW Group. From Japan: Honda, Mazda, Mitsubishi, Subaru, Suzuki, Toyota. Other: Tata Group (India), Hyundai (Korea). These companies have revenues accounting for nearly three-quarters of global sales.

The sample of the 26 largest automotive suppliers comprises: Aisin (Japan), BorgWarner (United States), Bosch (Germany), Bridgestone (Japan), Continental (Germany), Denso (Japan), Eve Energy (China), Farasis Energy (China), Forvia (France), Gotion High-tech (China), Hyundai Mobis (Korea), Lear (United States), Magna (Canada), Michelin (France), Samsung (Korea), Tenneco (United States), Toyota Boshoku (Japan), Valeo (France), Weichai Power (China) and ZF Friedrichshafen (Germany).

Annex C: Regional and country groupings

Unless otherwise specified, regional groupings used in this report are as follows:

Africa

Algeria, Angola, Benin, Botswana, Cameroon, Côte d'Ivoire, Democratic Republic of the Congo, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Ghana, Kenya, Kingdom of Eswatini, Libya, Madagascar, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Republic of the Congo (Congo), Rwanda, Senegal, South Africa, South Sudan, Sudan, United Republic of Tanzania (Tanzania), Togo, Tunisia, Uganda, Zambia, Zimbabwe and other African countries and territories.[31]

Asia Pacific

Australia, Bangladesh, Democratic People's Republic of Korea (North Korea), India, Japan, Korea, Mongolia, Nepal, New Zealand, Pakistan, The People's Republic of China (China), Sri Lanka, Chinese Taipei, and other Asia Pacific countries and territories.[32]

Central and South America

Argentina, Plurinational State of Bolivia (Bolivia), Bolivarian Republic of Venezuela (Venezuela), Brazil, Chile, Colombia, Costa Rica, Cuba, Curaçao, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Nicaragua, Panama, Paraguay, Peru, Suriname, Trinidad and Tobago, Uruguay and other Central and South American countries and territories.[33]

Eurasia

Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, the Russian Federation (Russia), Tajikistan, Turkmenistan and Uzbekistan.

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[31] Individual data are not available and are estimated in aggregate for: Burkina Faso, Burundi, Cabo Verde, Central African Republic, Chad, Comoros, Djibouti, Gambia, Guinea, Guinea-Bissau, Lesotho, Liberia, Malawi, Mali, Mauritania, Sao Tome and Principe, Seychelles, Sierra Leone and Somalia.

[32] Individual data are not available and are estimated in aggregate for: Afghanistan, Bhutan, Cook Islands, Fiji, French Polynesia, Kiribati, Macau (China), Maldives, New Caledonia, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor-Leste, Tonga and Vanuatu.

[33] Individual data are not available and are estimated in aggregate for: Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Bermuda, Bonaire, Sint Eustatius and Saba, British Virgin Islands, Cayman Islands, Dominica, Falkland Islands (Malvinas), Grenada, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Pierre and Miquelon, Saint Vincent and Grenadines, Saint Maarten (Dutch part), Turks and Caicos Islands.

Europe

European Union regional grouping and Albania, Belarus, Bosnia and Herzegovina, Gibraltar, Iceland, Israel,[34] Kosovo, Montenegro, North Macedonia, Norway, Republic of Moldova, Serbia, Switzerland, Türkiye, Ukraine and United Kingdom.

European Union

Austria, Belgium, Bulgaria, Croatia, Cyprus,[35,36] Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain and Sweden.

Latin America and the Caribbean (LAC)

Central and South America regional grouping and Mexico.

Middle East

Bahrain, Islamic Republic of Iran (Iran), Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic (Syria), United Arab Emirates and Yemen.

North America

Canada, Mexico and United States.

Southeast Asia

Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic (Lao PDR), Malaysia, Myanmar, Philippines, Singapore, Thailand and Viet Nam. These countries are all members of the Association of Southeast Asian Nations (ASEAN).

