

Phenomenal Growth in Energy Storage

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Legal Statement

The purpose of the information in this presentation is to guide ICA programs and provide members with information to make independent business decisions.

Antitrust Guidelines

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.

Rising Demand for Energy Storage

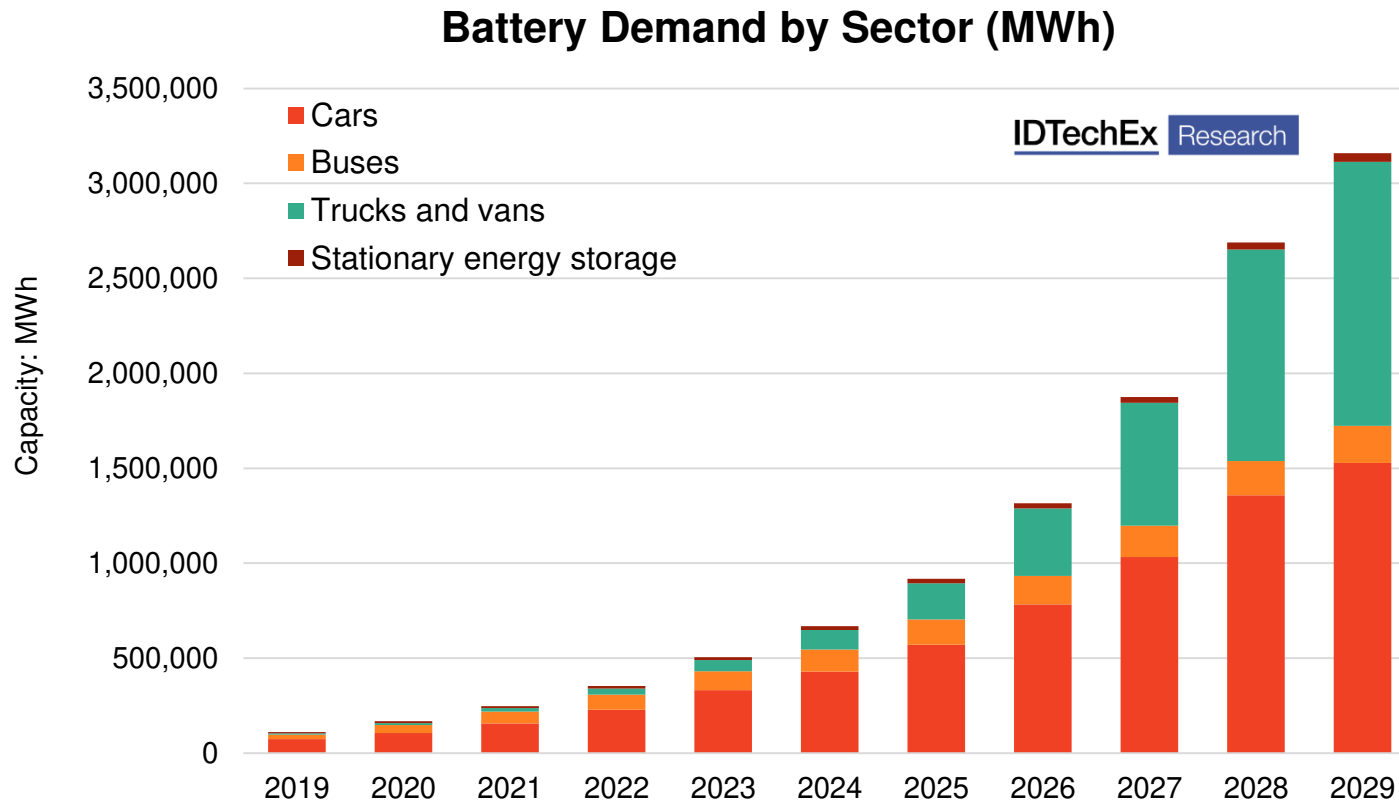
- Energy storage—battery technology in particular—is often seen as having great potential to decarbonise power and transport systems. Recent cost reduction of Li-ion batteries has raised penetration levels of e-mobility and stationary energy storage applications.
- Global sales of plug-in electric vehicles (PEVs) hit 2 million in 2018 and the total PEVs on the road reached 5.3 million by the end of 2018.
- In IDTechEx's 10-year forecast, the electric vehicle (EV) market—including cars, buses and trucks—will grow to 52 million annual sales by 2029, driving up demand for batteries to around 3.1 terawatt hours (TWh) per year.
- Widespread EV deployment will lead to a further decrease in Li-ion battery costs, which will spill over to stationary storage systems at household, commercial, industrial and grid levels.



