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S&P Global Mobility

Technology and Market Overview of the Electric-Motor Value Chain

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Authors

Amit Panday
Senior Research Analyst,
S&P Global Mobility

Priyanka Mohapatra
Senior Research Analyst,
Propulsion,
S&P Global Mobility

Kartik Ganesh
Senior Research Analyst,
S&P Global Mobility

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Overview

Report summary

This whitepaper aims to examine the technological aspects of electric-motors (e-motors) used in battery-electric vehicles (BEVs) and hybrid vehicles, analyzing current market demand and its projected evolution. It assesses which motor topologies are expected to gain prominence, the technological advancements that suppliers are prioritizing and the adoption trends of different stator winding configurations. Additionally, the whitepaper addresses various elements of the e-motor supply chain, including concerns and ongoing tensions related to tariffs on rare earth elements (REEs) and permanent magnets, as well as the sourcing strategies for e-motors and their subcomponents, with a particular focus on the growing trend of insourcing by major original equipment manufacturers.

Research methodology

All research in this report is based on the S&P Global Mobility e-motor and inverter forecast. This report is sequentially based on the September 2024 S&P Global Mobility Global Light-Vehicle (LV) Production Forecast. The data in this report only accounts for global light passenger vehicle production up to 6-metric-ton gross vehicle weight (GVW) and excludes other vehicle segments.

The analysis and opinions put forward in the report are based on the information gathered from relevant and trusted automotive sources, such as published reports, government publications, industry news and press releases from key players.

Note:
The research and forecasts used in this e-motor and inverter market analysis report cover markets in the following regions:

North America

Japan/South Korea

Europe

Greater China

South Asia

South America

1

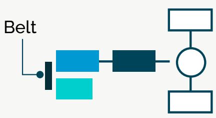
E-motor landscape in 2024

Px architecture

As the industry navigates its transition toward zero-emission vehicles (ZEVs), a variety of complex applications for e-motors are evolving. For the purpose of this report, we will aim to break down the trajectory for all motors. The differentiator here will be the Px definition, which indicates the position of the e-motor in the powertrain.

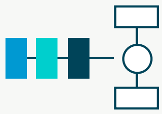
Different Px architectures

P0



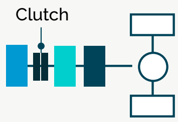
Motor connected to engine crankshaft via belt

P1



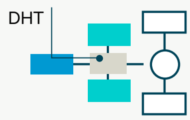
Motor connected to engine output shaft so motor speed is always the same as engine

P2



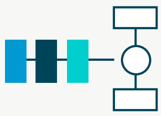
Motor connected to transmission input shaft, so clutch is between engine and motor

P2.5



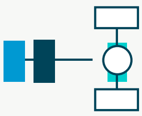
DHT used in the system

P3a



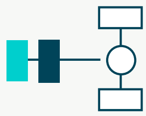
Motor connected to transmission output shaft

P3b



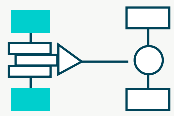
Motor integrated into differential gear unit

P4



Motor connected to drive shaft

P5



Hub-motor system

In a P0 architecture, the e-motor is connected to the internal combustion engine (ICE) and supports the operations of the ICE during peak torque demand to maintain the conventional ICE within reasonable efficiency range.

In the P1, P2, P2.5, P3a and P3b architectures, the e-motor is located on the input or output shaft of the transmission. In the P4 configuration, the e-motor is placed on the axle, whereas in the P5 architecture, the e-motors are placed in the hub of the wheel.

Motor location

E-motors can be placed at multiple locations in an electric powertrain architecture based on its design. **Based on their location in the electric powertrain architecture, the e-motors can be categorized as:**

Electric-axle (e-axle) motors — Motors that are located on the e-axle region, i.e., the front e-axle, rear e-axle, rear-stability e-axle, twin front e-axle and twin rear e-axle.

Non-e-axle motors — Motors located on the engine or on the transmission, i.e., the belt, coaxial input, coaxial output, flywheel, power split — parallel (Axle side) and power split-parallel (engine side).

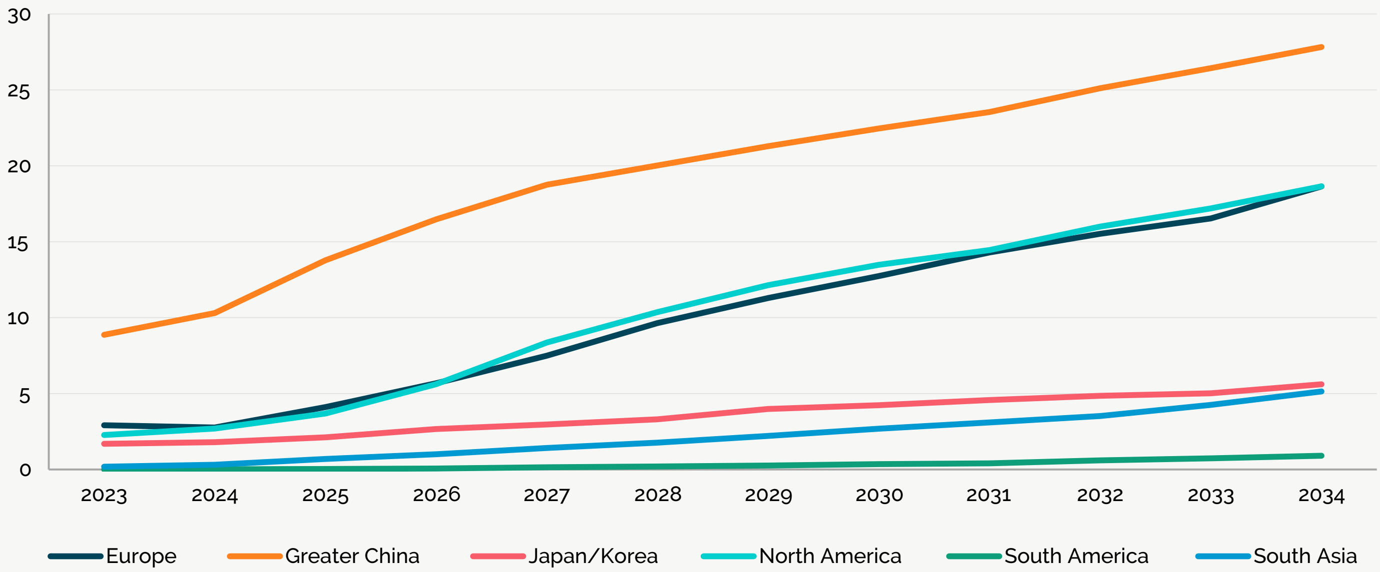
Hub motors/in-wheel motors — These motors are located on the wheels of an electric vehicle. This configuration allows the placement of the e-motor at the center of the wheel, reducing the components required in the transmission and energy losses associated with the gears, bearings and universal joins. However, since hub motors are incorporated within the wheel of a vehicle, they add to the unsprung weight of a vehicle. Companies such as Protean Electric and DeepDrive are developing in-wheel motors. BMW Startup Garage is teaming up with Munich's DeepDrive to test a dual-rotor electric motor, which, as per the DeepDrive's claims, provides high efficiency, strong performance and extended range. DeepDrive's dual-rotor e-motor merges two motors into a compact unit, offering energy efficiency and high torque density for use in both in-wheel and centralized drive systems.

E-motor volume breakdown

According to S&P Global Mobility forecast data, Greater China will continue to be the largest market when it comes to the demand of P4 or e-axle motors as well as the demand for non-P4 motors in hybrid vehicles over the next decade.

