

The Role and Demand for Copper in the Future Automotive Market

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Antitrust Guidelines for Copper Industry Trade Association Meetings

The following guidelines with respect to compliance with antitrust laws of the United States, Japan and European Community¹ are intended to govern the conduct of participants in copper industry trade association meetings, both at the meeting itself and in informal discussions before or after the formal meeting.

Price: Competitors should not discuss future prices (including terms of sale) of their products. There is no blanket prohibition against the mention of or reference to current or past prices but limits must be observed. Such references or mentions should occur only when necessary in connection with the development of association programs. For example, reference to a particular price level in comparing the cost of a copper product to a competing product is permitted. Whenever possible, such references should be discussed in advance with legal counsel.

Competitive Information: Competitors should not discuss the market share of a particular copper producer or copper fabricator's products. Furthermore, nothing should be said at a meeting which could be interpreted as suggesting prearranged market shares for such products or producer production levels. The overall market share of copper products may be discussed with regard to competition with non-copper products and general market acceptance.

New Products: Competitors should not encourage or discourage the introduction of a new product by another competitor or reveal a particular copper company's plans to change the production rate of an existing product or to introduce a new product. No company should disclose to another company whether it is in a position to make or market a new product. New products may be discussed in a technical manner or from the standpoints of competition with non-copper products and general market acceptance. In addition, proposed methods for and results of field and laboratory testing can be considered.

The Role of Legal Counsel: Legal counsel attends association meetings to advise association staff and other meeting attendees regarding the antitrust laws and to see that none of the matters discussed or materials distributed raise even the appearance of antitrust improprieties. During the course of a meeting, if counsel believes that the discussion is turning to a sensitive or inappropriate subject, counsel will express that belief and request that the attendees return the discussion to a less sensitive area.

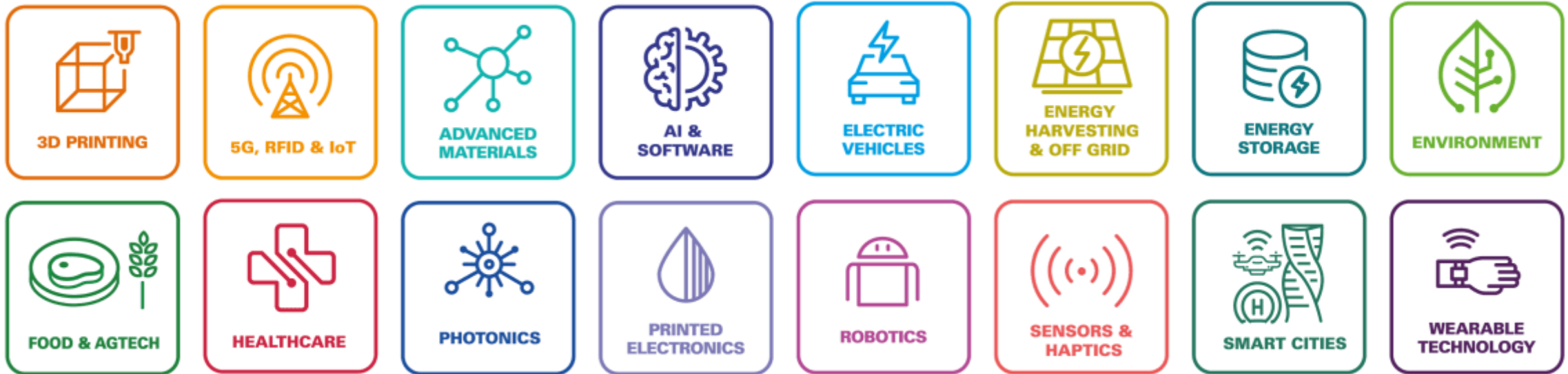
A paper entitled 'Copper Industry Trade Associations and Antitrust Laws' is available upon request.

10/92, 5/93, 10/10

1. Other foreign competition laws apply to International Copper Association, Ltd. (ICA)'s activities worldwide.

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The Future of the Car Market

Dominant today

Traditional Internal
Combustion
Engine (ICE) Cars

- Copper content in wiring loom, small motors, alternator...



*Exponential growth
phase this decade*

Electric Cars

- Copper requirements for traction motors, energy storage, power electronics and high voltage cabling in battery electric, hybrid and fuel cell vehicles.



