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The Electric Drive Value Chain and Technologies to Drive Performance

Copper Alliance Webinar

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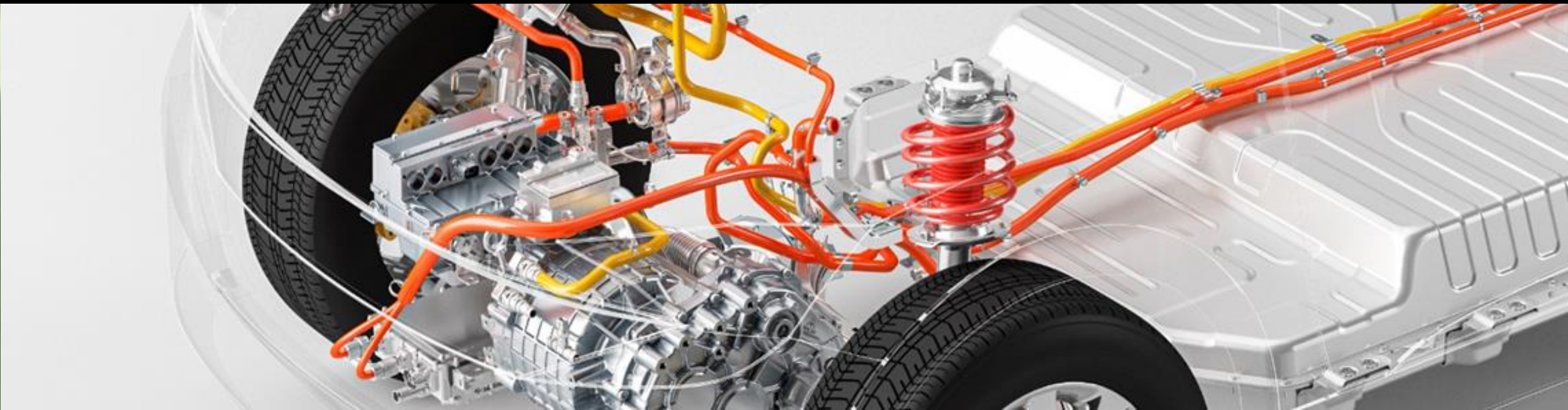
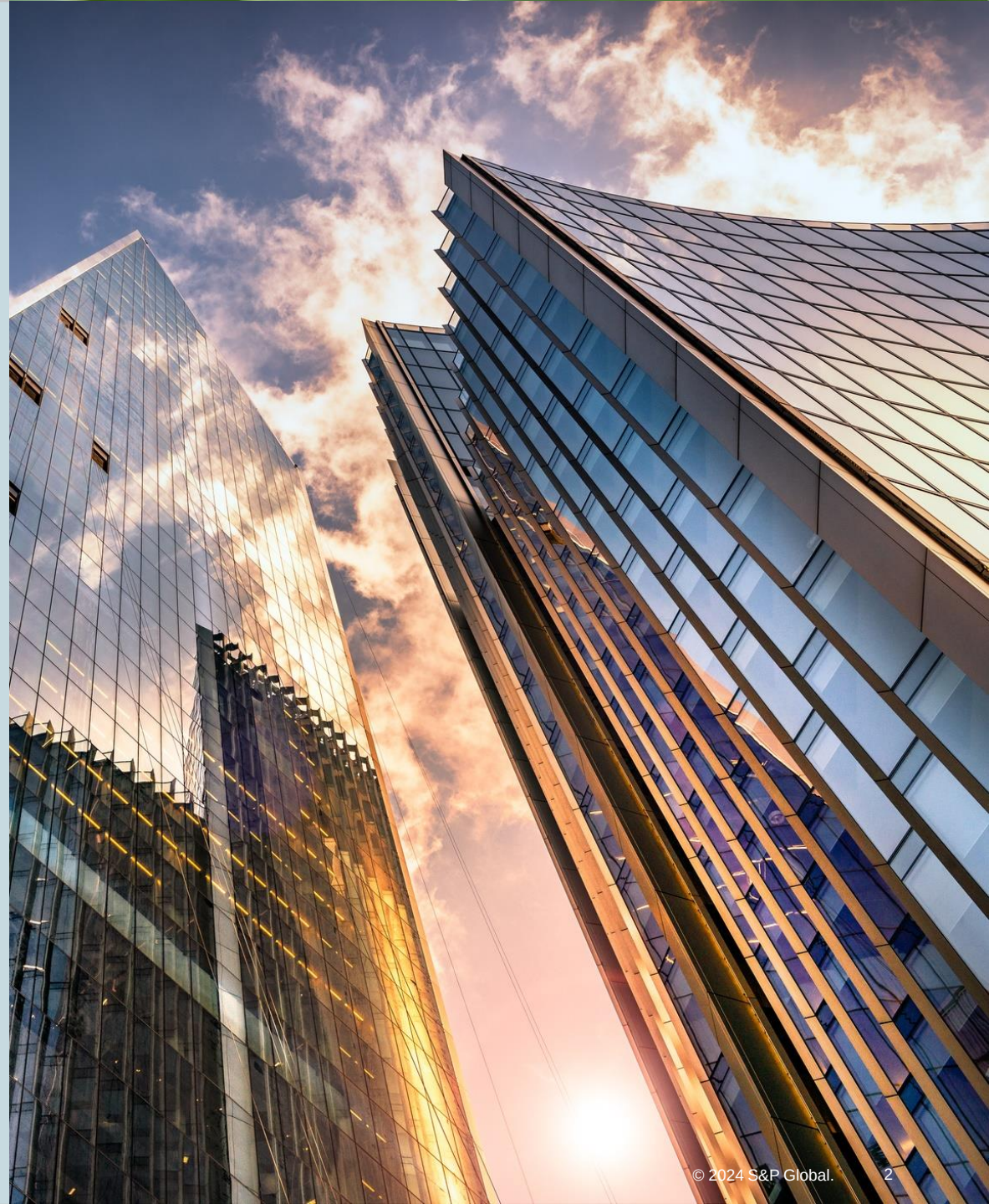
March 2024



Agenda

- Overview of the electric vehicle market
- eDrive technologies and their impact on motor design
- Critical materials & technology
- Evolving supply chain dynamics
- Summary



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with revenue greater than $5 billion

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automotive experts
on the ground in 16 countries, plus select experts across industries available

1000
data sets
across energy, financial, and transportation sectors within our Data Lake

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100%
coverage of global long-term forecasts
of light & medium/heavy commercial vehicle sales & production

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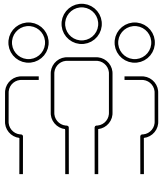
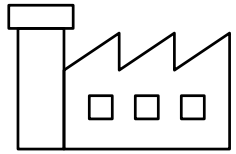
Supply Chain and Technology at S&P Global Mobility



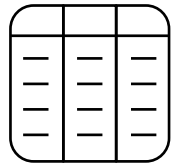
90+

Analysts in 18 offices, with dedicated data scientists and data architects



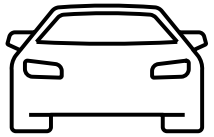
5000+

Suppliers tracked at model/nameplate level



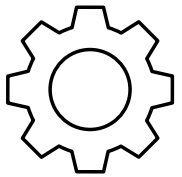
30M

Number of rows updated monthly



15 Vehicle Domains

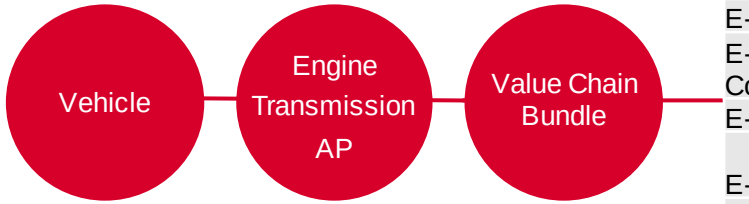
Autonomy, Battery, Charging, Chassis, Connected Car, Consumer Insights, E/E & Semi, Interior, Lighting, Materials, OEM Strategy, Propulsion, Software, Thermal and UI/UX



300+

Technologies tracked and mapped against 150+ vehicle, engine and transmission subsystems

Propulsion Value Chain



Propulsion Value Chain	
E-Motor Type	E-Motor Concentricity
E-Motor Architecture-Location	E-Motor Maximum Speed
E-Motor Assembly Supplier	E-Motor Cooling Medium
E-Motor Assembly Supplier Group	e-Axle Definition
E-Motor Assembly Supplier Region	Inverter Supplier
E-Motor Assembly Supplier Country/Region	Inverter Supplier Group
E-Motor Assembly Supplier Plant	Inverter Supplier Region
E-Motor Assembly Units	Inverter Supplier Country/Territory
E-Motor Architecture	Inverter Supplier Plant
E-Motor Function	Inverter Cooling Medium
E-Motor Location	Inverter Type
Px Definition	Inverter Integration Level
T: Drive Type	Inverter Position
Rotor Units	Rotor Winding Type
E-Motor Power (Hp)	Stator Units
E-Motor Power (Hp) Range	Stator Supplier
E-Motor Power (kW)	Stator Supplier Group
E-Motor Power (kW) Range	Stator Supplier Region
E-Motor Torque (LbFt)	Stator Supplier Country/Territory
E-Motor Torque (LbFt) Range	Stator Supplier Plant
E-Motor Torque (Nm)	Stator Winding Type
E-Motor Torque (Nm) Range	Rare Earth Material Usage
System Integration Supplier	Rotor Supplier
System Integration Supplier Group	Rotor Supplier Group
System Integration Supplier Region	Rotor Supplier Region
System Integration Supplier Country/Territory	Rotor Supplier Country/Territory
System Integration Supplier Plant	Rotor Supplier Plant
E-Motor Integration Level	
E-Motor Design Parent	

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Growth of the electric motor market

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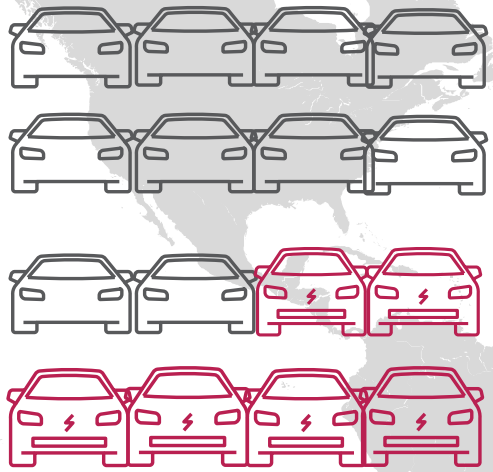
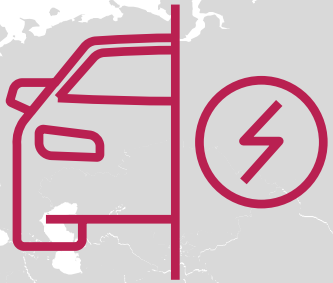
Propulsion outlook for 2024

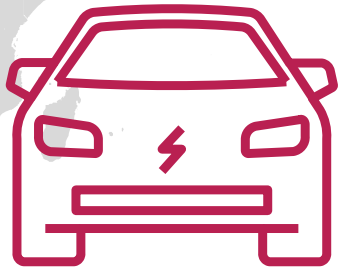
89.3million
vehicles produced globally in 2024



39.7%
will require an electric motor



22.7%
of vehicles produced will be some form of hybrid



17%
of vehicles produced will be full electric vehicles

Europe (20%), Greater China (59%) and North America (10.5%) lead the growth of electric vehicle production

Source: S&P Global Propulsion Bundle Oct 2023

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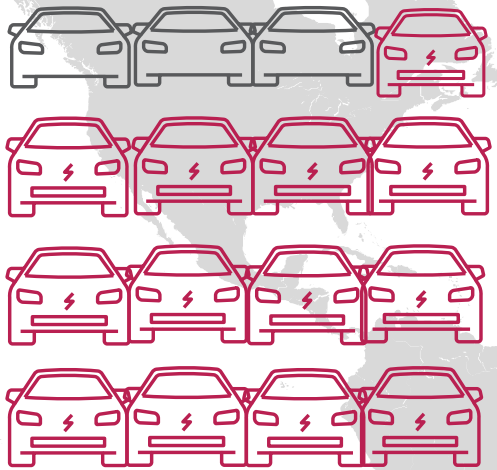
Propulsion outlook for 2034