Source: Renault

Battery Demand in Mobility and Stationary Storage

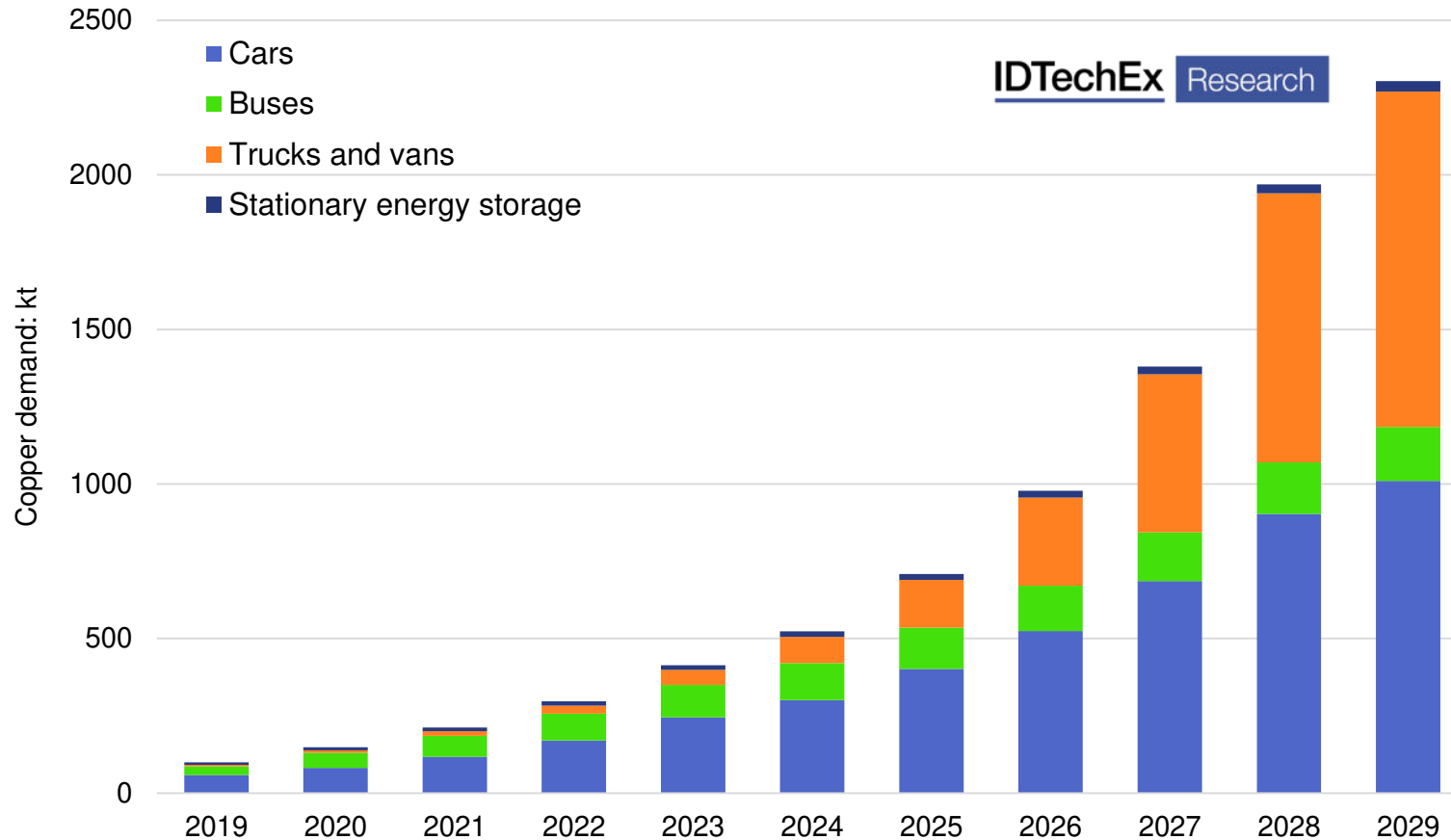
- IDTechEx's forecast shows annual demand for battery storage in e-mobility and stationary storage will grow from 0.1 terawatt hours (TWh) in 2019 to around 3.2 TWh by 2029.
- Batteries will predominantly be deployed in e-mobility applications, especially in cars, trucks and vans.



Source: IDTechEx

Copper Demand in Energy Storage Applications

Annual Copper Demand in Energy Storage for Mobility and Stationary Storage 2019–2029



Source: IDTechEx

— IDTechEx forecasts energy storage in mobility and stationary storage applications will raise annual copper demand by **2.3 million tonnes** by 2029.