Emerging mid decade

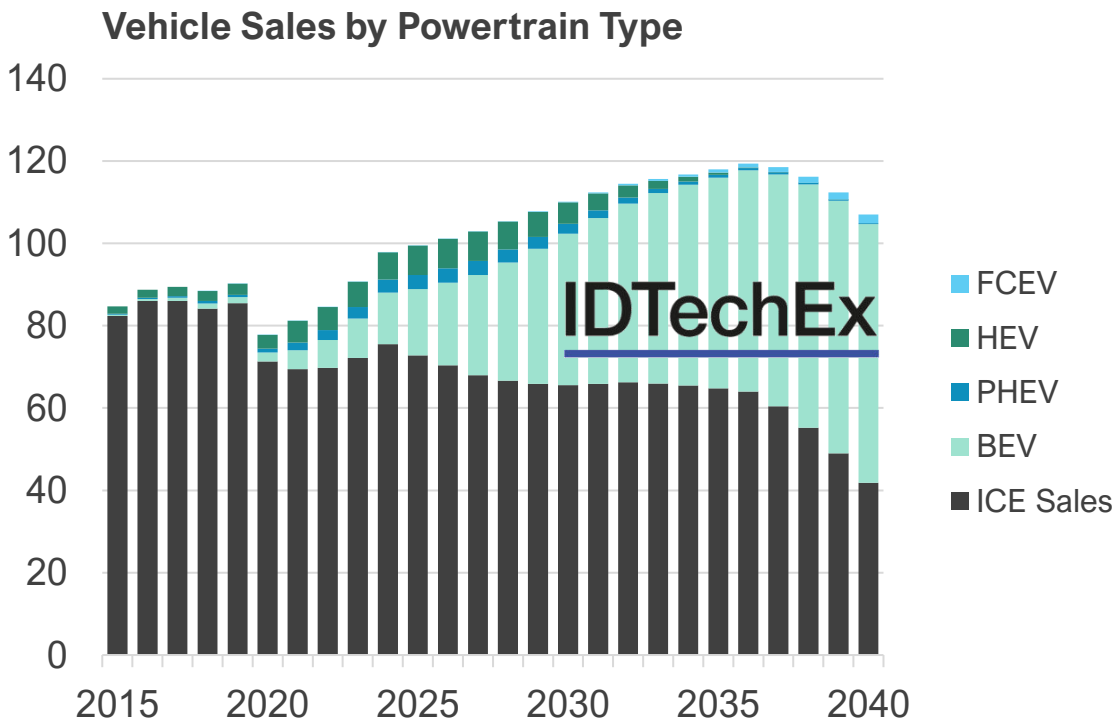
Autonomous
Cars

- Copper found in new components that enable autonomous vehicles. Radar, lidar, cameras...

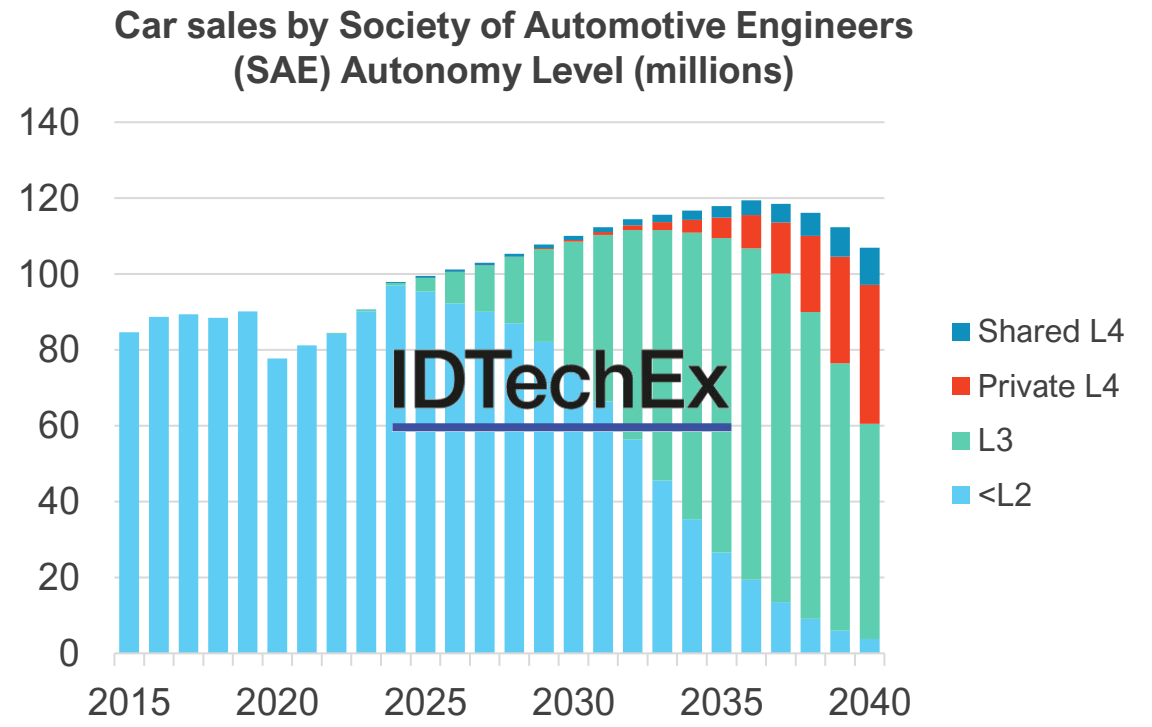


Car Market Forecasts

- Battery electric vehicles will dominate the market by 2040. Their emergence will cause a peak and decline in internal combustion sales.
- A fundamental peak in automotive sales is expected due to autonomy and other megatrends, with the decline beginning in 2037.