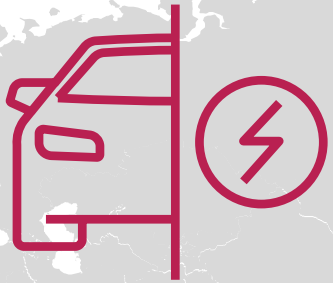
100.3million

vehicles produced globally in 2034



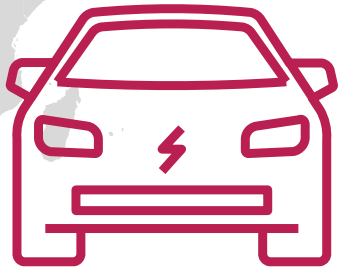
83.7%

will require an electric motor



20.3%

of vehicles produced will be some form of hybrid



63.4%

of vehicles produced will be full electric vehicles

Europe (25%), China (38%) and North America (19%) lead the growth of electric vehicle production

Source: S&P Global Propulsion Bundle Oct 2023

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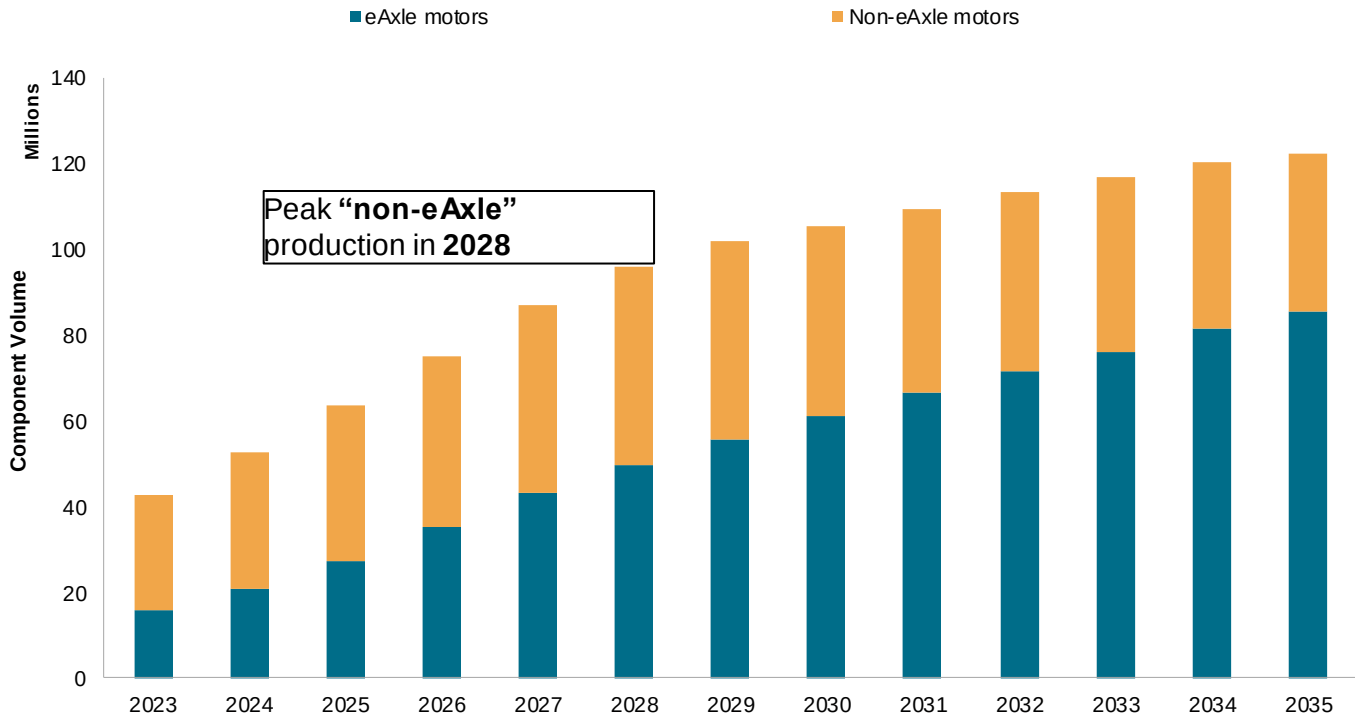
Electric motor market growth

Significant growth to come in the electric motor market with eAxle the significant driver

Growth of electric motor market to 2035



Data compiled February 2024

Source: S&P Global Mobility.

- Electric motor market in total forecasted to grow by over **300%** in the next 12 years exceeding **120million** motors produced in 2035
- The **eAxle** market will drive this, in 2023 **37%** of motors produced will be used in eAxles, by 2035 this has grown to over **69%**
- Non-eAxle (belt & transmission) will reach peak production in **2028** at just over **46.2million** units produced annually

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Emerging technology & key motor design trends

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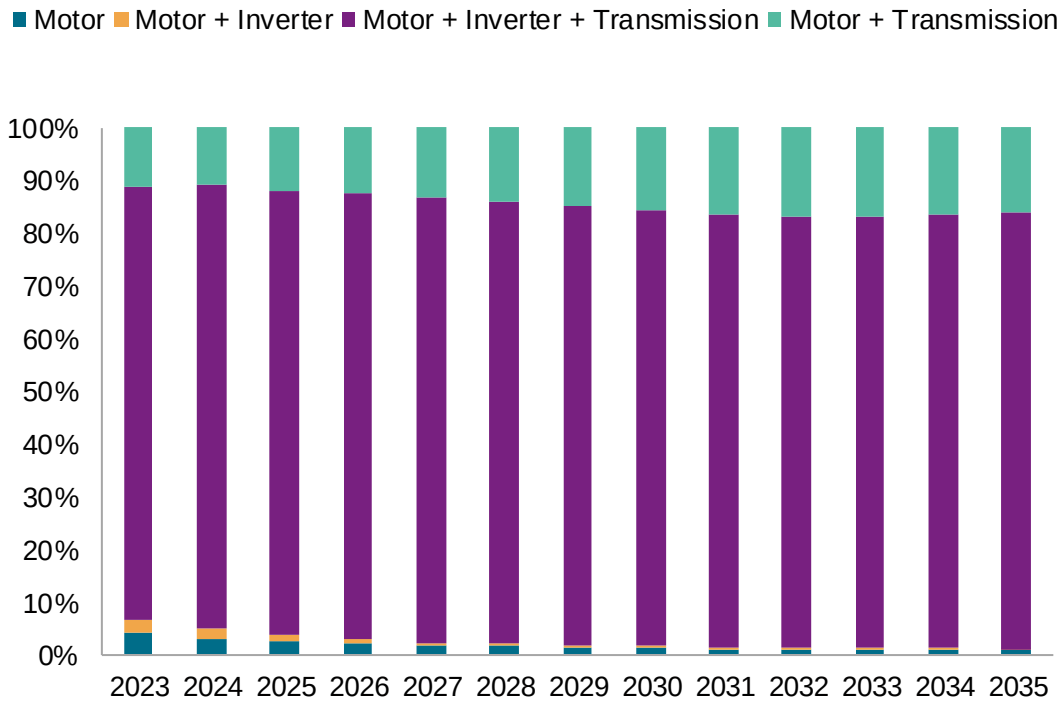
Shift towards highly integrated e-drive system

To optimize the e-drive system such as reduce its cost, lower its weight and optimize space utilization and its thermal management system, a **growing trend of integrating various e-drive components (e-motor, inverter, gearbox etc.) into a single module is witnessed**.

- Based on level of integration, we have
  - "2-in-1" systems: E-Motor is integrated with the inverter or transmission
  - "3-in-1" system: E-motor is integrated with both the inverter and transmission.
- As per the S&P Global Mobility forecast, **"3-in-1" system** i.e., e-motor is integrated with both inverter and transmission, is the most widely used integration type and is expected to remain so in the coming years. By 2035, "**3-in-1" system will account for 83% of total eAxle motor market.**
- By 2035, Motor + Transmission configuration is expected to account for 16% of total eAxle motor market – up from 11% in 2023.
- Apart from e-drive components, suppliers and automakers are also working to integrate thermal management system also into "3-in-1" system.

eAxle motor integration level, 2023-35



Data compiled Feb. 13, 2024.
Source: S&P Global Mobility.

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Shift towards highly integrated e-drive system

Automakers and suppliers are exploring and moving towards integrated eAxle systems in a bid to improve efficiency, reduce installation space, lower weight and reduce costs

Nissan's X-in-1 e-drive system

- In March 2023, Nissan announced that it adopted a new approach called **X-in-1** to develop electrified powertrain in which the components will be shared and modularized that will result in **30% reduction in development and manufacturing costs by 2026 (compared to 2019).**
- The company has developed **3-in-1 powertrain prototype** for EVs that integrates motor, inverter, and reducer. Its **5-in-1** powertrain integrates motor, inverter, reducer, generator and increaser, is planned for use in e-POWER vehicles.

Schaeffler's 4-in-1 eAxle with integrated thermal management system

- Schaeffler's eAxle system integrates the electric motor, power electronics, transmission and thermal management system into the axle drive. Integration of components also reduces cost and development time.
- As per the company, the integrated system is highly compact and has less energy losses due to the elimination of unnecessary hoses and cables. It can achieve **96% efficiency** in an optimally designed system.

Valeo's 6-in-1 eAxle system

- Valeo's 6-in-1 eAxle system integrates the inverter, on-board charger, DC/DC converter, power distribution unit, e-motor and reducer into a single unit.
- The system can cover peak power from 40 kW up to 300 kW and is compatible with both 400V and 800V architecture.

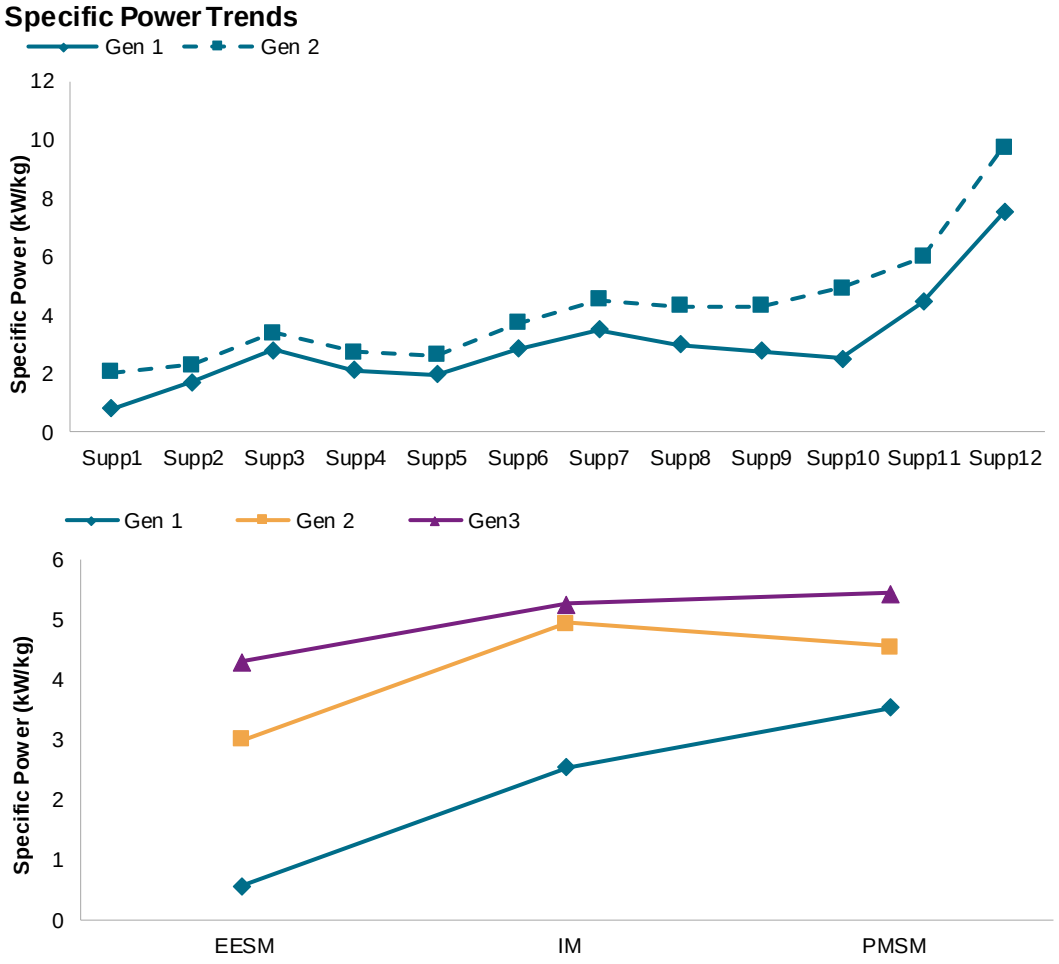
Data compiled Feb. 14, 2024.
Source: S&P Global Mobility.