— The total copper demand in energy storage over the next decade will total just over **9 million tonnes** by 2029.

Li-ion Batteries: From Cell to Pack

Li-ion cell

Battery management system (BMS)

Thermal management

Electrical interconnects

Safety components

Housing



Battery pack

Note: A battery pack, together with power conditioning systems (PCS)—including inverters, battery chargers and energy management systems—comprise a **battery system**.

Source: Yole

Different Li-ion Cell Formats

Cylindrical



- ✓ Low-cost option
- ✓ Highly optimized manufacturing process
- ✓ Highest cell-level volumetric efficiency
- ✗ Difficult to cool
- ✗ Packaging efficiency

Used by:



Faraday Future

Pouch



- ✓ Highest module design flexibility
- ✓ Highest capacity flexibility
- ✓ Wider supplier selection
- ✗ Poor mechanical containment
- ✗ Good compression control required

Used by:



RENAULT



CHEVROLET

Prismatic



- ✓ Simple, lower-cost manufacturing
- ✓ Easier to cool
- ✗ Poor cell-level energy density
- ✗ Poor flexibility
- ✗ Lifecycle challenges

Used by:

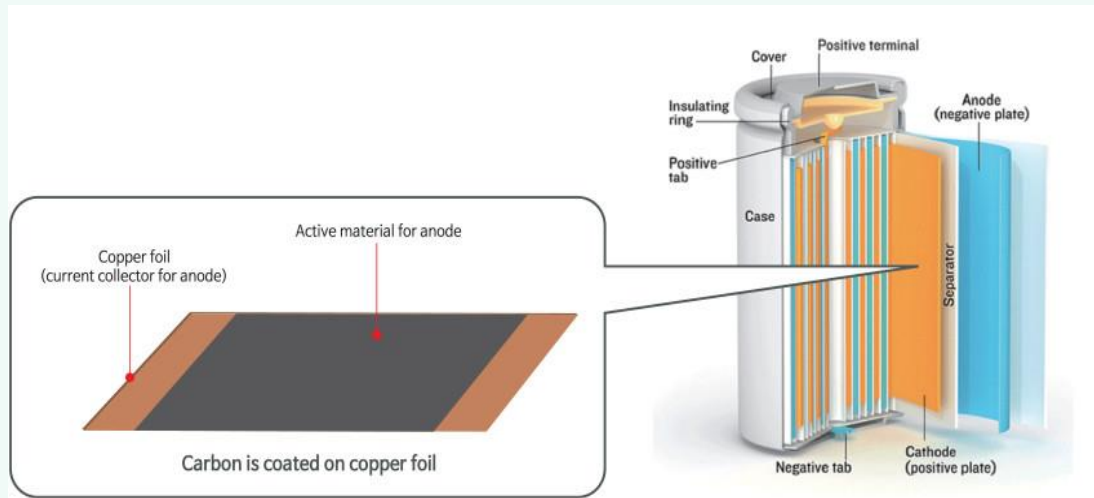


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Copper Content in Li-ion Battery Packs

- Li-ion batteries rely on raw materials not originally present in cars—such as lithium and graphite—but also other materials that may see a significant boost in their demand, like nickel, cobalt, and **copper**.
- Copper is used in current collectors for Li-ion cells and cannot be replaced because of corrosion issues. At the pack level, copper is used in the electrical interconnects, e.g. busbars, cables and wiring.

Li-ion cell: anode current collector



Li-ion battery pack: electrical interconnects

- Busbars



- Cables and Wiring



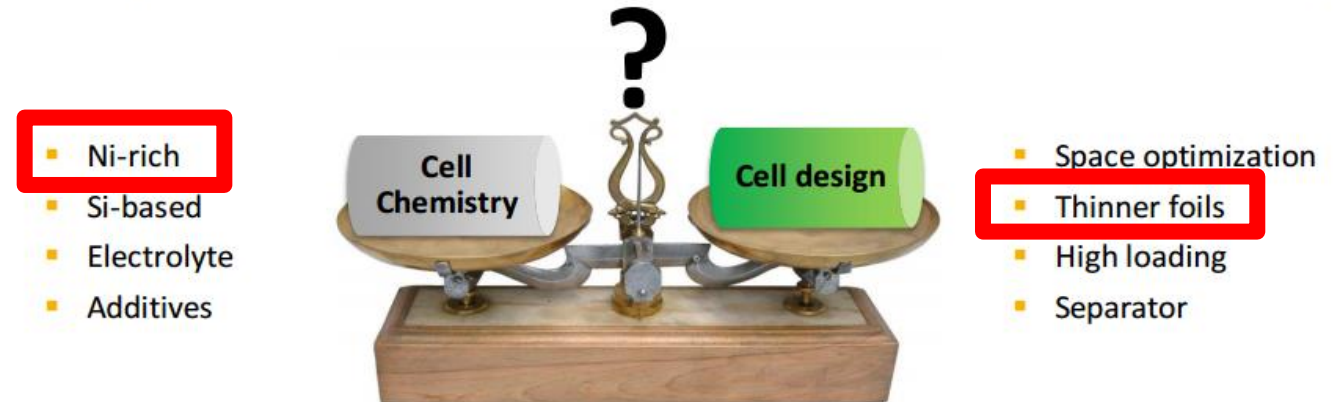
Material Minimization and ‘Lightweighting’

