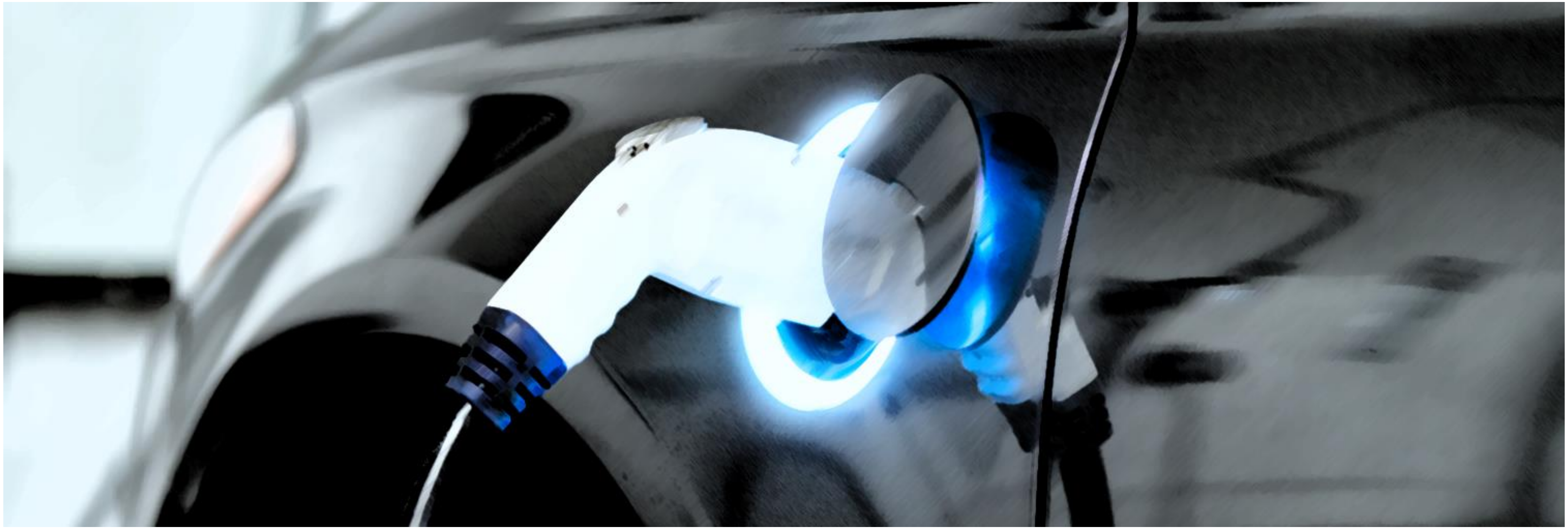
The Electrifying Cost of Electric Vehicles



NOVEMBER 2022

Speakers

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CRU London

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Multi Commodity Analyst
CRU London

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Chief of Staff
A2MAC1

CRU: Provider of market-leading insight for more than 50 years

Expertise, Experience & Coverage

- B2B **metals, mining and fertilizer intelligence experts**
- CRU is recognised for the **quality and integrity of our data-led analysis** and our people and as the **premier source of data**, analytics and insights for pricing, benchmarking, forecasting and business decisions.
- **Price Assessment**, **Market Analysis**, **Consulting** & **Events** capabilities for over 50 years
- Primary research and robust, transparent, methodologies
- A **global team of over 300 analysts**, consultants and other experts.
- We provide customers with the best service and the closest contact: flexible, personal and responsive

A2MAC1: The automotive standard for teardown data and technical insights

Our approach

- A2MAC1 analyzes more than 100 new best-in-class vehicles every year
- We are identifying design, technology, and performance highlights for the full vehicle, on domain-level (e.g. powertrain) and down to the level of individual parts.
- We connect technology, performance, and supply chain insights with a detailed evaluation of cost and sustainability implications. This way, we reveal the secrets behind specific features and discover areas of optimization potential which will give our customers a head start on their competitors and emerging market trends.

25 Years

600+ Staff worldwide

1500+ Analyzed vehicles

650+ OEM and Supplier customers

Global Footprint with 17 locations

40Million Images and digital twins in our database

100+ New vehicles per years

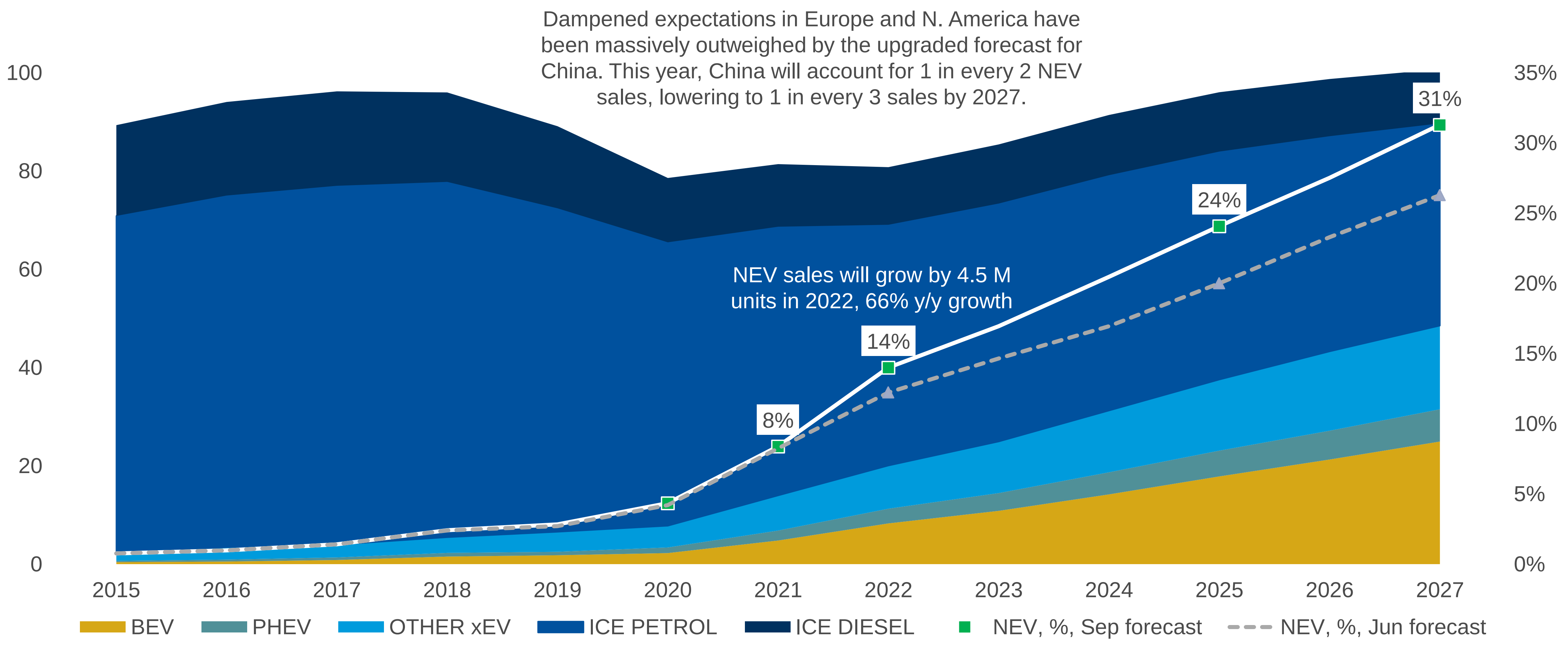
>650k Users worldwide

- What is happening with the transition to EVs?
- How can data analytics help you navigate this change?
- How does the transition to BEV impact material composition?
- What does this mean for the cost of automotive raw materials going forward?

Global automotive markets are set for huge change

Global light vehicle sales by powertrain

LHS Million units, RHS %



DATA: CRU Note: NEV refers to battery-electric and plug-in hybrid vehicles. LDV (light duty vehicles) data presented, not including HDV and Buses