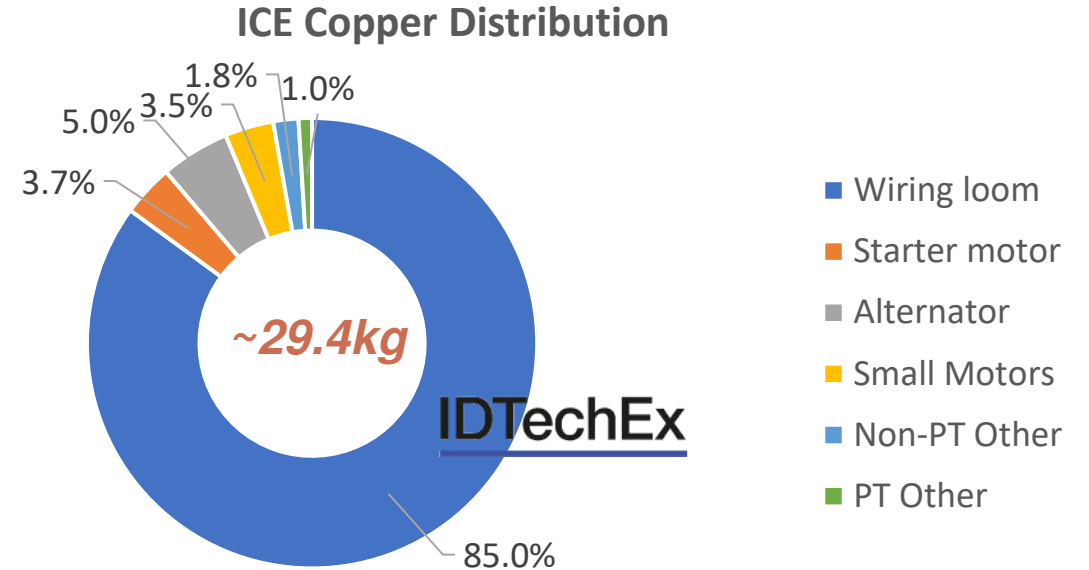
Source: IDTechEx



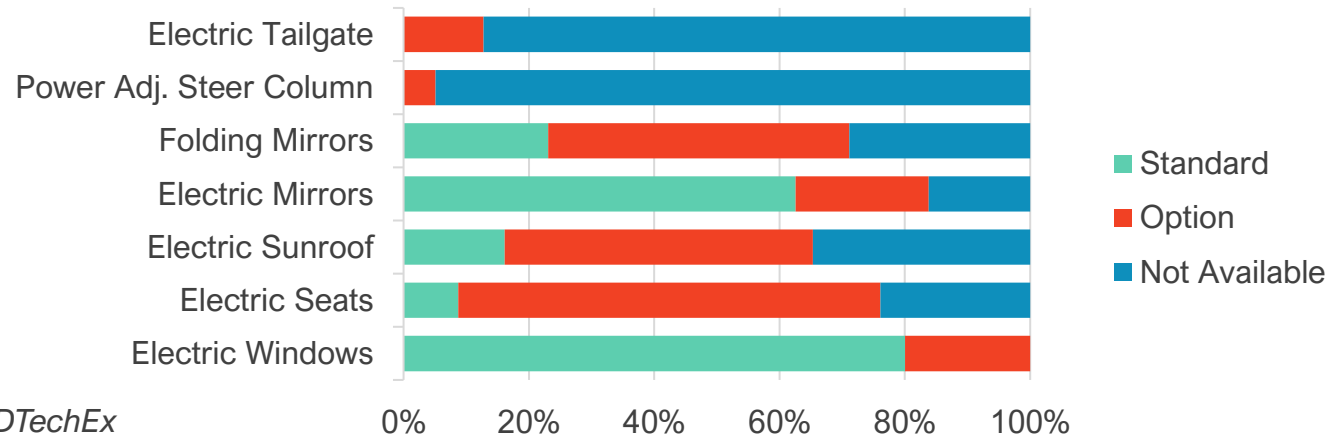
Source: IDTechEx

Copper in Today's Conventional ICE Car

- **Most copper is in the wiring loom.**
- The starter and alternator are the next biggest contributors and have been unchanged for decades.
- Many more small motors are used in luxury vehicles. While individual copper per motor is small, when all motors are counted it leads to ~0.5kg of copper.



Luxury Feature Analysis



Source: IDTechEx



IDTechEx small motor teardown.

Copper Presence in Electric Motors

Motor Type	Permanent Magnet (PM) Motor	AC Induction Motor (ACIM)	Wound Rotor Motor (WRSM)	Reluctance Motors (RM)
Rotor Key Material	Rare Earth Magnets	Copper or Aluminium	Copper	Silicon Steel
Stator Key Material	Copper	Copper	Copper	Copper

Rotor geometry:

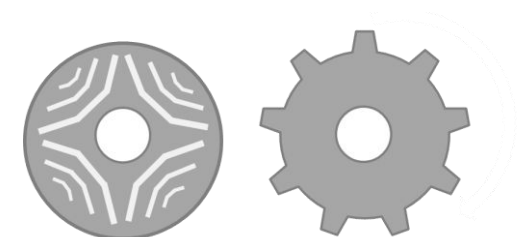
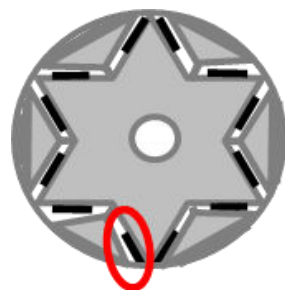