- Copper foil is normally used at a thickness of around 10 microns. This guarantees both a satisfying electronic conductivity and structural integrity.
- Efforts are in place to reduce the thickness of copper foil, as can be seen from Renault’s AABC 2017 presentation.
- Reduction of inactive weight is crucial to attaining higher performance, as well as lower cost per kWh.

Cell performance evolution

❑ How to go from 500Wh/l cell energy density?

500Wh/l  800Wh/l

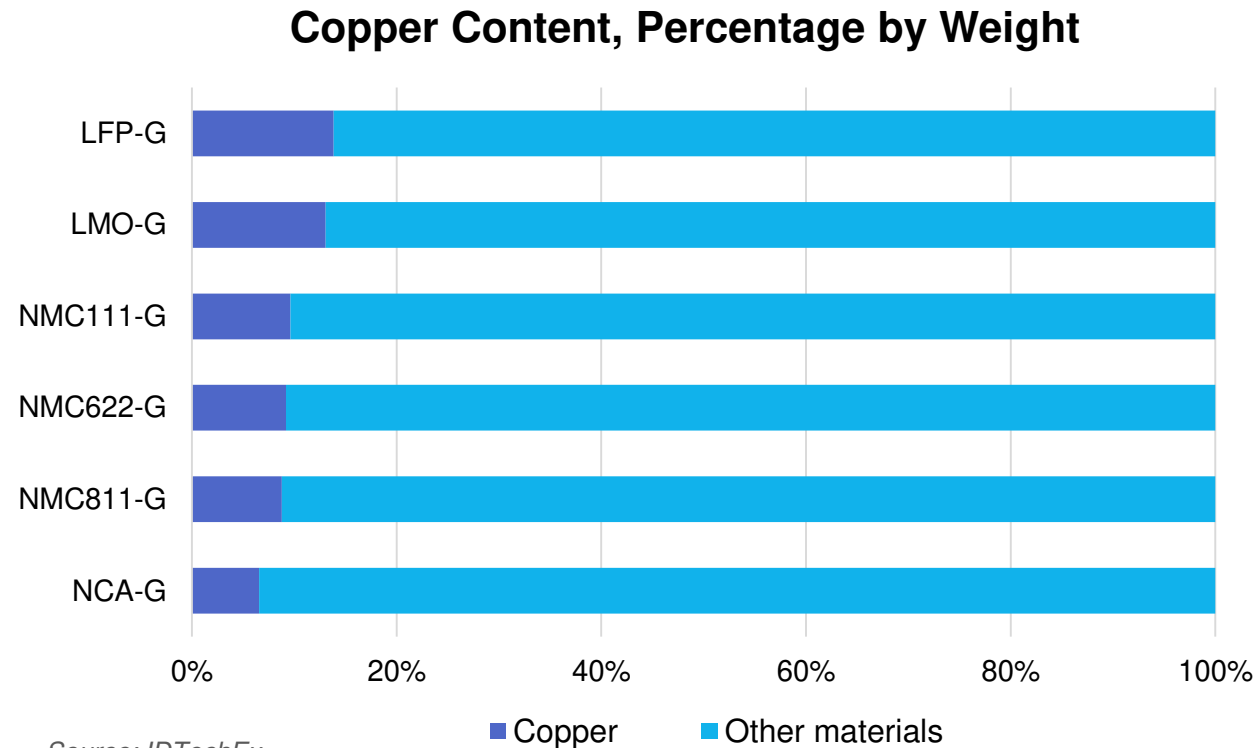


❑ ‘New’ chemistries needed for reaching 800Wh/l

Source: Renault

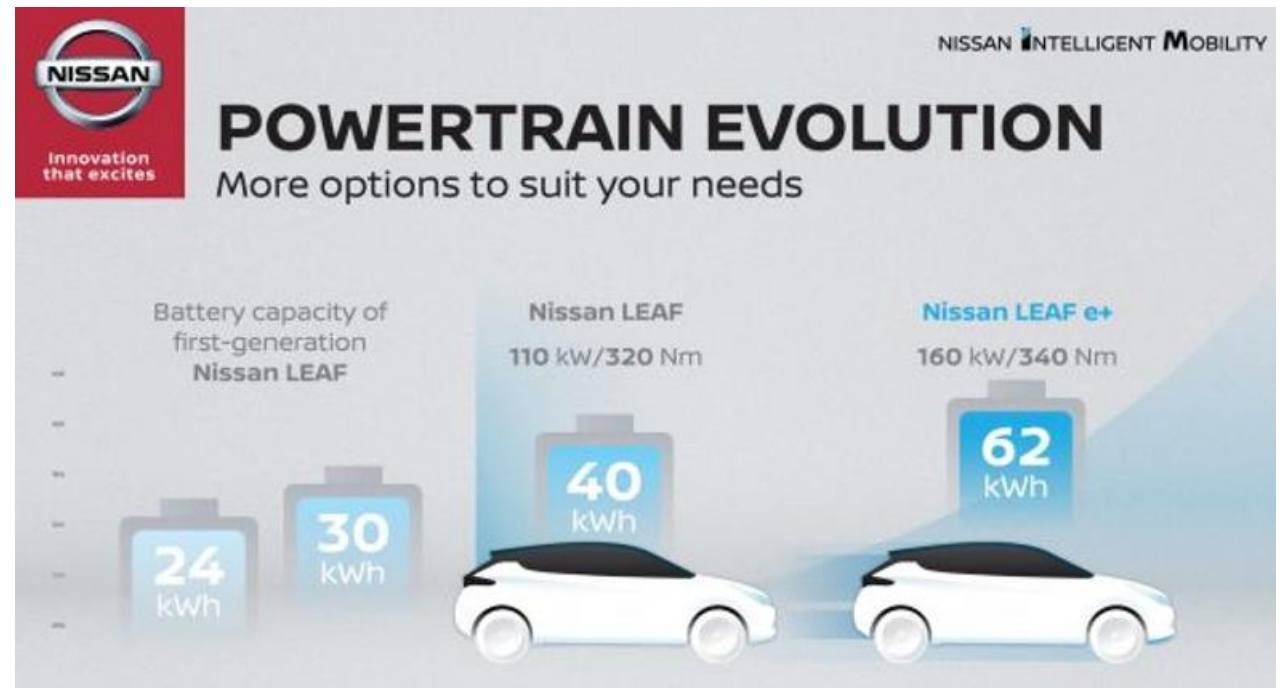
Copper Intensity at Cell Level: Different Cell Chemistries

- Lithium nickel cobalt aluminum oxide (NCA), lithium nickel manganese cobalt oxide (NMC), lithium iron phosphate (LFP) and lithium ion manganese oxide (LMO) are the most commonly used cathode materials in energy storage Li-ion batteries. Consumer batteries are beyond the scope of this study.
- In general, as cell performance (e.g. specific energy) goes up, copper intensity in Li-ion cells decreases.



Battery Size (Capacity) is Increasing

- Although some factors will cause copper demand to decrease at the cell and pack level ($\text{kg}_{\text{Cu}}/\text{kWh}$), this doesn't mean overall demand will decline. The automotive sector has been moving towards not only higher energy density, but also higher capacity batteries.
- Many OEMs have announced new EV models with higher capacity batteries. For example, the old Nissan LEAF model only has a 24kWh while the latest model LEAF e+ announced at CES 2019 carries a 62kWh battery.
- Although range anxiety cannot be solved by increasing battery capacity alone, we expect battery capacity will increase over the coming years to catch up with the range of gasoline cars, driving up copper demand.



Source: Nissan

Redefining the 'End-of-life' of EV Batteries

- Consumer batteries such as those in power tools, mobile phones and laptops are normally recycled/disposed after their service life. We normally refer to this as the 'end-of-life' of the batteries.
- However, retired car batteries no longer suitable for electric cars could still hold sufficient capacity for low-demand applications, such as stationary storage.
- The 'end-of-life' of an electric car battery needs to be redefined as they continue to be used, for example, for another 10 years or even longer in various post-vehicle applications before they are finally recycled/disposed.