- What is happening with the transition to EVs?
- How can data analytics help you navigate this change?
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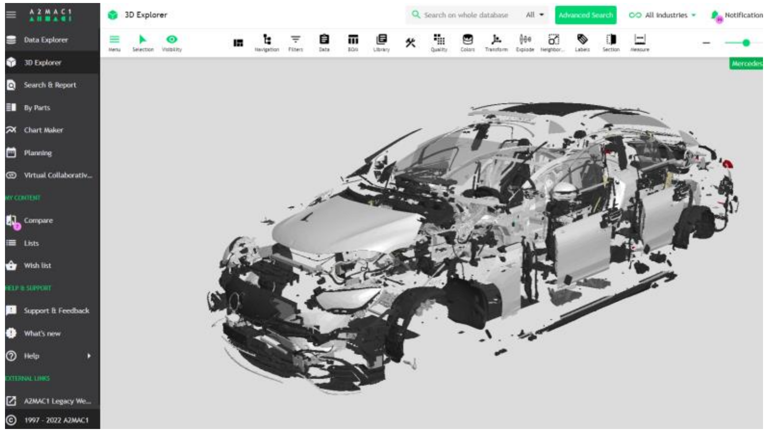
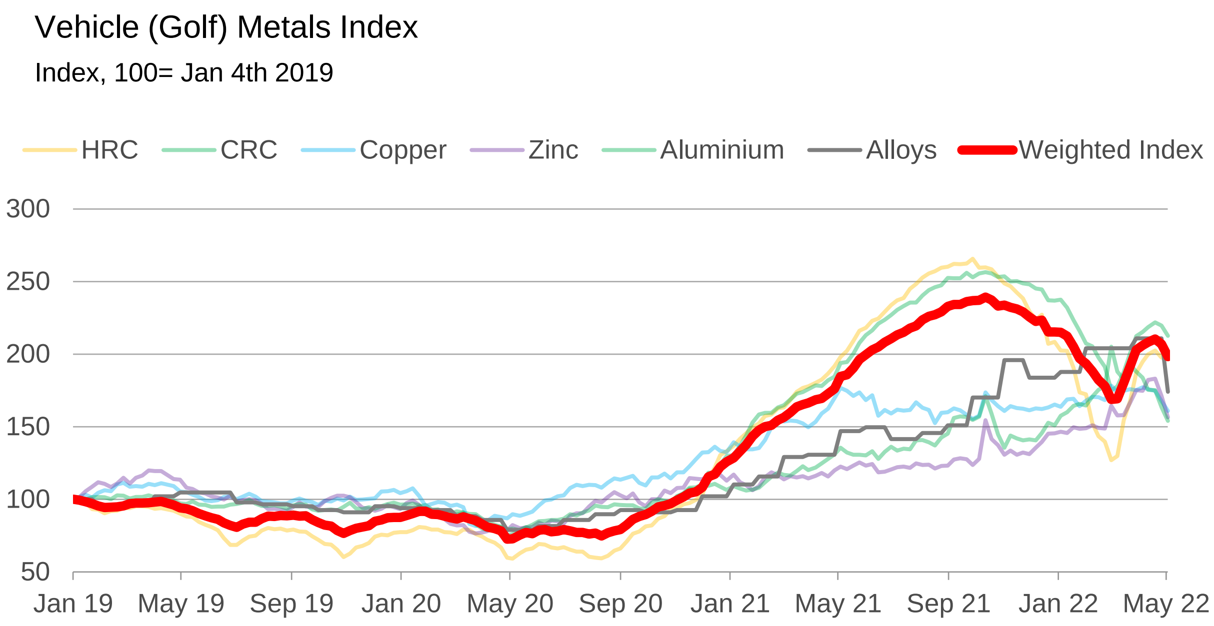
Combining expertise to create vehicle price indices…

CRU's commodity price indices



A2MAC1's teardown component data

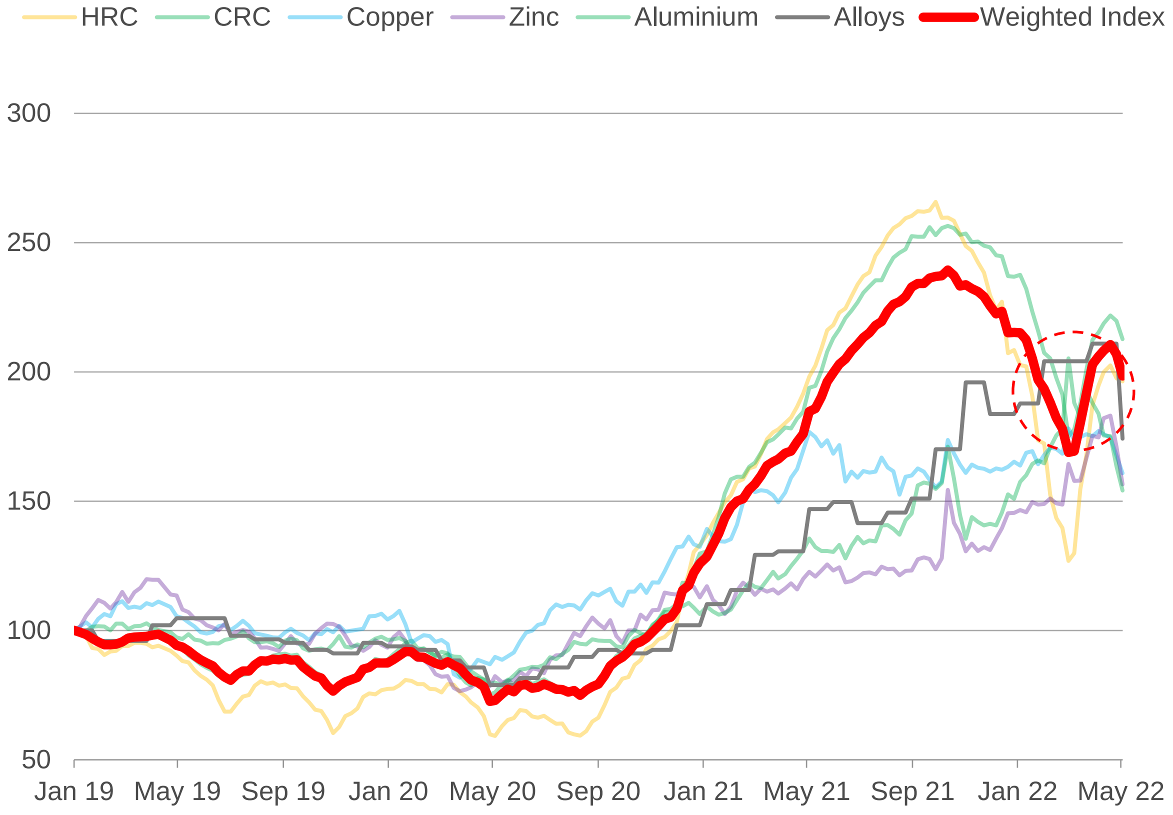


We have the data to generate raw material indices for the entire automotive market