Evolution of specific power: Emerging Trends

Specific power has emerged as a pivotal parameter warranting thorough consideration

Optimizing power output in relation to size and weight is essential to improve energy efficiency and extend vehicle range

- On average, a **35%** improvement in specific power has been noted
- Improvements spanning a range of **20% to 40%**
- Supplier adopting diverse strategies to achieve these enhancements
  - **Augmenting power** output while maintaining constant motor weight
  - Retaining the same power rating with a **reduction in motor weight**
  - Achieving **increased power** with concurrent reduction in motor weight



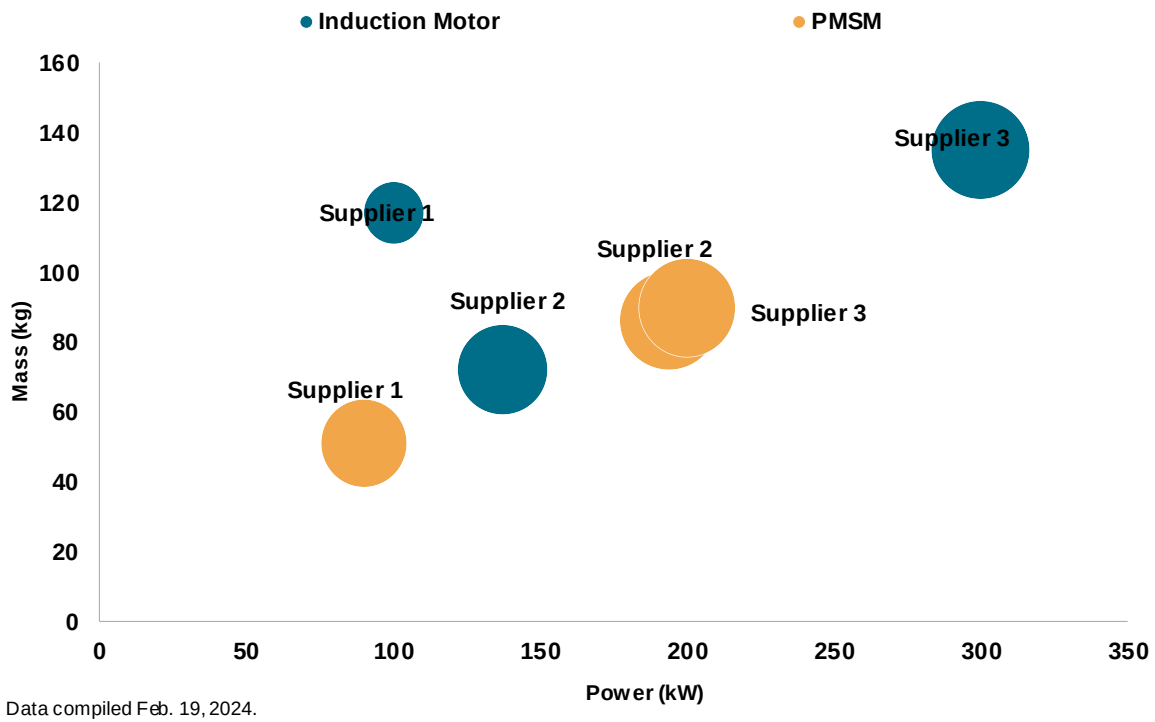
Data compiled Feb. 19, 2024.
Source: S&P Global Mobility.

Uncovering Specific Power Trends Across Motor Types

PMSM typically exhibit a **greater specific power rating** when compared to induction motors (IM)

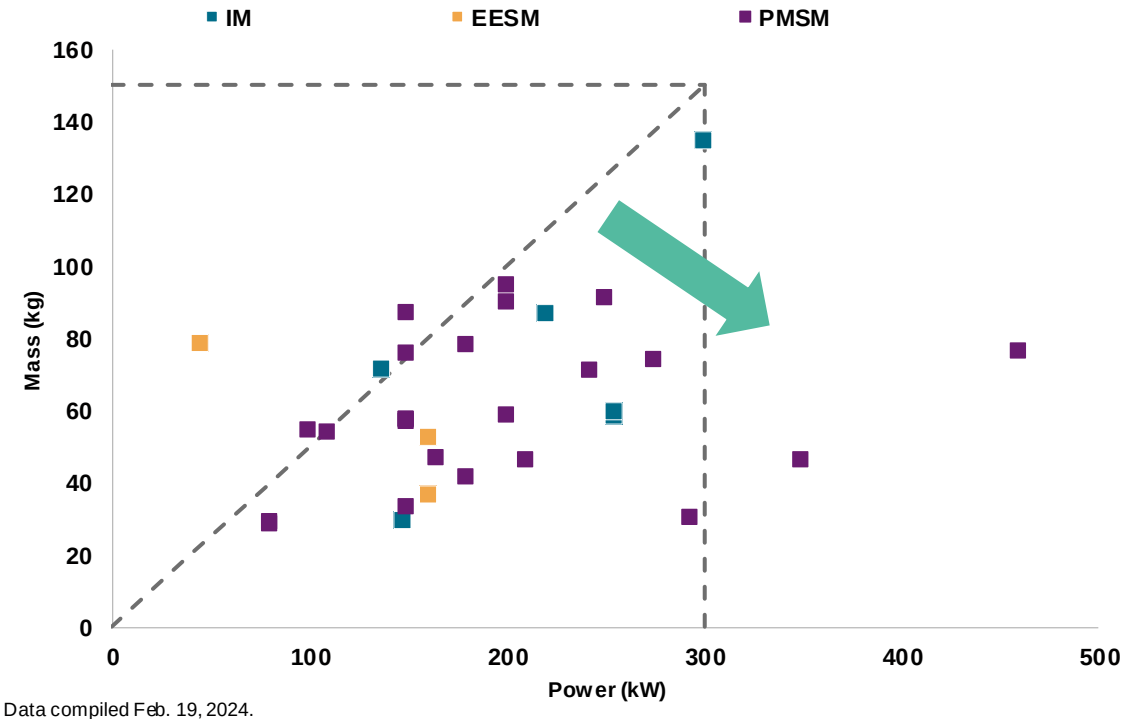
Achieving similar power ratings may come with the **trade-off** with parameters such as **weight, efficiency** etc.

Specific power based on motor type



Data compiled Feb. 19, 2024.
Source: S&P Global Mobility.

Motor Power and Weight Relation Trend



Data compiled Feb. 19, 2024.
Source: S&P Global Mobility.

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Quick Facts: Winding Type Analysis

Present and Future Windings technologies of traction motors

Insertion

Currently occupies a large portion of the eAxle market

Hairpin u-Pin

Square wire to replace traditional round wire in insertion technology provides a higher efficiency due to improved fill factor

Continuous wave

Growing development on eAxle to remove the **welding process** but does make the manufacturing more complicated

Several Tier 1s exploring this, first introduction expected in **2023***

Concentric Spool

Common technology for hybrid applications, particularly P2.

For eAxle, it does become relevant when looking into **rotor windings** for certain motor types

I-Pin

Not expected to see much growth on eAxle applications, some Tier 1s have explored and will look to run this, it appears to be more a niche technology for high performance vehicles.

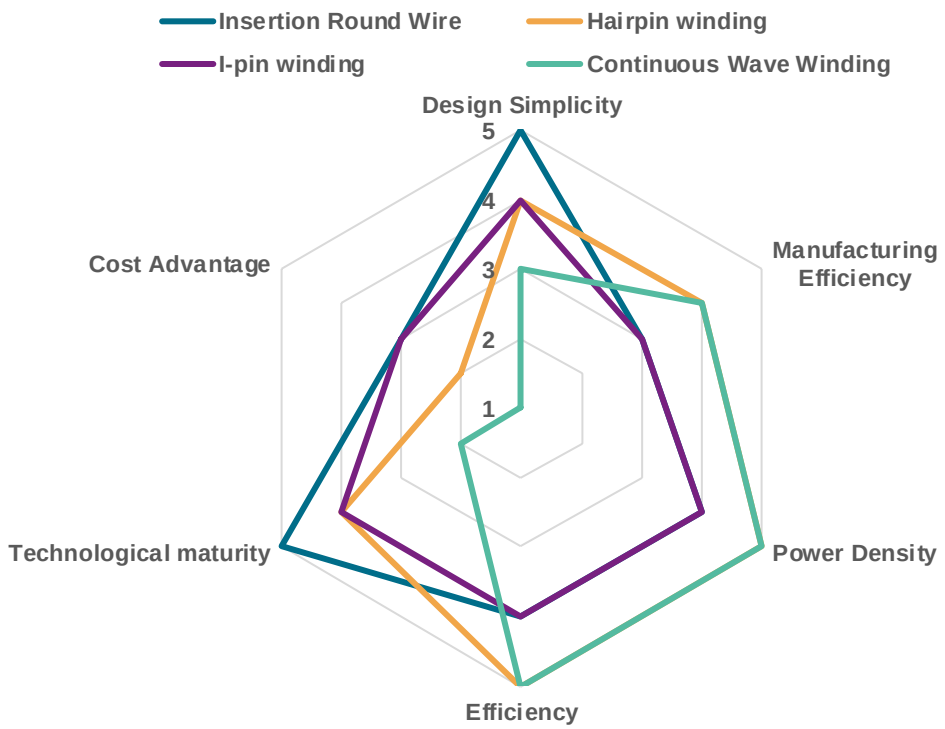
X-Pin

A new technology emerging in the Greater China market, an expectancy this could grow outside of the region moving forward as a viable option for BEVs.

Spider Diagram Analysis of Winding Technologies

Optimizing the performance of electric vehicles hinges on selecting the appropriate motor winding technique

Winding technology directly impacts performance, efficiency and overall driving experience



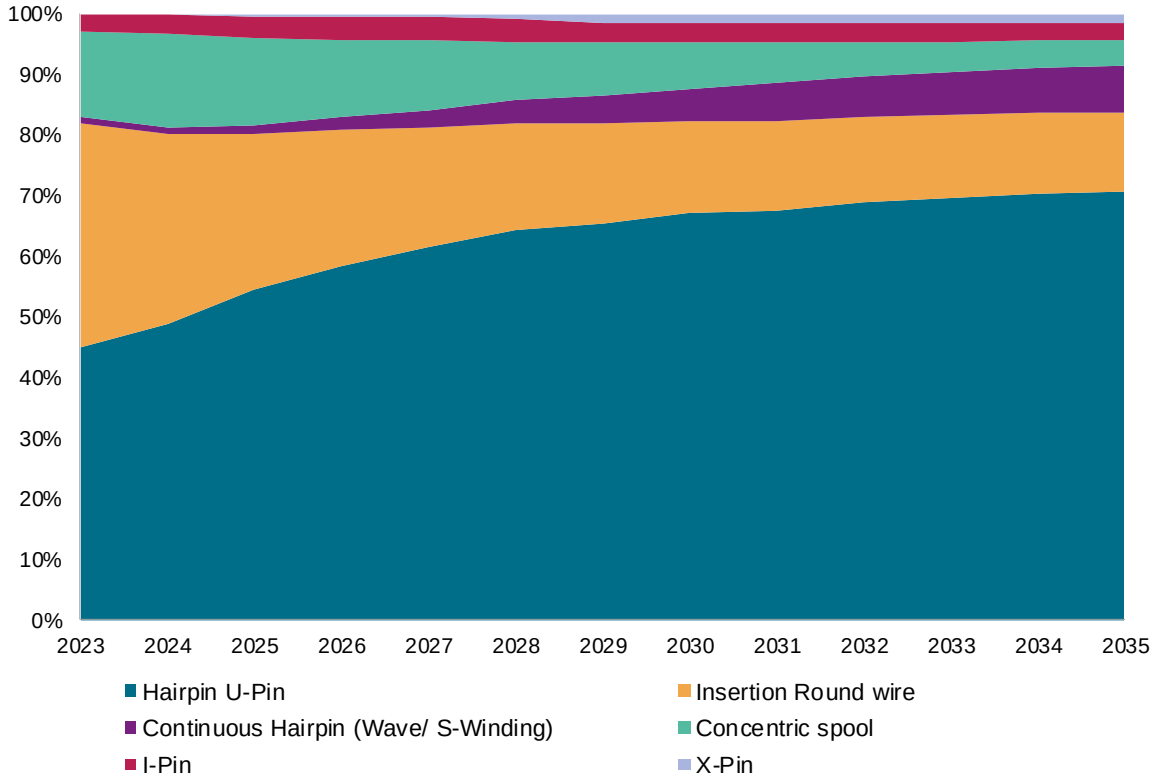
- Hairpin winding technology has matured and is gaining recognition for its combination of **efficiency** and **power density**
- Hairpin winding results in lower copper losses and improved efficiency due to its **design**
- While it may be more complex to manufacture compared to some traditional winding methods, Hairpin winding offers a good balance of **manufacturing efficiency** and **high performance**
- Hairpin winding strikes a balance between **high performance** and **cost-effectiveness**, thus positioning itself as the go-to solution for winding technology

Winding Tech Outlook

Hairpin Technology is going to see significant growth in the coming years, especially as **eAxle** applications grow in volume. **Europe and North America** in particular will see a very quick ramp up in hairpin production lines in the short term.