The demand for P4 motors in Greater China is expected to grow from 10.3 million units in 2024 to 27.8 million units in 2034. Following the same pattern, the demand volumes of P4 motors in North America (2.3 million units in 2024) and Europe (2.9 million units in 2024) are estimated to surge to 18.65 million units and 18.64 million units in 2034, respectively.

Use of P4 motors globally

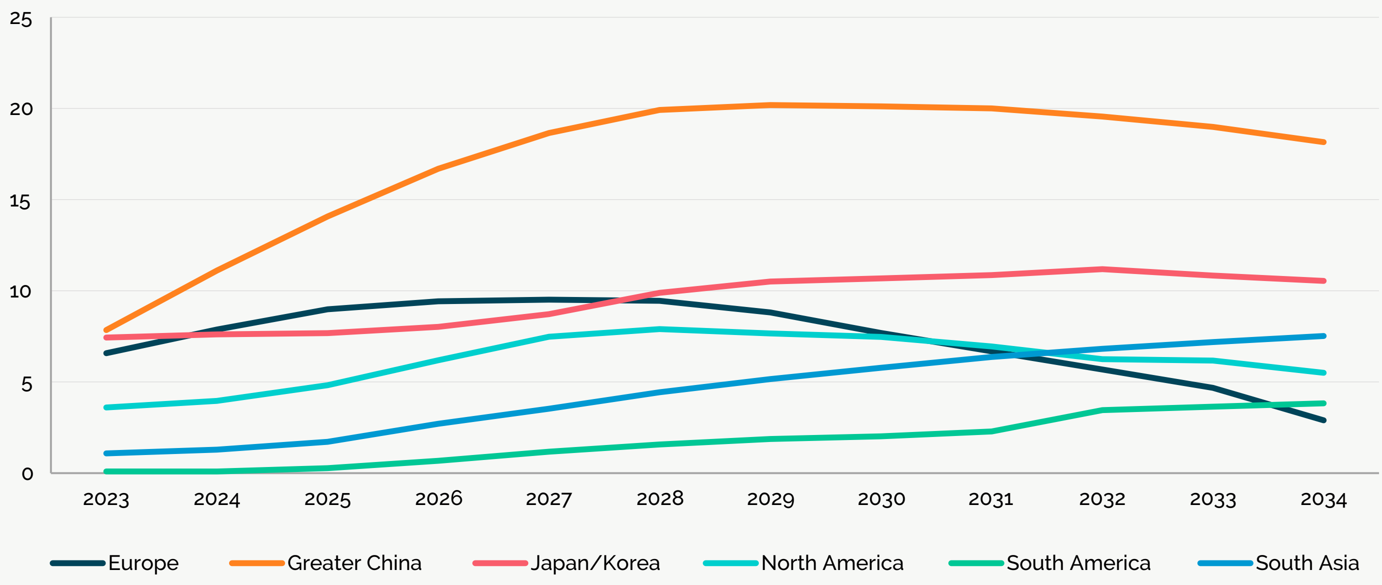


That said, it is important to take note of the anticipated global demand patterns for non-P4 motors, as it underlines the rising demand trend for hybrid vehicles amid a global slowdown in BEV volumes. S&P Global Mobility data suggests that the demand volumes for hybrid vehicles' non-P4 motors in Greater China will continue to increase until 2029, when it is expected to peak at 20.18 million units. From there, the demand for non-P4 motors used in hybrid vehicles is estimated to saturate and see a linear decline due to BEV uptake.

Similarly, the demand for these motors used in hybrid vehicles will keep increasing in North America and Europe and is expected to hit the peak volume of 7.89 million units in 2028 and 9.5 million in 2027, respectively.

Meanwhile, Japan and Korea will continue witnessing the surge until 2032, when these markets are expected to hit the peak volumes of 11.18 million units. This demand for non-P4 motors used in hybrid vehicles is going to be mainly driven by Japanese car companies, which are betting big on hybrid technologies in the midterm, before transitioning to BEVs in the long run.

Use of non-p4 motors in hybrid vehicles



Global uptake of BEVs is directly dependent on regional policy measures that must be drafted in line with consumer abilities to embrace new technologies amid practical challenges. In this context, the UK pushed back its decision to implement a ban on the sale of ICE vehicles from 2030 to 2035, as EV charging infrastructure continues to lag behind earlier targets. BEVs are still more expensive than their ICE equivalents, and energy and capital costs continue to soar.

The same factors mar Europe, which may reportedly see the ban on ICE cars pushed from 2035 to 2040, all thanks to the European People's Party's recent election win. The political party is looking to revise rules on CO2 emission standards for cars and vans from 2035. Volvo Cars has been the only major legacy carmaker to publicly oppose the revision of the 2035 ICE ban. According to the company CEO Jim Rowan, the 2035 target is critical for aligning all stakeholders on the Net Zero path and to ensure Europe's competitiveness.

The persisting slowdown in global BEV sales is driving almost all major carmakers to scale back their pure EV investments, change course and double down on hybrid vehicles. Just last month, Volvo Cars abandoned its goal of selling only BEVs by 2030 and is now aiming to also sell hybrids during that timeline. Hyundai plans to double its current hybrid range from seven models to 14 models, expanding the hybrid propulsion technology beyond compact and midsize cars to small, large and luxury vehicles, including model offerings under the premium Genesis brand. The South Korean carmaker is also developing the next-generation transmission-mounted electric-drive (TMED-II) system, a form of parallel full hybrid system, and plans to integrate it into production vehicles starting from January 2025. At its 2024 CEO Investor Day, it disclosed its plan to counter the recent slowdown in BEV demand by developing a new extended-range EV technology, which could help maximize the use of the existing engines. Hyundai, which has explicitly said that it anticipates a surge in the demand for hybrid vehicles particularly in North America, plans to produce hybrids alongside BEVs such as the Ioniq 5 and Ioniq 9 at Hyundai Motor Group Metaplant America (HMGMA) facility in Georgia, US — a global strategy deployed across multiple facilities to save costs.

Meanwhile, Ford has cancelled its plan to build an all-electric, three-row sport utility vehicle and is reducing capital expenditure meant for pure EVs from 40% to 30% of its annual capex budget. The challenging transition to pure EVs is also driving General Motors (GM) and Volkswagen to beef up their plug-in hybrid lineup in the near future.

A fully electric car or one with a hybrid propulsion technology will need e-motors, and in this context, it is important to understand the evolving challenges that the supply chain stakeholders have to steer through. Global availability of critical materials used in producing e-motors and disruptive tariffs remain the biggest puzzle for the supply chain to solve.

Tariff wars between China-US and Europe

The materials utilized in e-motors, particularly permanent magnets, windings and motor-core laminations, are vital for their performance. While copper is commonly used in windings due to its excellent conductivity and affordability, REEs such as neodymium, dysprosium and terbium are essential for the permanent magnets that are used in manufacturing e-motors.

As per S&P Global Mobility forecast, as of 2024, 83% of e-motors used in BEVs are based on permanent magnets, which underlines a huge dependency on REEs. Car manufacturers worldwide favor the use of permanent magnet-based e-motors in their EVs because they deliver higher efficiency and power density, which in turn helps in offering improved performance and enhanced driving range. As per S&P Global Mobility's forecast, demand for e-axle permanent magnet motors will grow from 14.8 million units (in 2024) to 45.8 million units in 2030, at a compound annual growth rate (CAGR) of 21%.

Moreover, S&P Global Mobility forecasts that the demand for permanent magnet e-motors (used in BEVs, fuel cell electric vehicles [FCEVs] and hybrid electric vehicles [HEVs]) is expected to increase from 41.4 million units in 2024 to reach 93.5 million in 2030, growing at a CAGR of 15%. During the same time, demand for permanent magnet e-motors in mainland China is expected to increase at a CAGR of 12% to reach approximately 39.5 million units. The rapid increase in the demand for permanent magnet-based e-motors globally is expected to lead to an increased demand for REEs and REE magnets.