…enabling the identification of trends based on real data

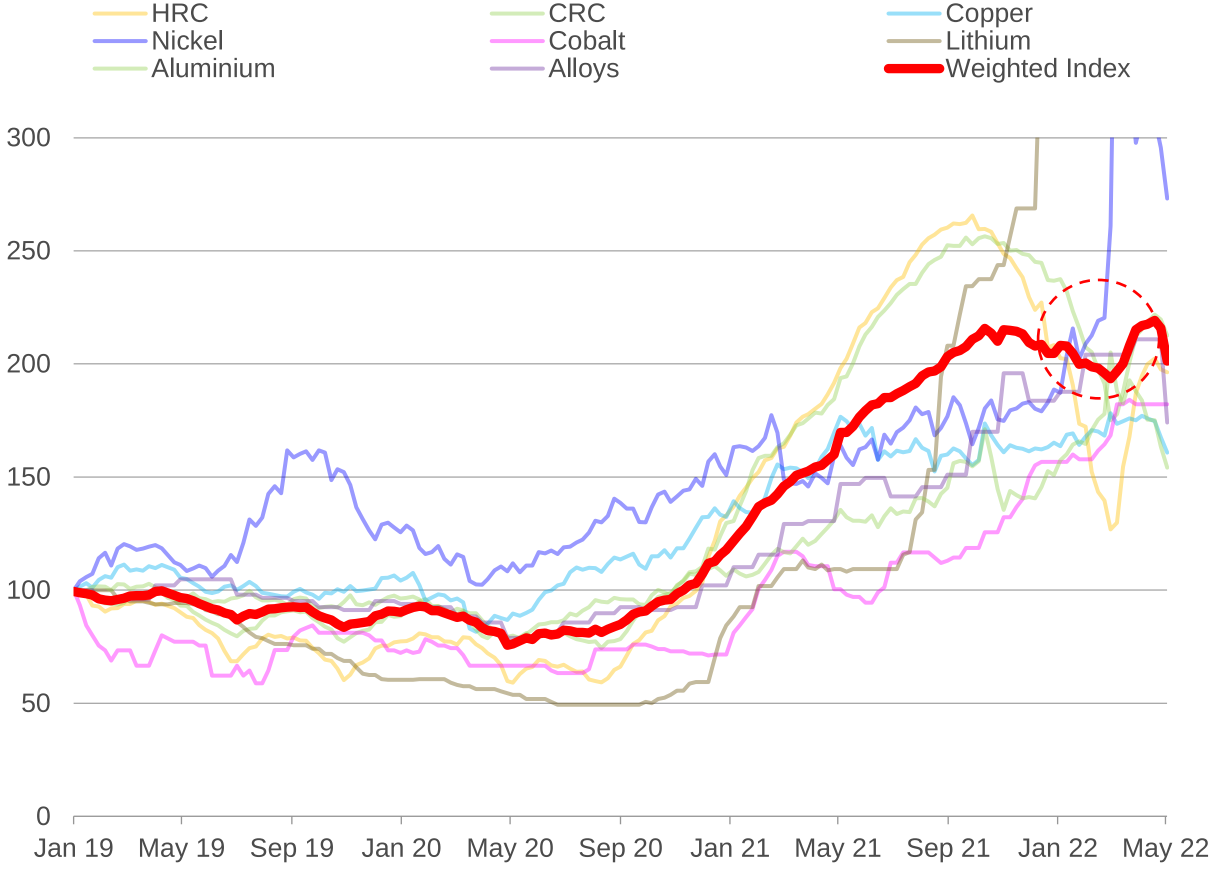
Vehicle (Golf) Metals Index

Index, 100= Jan 4th 2019



Vehicle (ID3) Metals Index

Index, 100= Jan 4th 2019

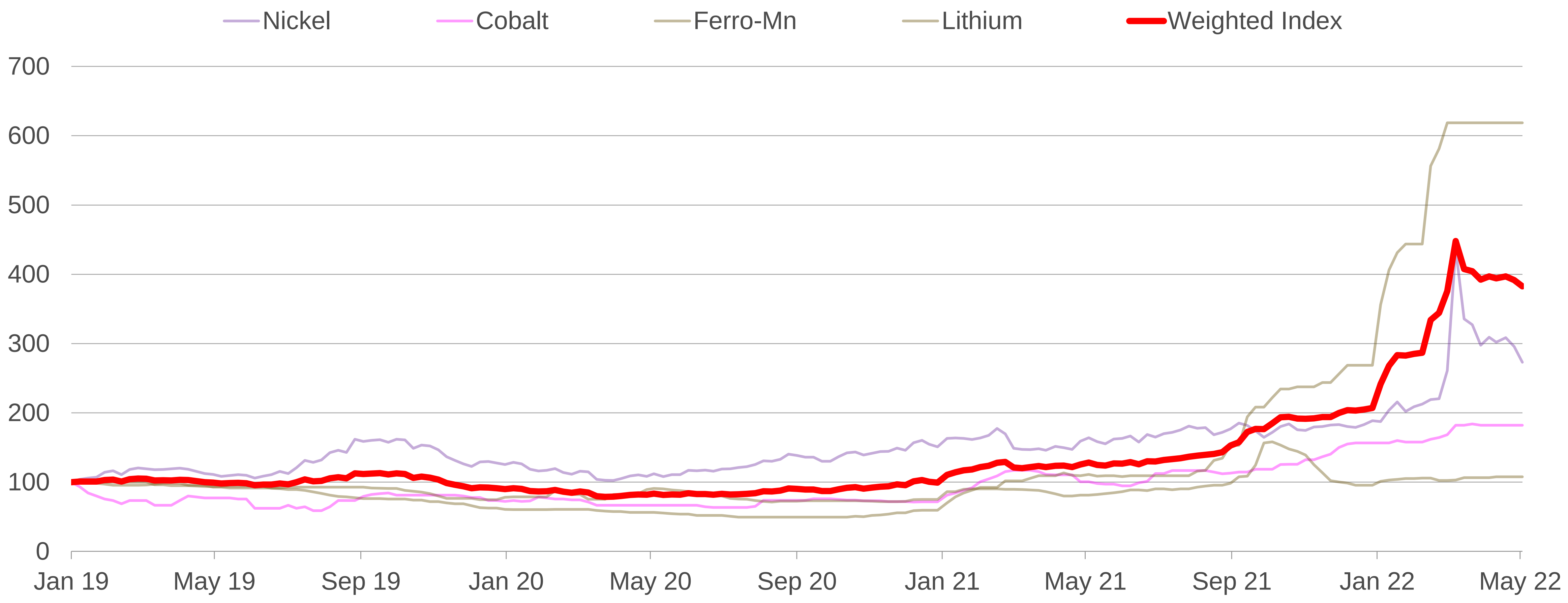


DATA: CRU, A2MAC1

The methodology can be applied to batteries too

Battery NMC Index

Index, 100= Jan 4th 2019

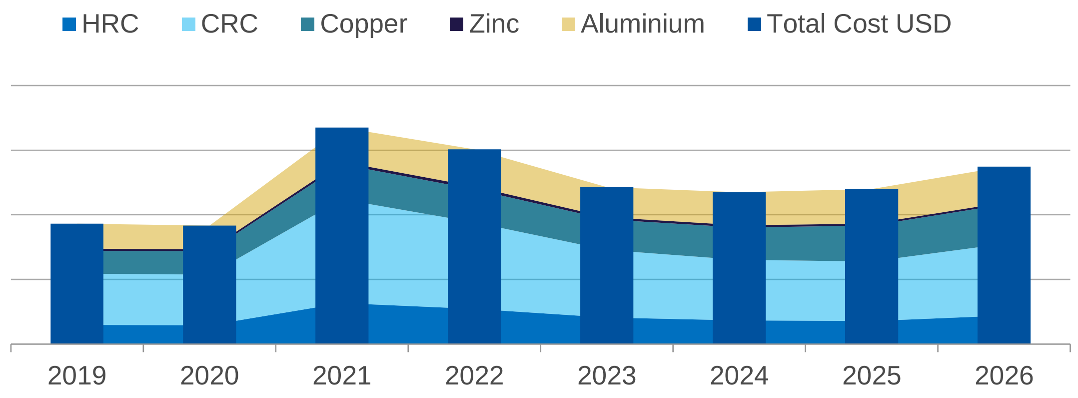


DATA: CRU, A2MAC1

Looking ahead a “step-change” in total metal costs is clear

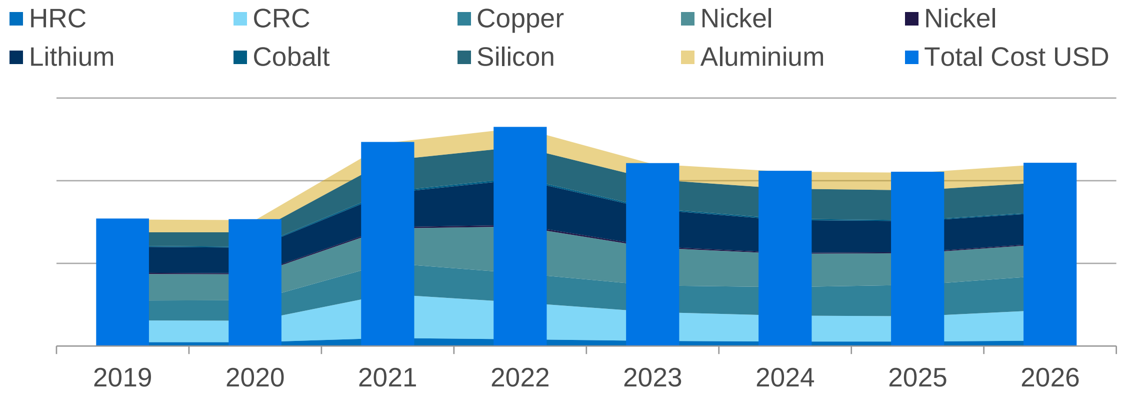
Metals (Costed Weight of Metal) Price Forecast Golf

Price USD



Metals (Costed Weight of Metal) Price Forecast ID3

Price USD



- Metal cost for an both an ICE and an EV vehicles up 80% in 2022 from pre-pandemic levels
- Short-term price decline expected but level to remain above pre-pandemic levels in the medium-term
- A ‘battery metal premium’ also exists, EV metal cost is double that of an ICE vehicle
- Metal cost remain over ~40% up on pre-pandemic suggesting a step-change to a new ‘new normal’.

DATA: CRU Market Outlooks (November 2022)

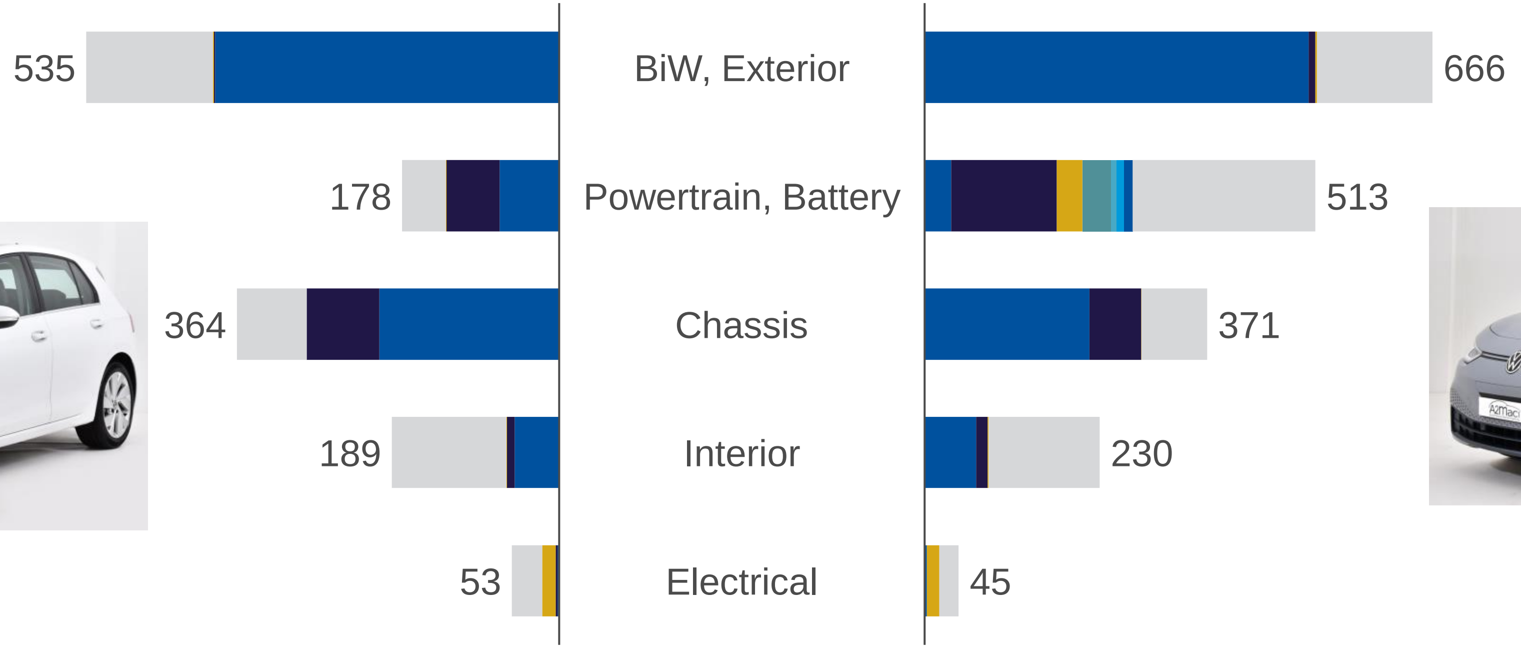
- What is happening with the transition to EVs?
- How can data analytics help you navigate this change?
- How does the transition to BEV impact material composition?
- What does for the cost of automotive raw materials going forward?