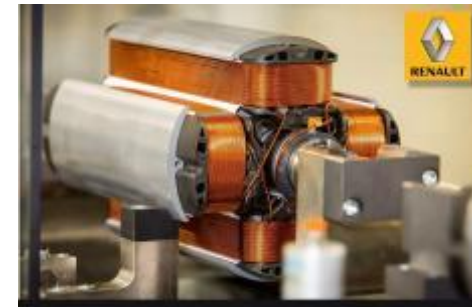
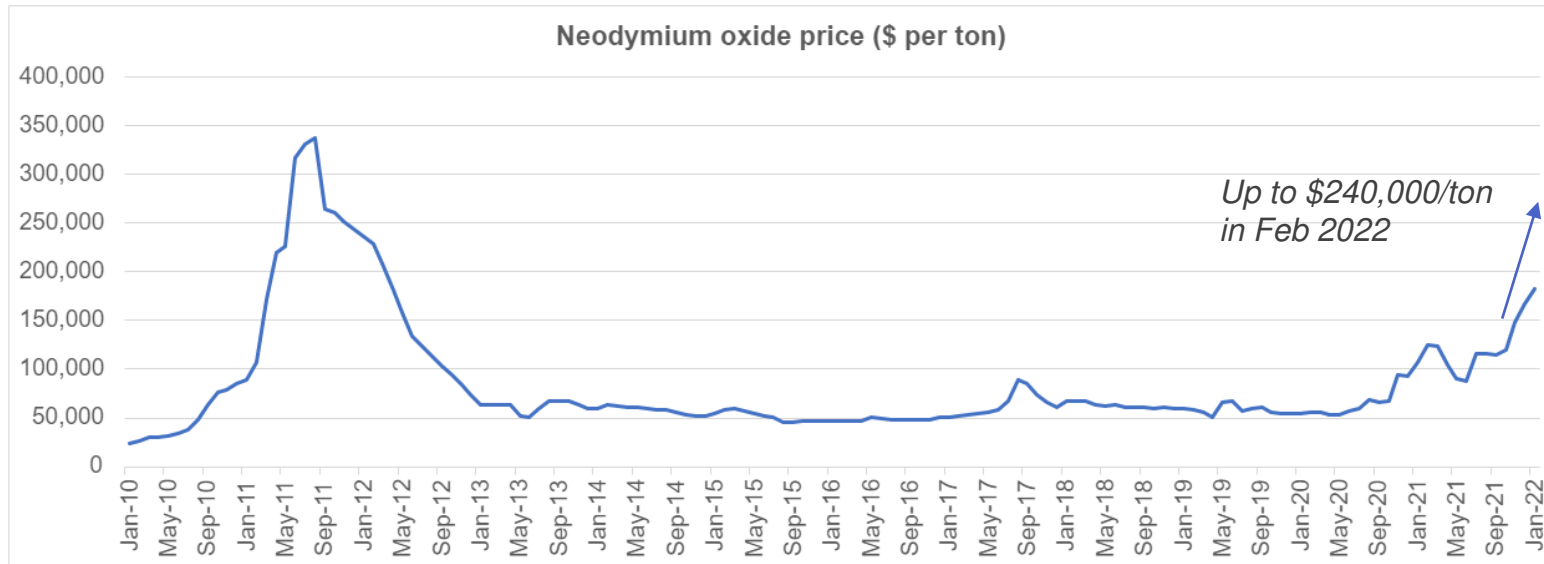
Image sources: Renault, Shutterstock, IDTechEx

Reducing Rare-Earths in Motors Can Increase Copper

- Some manufacturers are looking to reduce dependency on magnets due to environmental impact and cost volatility, **this increases copper content.**
- Induction and WRSM motors are rare-earth free alternatives, and are used by BMW, VW, Audi and Renault.



Manufacturing images of BMW's rotor for the new 5th generation electric drivetrain, suggesting a WRSM configuration.
Source: BMW Group



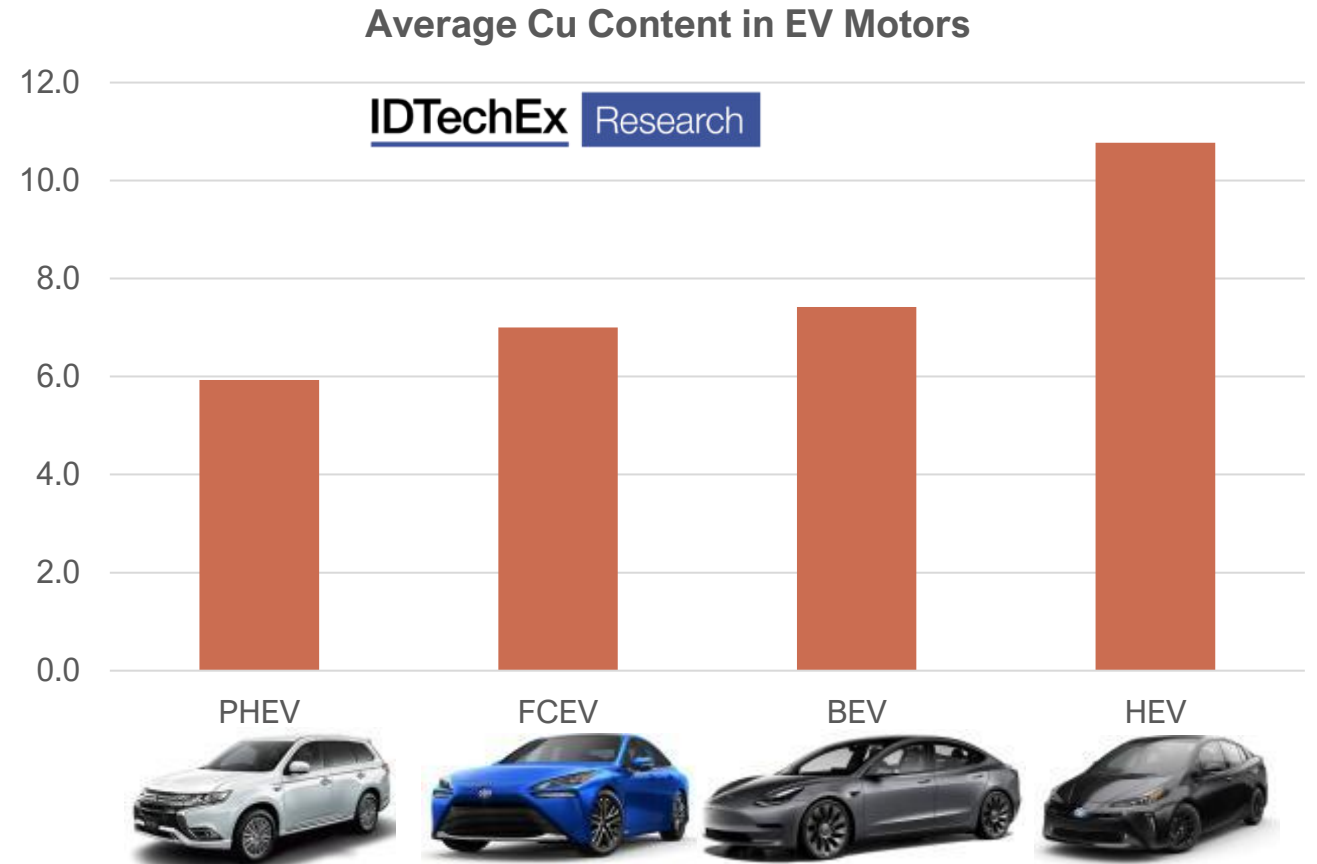
Renault has used a wound rotor design since their Zoe released. However, they use a PM motor in their hybrids.
Source: Renault