According to the International Energy Agency (IEA), while mainland China accounts for about 60% of the world's rare earth mining production, it commands a monopoly of about 90% when it comes to the processing and refining of these REE materials. Several countries worldwide heavily depend on mainland China for the supply of processed REE materials as it benefits them in terms of costs and availability. However, this monopoly often becomes a soft tool to arm-twist dependent nations amid trade disputes and growing geopolitical insecurities among large economies.

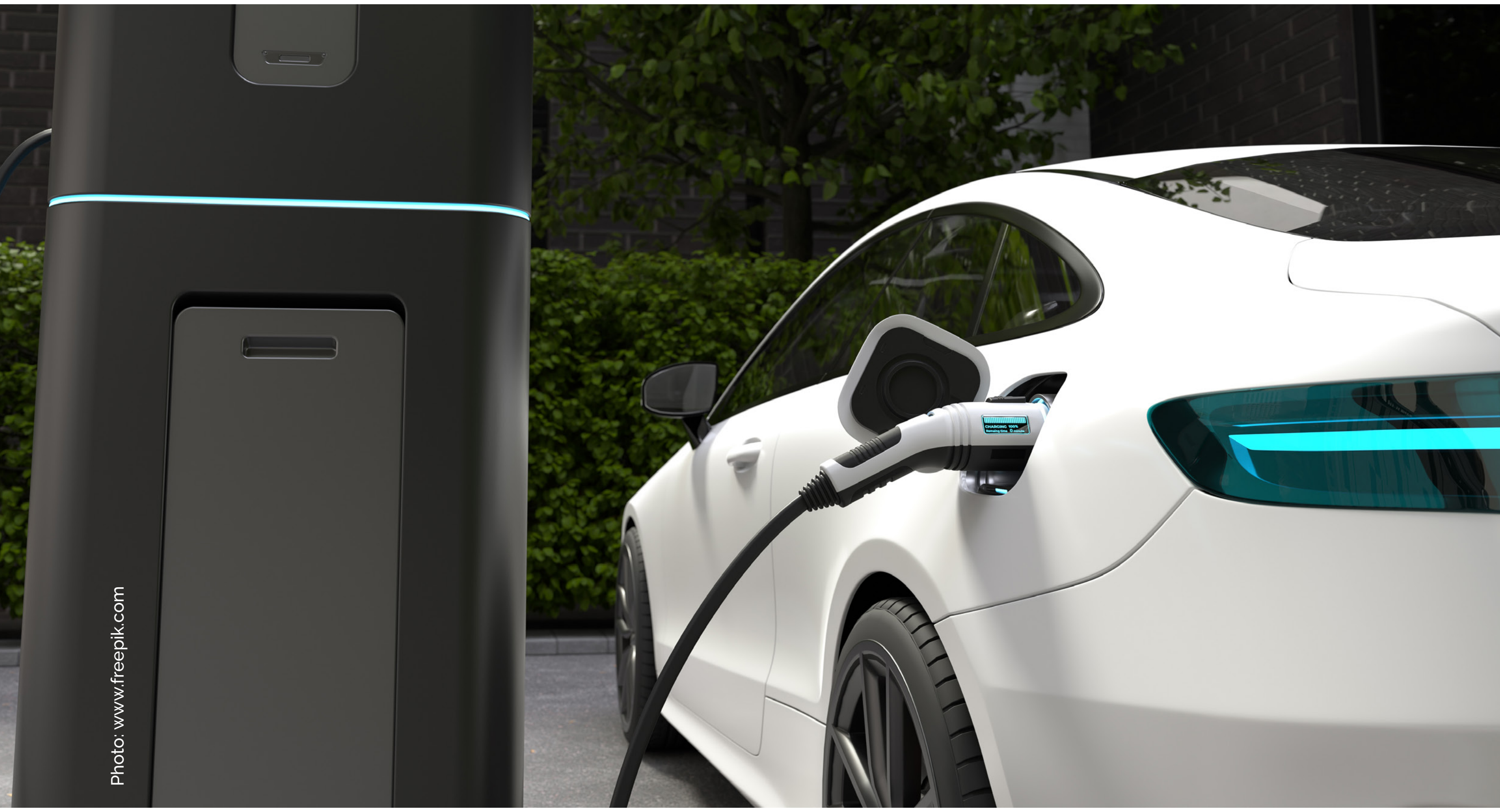


Photo: www.freepik.com

Mainland China's deep-rooted mining footprint in Africa

Anticipating a sharp surge in the global demand of critical minerals and rare earth, the mainland Chinese government moved quickly to acknowledge these as strategic resources. For more than two decades, mainland China has been investing heavily in securing and developing mines to extract critical materials and rare earth in the African continent.

Mainland China's state-owned enterprises as well as mining and battery companies have been investing in African countries to dominate Africa's mining sector. For example, mainland China has invested in 15 out of 17 to 19 cobalt mines in the Democratic Republic of Congo (DRC) alone, which underlines the country's dominance in Africa.

While mainland China continues to be the largest buyer in Africa's mining industry, it imported about a third of Africa's minerals and metals exports worth $16.6 billion in 2020, marking a 28% growth from 2018. When it comes to rare earth alone, African countries such as Kenya, Namibia, Mozambique, Tanzania, Zambia, South Africa, Madagascar, Malawi and Burundi are expected to have significant natural reserves of neodymium, praseodymium and dysprosium.

On tariffs, mainland China has a history of imposing restrictions on the export of REEs. The country had banned the shipments of REEs to Japan amid disputes from as early as 2010–11. This led to a sharp hike in the prices of REEs. Such export restrictions on REEs became more apparent in the following years.

Concerns within Europe about mainland China's control over the market are nothing new. A memo dated Aug. 7, 2014, released by the European Commission, made reference to export restrictions on REEs as a significant threat impacting EU trade, employment and production. The memo alleged that such a move offers an unfair, competitive edge to the industries in mainland China. In some instances, non-mainland Chinese buyers have had to pay more than double the price for raw materials compared to their mainland Chinese counterparts.

Mainland China announced a ban of rare earth extraction and separation technologies on Dec. 21, 2023. Its Ministry of Commerce released a revised version of the Catalogue of Technologies Prohibited and Restricted from Export, which included a ban on the export of technology used for making rare earth magnets. The move, which followed mainland China rolling out additional export restrictions in the form of export permits for gallium, germanium and graphite in 2023, was termed as a measure to safeguard national security and public interest.

The list of technologies prohibited from exports also included the ban on solutions used in the refining of rare earth metals and in-situ leaching technologies for mining applications.

These export restrictions should not be viewed in isolation but in the context of similar steps taken by the US and Europe against mainland China. In August 2022, the US President Joe Biden signed proposed measures under the Inflation Reduction Act (IRA) into law, discouraging US and global automakers operating in the US from sourcing EV batteries and battery components from mainland China.

In October 2023, the Europe Commission announced an anti-subsidy probe against BEVs imported into the EU region from factories in mainland China. The European Commission alleged that domestic mainland Chinese carmakers were able to keep the cost of manufacturing EVs artificially low, thanks to government subsidies, and that these aggressively priced BEVs were distorting the emerging EV market and threatening the survival of an already established automotive ecosystem in Europe.

In response to mainland China's export restriction on rare earth extraction and separation technologies in December 2023, the US rolled out a series of tariffs aimed at discouraging the import of EVs, lithium-ion batteries and critical minerals such as graphite and permanent magnets from mainland China in May 2024. The US announced plans to raise tariffs on permanent magnets imported from mainland China from 0% to 25%, starting from Jan. 1, 2026. The move was part of the US government increasing tariffs under Section 301 of the Trade Act of 1974 on $18 billion worth of imports from mainland China. The Biden administration called it a measure to protect US manufacturers from mainland China's unfair trade practices.