Electric vehicles with high increases of copper and aluminium content

Component weight by raw material /kg

ICE Vehicle – Volkswagen Golf

EV – Volkswagen ID3

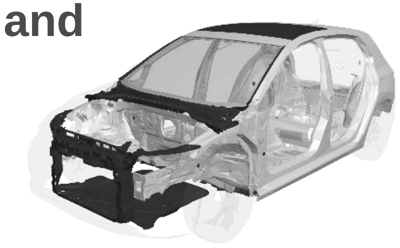
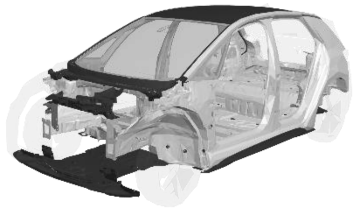
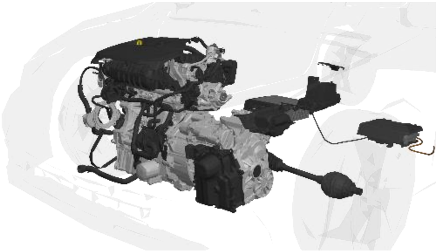
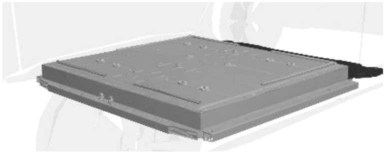


High raw material cost baseline driven by higher use of high-cost materials such as:

- Aluminium (~30-80% increase depending on battery and body design)
- Copper (increase by factor of 2-3)
- Battery metals (Lithium, Nickel, Cobalt, etc)

DATA: A2MAC1, CRU

Electrification is changing material composition in 3 main areas

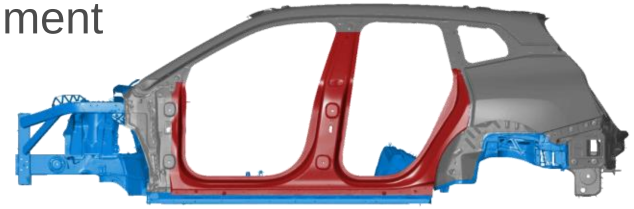
	ICE/Mild Hybrids		BEV
BiW, exterior, and Chassis		▪ BEV apply lightweighting, but with high cost sensitivity ▪ Advanced BEV designs with reduced material usage in underbody due to battery pack carrying structural load	
Powertrain		▪ Heavy steel combustion engine replaced by e-motor ▪ BEV uses simplified gearbox (only 1 translation ratio in >95% of BEVs) and propulsion shafts	
Battery		▪ BEV with heavy battery housing (mostly aluminum currently) and aluminum cooling panels ▪ Aluminum, Copper, and other metals usage in battery cells varying by chemistry	

BiW: Light-weighting is relevant especially for performance BEVs

Volume segment

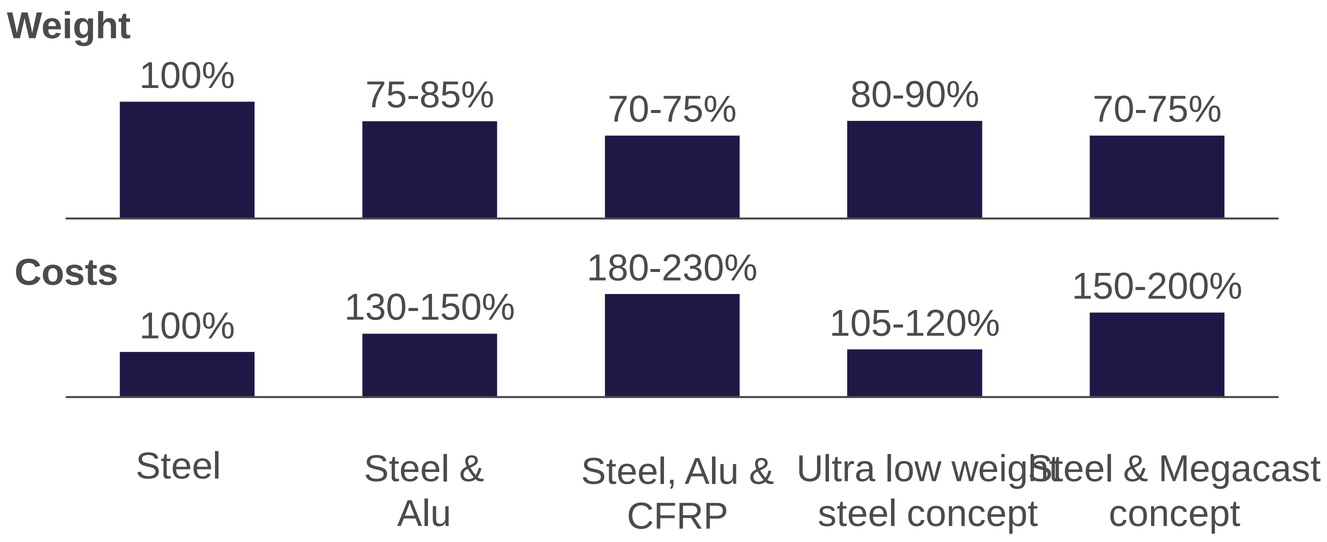
VW ID.3 **375 kg Steel BiW**

Performance segment



BMW iX **408 kg hybrid BiW**
40% steel and 55% aluminum (incl. 60 kg of die-casted parts) and 5% carbon fiber

Model calculation of expected weight and costs effects of different light-weighting technique

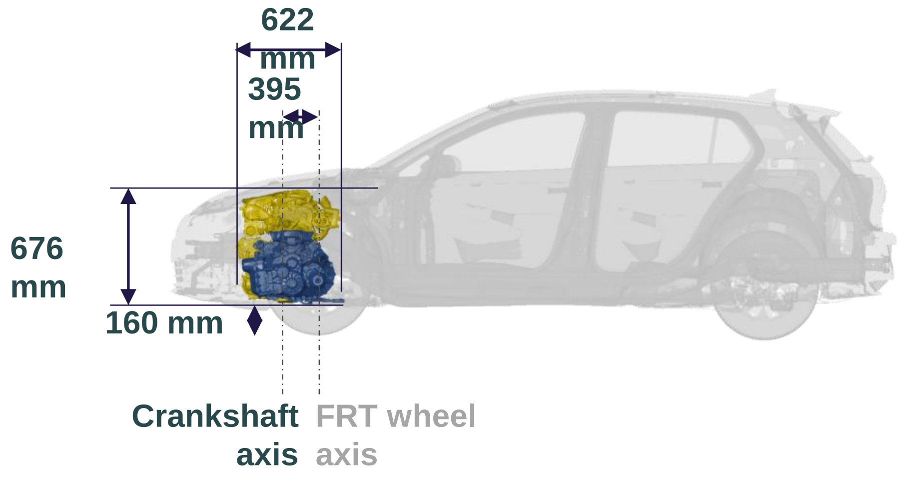


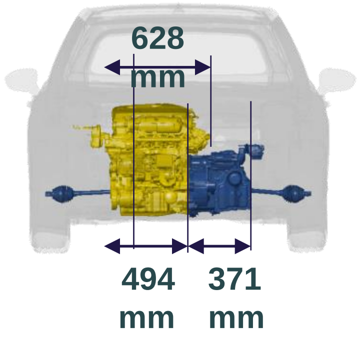
Expected to stay standard solution for small and mid-sized volume models

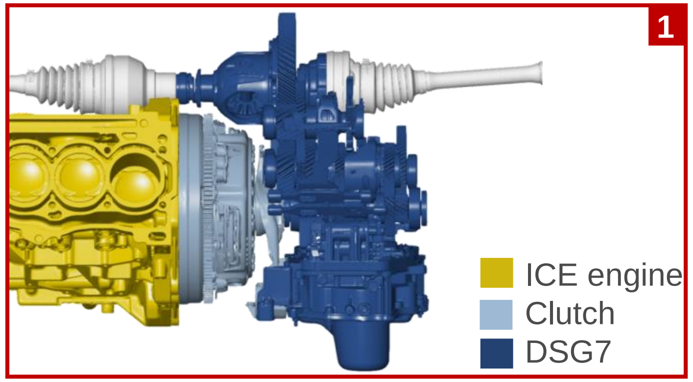
Different light-weighting techniques, relevant especially for large-size and high performance BEVs; Megacasting with additional CAPEX savings for the assembly line