X-Pin and Continuous wave windings are key technologies to watch in the **mid-long term** in all key motor production regions.

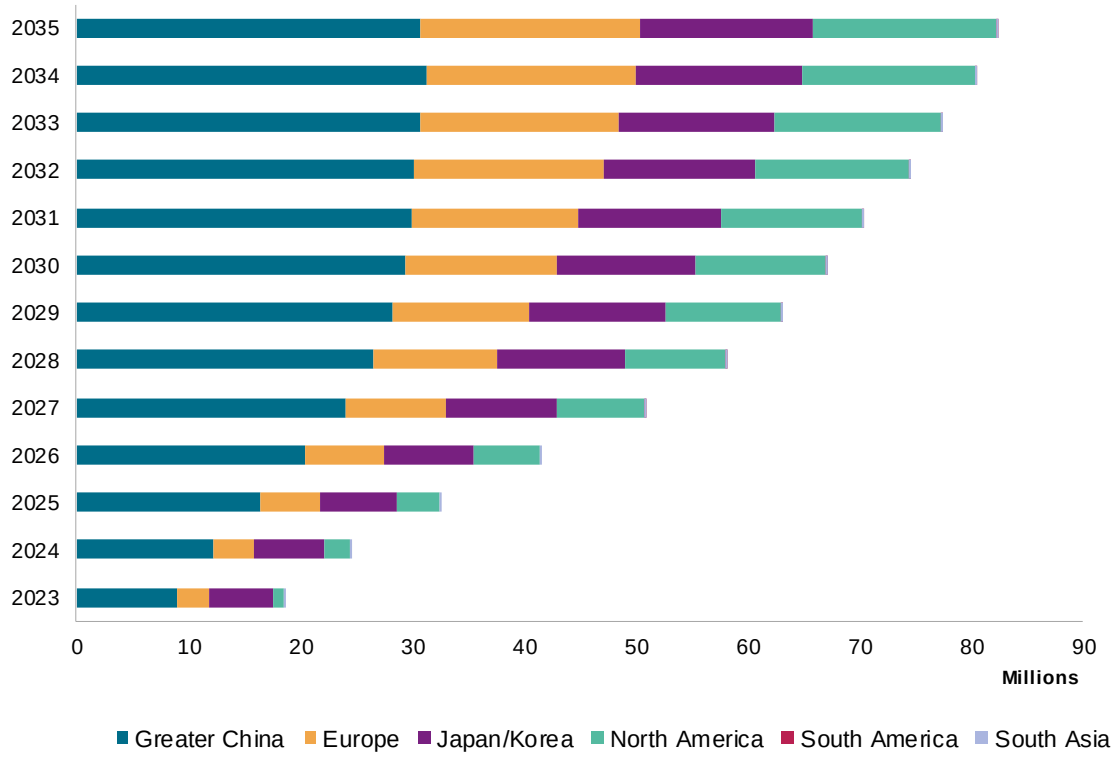
Growth of stator winding types



Data compiled February 2024

Source: S&P Global Mobility.

Growth of Hairpin windings



Data compiled February 2024

Source: S&P Global Mobility.

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E-Motor Speed

eAxle based motors only

- Increases the maximum operating rpm of the electric motor can, in some cases, drive performance gains around power density and efficiency.
- 20krpm has for a long time been seen as the “limit” for mass production.
- Developments in this space are growing, with motor developers looking to push the boundaries, thanks in part to improved manufacturing and cooling performance.
- 20k+ rpm market will grow from 2% to 23% by the time we reach 2035.

Growth of electric motor market to 2035

Data compiled February 2024

Source: S&P Global Mobility.

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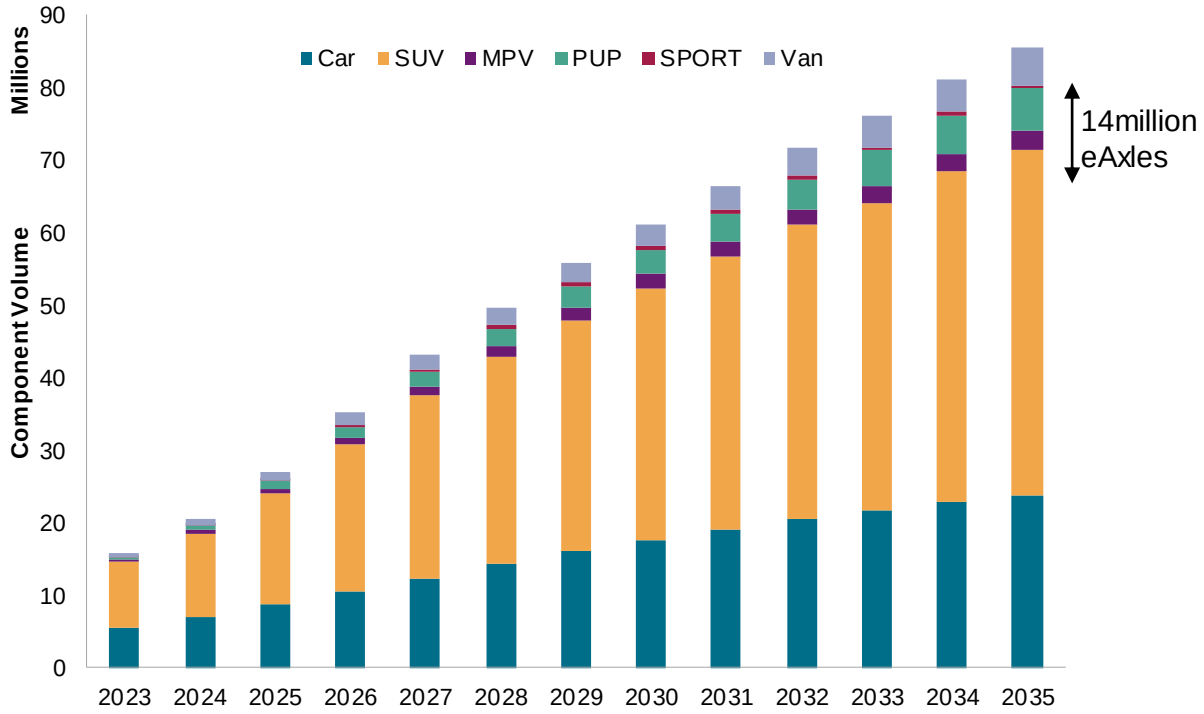
eBeam market location

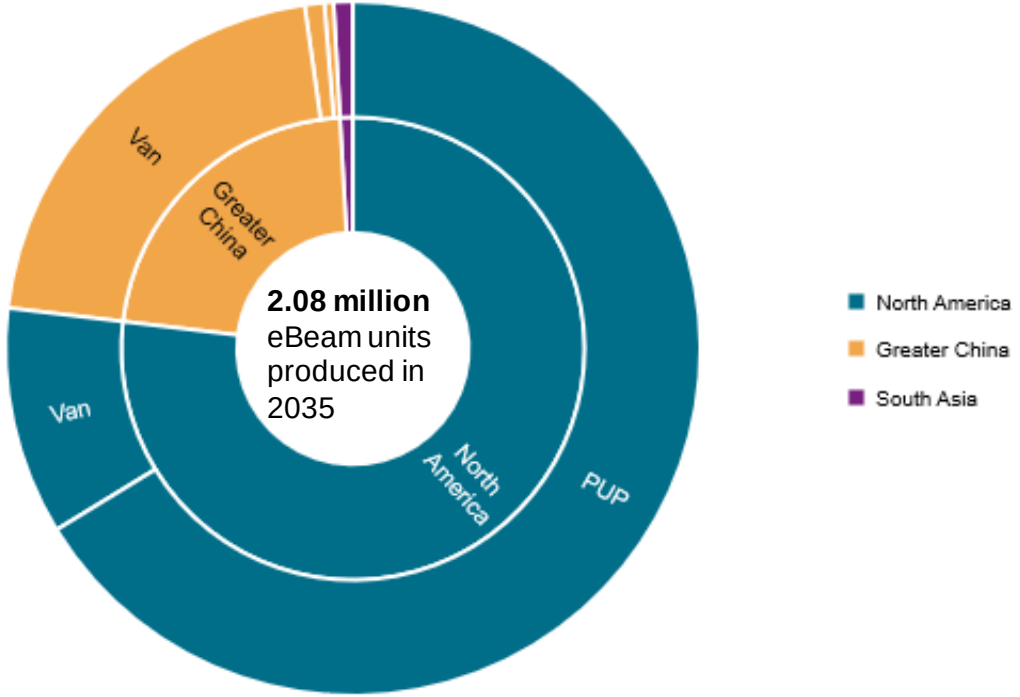
As Electric Vehicle adoption grows in the coming years, **use cases will evolve** into different vehicle segments such as **Vans** and **Pick Up** vehicles will require over **10.9 million** drive units by **2035**
Multiple suppliers are developing **eBeam technology** to try and fill the requirement for increased **towing capability**

Vehicle Type for eAxle applications



Data compiled February 2024
Source: S&P Global Mobility.

eBeam market segmentation



Data compiled February 2024
Source: S&P Global Mobility.

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Efficiency: The Core Imperative for Electric Motors

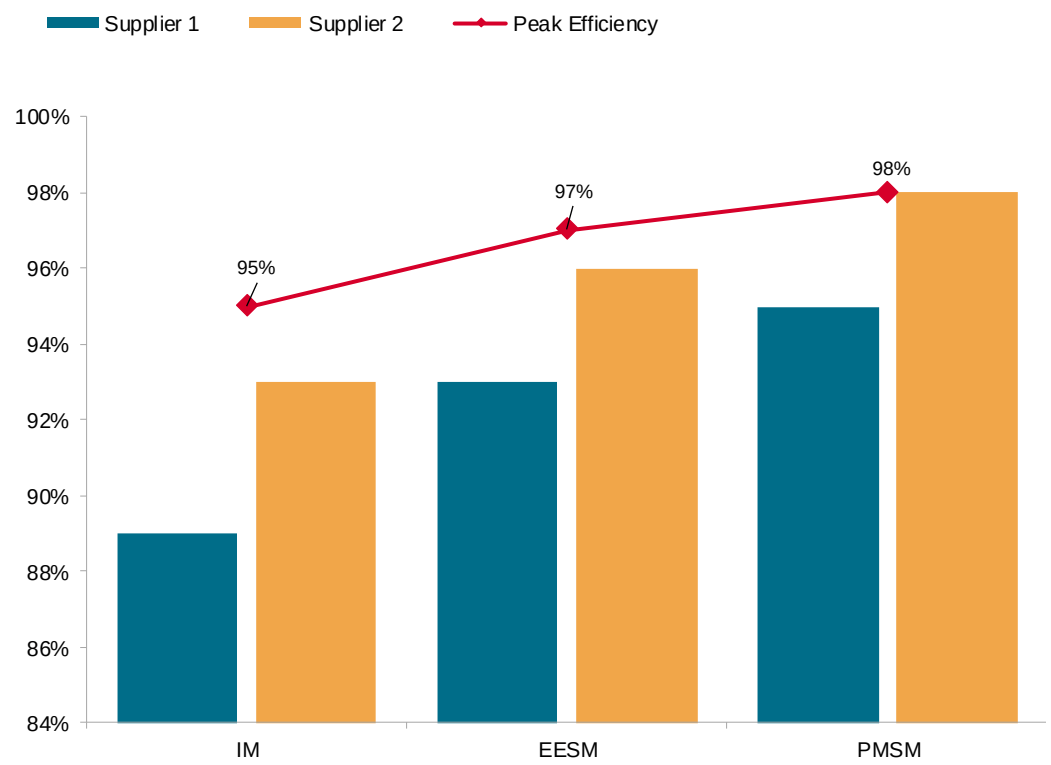
Efficiency is of paramount importance in electric vehicle (EV) systems for several key reasons

Efficient systems require **less electrical energy** while maintaining performance

Effective power electronics and motors reduce strain on the EV's battery, **promoting longevity**

- Efficiency improvements of **2-5%** or more are achievable by choosing PMSMs over EESMs and IMs
- SiC based inverters have demonstrated higher overall system efficiency, efficiency improvements of up to **1-2%** are achievable
- These improvements in component efficiencies enable the system to operate at a **higher overall efficiency**

Motor Efficiency Trends



Data compiled Feb. 19, 2024.