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[34] The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD and/or the IEA is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

[35] Note by Republic of Türkiye: The information in this document with reference to "Cyprus" relates to the southern part of the island. There is no single authority representing both Turkish and Greek Cypriot people on the island. Türkiye recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Türkiye shall preserve its position concerning the "Cyprus issue".

[36] Note by all the European Union Member States of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of Türkiye. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

Annex D: Glossary

Abbreviations and acronyms

AAM	anode active material
AHSS	advanced high-strength steel
AI	artificial intelligence
BEV	battery electric vehicle
CAAM	China Association of Automobile Manufacturers
CAFE	Corporate Average Fuel Efficiency
CAM	cathode active material
CAPEX	capital expenditure
CATL	Contemporary Amperex Technology Co. Limited
CO_2	carbon dioxide
CPC	co-operative patent classification
CPI	Consumer Price Index
DC	direct current
EBITDA	earnings before interest, tax, depreciation and amortisation
ECU	electronic control units
EMDE	emerging market and developing economy
EPO	European Patent Office
ETP	Energy Technology Perspectives
EV	electric vehicle
FCEV	fuel cell electric vehicle
FHEV	full hybrid electric vehicle
GACC	General Administration of Customs of the People's Republic of China
GaN	gallium nitride
GM	General Motors
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Technologies
GVA	gross value added
HDV	heavy-duty vehicle
HEMT	high-electron-mobility transistors
HEV	hybrid electric vehicle
HVAC	heating, ventilation and air conditioning
ICCT	International Council on Clean Transportation
ICE	internal combustion engine
ICEV	internal combustion engine vehicle
IGBT	insulated gate bipolar transistors
IPF	international patent family
IRA	Inflation Reduction Act
ISIC	International Standard Industrial Classification
JV	joint venture
LGES	LG Energy Solution
LDV	light-duty vehicle

LFP	lithium iron phosphate
LMFP	lithium manganese iron phosphate
LMR	lihium manganese rich
MER	market exchange rate
MHEV	mild hybrid electric vehicle
MIIT	Ministry of Industry and Information Technology
MOSFET	metal-oxide-semiconductor field-effect transistors
NACE	Statistical Classification of Economic Activities in the European Community
NCA	lithium nickel cobalt aluminium oxide
NEV	new energy vehicle
NEVI	National Electric Vehicle Infrastructure
NMC	nickel manganese cobalt oxide
NMCA	lithium nickel manganese cobalt aluminium oxide
NZE	Net Zero Emissions by 2050 Scenario
OEM	original equipment manufacturer
OPEX	operating expenditure
PECM	power electronics combination module
PHEV	plug-in hybrid electric vehicle
PMSM	permanent magnet synchronous motors
PPA	power purchase agreement
REE	rare earth elements
SiC	silicon carbide
STEPS	Stated Policies Scenario
SUV	sports utility vehicle
TCO	total cost of ownership
TRL	technology readiness level
UHSS	ultra-high-strength steel
UNIDO	United Nations Industrial Development Organization
USMCA	United States-Mexico-Canada Agreement
VW	Volkswagen
WLTC	Worldwide Harmonized Light Vehicles Test Cycle
ZEV	zero emission vehicle

Units of measure

bbl	barrel of oil
EJ	exajoule
GJ	gigajoule
GWh	gigawatt-hour
kg	kilogramme
km	kilometre
kt	kilotonne
kW	kilowatt
kWh	kilowatt-hours
mAh	milliampere hour

Mt	million tonnes
USD	United States dollars
USD/kWh	United States dollars per kilowatt-hours
V	volt
Wh/kg	watt-hour per kilogramme
Wh/L	watt-hour per litre

See the IEA glossary for a further explanation of many of the terms used in this report.

International Energy Agency (IEA)

Unless otherwise indicated, all material presented in figures and tables is derived from IEA data and analysis.

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