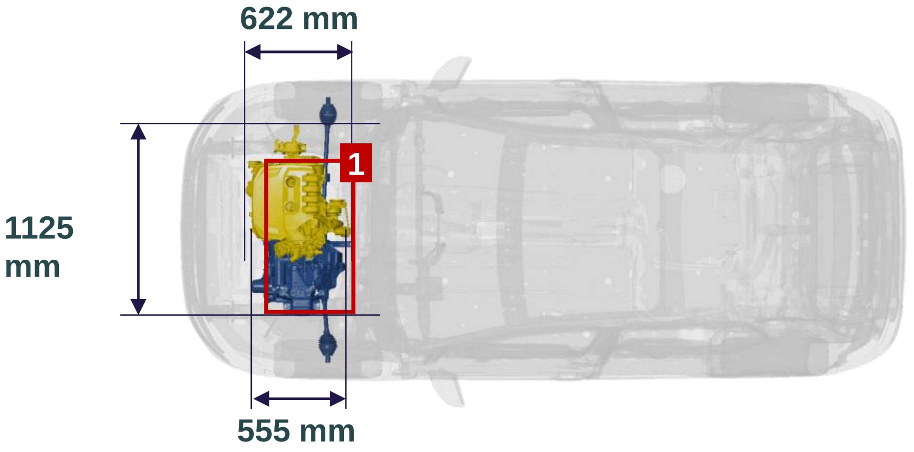
DATA: A2MAC1

Powertrain: ~200kg of steel and aluminium which are replaced









TOTAL WEIGHT = 206.5 kg

ENGINE : 108.4 kg

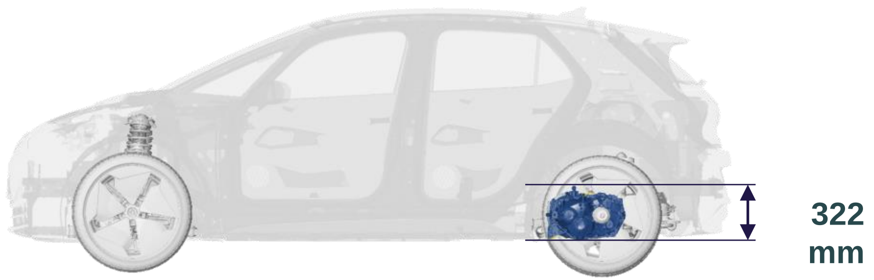
ICE Engine	1.5 Turbo Mild Hybrid (Transversal engine)
ICE Horsepower / Max. Torque	150 Hp / 250 Nm (source : OEM)
E-motor power	-
Combination Horsepower / Max. Torque	-
Bore / Stroke	74.5 / 85.9 mm (source : OEM)
Compression ratio	10.5 (source : OEM)

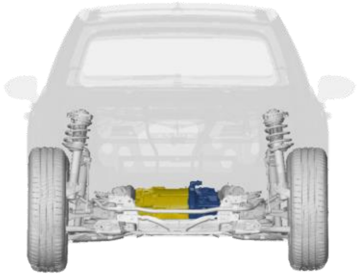
TRANSMISSION : 98.1 kg

Drivetrain	FWD
Gearbox	Dual clutch automatic 7 (DSG7)

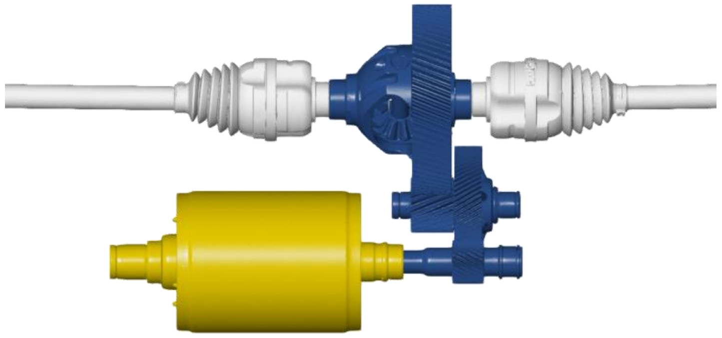
SCOPE :
Included : ICE Engine + turbo, gearbox, differential, FRT & RR drive shafts, oil, engine mounts, rear differential, intermediate transmission, clutch, starter motor
Not included : Cooling system, Alternator, AC compressor, fuel system, air system

Powertrain: ID.3 e-motor & differential weight <100kg

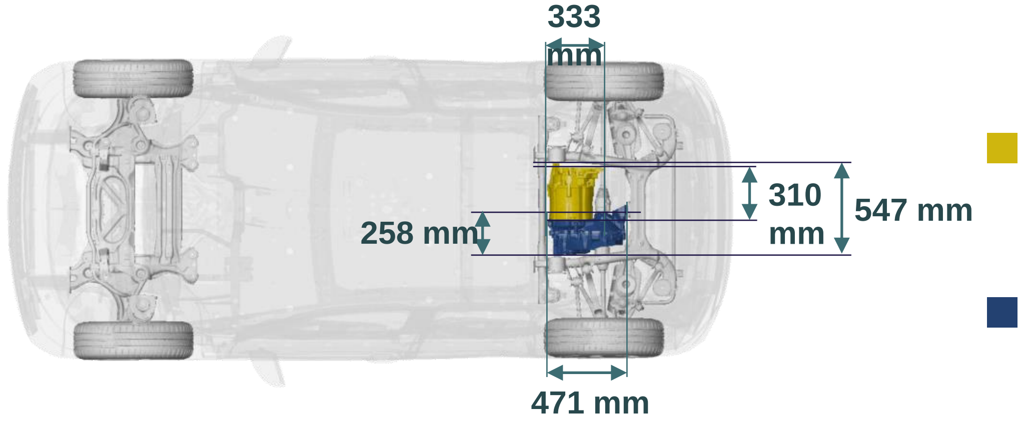




Top view without housing : e-machine details



- ➢ **No epicyclic train**



TOTAL WEIGHT = 96.1 kg

E-MOTOR : 54.2 kg

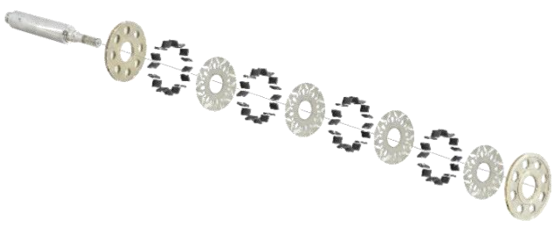
Power	150 kW, 204 Hp (source : OEM)
Max. Torque	310 Nm (source : OEM)

TRANSMISSION : 41.9 kg

Drivetrain	RWD
Gearbox	Direct Drive

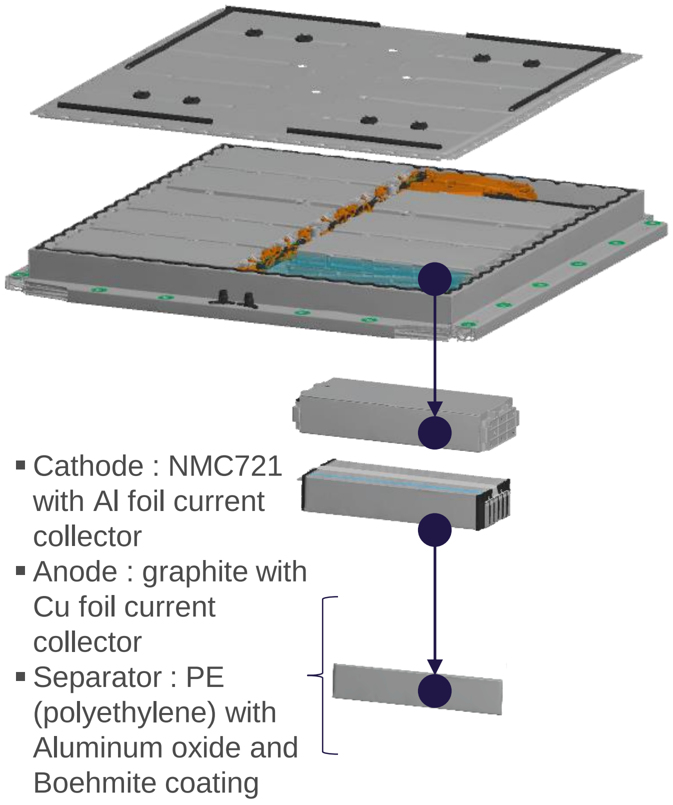
SCOPE :
Included : ICE Engine + turbo, e-motor, gearbox, differential, FRT & RR drive shafts, oil, engine mounts, rear differential, intermediate transmission, clutch, starter motor
Not included : Cooling system, HV Cable, Alternator, AC compressor, HV management, HV Battery, fuel system, air system

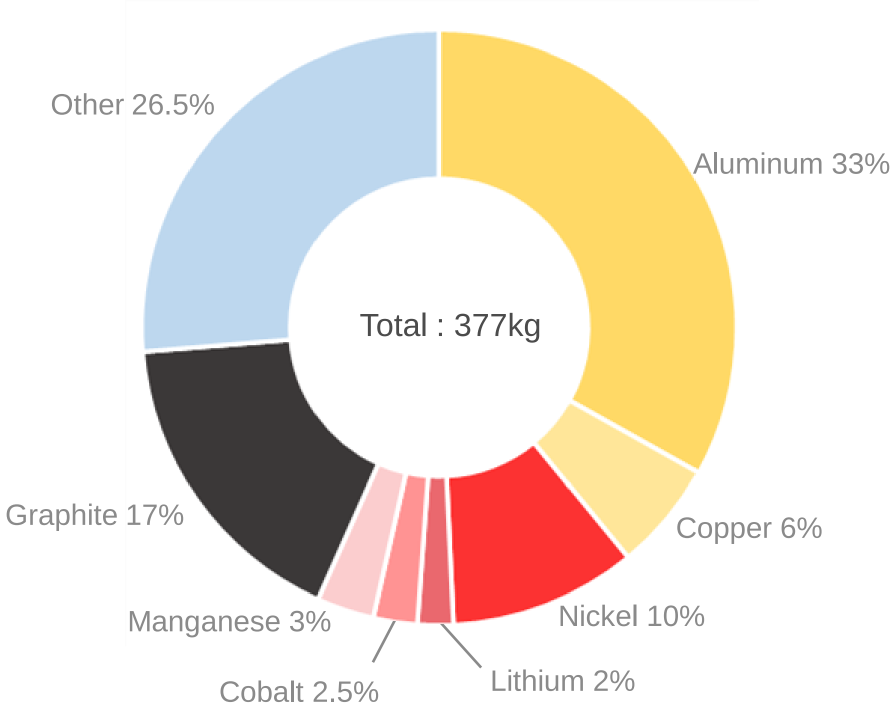
Powertrain: Different motor design concepts are applied