Data source: Trading Economics

Motor Copper Intensity in Different Drivetrains

Battery electric vehicles and non plug in hybrids contain the most copper.

It is more common for BEVs to use two motors than PHEVs or FCEVs.

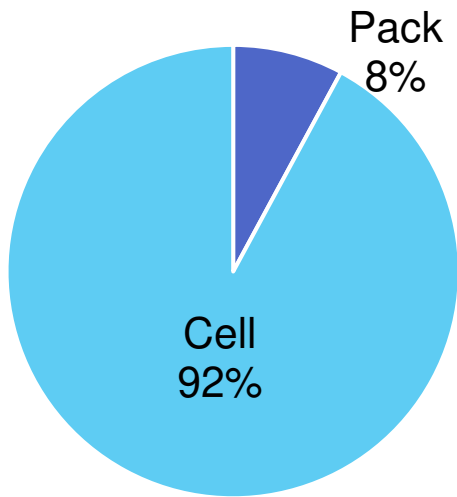


Source: IDTechEx
Image sources: Tesla, Toyota, Mitsubishi

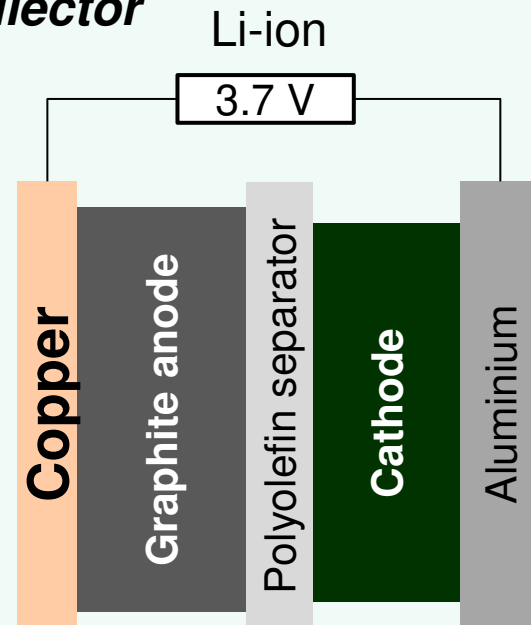
Copper in Li-ion Battery Packs

Most copper by weight is used as anode current collectors for Li-ion cells and cannot be replaced because of corrosion issues. Other sources of copper include electrical interconnects such as busbars, cables and wiring.