Source: S&P Global Mobility.

Types of e-motors

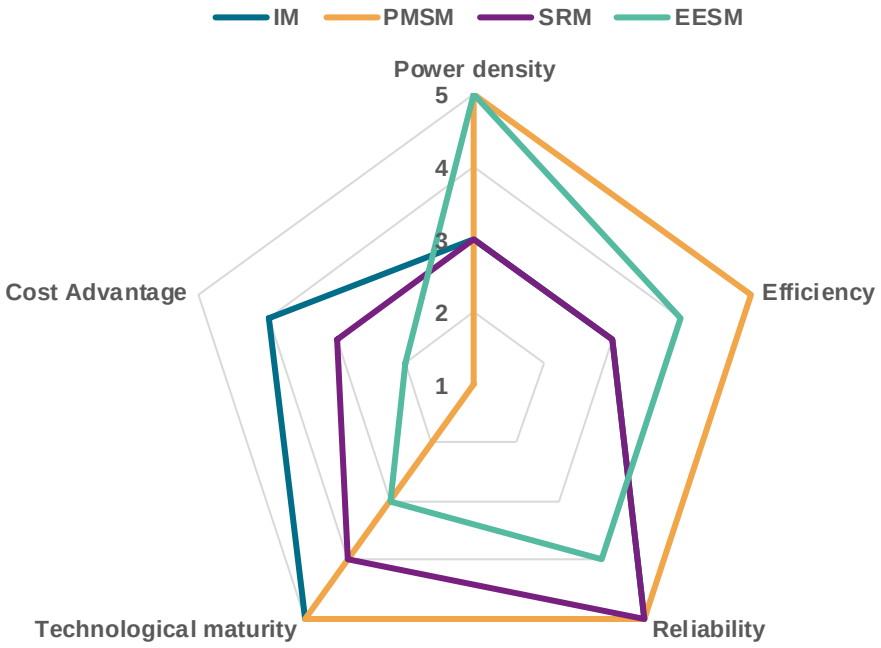
Axial flux permanent magnet motors	• A stator is sandwiched between two permanent magnet rotors. • These motors offer extremely high power and torque density. • Has compact fabrication and is difficult to manufacture and is costly.
Claw-pole synchronous motor	• Includes windings in the rotor and stator that include magnets between the claws. • Primarily used for alternators and starter-generators (12V and 48V)
Current-excited wound rotor synchronous motor	• Generates a magnetic field via current excitation i.e. The rotor uses copper windings to generate a magnetic field. • produce robust torque and constant power across their speed range. • More economical but less efficient than permanent magnet motors.
Interior/surface-mounted permanent magnet motor	• Lighter and provides higher torque density. • More efficient than AC induction motors owing to the permanent magnetic field and offer packaging advantages • Surface-mounted design offers good performance characteristics, but the power output is not consistent with speed,
Induction motor	• highly flexible motors and are capable of catering to high load demands. • cost effective to manufacture, very reliable, and generate strong low-end torque. • Less efficient than permanent magnet motors.

Data compiled Feb. 13, 2024.
Source: S&P Global Mobility.

Spider Diagram Analysis of Motor Types

Why Permanent Magnet Motors Lead the Way

The impact of motor efficiency on battery remains paramount to system designers



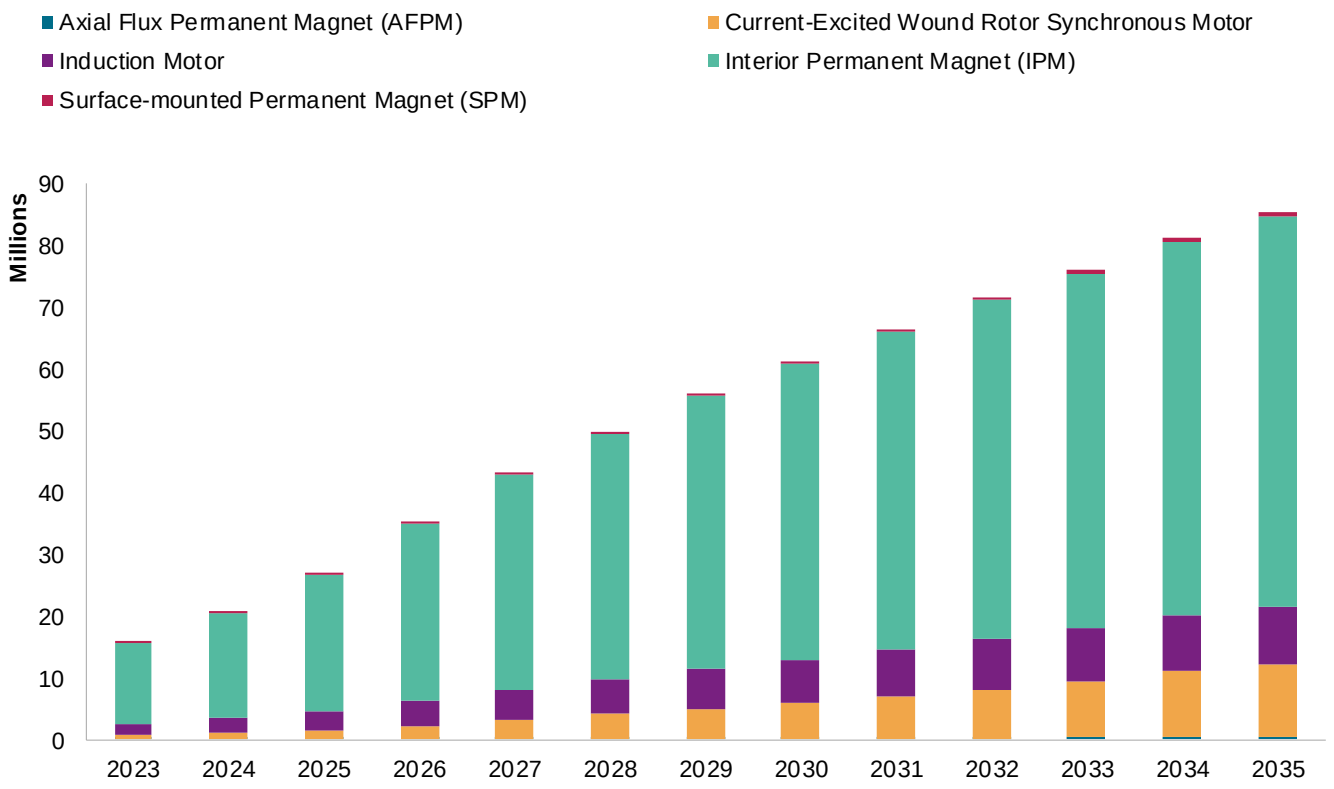
IM= Induction Motor
PMSM = Permanent Magnet Synchronous Motors
SRM = Switch Reluctance Motor
EESM = Externally Excited Synchronous Motors

- **High power density** enables PMSMs to deliver a substantial amount of power in a compact and lightweight form
- **Superior efficiency** of PMSM translates to better energy conversion and longer driving range
- Well established technology with years of refinement contributes to long term performance and durability of electric vehicles
- Higher costs of PMSMs attributed to the utilization of rare earth elements
- PMSMs are often chosen for electric vehicles despite their higher cost due to their unmatched combination of **high power-density, efficiency**, and **proven reliability**

Magnet based motors remain dominant

The impact of motor efficiency on battery remains paramount to system designers

Motor Type for eAxle motors



Data compiled February 2024

Source: S&P Global Mobility.

- **Peak efficiency** of **permanent magnet** based electric motors is too high for the manufacturers to pivot away from in significant volume.
- Suppliers are actively developing alternatives such as **Externally Excited** and **Induction** Machines
- **Tesla** announced in 2023 their latest developments of a **rare earth free** magnet motor, likely to be targeted at **lower cost** vehicles, with **GM** and **Stellantis** also investing in this area
- **74%** of the eAxle market is currently forecast to be **permanent magnet** in 2035.

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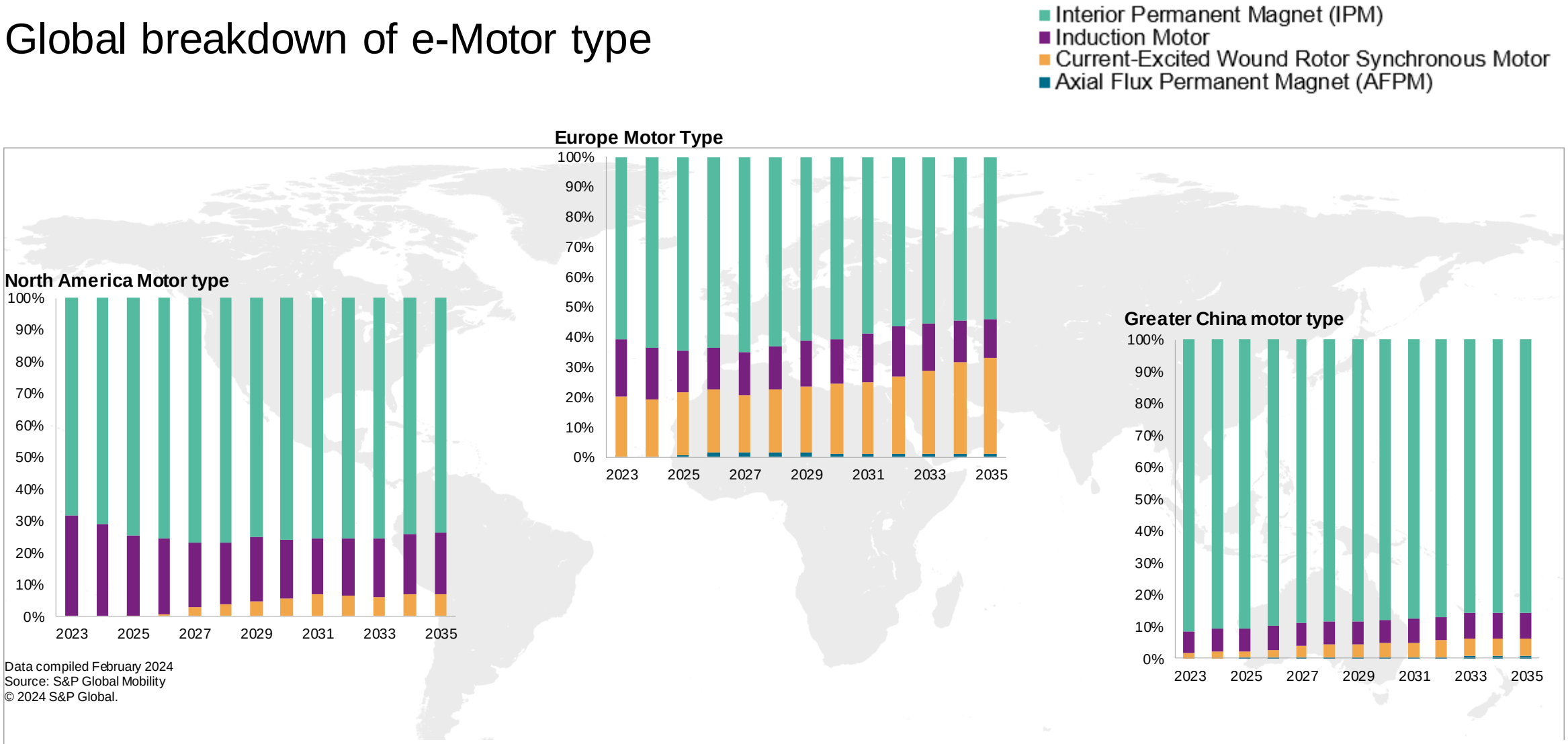
Global breakdown of e-Motor type



Data compiled February 2024
Source: S&P Global Mobility

North America and **Europe** are now actively attempting to reduce the reliance on REE based motors. In **Europe**, around **45%** of motors will not be PM solutions by **2035**, whilst **North America** are seeing significant investment in **non-REE based motors.**