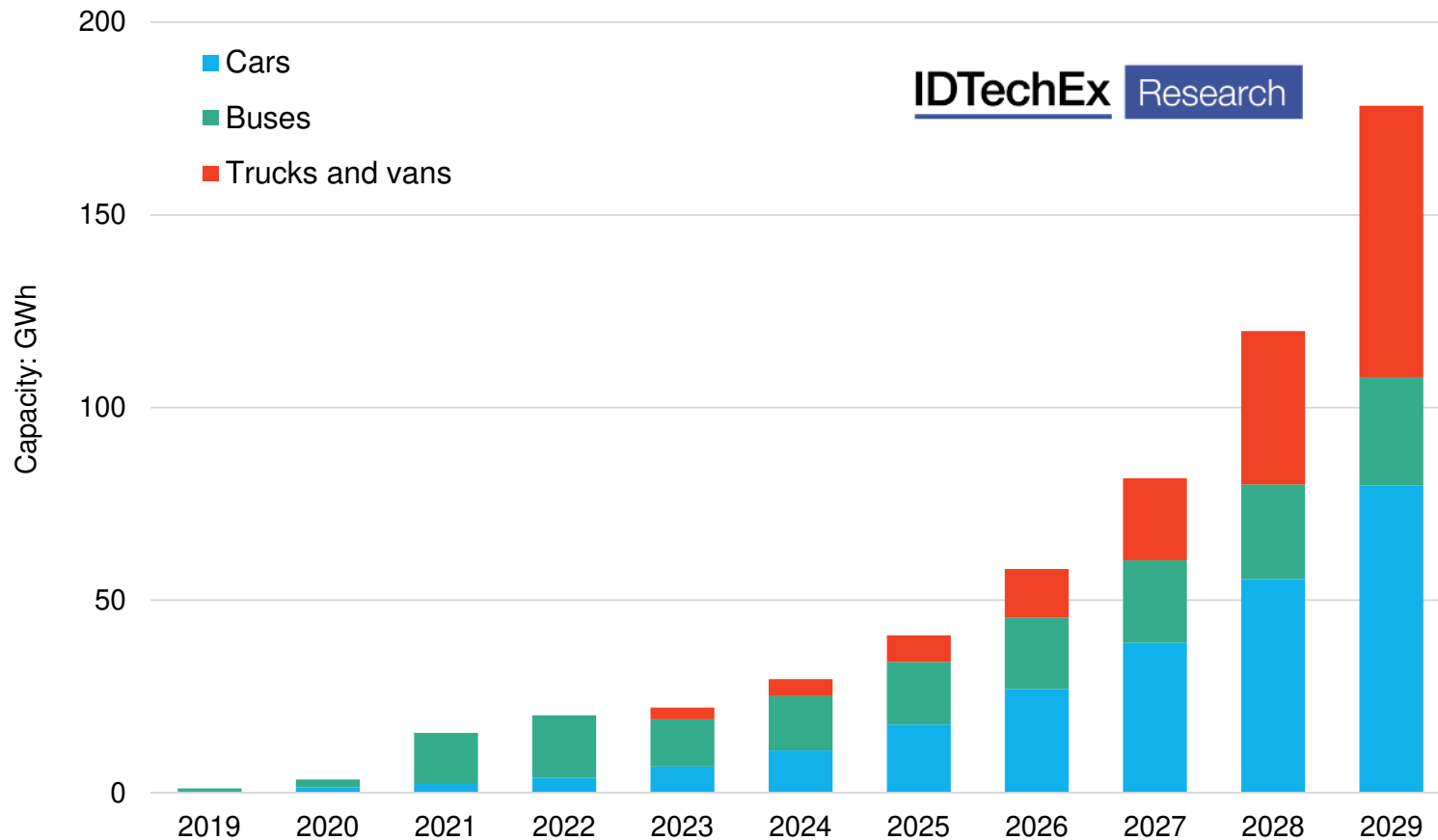
End-of-service ≠ End-of-life



Source: BMW

Available Second-life Battery Capacity

Second-life Battery Availability Forecast 2019–2029



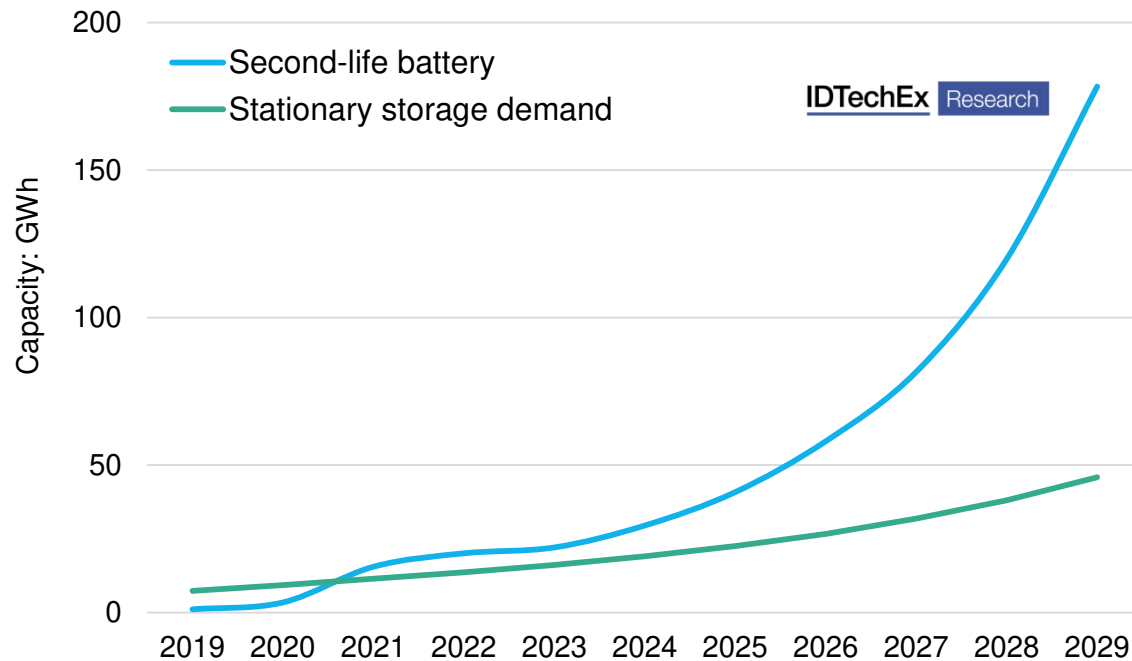
IDTechEx Research

- By 2029, available storage capacity from second-life batteries will hit **178 GWh** per year.
- Available second-life battery capacity is a portion of retired EV batteries because some of those batteries are not suitable for second-life, e.g. battery damage, premature degradation and low residual capacity.