Sources of copper in a BEV battery pack



Li-ion cell: anode current collector



Li-ion battery pack: electrical interconnects

➤ Busbars



➤ Cables and Wiring

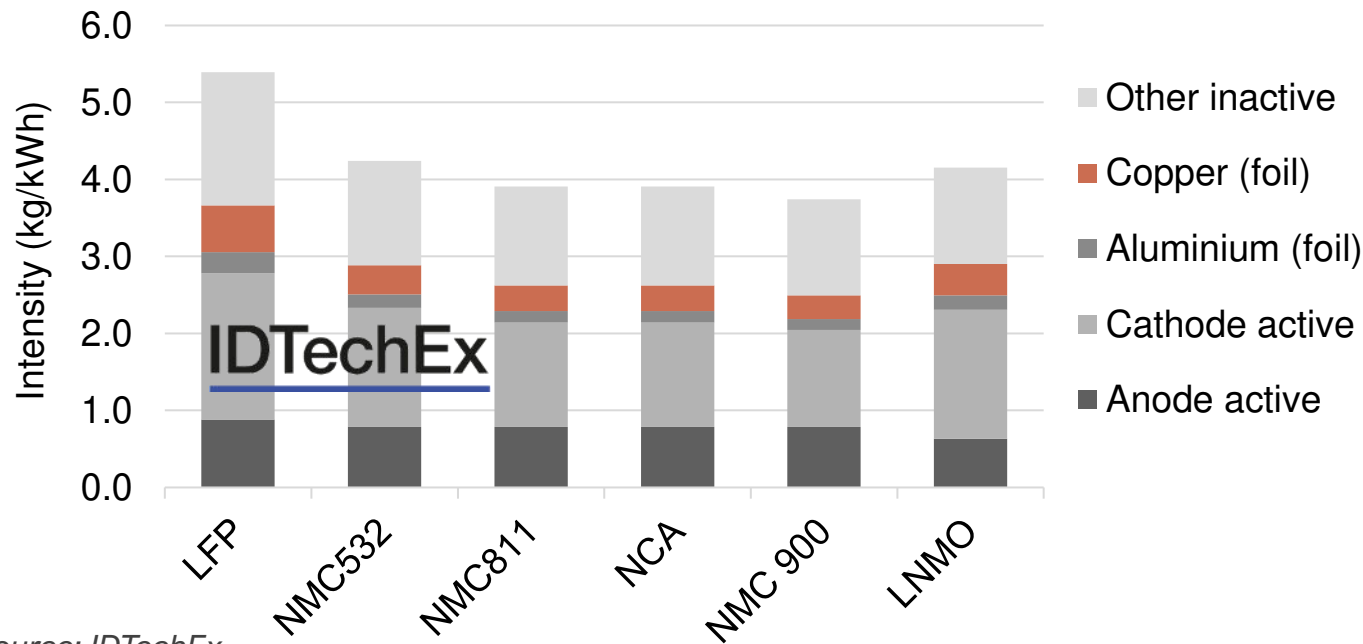


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Copper Intensity in Battery Cell Chemistries

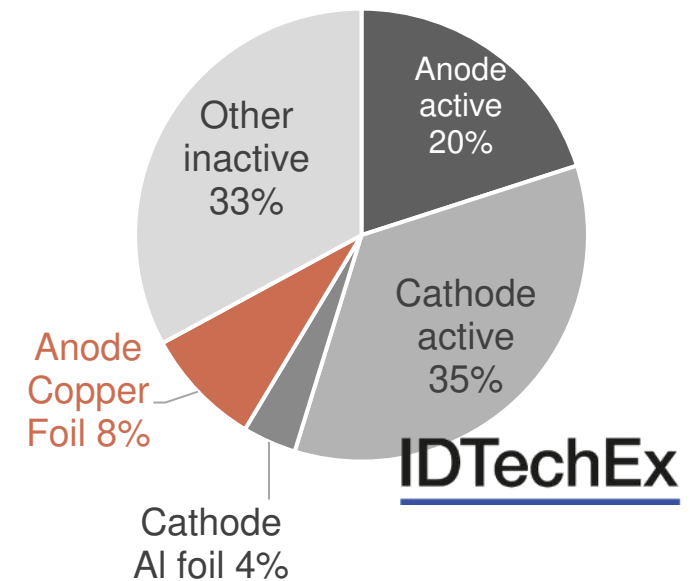
- Material intensity at the cell level increases with lower gravimetric energy density cathode chemistries.
- **A copper foil thickness of ~10 μm leads to a copper intensity between 0.3 – 0.4 kg/kWh** for various NMC/NCA type cells. This corresponds to approximately 8% of the mass of an NCA or NMC 811 pouch cell.