	Permanent Magnet Synchronous Motor (PMSM)	Asynchronous Motor (ASM)	Externally Excited Synchronous Motor (EESM)
			
Advantages	• Compact Design, High power density- Saves package space and weight • Higher efficiency- high continuous power • Good thermal behavior- consistent performance and service life	• High power density • No magnets installed- lower costs	• High efficiency for given application • No expensive materials used- lower costs • High efficiency field-weakening operation • High overload possible
Disadvantages	• Use rare earth materials for magnets • Magnets installed- higher cost	• Requires more installation space • High heat generation- restricted repeatablity / limited continuous power	• Additional excitation circuits required • Not compact for a given power rating
OEMs	BYD, 北汽集团 BAIC Group, HYUNDAI MOBIS, HONDA	TESLA, Audi	RENAULT Passion for life, BMW

Battery: Aluminum with highest share of raw material

2020 VW ID.3 1st Max (58kWh)





Critical raw materials

(as per the European Commission classification*)

- Cobalt (Co)
- Lithium (Li)
- [Natural] Graphite (C)
- Silicon Metal (Si)

+

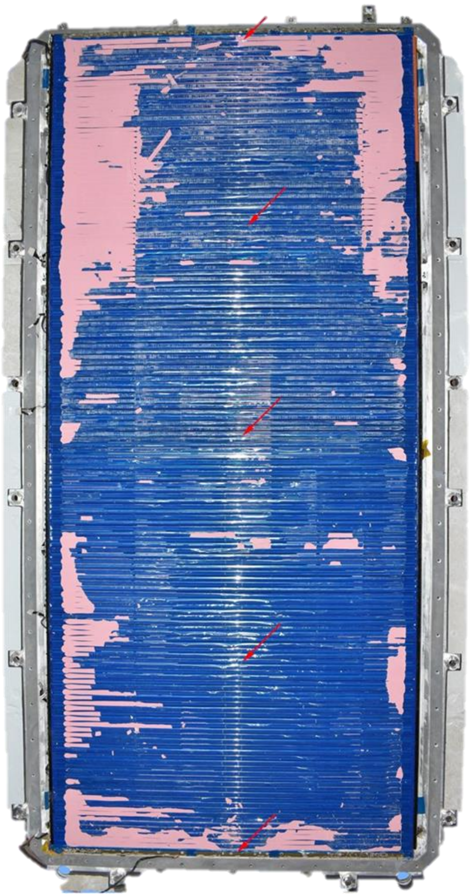
- Nickel (Ni) "monitor[ed] closely"

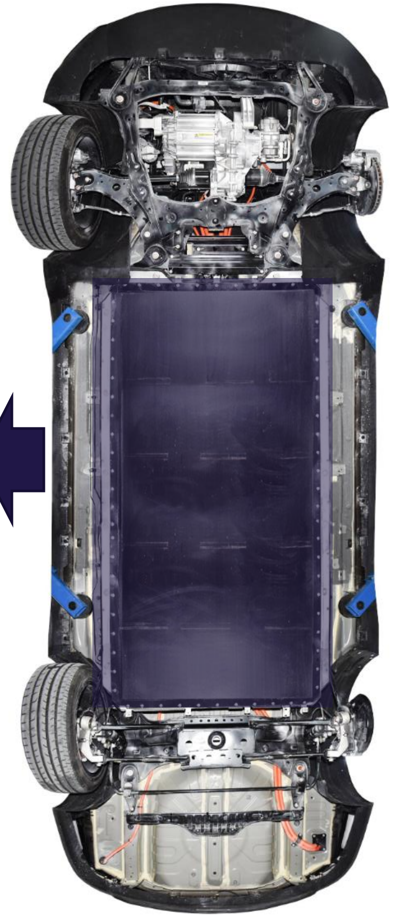
DATA: A2MAC1. (*) : European Commission, "Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability", 3rd Sept 2020

Cell-to-Chassis and -to-Pack concepts are applied in recent designs

Benchmarking vs. other cell packaging concepts

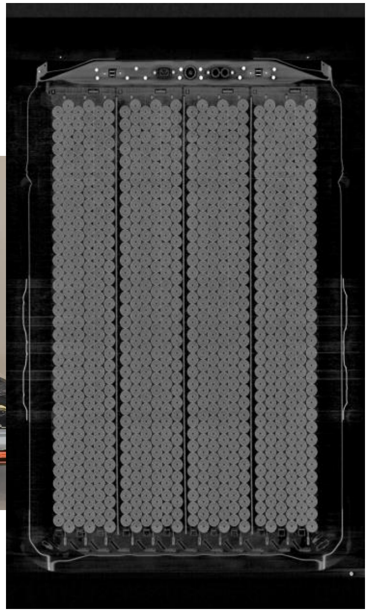
Cell-to-Pack

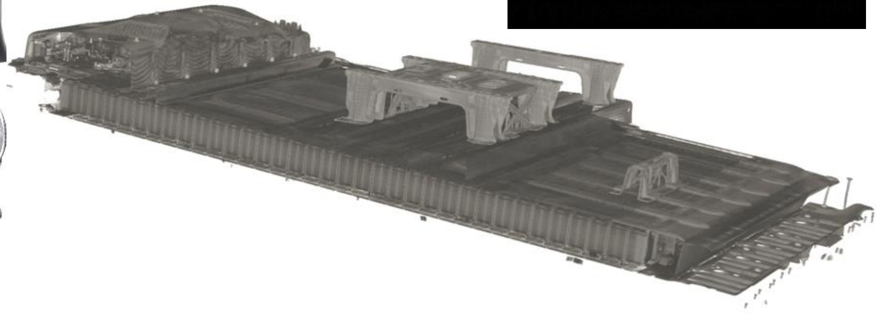




2020 BYD Han

Cell-to-Chassis

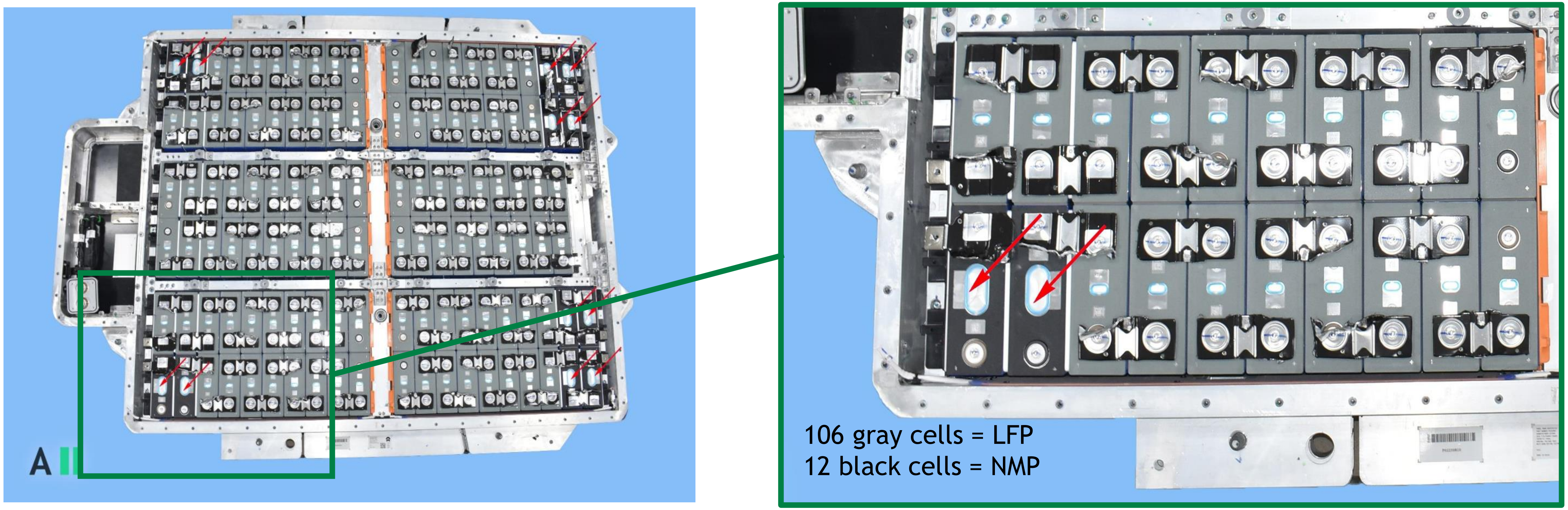




2022 Tesla Model Y

Battery chemistry: Hybrid Battery concept

NIO has introduced in 2022 a LFP + NMC hybrid battery (75 kWh, NIO ES6)



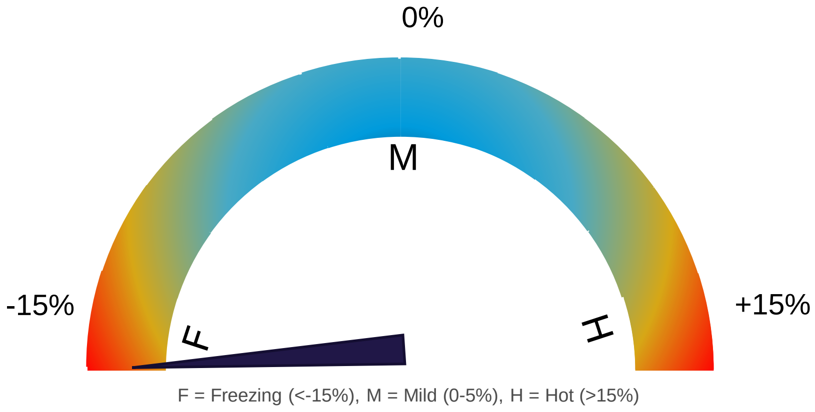
The Hybrid battery: 90% LFP and 10% NMC cells

- What is happening with the transition to EVs?
- How can CRU and A2MAC1 help track this?
- How does the transition to BEV impact material composition?
- What does this mean for the cost of automotive raw materials going forward?