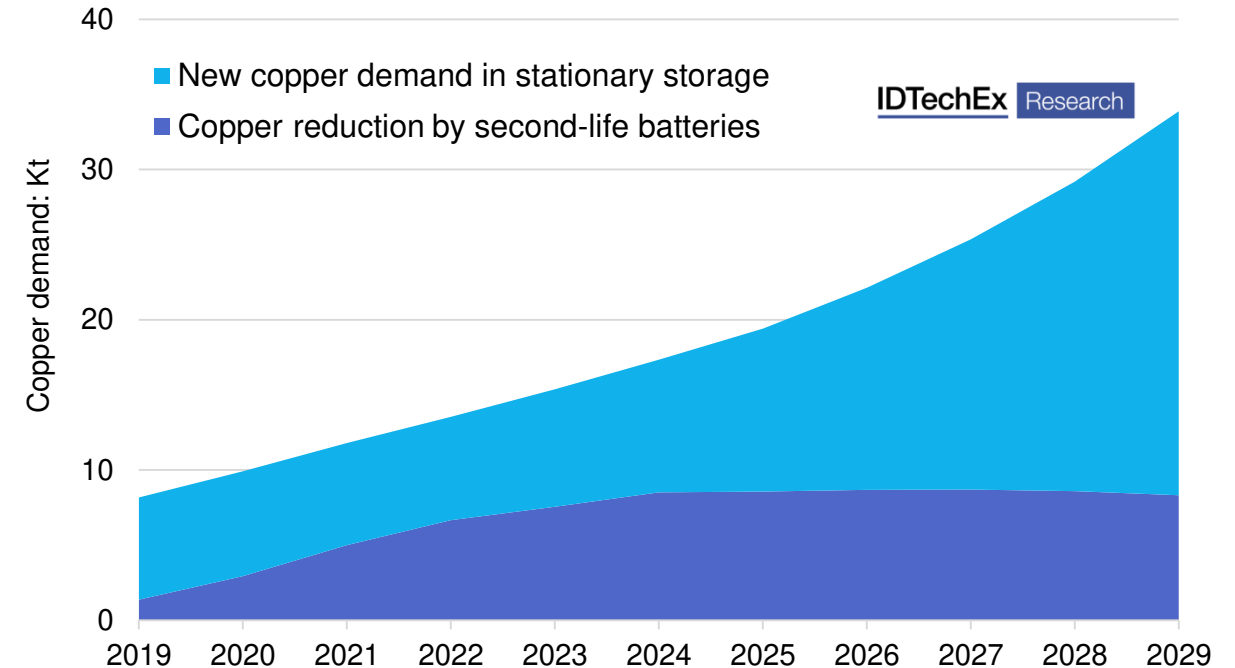
Source: IDTechEx

Second-life Battery Demand and Impact on Copper

Second-life Battery vs. Stationary Storage Demand 2019–2029



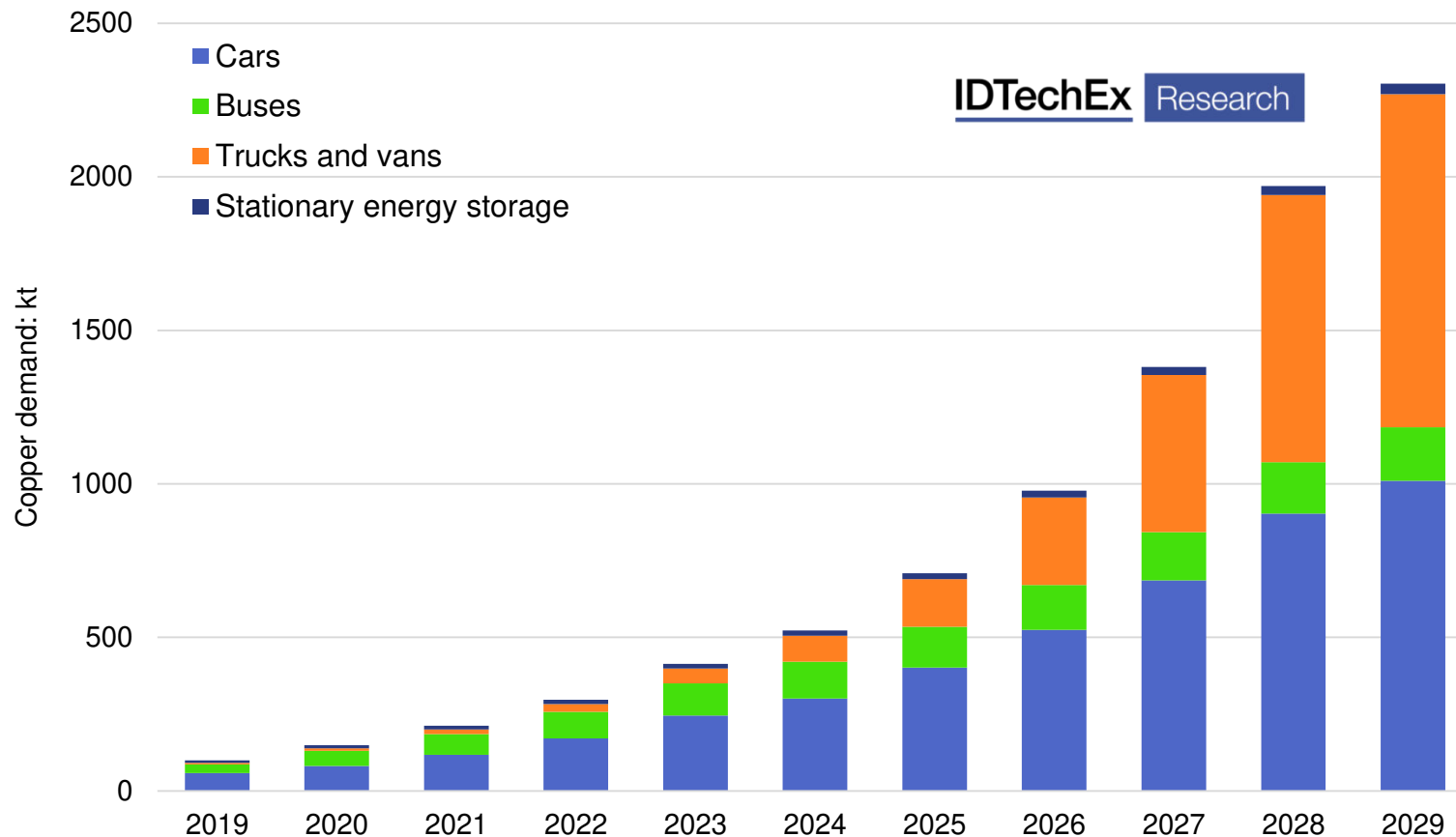
Copper Demand Reduction from Second-life Batteries?



Source: IDTechEx

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Source: IDTechEx

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