Material intensity by cathode

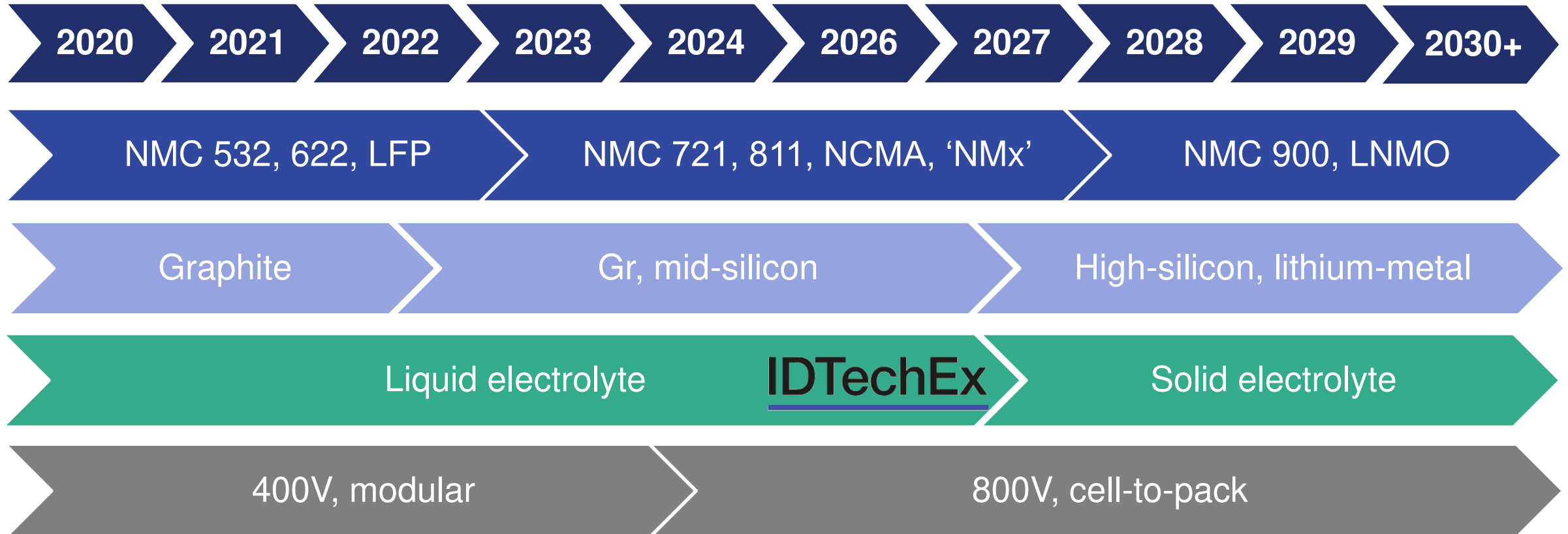


Source: IDTechEx

2021 NCA cell material breakdown



IDTechEx Li-ion Battery Timeline

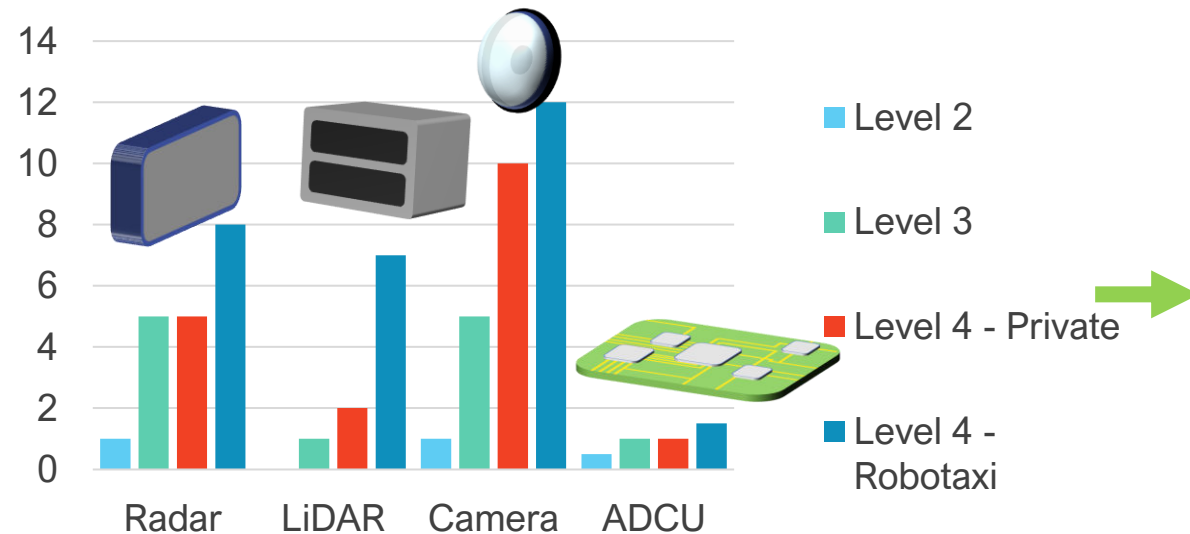


Source: IDTechEx

Copper in Autonomous Vehicles

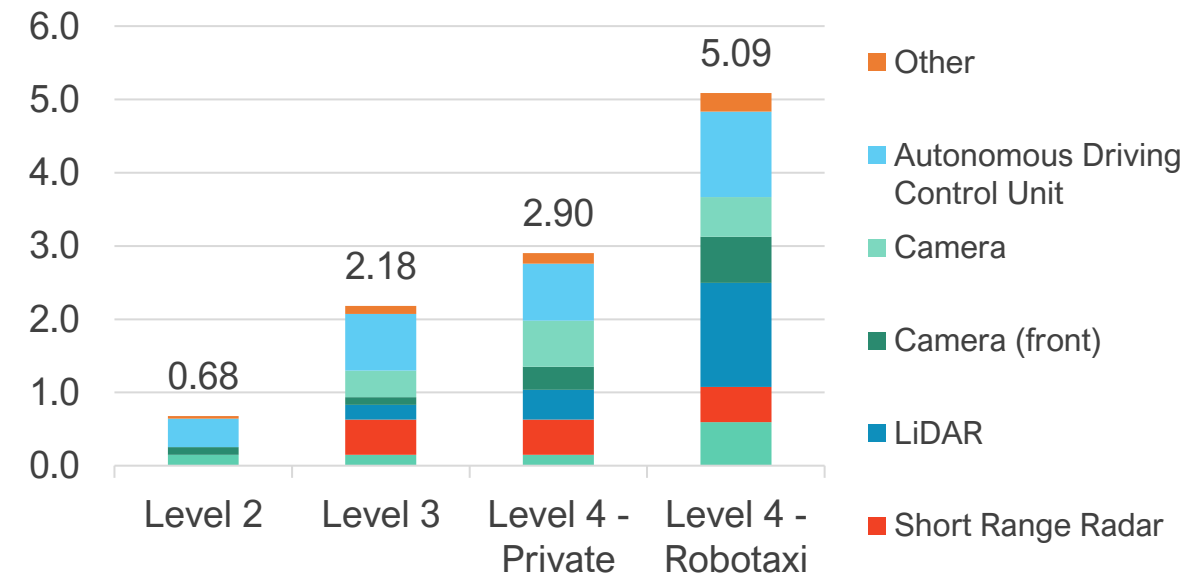
- Vehicle automation requires the addition of many sensors, as well as additional on board computers.
 - Each sensor and computer contains printed circuit boards using ~50-100g of copper depending on the size.
 - Each sensor and computer also contributes additional wiring to the wiring loom.