Despite recent rises prices are expected to cool in the medium term…

CRU basket of 38 mining, metals and fertiliser price forecasts | 2026 over 2022*

Hot >15%	Platinum | Bauxite | **Copper** | Silver
Warm 5% to 15%	Alumina
Mild 0% to 5%	Gold
Cool -5% to 0%	**Cobalt** | **Aluminium** | Lead
Cold -15% to -5%	Pet Coke | **Manganese Ore**
Freezing <-15%	Aluminium MW | **Steel HRC China** | Molybdenum | Brent Crude | Silico-Manganese | Coal Tar | **Lithium** | Steel Scrap | Iron Ore | **Nickel** | Chrome Ore | **Steel HRC US** | **Zinc** | Urea | Met Coke | Phosphate DAP | Sulphur | Palladium | Potash KCl | Silicon | Phosphate Rock | Ferrochrome | Sulphuric Acid | Ammonia | Met Coal | Thermal Coal | Tin**

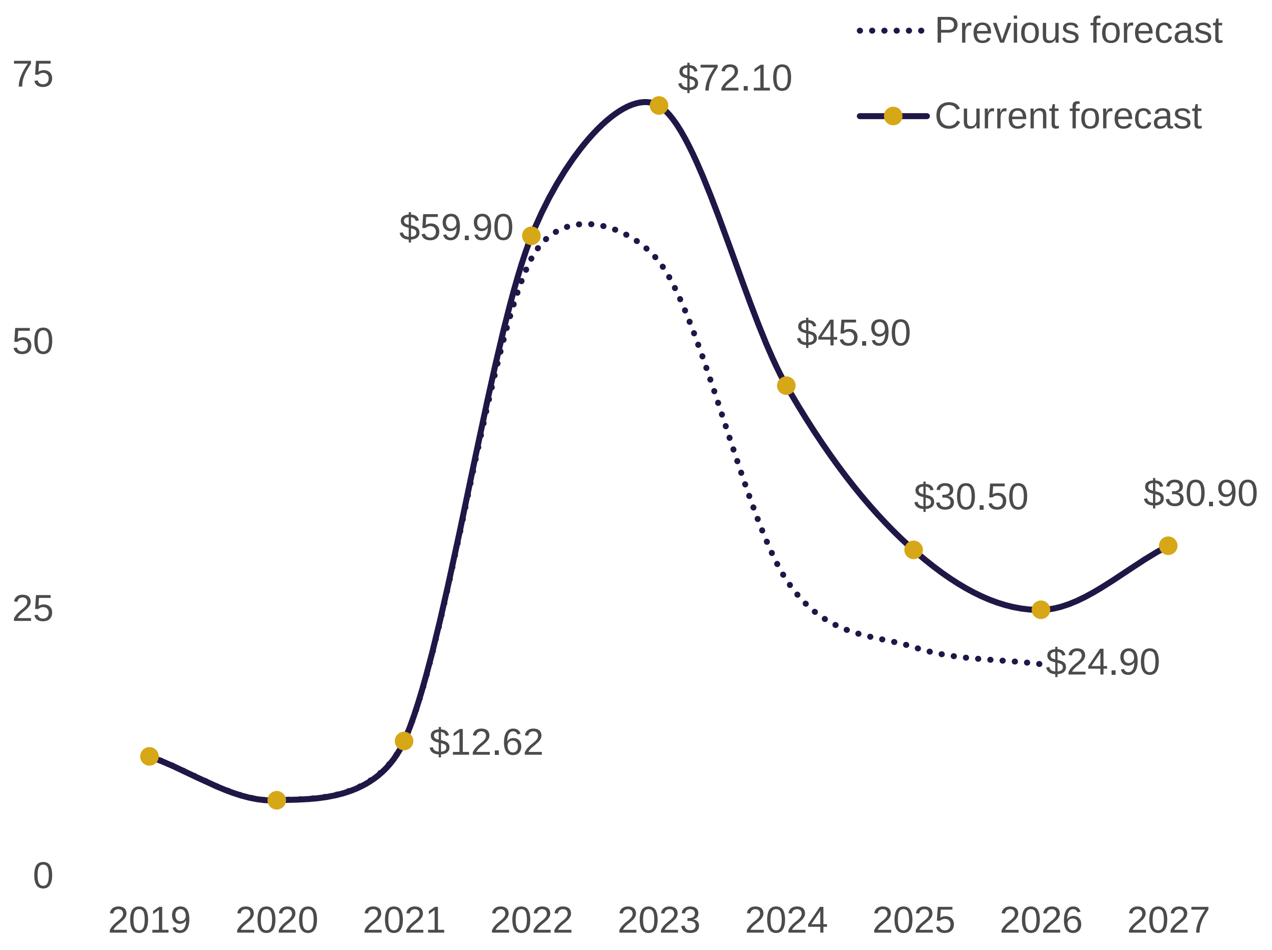


CRU Basket	↓ **-27.2%**
Raw Materials	↓ **-25.5%**
Metals	↓ **-26.8%**
Precious Metals	↑ **+2.3%**
Fertilisers	↓ **-47.6%**

DATA: CRU Market Outlooks *2026 annual average price forecast over 2022 (forecasts as released before 25th November 2022). **ITA

Short-term lithium price decline could soften the battery premium

Li carbonate **contract** price forecast, $/kg

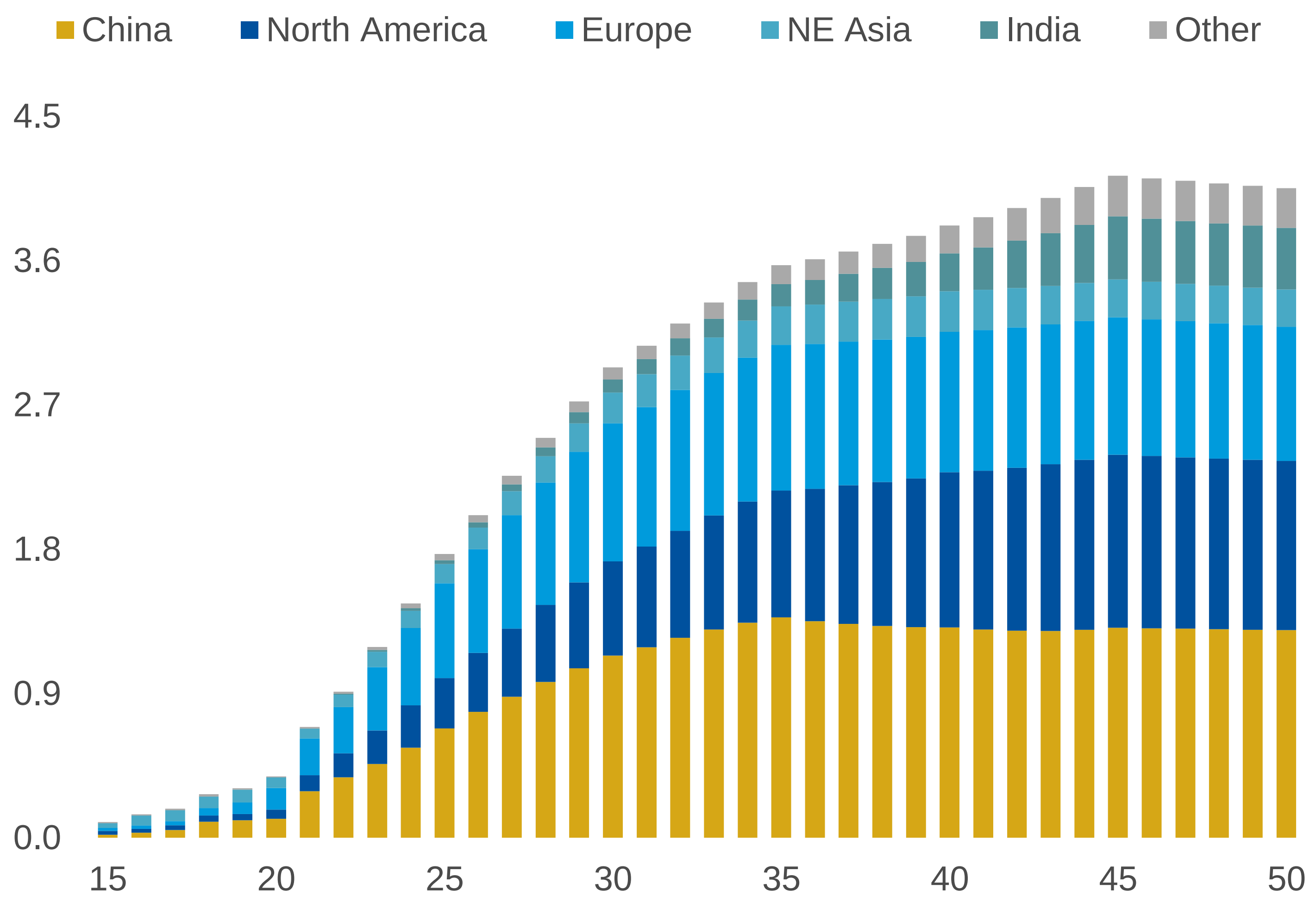


- Lithium a key component of cost despite being one of the lowest components by weight accounts for a significant amount of battery premium cost in 2022.
- In the short-term we expect prices to decline as supply improves but as demand rises from EV and renewables, a deficit will grow in 2027, pushing prices back up.
- While prices are expected to stay higher for longer, the decline in the medium term will have a significant impact on EV metal cost

Copper should not be ignored, it's use in EVs will quadruple by 2030

- Total copper demand in LDV EVs (and associated charging infrastructure) to increase from 692,000 t in 2021 to 2.9 Mt in 2030 and 4.0 Mt in 2050.
- Growth in NEV sales will be led by China, North America and Europe with BEVs responsible for most of EV copper demand.
- CRU forecasts a rapid increase in NEVs penetration rates from a low base, under 10% of sales in 2021, to 30% of LDV sales in 2030.