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Critical materials

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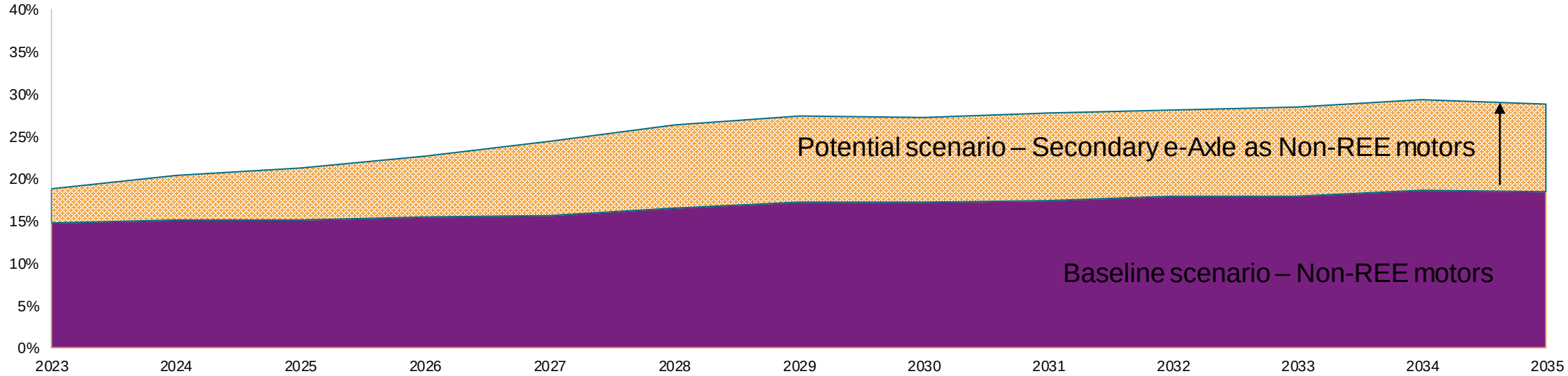
Prospects for Neodymium Consumption Reduction in Traction Motors outside Greater China

Exploring Sustainable Alternatives and Technological Innovations

The potential for difficulties in both the availability and market price of Rare Earth Materials such as Neodymium means the industry are exploring options to reduce their reliance on these.

The installation of non-rare earth-based motors in each **secondary e-Axle**, combined with the baseline forecast, would yield approximately a **19%** reduction in neodymium (Nd) consumption in 2023, with expectations of a total increase to approximately **29%** by 2035

Potential reduction in Nd usage in Traction Motors



Data compiled Feb. 19, 2024.
Source: S&P Global Mobility.

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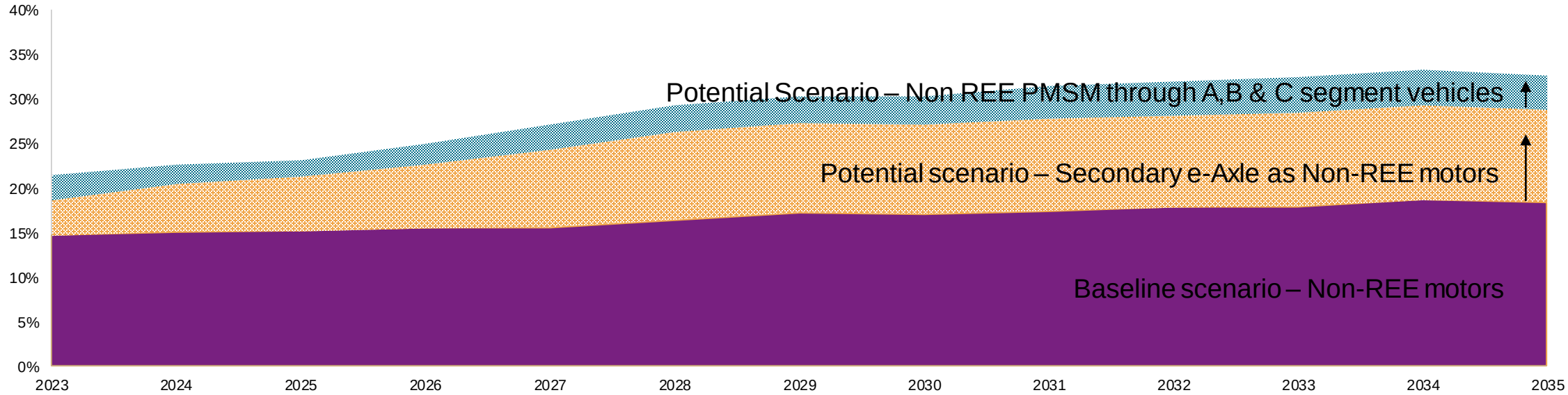
Prospects for Neodymium Consumption Reduction in Traction Motors outside Greater China

Exploring Sustainable Alternatives and Technological Innovations

On top of the potential for secondary eAxles, non REE based magnets are being investigated by many suppliers and OEMs. A further **3%** reduction is possible with the use of Non-REE based motors in A,B & C segments with lower power requirements in EU & NA

Potential reduction in Nd usage in Traction Motors



Data compiled Feb. 19, 2024.
Source: S&P Global Mobility.

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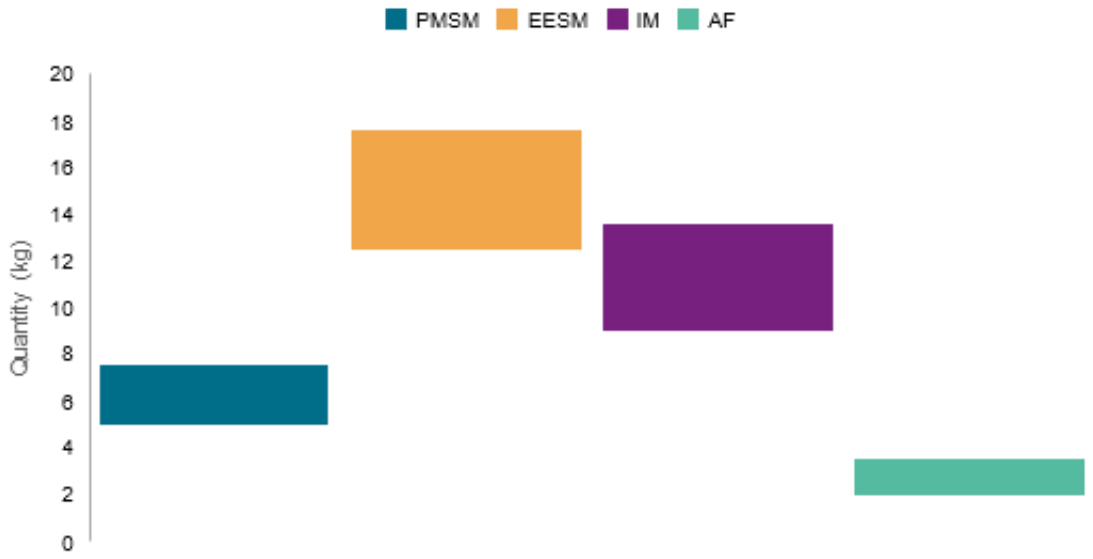
Copper Usage in e-motors

Copper content in motor types

Copper intensity fluctuates between the various types of electric traction motors

Copper quantity range



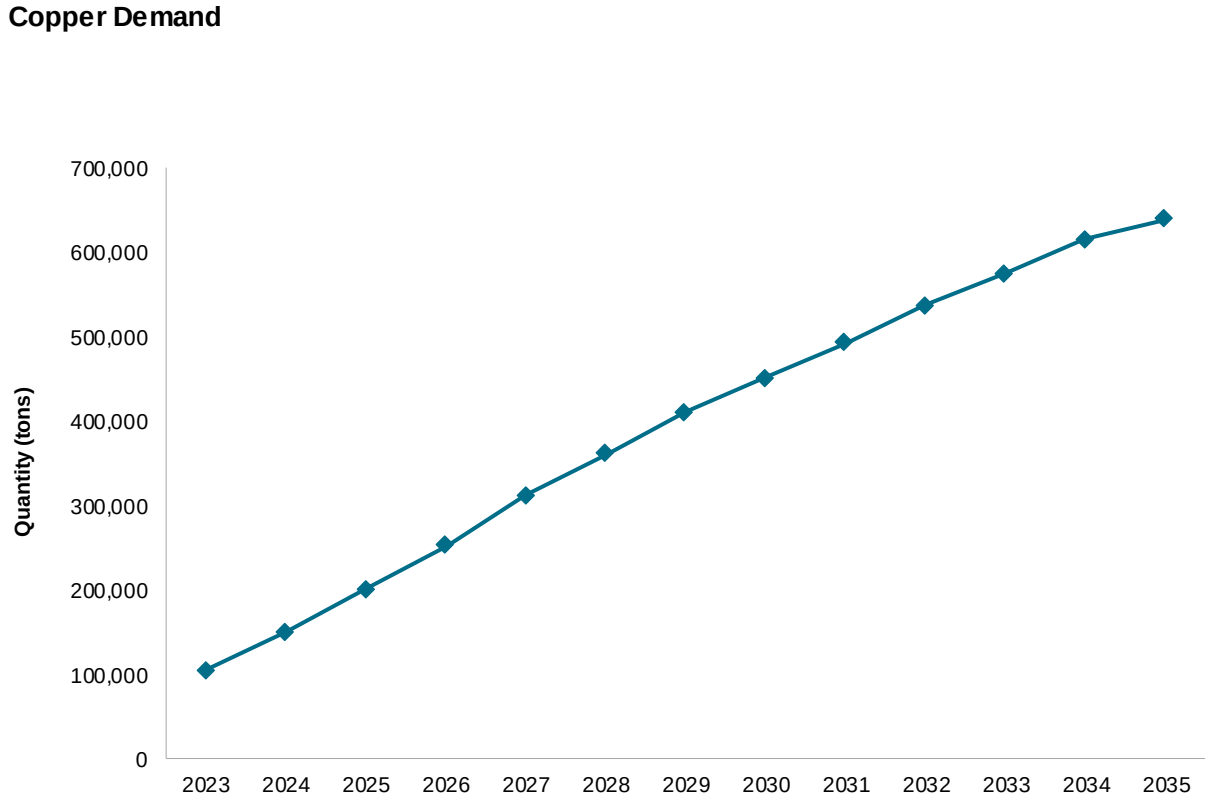
Data compiled Feb. 19, 2024.
Source: S&P Global Mobility.

- Increased power output typically correlates with a greater requirement of copper within a given motor type.
- The demand for copper in Permanent Magnet Synchronous Motors (PMSM) primarily stems from its stator winding
- Whereas Induction Motors (IM) and Electrically Excited Synchronous Motors (EESM) exhibit higher copper intensity due to their utilization in both the stator and rotor components.
- With increasing trend towards non-REE based motors such as IM and EESM, the industry demand for copper would increase

Copper Demand in electric motors (eAxle only)

Copper used within rotors and stators

Copper intensity fluctuates based on choice of motor type and winding technology



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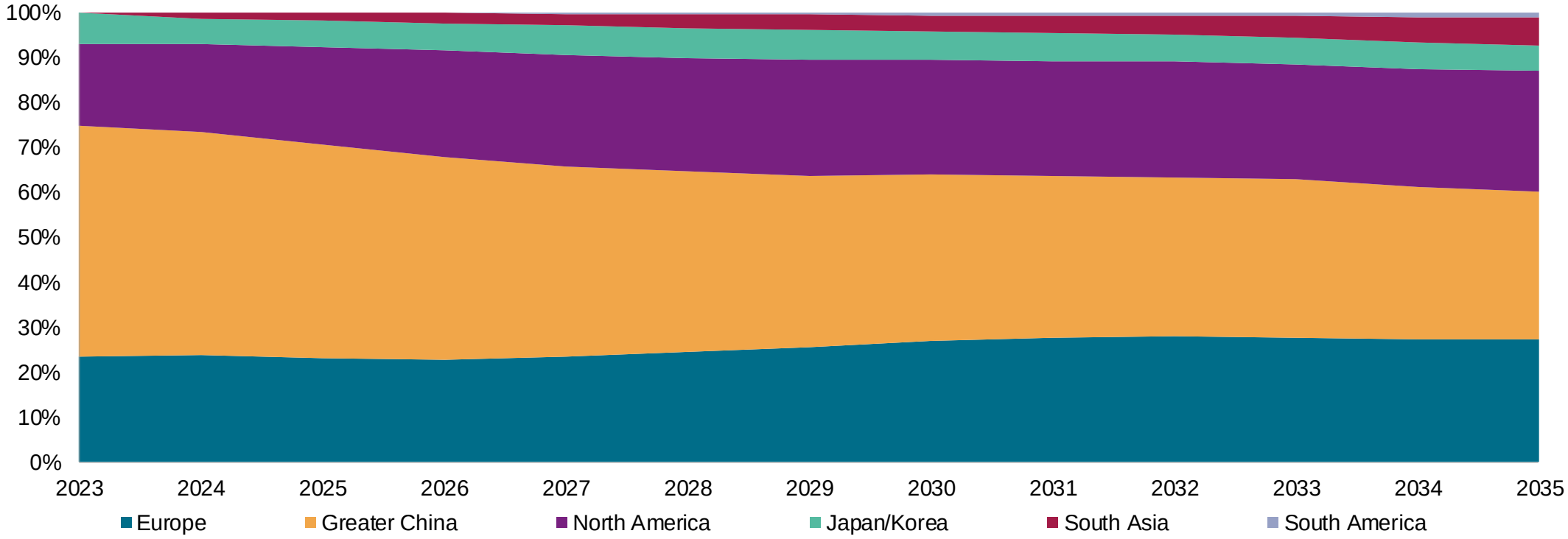
- Copper utilization further optimized with use of rectangular wires to enable better fill factor
- ~0.25 to 0.5 kg reduction achieved when moving from round wire to hairpin winding

Regional Copper Breakdown

Growth of **hairpin production** in Europe and North America will increase their copper demand throughout the next decade.