Implications of tariff war on global rare earth supply chain

The evolving global rare earth supply chain dynamics are expected to have the following implications:

1) Diversifying of supply chain from a single source

For some time now, the US and Europe have been looking to reduce their over-dependency on a single source for rare earth elements supply, along with several other critical materials that are key to the global energy transition.

Although new mining facilities can be potentially developed in countries with large natural reserves of rare earth, REE production and distribution can involve several challenges. Rare earth deposits are mixed, and it is difficult and expensive to process and separate them. The extraction technologies and processing plants are extremely capital and CO2 intensive, and it is expected that companies investing in this ecosystem might take a decade or more to breakeven and turn profitable. There are also pricing challenges from mainland Chinese companies to be considered, as they command a stronghold in the pricing of rare earth globally.

While some efforts are underway, one of the more practical routes that developed nations such as the US, Europe and Japan are taking is leveraging international cooperation, mainly with African countries, to rapidly turnaround sourcing of REEs and developing REE processing capacities.

1.1 Steps taken by the US and Europe to secure REE supply chains

According to S&P Global Mobility, the US market is estimated to see a sharp surge in the consumption of permanent magnet e-motors, rising 4.5 million units in 2024 to 13.8 million units in 2036. This is viewed in the context of the US' current dependency on mainland China for rare earth. According to the US Geological Survey January 2024 report, at 72%, mainland China stood as the single largest source of all rare earth compounds and metals imported by the US between 2019 to 2022. This was followed by Malaysia at 11%, Japan at 6%, Estonia at 5% and 6% from all other sources.

To address this dependency, the US has lately released a few policies that allocate government funding for research and development initiatives aimed at improving the extraction and processing of REEs, encourage collaboration between federal agencies and private companies to build more resilient domestic REE supply chains. For example, under the IRA, the US grants a production tax credit to domestic manufacturers of eligible components, which include critical minerals and REEs. This tax credit covers up to 10% of the manufacturer's production costs and constitutes a significant incentive to develop and continue local production of critical minerals and REEs.

Meanwhile, the Bipartisan Infrastructure Law grants a $20 per kilogram production tax credit to companies manufacturing magnets in the US and a $30 per kilogram production tax credit to companies that not only locally produce magnets in the US, but also ensure that all components are produced and recycled within the US.

MP Materials (MPM) would be an appropriate example of how government policies in the US are benefiting companies engaged in the REE supply chain. In April 2024, the company received $58.5 million in a federal award aimed at advancing the construction of US' first fully integrated rare earth magnet manufacturing plant in Texas. MPM anticipates commencing commercial production of finished magnets by late 2025. These magnets will be supplied to GM. The project, which is evaluated by the US Energy Department (DOE), will source raw materials from Mountain Pass, Calif., where MPM owns and operates US' only scaled and operational rare earth mine and separations facility.

MPM previously received $35 million in February 2022 and $9.6 million in November 2020 by the US Defense Department, mainly to build REE separation capacity and processes at its Mountain Pass facility.

For Europe, the import dependency on mainland Chinese REE products is as high as 98%. To systematically address this challenge, the EU proposed the Critical Raw Materials Act, which was turned into law in May 2024. The act has set ambitious 2030 targets, and local stakeholders are expected to deliver on the following benchmarks:

a) 10% of the EU's annual consumption of strategic raw materials must come from local mining operations

b) 40% of the EU's annual raw material requirements to be locally processed

c) 25% of the EU's annual raw material requirements must be addressed via recycling

d) No more than 65% of the EU's annual needs of each strategic raw material at any stage of processing should come from a single third country

2) Establishing a circular economy for rare earths

Sustainability and environmental, social and governance-linked goals are beginning to drive the buildout of a circular economy for critical materials and rare earths with an aim of reducing future overall mining activities as much as possible. A circular economy mainly entails obtaining usable rare earth materials by recycling end-of-life products where REEs are used. Upcoming companies such as Noveon Magnetics, REEcycle Inc. and ReElement Technologies are a few examples that are developing innovative recycling processes to recover rare earth from end-of-life motors, batteries and electronic waste.

3) Product innovation

Several industry players are developing new-age designs that can either reduce the quantity or eliminate the use of REEs in e-motors. These innovations are not limited to a certain geography, but companies spread across key markets are working to develop new solutions in this area. Among carmakers, while Tesla (induction motors) and BMW (externally excited motors) use e-motors without permanent magnet to avoid dependency on the complex supply chains, Toyota began developing their own e-motors that can reduce the use of REEs by 50% in 2018.

Meanwhile, Japan's Proterial Ltd. is teaming up with several automakers to produce e-motors with ferrite-based magnets, replacing neodymium-based magnets.

BMW's popular fifth-generation e-Drive, which went into production in 2021 and powers several BEVs and plug-in hybrids, has no magnets, offers a higher energy density, better heat management, and is smaller and lighter than previous generations. At its Investor Day conference in 2023, Tesla announced that it will design and develop a permanent magnet motor with no REEs in it.

On Oct. 14, 2024, Mahle, which first developed a magnet-free e-motor in 2021, announced that it is joining forces with Valeo to develop an innovative magnet-free e-axle system, targeting upper segment EVs with peak power ranging from 220 kW to 350 kW.

Furthermore, legacy carmakers are directly investing in upcoming startups to fund the development of magnet-free e-motors. For example, US-based Niron Magnetics, which has received funding from the venture capital arms of GM, Stellantis and Volvo Cars, has developed a rare earth-free, iron nitride-based clean magnet technology that can be further used in producing REE-free e-motors. On Oct. 10, 2024, the startup announced that it had opened its commercial pilot plant in Minneapolis to scale up production.

Overview of motor topology

Key electric motor topologies have been discussed below.

a) Axial flux permanent magnet motors: Axial flux motors have a unique construction where the gap between the rotor and stator and the direction of the magnetic flux is parallel to the direction of rotation. A stator is placed between two permanent magnet rotors to provide high power and torque density. However, axial flux motors are costly and complex to make, and packaging may force OEMs to make necessary design changes to use them in EVs. As a result, it is expected that axial flux motors will remain limited to luxury vehicles and performance-car segments.

Two key examples are YASA and Whylot. The former is a British axial flux e-motor startup, which was acquired by Mercedes-Benz in 2021 to develop ultrahigh-performance e-motors for its AMG EV platform that is slated to go into production in 2025. Renault acquired a 21% stake in Whylot, a French axial flux e-motor startup, in 2021, with the aim of beginning large-scale production of axial flux motors in 2025.

b) Claw-pole synchronous motors: They feature windings in both the rotor and stator, with magnets positioned between the claws. While these were initially developed for alternators, they later evolved into a starter-generator. Many OEMs employ claw-pole synchronous motors in mild-hybrid powertrains as motor-generator units that support stop-start functions and auxiliary systems. Known for being a cost-effective solution, these are predominantly used in 48V P0 starter-generator applications.