World EV copper consumption, Base Case, Mt

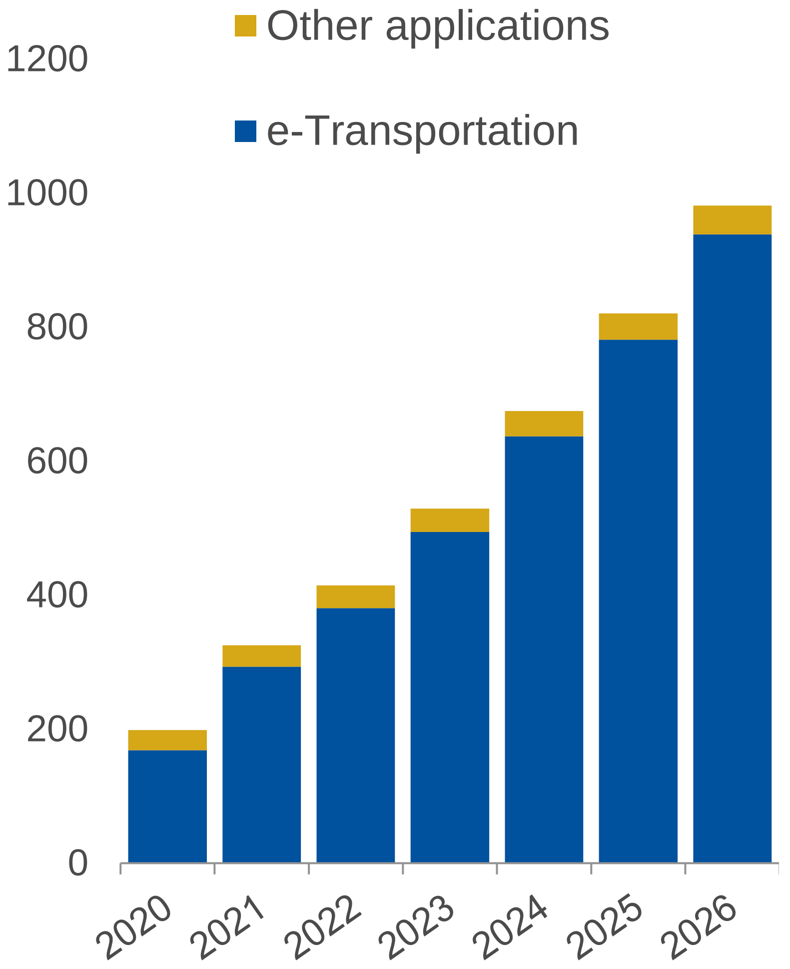


DATA: CRU, note LDVs only

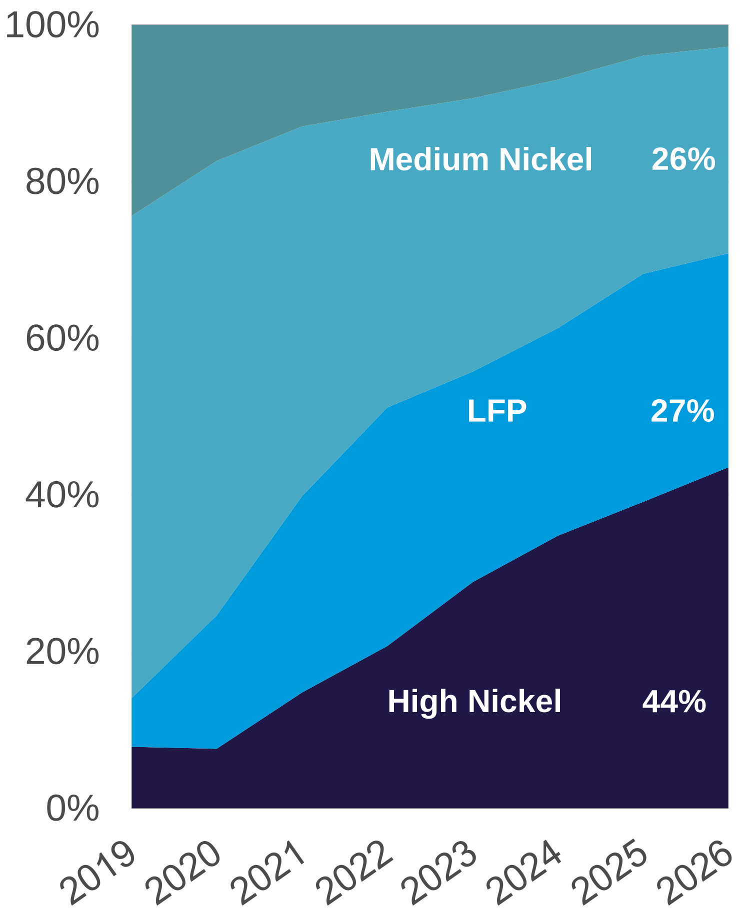
Nickel also remains crucial for EV batteries

- Lithium/nickel battery chemistry balance remains the most used battery chemistry.
- Nickel's superior energy density expected to secure demand for larger and longer range vehicles.
- Demand to be higher in markets that value long range, principally North America.
- Nickel battery chemistries expected to account for ~70% market share by 2026 although threatened by LFP growth.

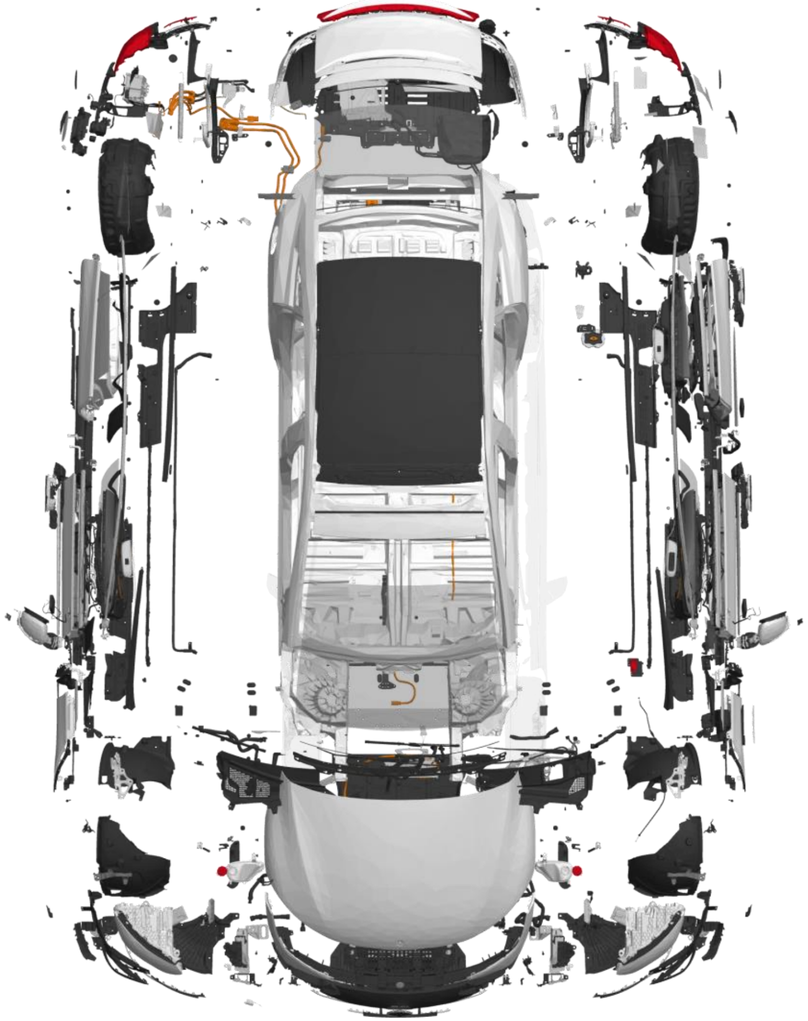
LHS: Nickel demand in batteries, kt



Forecast of global light duty EV cathode chemistry share (GWh), %



Key takeaways



- EVs metals costs approximately at a factor of two compared to ICE vehicles
- Aluminium content increasing typically by ~50% in EVs compared to ICE, and copper content at approximately doubling, leading to a four-times increase of global demand by 2030
- We are expecting raw material prices to settle from a peak in 2022, however at a level of 40% higher than 2019

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