As markets shift towards **new motor topologies**, expect these numbers to potentially fluctuate further

Regional Copper Demand for eAxle motors only



Data compiled February 2024

Source: S&P Global Mobility.

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Significant Material investment & partnerships

With a current **significant reliance** on **Greater China** for **REE supply**, several suppliers and OEMS have been **investing** and establishing **future partnerships** to reduce the reliance on a single nation

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Supply Chain trends and developments

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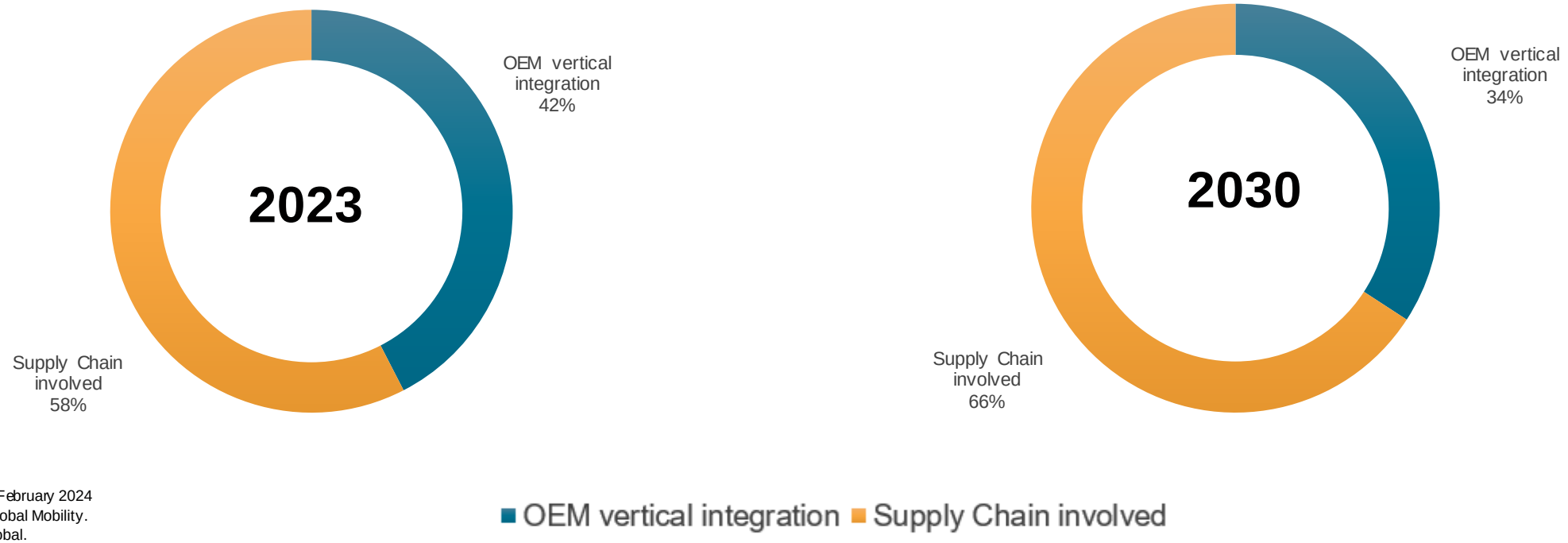
Assessing OEM Vertical Integration

Analysis of the **eAxle system** (Integration, Motor Assembly, Rotor and Stator) shows how total OEM vertical integration of the eAxle motor supply chain will reduce in the coming years from **42%** to **34%**

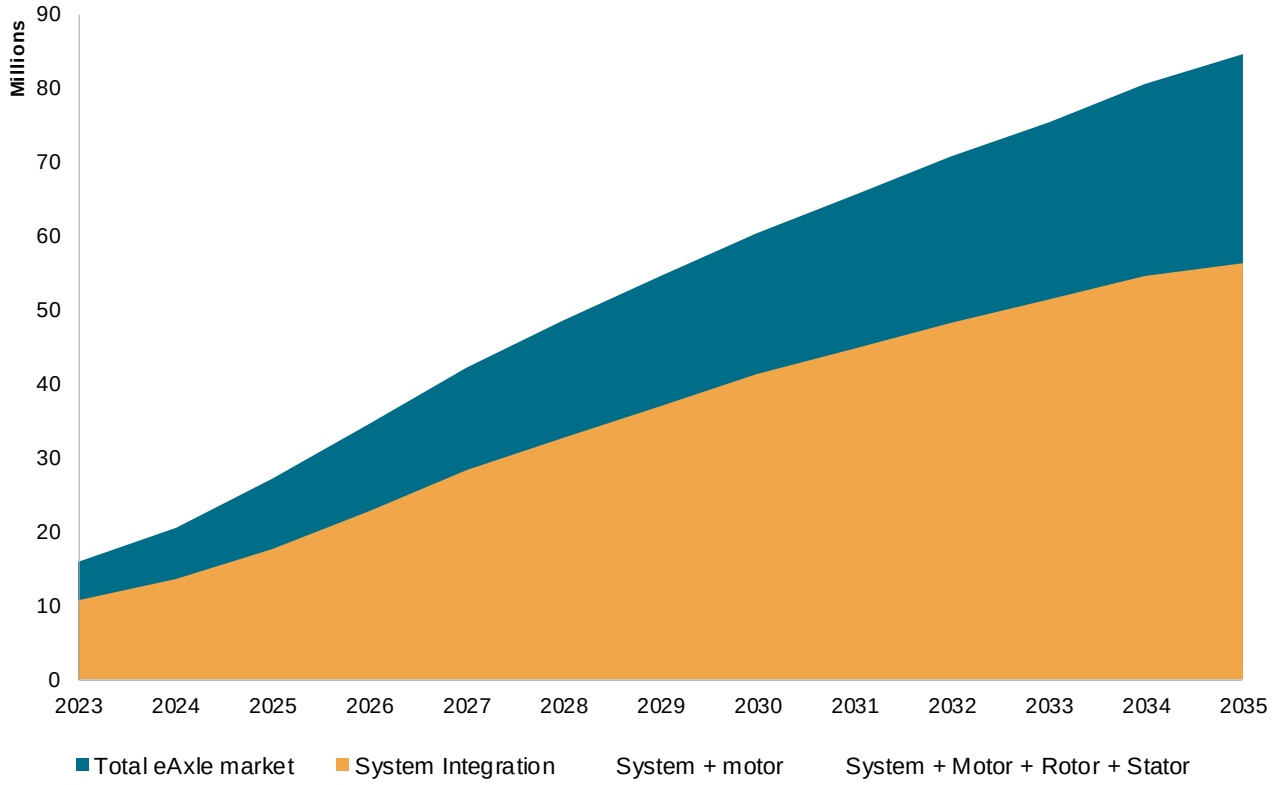


Data compiled February 2024
Source: S&P Global Mobility.

eAxle in-house production levels

The design & integration of the motor is increasingly moving towards the OEM

eAxle in-house breakdown



Data compiled February 2024

Source: S&P Global Mobility.

The electric motor, and it's sub-components such as Rotor & Stator, are increasingly presenting opportunities to the supply chain.

Increasing eAxle volumes mean diversifying the supply chain and generating **production volume** will result in the OEMs leveraging the supply chain, quite often **Print-to-Build** with the OEM owning the entire design.

Taking 2030 as the reference, the levels of OEM in-house production are:

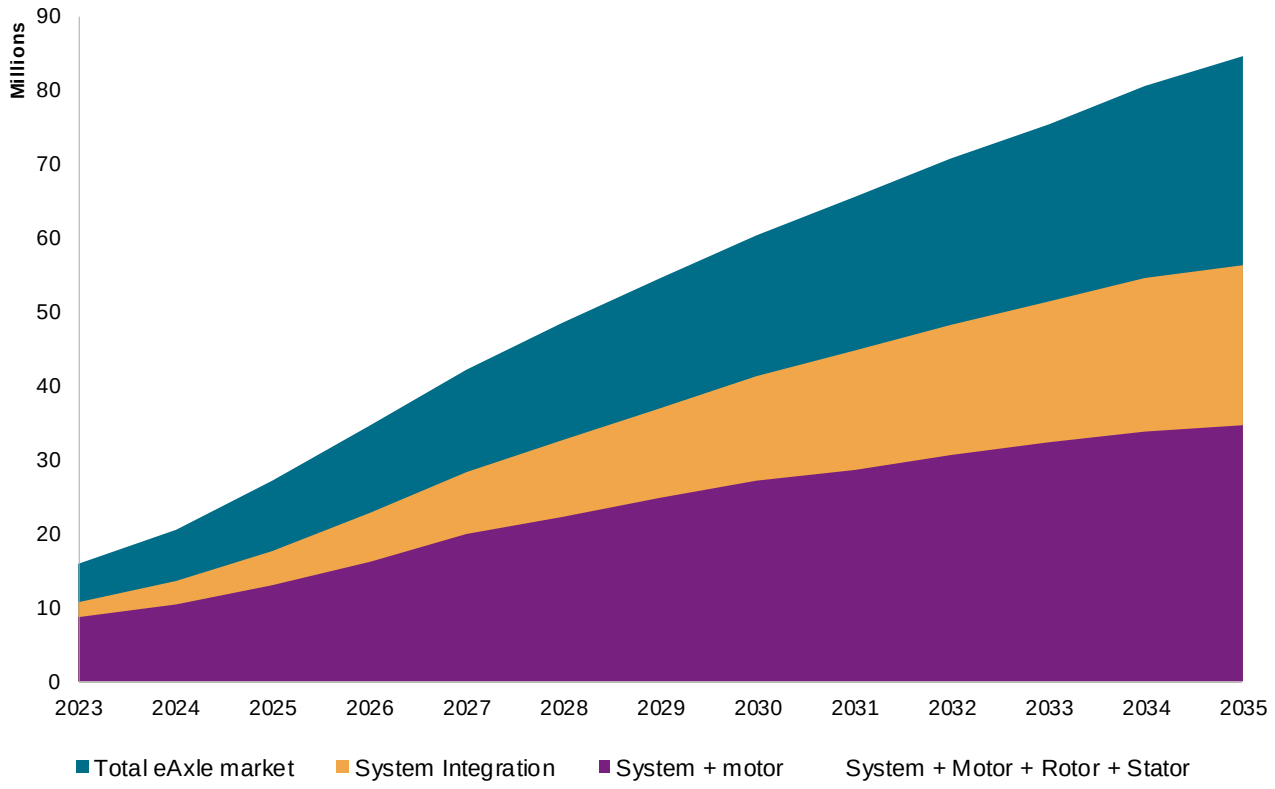
System Integration – 68%

Around **60million** eAxles being produced in **2035** where the supply chain has some involvement in the system

eAxle in-house production levels

The design & integration of the motor is increasingly moving towards the OEM

eAxle in-house breakdown



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Taking 2030 as the reference, the levels of OEM in-house production are:

System Integration – 68%
System + Motor – 45%

Around **60million** eAxles being produced in **2035** where the supply chain has some involvement in the system