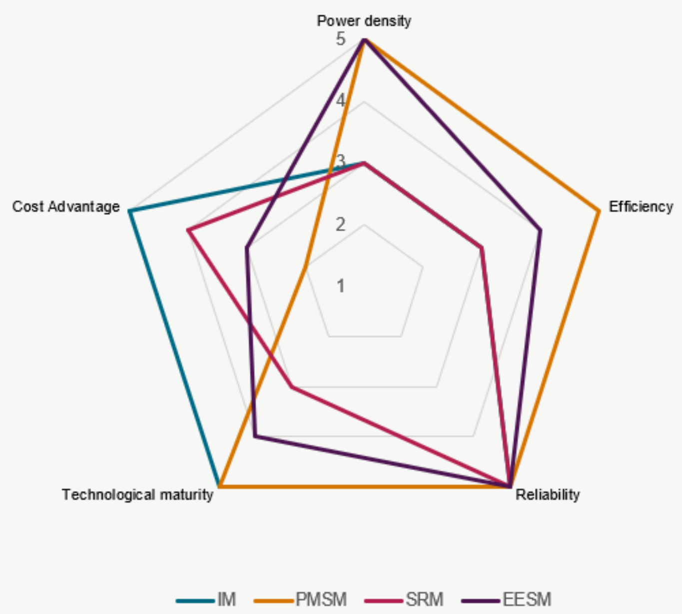
c) Current-excited wound rotor synchronous motor: This type of motor generates magnetic field via current excitation. They do not use rare earth permanent magnets in their design and are more economical to manufacture. This type of motor makes use of slip rings to deliver current to the rotor, which uses copper windings to generate a magnetic field. Notably, these motors deliver strong torque and maintain constant power throughout their speed range, with the capability to achieve higher peak torque during brief high-current bursts. However, their efficiency is lower compared to other motor topologies and are not thermally efficient.

d) Induction motor: In induction motors, the stator magnetic field created by AC induces a current in the rotor, creating a rotor magnetic field. The two magnetic fields then interact with each other with a slip. The induction motors are flexible and can handle high load demands, running slightly slower than the supply frequency. They are cost-effective, reliable, and can produce strong low-end torque, although they are considered to be less efficient than permanent magnet motors. Made without costly REE magnets, they are seen as an economical choice for EV traction applications.

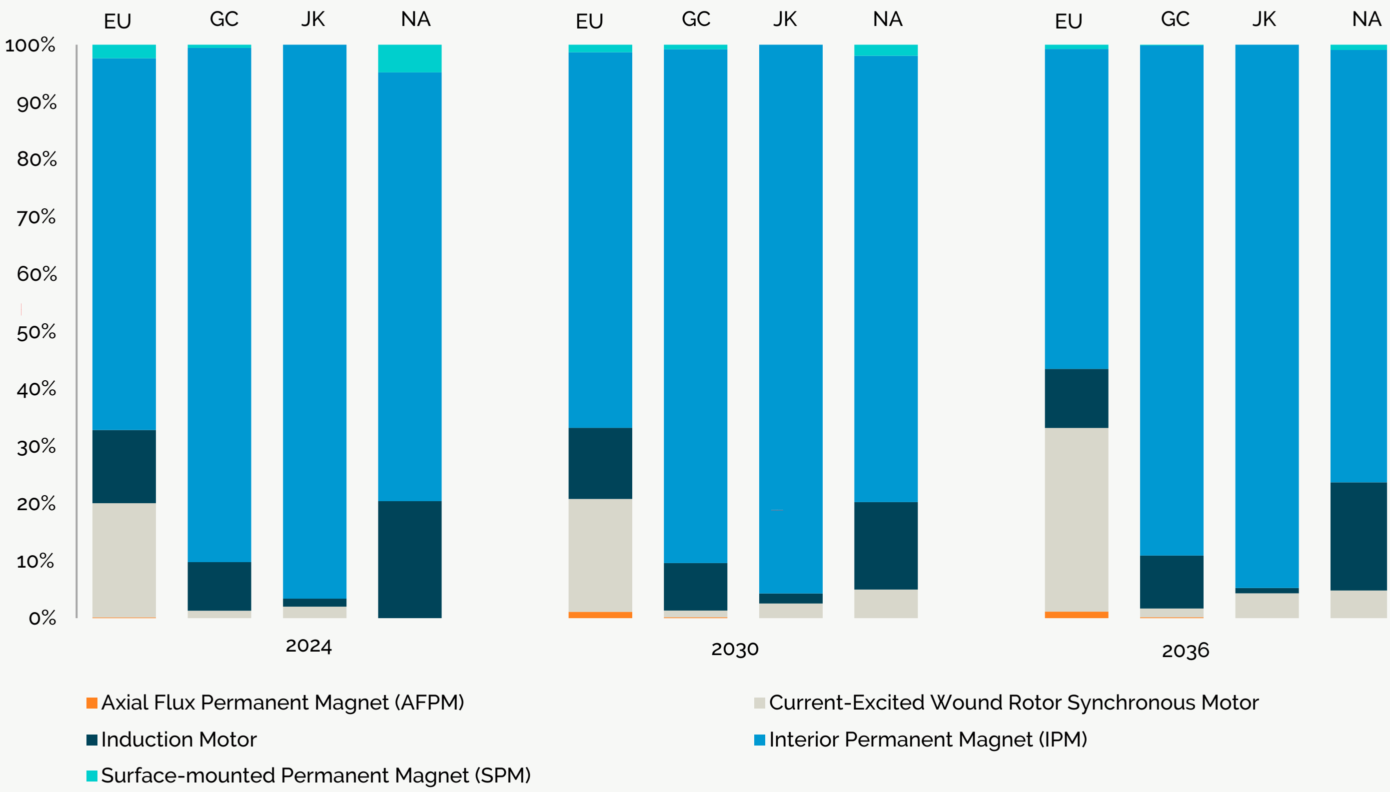
e) Interior/surface-mounted permanent magnet motor: In this type, the stator and rotor magnetic fields rotate at the same speed. Considered to be more efficient than AC induction motors due to the permanent magnetic field, they can be miniaturized, resulting in lighter design and can provide high torque density, which is an attractive proposition for OEMs. However, it poses functional safety issues as the rotor remains magnetized even when power is off. Their reliance on REEs is a significant drawback.

The increasing adoption of permanent magnet-based motors (PMSMs) is driven by their high-power density, superior efficiency and proven reliability, making them ideal for EVs. Although they are more expensive due to the use of REEs, their benefits outweigh the costs. The spider chart below explains how the different types of motors differ on key parameters.

Feature comparison of different motor types



Motor type regional breakdown



As of 2024, interior permanent magnet (IPM) e-motors account for nearly 90% of the total e-motor demand in Greater China and about 97% in the Japan/Korea region. S&P Global Mobility's forecast for the 2024 to 2036 period suggests that the IPM e-motors will maintain a significant share of the regional e-motor market in Greater China and Japan/Korea. High adoption of IPM e-motors in Greater China is attributed to the country's existing expertise and infrastructure for the REE technology.

In contrast, regions like Europe and North America are actively seeking alternatives to magnet-based e-motors. As of 2024, current excited wound rotor synchronous motors and induction motors make up 20% and 12.7% of the total e-motor market in Europe, respectively. This trend is expected to persist, with these two types of motors projected to represent 42% of the total e-motor market in Europe by 2036.

Similarly, induction motors account for 20.4% of the total e-motor market demand in North America in 2024. But by 2036, it is projected to decrease to 18.8%. Known as a low-cost technology commonly employed in budget-friendly vehicles, induction motors function as secondary e-drive systems in all-wheel drive (AWD) and four-wheel drive (4WD) setups, supporting the primary drive provided by permanent magnet synchronous motors or electrically excited synchronous motors (EESM). Tesla uses induction motors and is developing solutions that can eliminate REE content from e-motors altogether.

Meanwhile in Europe, BMW's fifth-generation e-motors operate as three-phase AC synchronous motors without magnets, utilizing brushes and a commutator to power the rotor windings. The carmaker claims that this design offers higher energy density, faster switching frequency and improved heat management.