Additional Sensors for Different Autonomy Levels



Source: IDTechEx

Copper per Car for Different Autonomy Levels (kg)



Copper in the Autonomous and Electrified Future

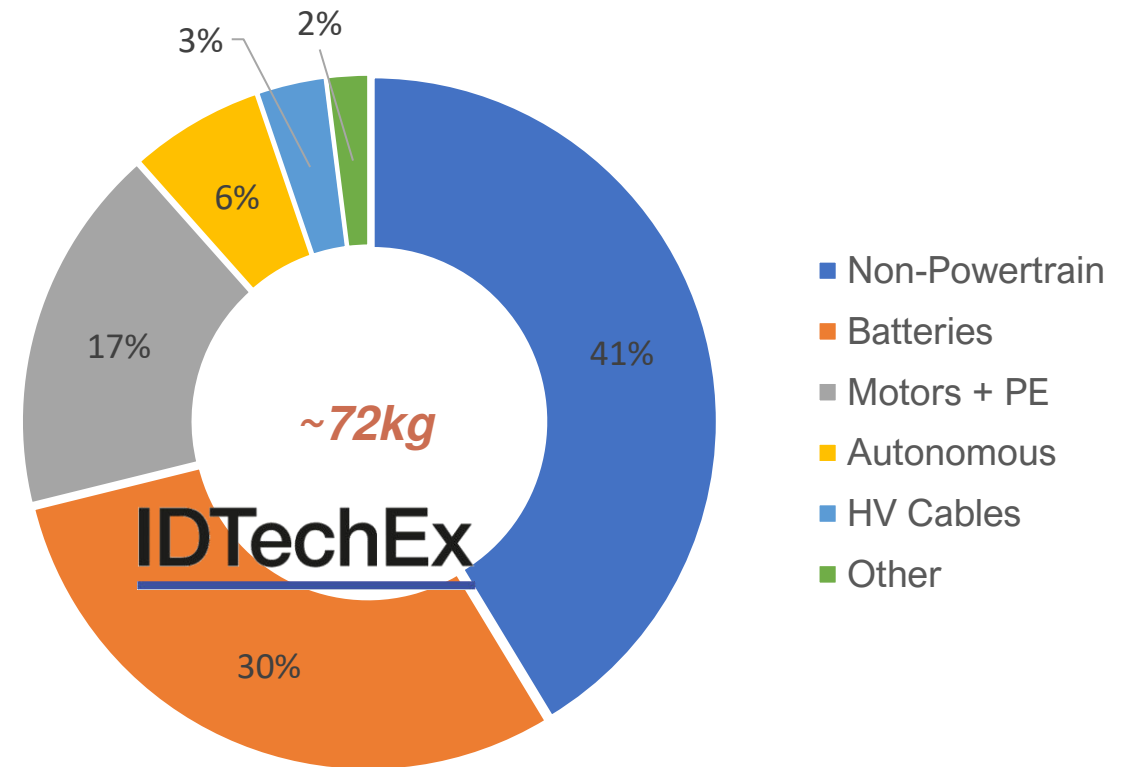
Future **battery electric vehicles with high levels of automation will require more than double the copper** of a conventional internal combustion vehicle today.

In 2040 we expect a typical vehicle to have:

- 108kWh battery
- 195kW motor
- An autonomous system with
 - o 12 cameras
 - o 7 LiDARs
 - o 8 radars
 - o 1 automated driving control unit.

All in, this vehicle contains 72kg of copper.

Distribution of Copper in a 2040 Vehicle



Source: IDTechEx research

Copper in Cars Forecast – 2020-2040

IDTechEx has compiled its total copper forecast by considering contributions from more than 30 components, across five different powertrain variants and four variations of autonomous vehicle.

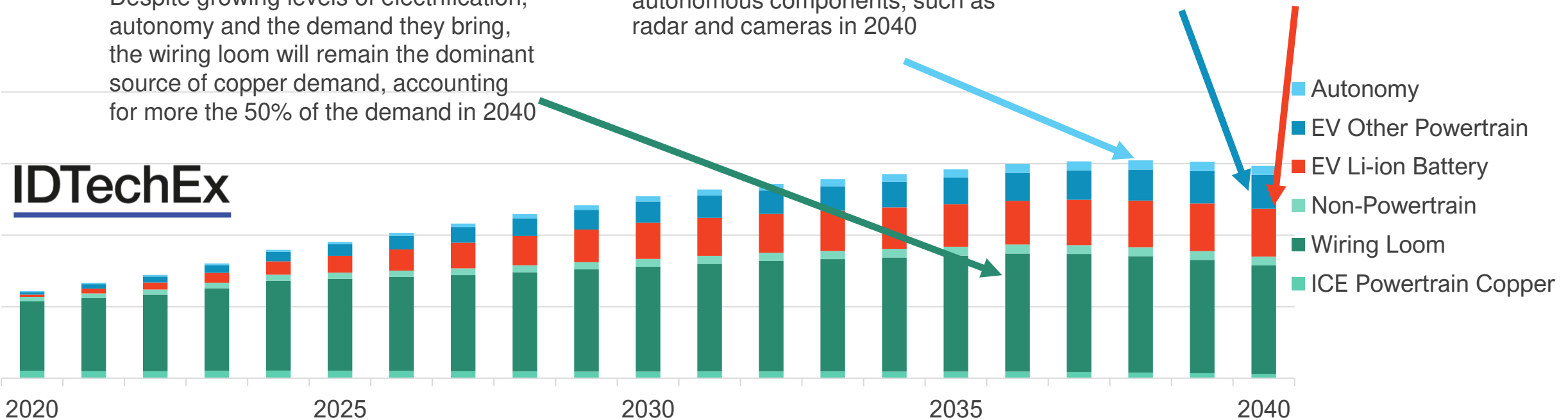
Copper demand in different areas (million tonnes)

Despite growing levels of electrification, autonomy and the demand they bring, the wiring loom will remain the dominant source of copper demand, accounting for more the 50% of the demand in 2040

More than 250kT will be required for autonomous components, such as radar and cameras in 2040

Electric powertrains will account for ~39% of the automotive copper demand in 2040

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Source: IDTechEx research