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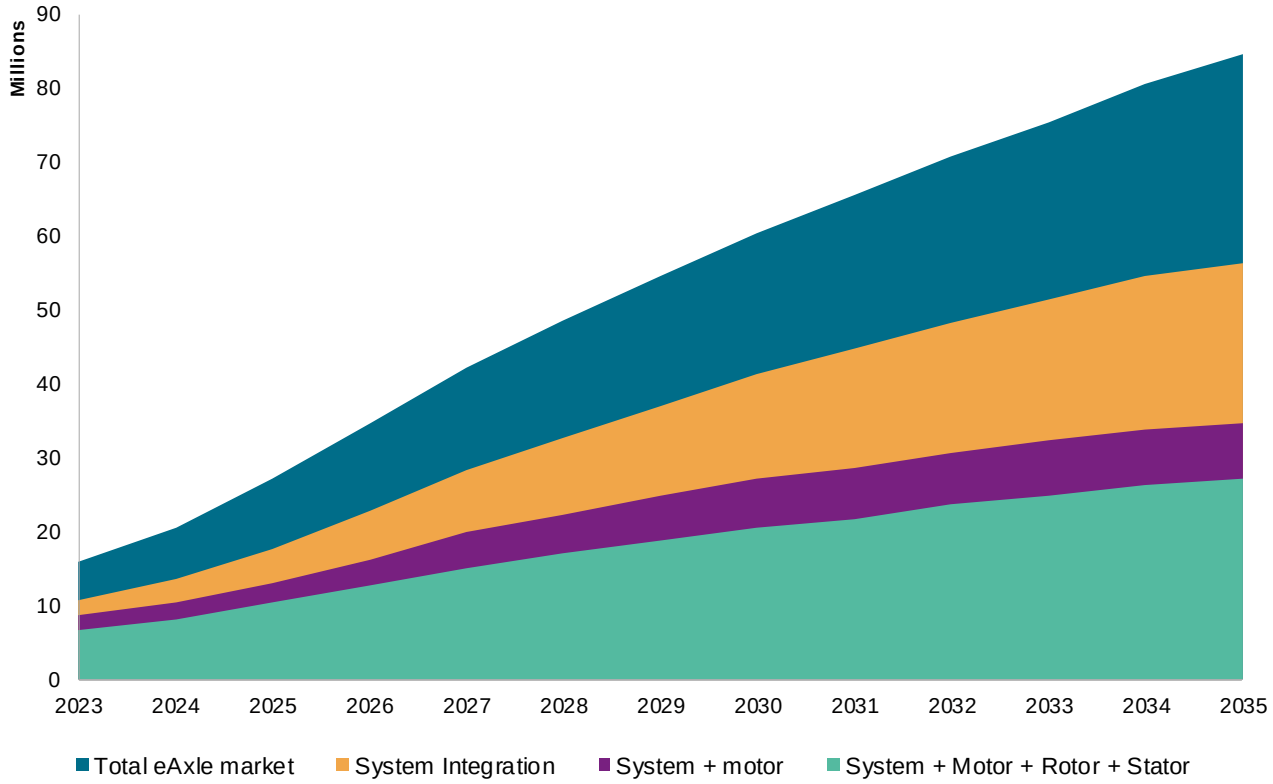
eAxle in-house production levels

The design & integration of the motor is increasingly moving towards the OEM

eAxle in-house breakdown



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System + Motor + Rotor + Stator – 34%

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Data compiled February 2024

Source: S&P Global Mobility.

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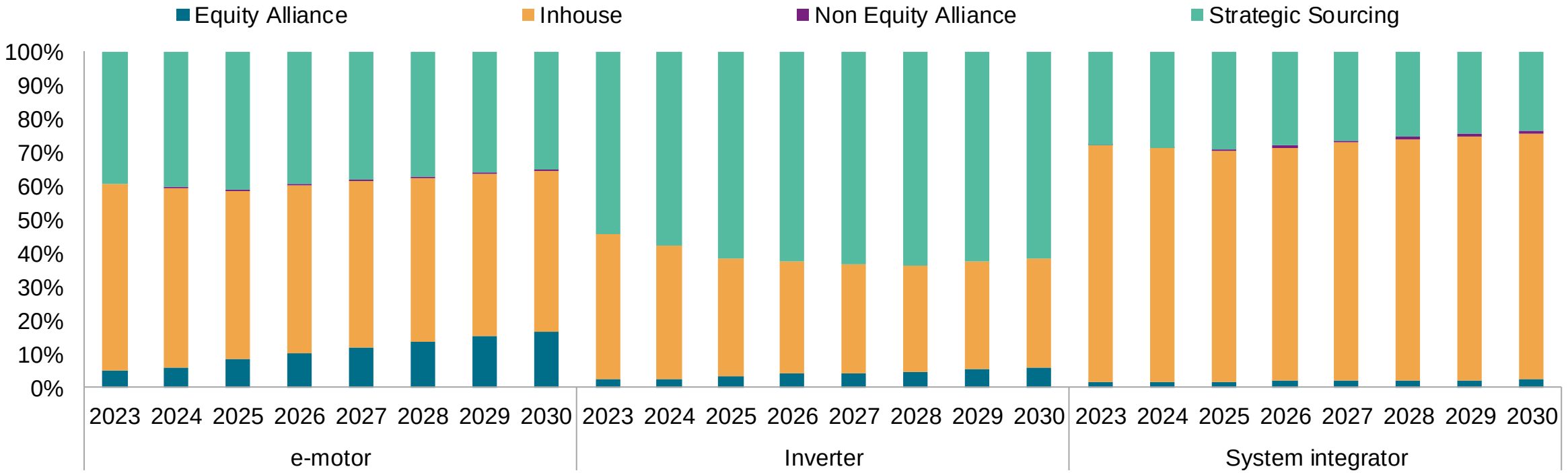
In-house v outsource (eAxle only)

System integration of the eAxle is expected to remain as a majority **in-house** production out to 2030

For the **electric motor**, we are beginning to see more OEMs bring the design in-house, but looking to **outsource** the production of either the entire motor, or sub-components within either via **strategic sourcing** or **alliances/joint ventures**.

Sourcing trends of e-drive components (2023-30)



Data compiled Feb, 2023.
Source: S&P Global Mobility.

*outsource is based on the Vehicle Brand = in-house

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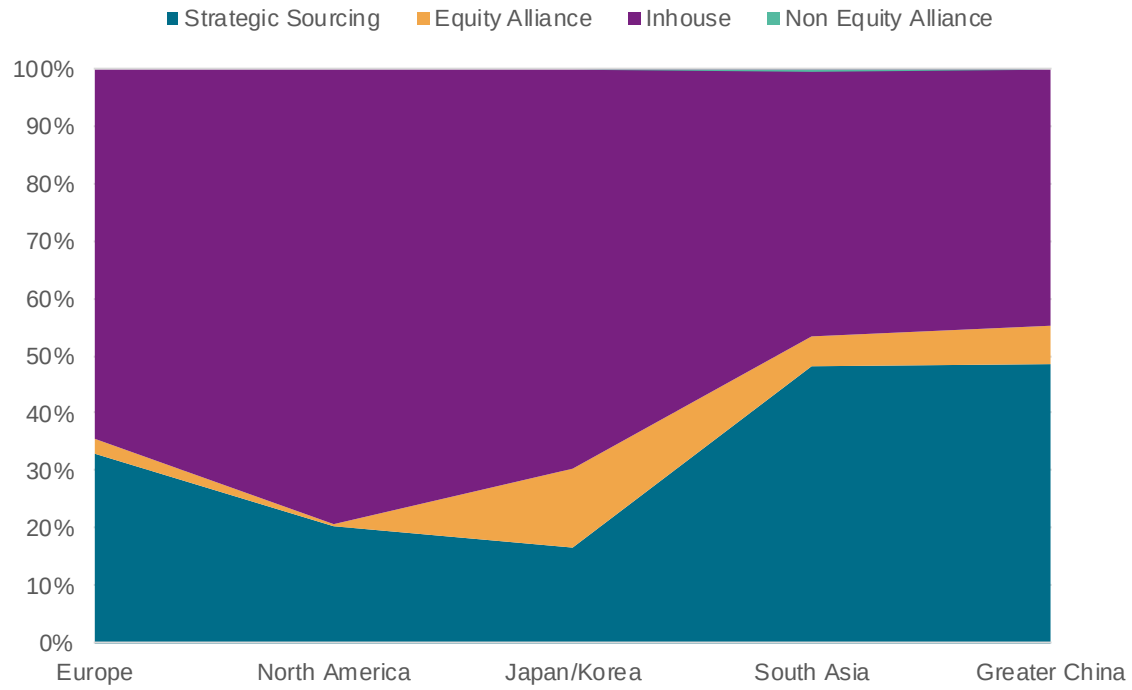
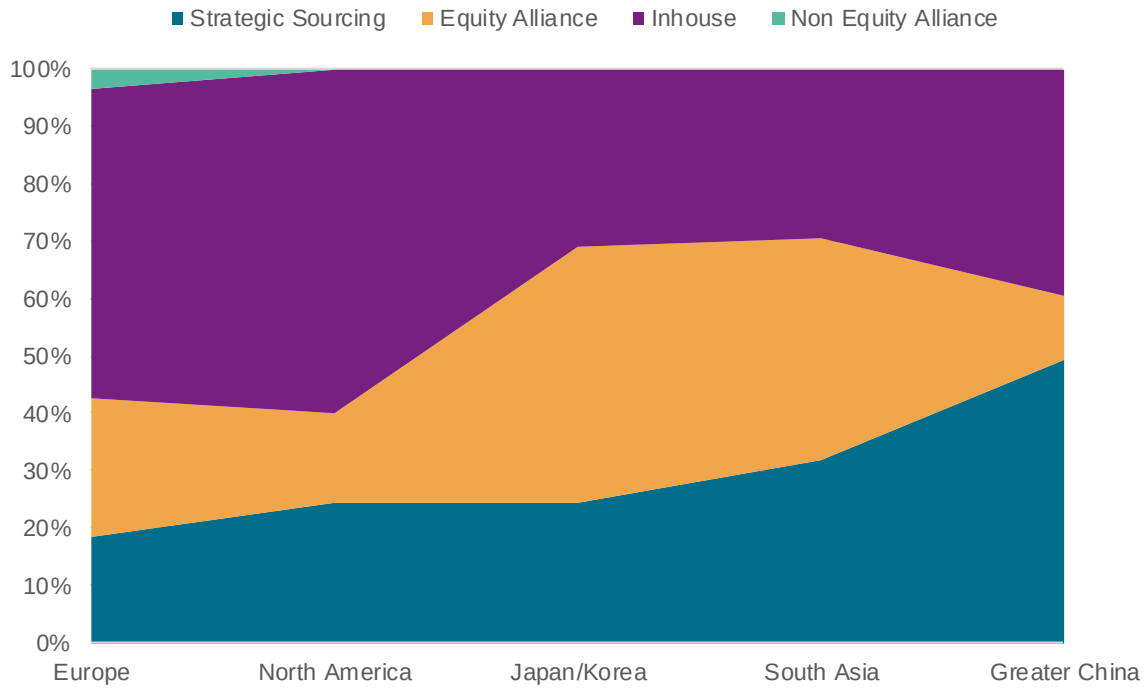
Regional Sourcing Strategies (eAxle only)

Regional Supplier Profile - 2023



Regional Supplier Profile - 2035



As in 2023, **Japan/Korea** witnesses substantial **equity alliances**. Anticipated trends suggest **South Asia and Europe** could follow suit by 2035, while **North America** continues to **prioritize in-house** sourcing strategies.

*Charts are based on E-Motor Assembly Supplier

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Summary

Summary

The **eAxle** market will grow rapidly as EV uptake increases globally, total eAxle production is expected to exceed **85million** units by **2035.**

Power Density and **efficiency** are two hot topics for electric **motor design**, with many existing and **emerging technologies** being explored to improve these**.**

Rare earth magnets, whilst the most efficient and expected to remain the motor type of choice, potential **supply chain issues** moving forward may result in the longer term move **away from rare earth motors**.

Larger OEMs are expected to continue the trend of **vertical integration**; however, around **60million** eAxles are expected to be have some **supplier involvement** in **2035.**

The **electric motor, inverter** and now increasingly it's **sub-components** such as rotor and stator are emerging as key targets for the **supply chain** as volumes increase in the coming years.

Use cases for EVs will drive differing technical solutions such as **cheaper motors** for affordable vehicles and **eBeam for** PUP/Van markets.

Contact us

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