Renault and Valeo are developing the REE-free E7A motor for 800-volt systems, targeting up to a 200kW output with improved efficiency. The E7A motor, which uses hairpin technology and a wound rotor, reducing the carbon footprint by 30% and eliminating the need for REEs, offers a compact design 30% smaller than current motors used in Megane E-Tech and Scenic E-Tech models. Mass production of the E7A motor is expected to begin at Renault's Cléon factory in 2027.

2

Technology analysis

Evolution in key design trends

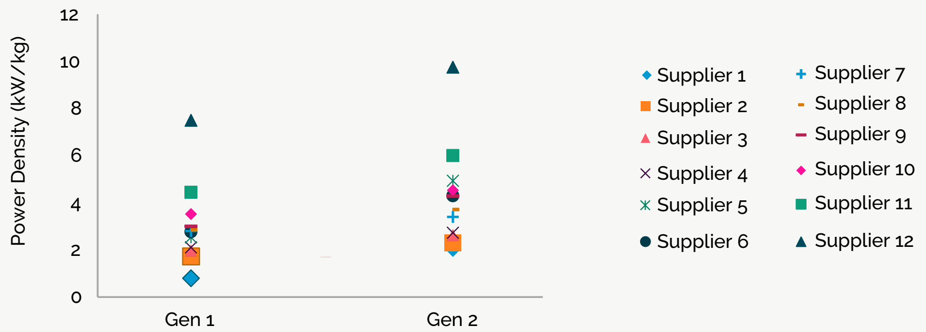
Let us take a look at the evolution in e-motor design trends that are driven by the OEMs' pursuit of technology enhancements across key parameters:

Power density

The specific power of e-motors plays a critical role in increasing the efficiency and driving range of BEVs. Optimizing the power output of e-motors with respect to their size and weight is essential to improve energy efficiency and extend vehicle range. That said, lately, the suppliers and automakers are focusing on improving the specific power of e-motors. The specific power of the current generation of e-motors has been improved by 20%-35% by augmenting power output while maintaining constant motor weight, retaining the same power rating with a reduction in motor weight and by achieving increased power with concurrent reduction in motor weight.

Additionally, a more power dense e-motor results in less energy waste in the form of heat and other losses.

Specific power trend

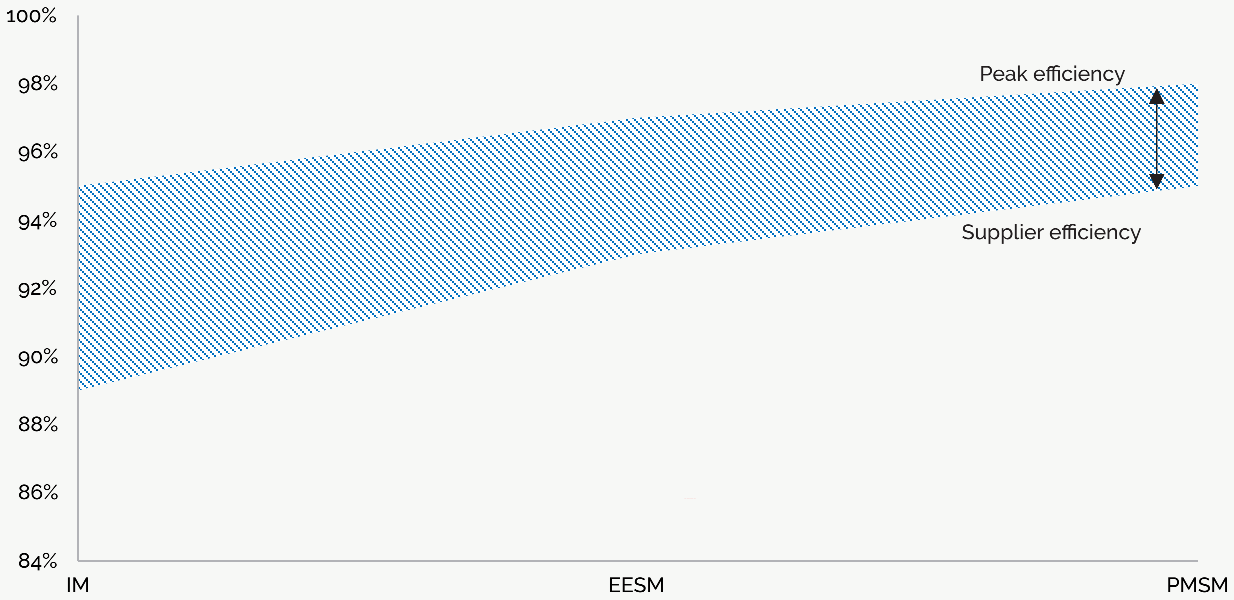


Efficiency

Most e-motor suppliers are concentrating on enhancing the efficiency of electric motors, which will subsequently boost the overall system efficiency and driving range of EVs. According to S&P Global Mobility's analysis, there is significant potential for further improving the efficiency of e-motors relative to their current performance levels. For example, as per the graph below, induction motors currently achieve an efficiency of approximately 89%, yet they have the potential to reach peak efficiencies close to 95%. A similar trend is observed in both EESM and PMSM motor types.

Recently, GAC has begun producing the Quark Electric Drive 2.0, a high-performance e-motor that can extend an electric vehicle's range by up to 50 kilometers without increasing battery size. The motor boasts a power density of 13 kW/kg and an efficiency of 98.5%.

Supplier efficiency improvement scope



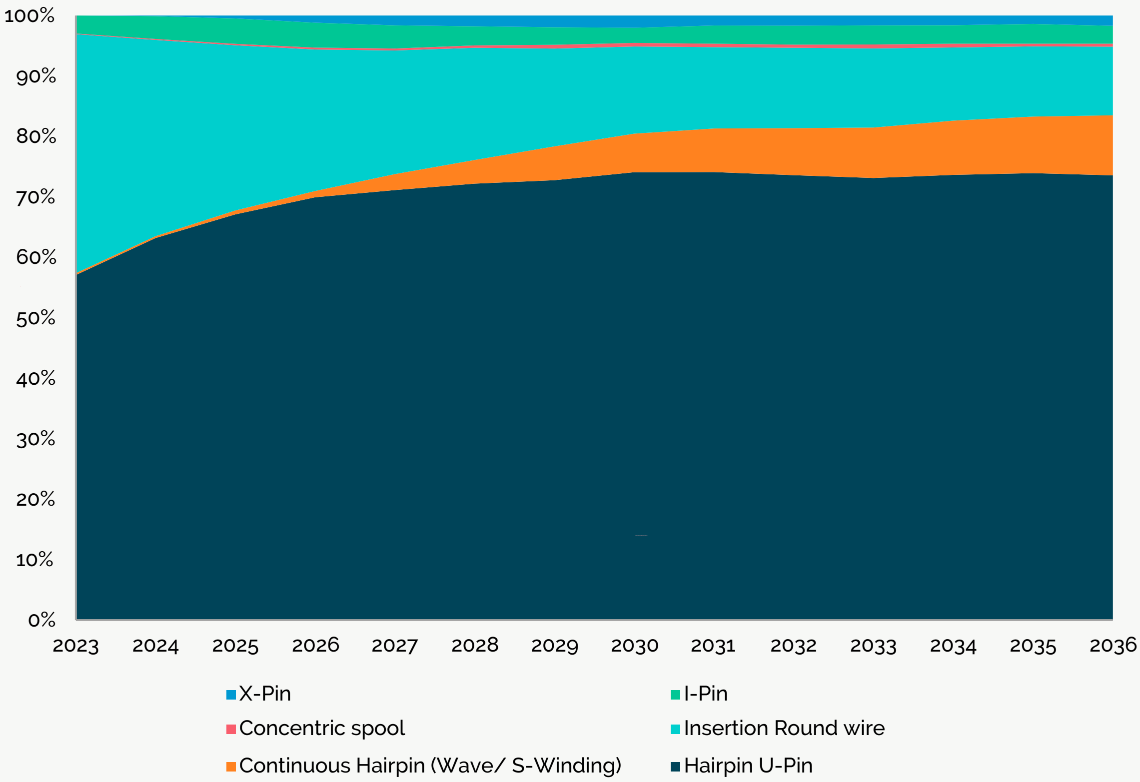
Winding types

Stator winding technology directly impacts performance, efficiency and overall driving experience. The table below details the main types of winding commonly used in automotive applications:

Main types of winding types in automotive applications

Winding type	Details
Insertion round wire	Currently occupies a large portion of the e-axle market and it is extensively used in BEVs.
Hairpin U-pin	Provides higher efficiency due to an improved fill factor.
Continuous wave	A growing development on the e-axle is to remove the welding process; it does make the manufacturing process more complicated.
Concentric spool	Mostly used in hybrid vehicles.
I-pin	• A niche technology that is expected to find application in high performance vehicles. • In August 2023, Bosch started production of new e-drive solutions (e-motors and inverters) suitable for 800V technology. For its e-motor (for 800V architecture), the company has used I-pin winding technology. It claims that the use of I-pin windings improved the e-motor's efficiency, compactness and automation of its production process
X-pin	• A new emerging technology in Greater China. • Tier 1 supplier UAES is one of few companies that have been working on X-pin windings since 2021.In August 2023, phase 2 of UAES' Taicang factory began mass production of e-motors with X-pin windings, with the expectation of produce reaching 0.7 million e-motors per annum. • Similarly, in August 2023, Haosen announced that it has successfully completed trial production of the X-pin motor stator. The company says that it is fully equipped with the mass production capabilities needed for X-pin motor stator production.

Global growth of stator winding types



Increased uptake of hairpin winding: Hairpin winding technology has matured and is increasingly recognized for its efficiency and power density, resulting in lower copper losses and enhanced performance due to its innovative design. Although it may be more complex to manufacture compared to traditional winding methods, hairpin winding effectively balances manufacturing efficiency with high performance. This technology strikes a harmonious balance between high performance and cost-effectiveness, establishing itself as the go to solution in the winding technology landscape.

Massive adoption of the hairpin U-pin winding type is expected in the coming years, especially due to the growth in e-axle volumes. With 62% market share (in 2024), hairpin winding is the go-to technology with many of OEMs leveraging this technology.

In April 2022, BorgWarner completed the acquisition of Santroll Automotive Components (part of Santroll's e-motor business) with an intent to strengthen its vertical integration, increase the scale of its light-vehicle e-motor portfolio and increase speed to market. Santroll is a mainland China-based company that designs and develops hairpin and concentrated-winding, technology-based e-motors for light vehicles.

ZF has developed a braided hairpin winding technology that, according to the company, requires 10% less installation space. The winding head is approximately 50% smaller than the conventional techniques, which leads to approximately 10% less raw material requirement.

Similarly, Volkswagen is using a permanent magnet synchronous motor that features hairpin winding. The coils of the stator are made of square copper wires, and the coils can be packed more tightly due to hairpin winding. This results in increased torque and efficiency of the motor.

Based on S&P Global Mobility's forecasts, as of 2023, hairpin U-pin windings accounted for 57% of the total winding market. By 2036, this winding type should comprise 74% of the total winding market. The continuous hairpin winding type is also expected to see growth during the forecast period 2023–36 — representing 10% of the total winding market by 2036. However, its complicated manufacturing process might impact its uptake. Since January 2023, two significant motor platforms have been announced running continuous hairpin technology. The first in production was Lucid Motors who have been looking to expand the use of their motor with other premium brands. Then, in March 2024, Nio announced the mass production of its 900V EDS named "Thunder," with the Nio ET9 set to be the first vehicle to feature it. Hairpin winding technology has matured and is increasingly recognized for its efficiency and power density, resulting in lower copper losses and enhanced performance due to its innovative design. Although it may be more complex to manufacture compared to traditional winding methods, hairpin winding effectively balances manufacturing efficiency with high performance. This technology strikes a harmonious balance between high performance and cost-effectiveness, establishing itself as the go to solution in the winding technology landscape.

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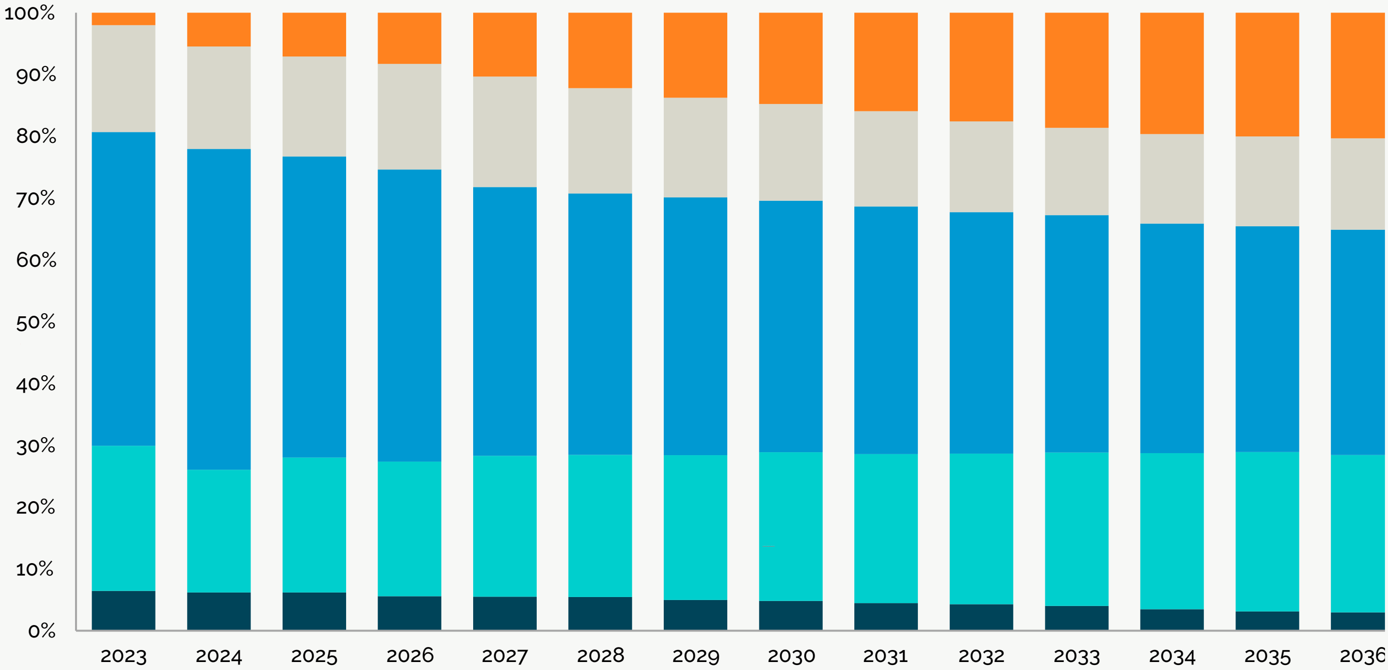
Speed

Increasing the speed of e-motors help in significantly improving the power density and efficiency of EVs and in turn improving the vehicle range. As of 2023, nearly 50% of electric motors operated within a speed range of 15,000 to 17,999 rpm, while only 2% exceeded 20,000 rpm. However, with a sustained emphasis on enhancing driving range and overall system efficiency in EVs, market dynamics are shifting. According to S&P Global Mobility forecasts, the demand for e-motors exceeding 20,000 rpm is projected to grow at a CAGR of 34%, increasing from 0.4 million units in 2023 to 18.3 million units by 2036. By that year, e-motors with speeds surpassing 20,000 rpm are anticipated to represent 20% of the total e-motor market.

Growth of e-motor speed



In December 2023, Xiaomi unveiled its new e-motors: the HyperEngine V6/V6s and HyperEngine V8s. The HyperEngine V8s is designed to achieve a maximum speed of 27,200 rpm, with an output of 425 kW and peak torque of 635 N·m. It employs high-strength silicon steel plates characterized by a tensile strength of 960 MPa. In comparison, the HyperEngine V6 reaches a maximum speed of 21,000 rpm, delivering a maximum power of 299 PS and torque of 400 N·m.

On similar lines, in August 2023, GAC began the production of Quark Electric Drive 2.0, which according to the company is a high-performance e-motor that can extend an electric vehicle's range by up to 50 kilometers without increasing battery size. The motor boasts a power density of 13 kW/kg, 98.5% efficiency, and a 30,000-rpm speed, utilizing an amorphous soft magnet material for enhanced performance. This motor will soon be installed in Hyptec models.

Hyundai Motor Group's e-motor for the EV6 GT boosts rotational speed from 15,000 rpm to 21,000 rpm for both front and rear motors. It features an integrated design combining the e-motor, inverter and reducer to reduce friction. The optimized bearing design and refined magnet and rotor arrangement enhance stress distribution, durability and efficiency during high-speed use.

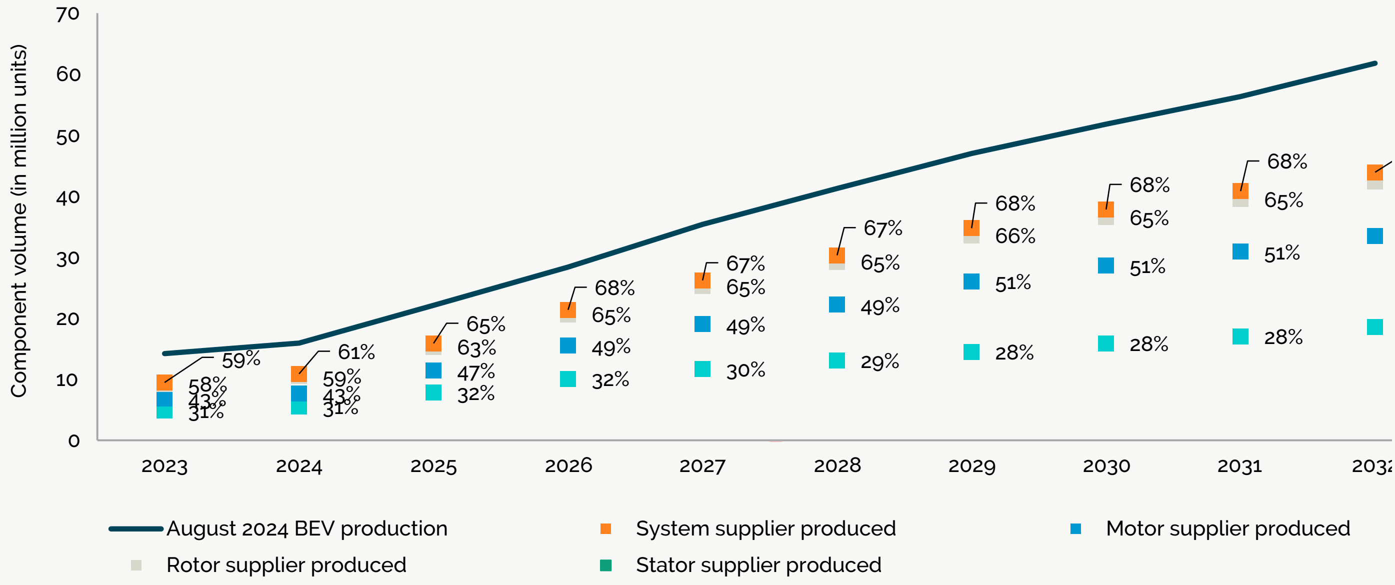
3

Market analysis

Supplier involvement in the P4 e-drive value chain

Many OEMs are increasingly leaning toward in-house production for e-motors and system integration, as evidenced by their investments in new plants and expansion of existing production lines. This shift can be attributed to several factors, including the desire to gain a competitive edge, expedite product development and reduce costs. According to S&P Global Mobility forecasts, in-house production is the preferred strategy for e-motors and system integration.

Supplier production levels for P4 supply chain



Tesla and BYD are leading the in-house sourcing of e-motor and e-drive units. Volkswagen on its Tech Day 2023 announced that it will manufacture its e-motors, batteries, pulse inverters and thermal management systems in-house for cost and efficiency reasons. In February 2024, Volkswagen Group Components has inaugurated a large castings competence centre at its Kassel site. The facility will produce rotors for asynchronous motors using forming technology.

E-motor sub-components an apt opportunity for suppliers

The electric motor and its subcomponents, including the rotor and stator, are creating significant opportunities within the supply chain. OEMs are unlikely to fully in-source e-drives or their components. Key factors such as profitability, cost reduction, product development timelines, resource availability and localization will continue to influence sourcing decisions.

Recently, many tier 1 suppliers have secured contracts to provide motor subcomponents, such as rotors, stators and motor sleeves, to OEMs. These suppliers are also aiming to capitalize on the growing e-motor subcomponent market. For instance, BorgWarner has begun producing e-motor rotors and stators for XPeng Motors, specifically for the X9 MPV and a new B-class electric sedan, with production slated to start in the third quarter of 2024. A further example would be SEG Automotive and recent announcements of series production of 800V stators and rotors in mainland China, supplying these components to a leading new energy vehicle manufacturer in the region.

Although currently in slowdown phase, EVs are still forecast to become mainstream in major automotive markets. As such, the volume of e-motor production is expected to rise significantly. The sourcing strategies of motor assembly and subcomponents like rotors and stators is likely to see heavy involvement from the supply chain. This trend will create further opportunities for tier 1 and tier 2 suppliers to expand their market presence. These suppliers can provide individual rotor and stator components to OEMs, and their success will depend on how effectively they leverage these opportunities to carve out a niche and generate profit.

Supply chain dynamics!

Michael Southcott
Manager, Technical Research,
Production & Design, S&P Global Mobility

The sourcing of electric drive units has shifted in recent years from being predominantly led by major tier 1 suppliers to in-house production at the OEM level. As production volumes rise and performance requirements for electric motors become increasingly critical, the supply chain is increasingly utilized for its expertise in manufacturing and design at the sub-component level. This trend is not limited to electric motors; components like inverters are also beginning to follow suit. Suppliers will need to adopt flexible strategies moving forward, but this shift presents significant opportunities for both tier 1 and tier 2 suppliers.

Conclusion

The ongoing slowdown in the global demand of BEVs is driving OEMs to revise their product strategies and take a relook at the hybrid propulsion technologies that best suit their customers. While the hybrid propulsion systems are expected to record growth in the near to mid-term, we forecast that pure BEVs will outsell hybrids in the long term as they are a better answer to the world's energy transition and sustainability goals. E-motors are a key propulsion component whether it is a BEV, plug-in hybrid vehicle or a range-extender electric vehicle. Even as the companies scramble to rework their supply chains to secure critical materials used in producing e-motors, they are innovating not just new types of e-motors that use more sustainable materials but also provide improved power density, performance, are smaller in size and lighter in weight that can contribute toward delivering on consumer expectations. The e-motor designs are evolving rapidly to become more efficient and sustainable, and it is seen that several carmakers are taking a lead in vertically integrating the development and production processes to drive these engineering innovations in addition to deliver on cost savings in the future.

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