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Technology-differentiating Battery-Electric Platforms

Powertrain study 2023

August 2023



The diversification of electric platforms will determine the next phase in eMobility transformation

Executive summary

1

Regulatory pressures remain high, while industries & **regions compete** to transform **value creation in the powertrain industry**
Given the 0 g CO₂/km emission target, countries offer billions in incentives to encourage the development of the eMobility value chain

2

To meet diverse relevant customer needs, future BEV powertrains require **differentiated platforms**
Enabled by technology, platforms will be differentiated by vehicle segments, price classes and required ranges

3

Cell and eDrive innovations are expected to be **competitive brand differentiators** and far from a commodity
The next innovation wave has the potential to increase vehicle range, doubling charging speed & reduce powertrain costs significantly

4

Battery cells to remain **key cost driver of the electric powertrain**, heavily affected by **raw material prices**
Cell costs are expected to decrease further in coming years, although material costs & vertical integration headwinds are approaching

5

While we expect **total cost of ownership parity** across segments **by 2025**, **powertrain cost parity** will be reached **from 2030**
With falling battery and powertrain costs and increasing ICE costs, the prevailing economics are expected to expedite electrification

6

By **2030**, **~40% BEV** vehicle sales share expected, moving towards **70% BEV share in 2040**, resulting in **~6.5 TWh battery demand**
BEV powertrain market is differentiated across segments, with each new platform generation taking the next decarbonization leap

7

Companies across sectors should participate in the BEV gold rush, taking advantage of the transformation opportunities
By 2030, up to 850 bn€ annual revenue are forecasted to be generated across sectors, driving the global eMobility transformation

Regulatory pressures remain high, while industries & regions compete to transform value creation in the powertrain industry



Regulatory motivation

Regulation continues to **spur zero-emission** electrification and is expected to **intensify further**. The regulation is **directed at both OEMs and consumers**. After selective ICE city bans, the **EU council confirmed EU-wide ICE ban** for cars and vans by 2035.



Economic motivation

OEMs are increasingly focusing on ESG, **encouraged by financial markets** as it is also a key factor in raising **capital** for the **transformation**. A **high proportion of EVs in the OEM portfolio** improves **overall rating** performance.



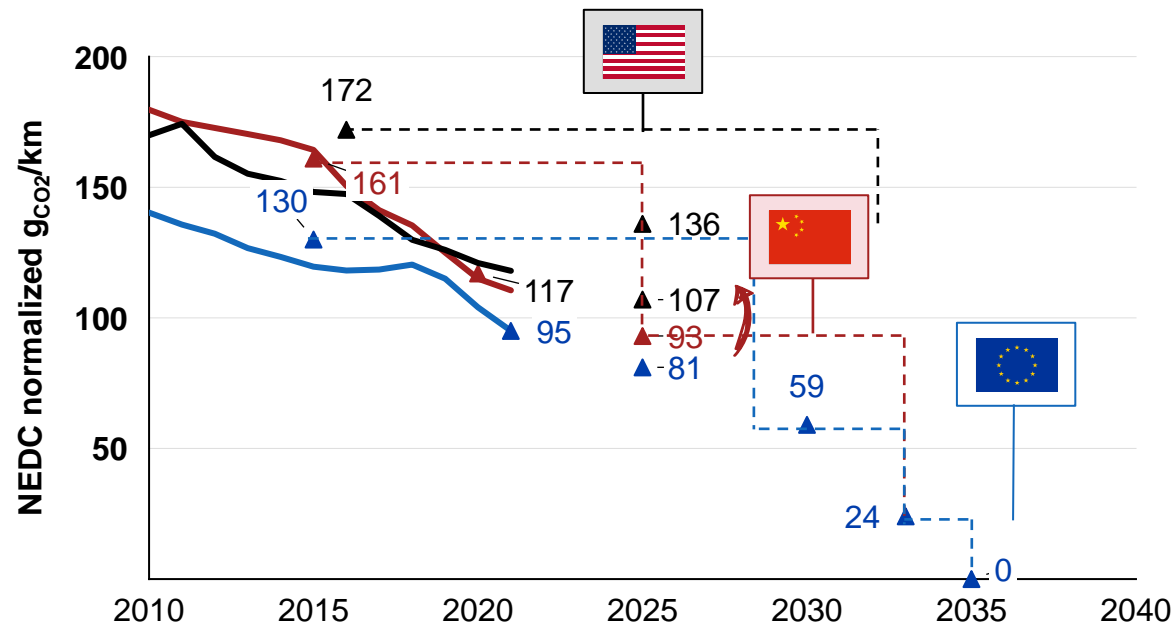
Geopolitical motivation

Various programs launched by the major regions, such as the **US Inflation Reduction Act (IRA)**, are vying with each other to galvanize a **local electric powertrain value chain**. A **European answer to the IRA is expected** and boost electrification in the EU further.

Regulation continues to spur zero-emission electrification - directed at both OEMs and consumers, it reinforces the transformation need

Legislative trends – CO₂ fleet targets and ICE city bans

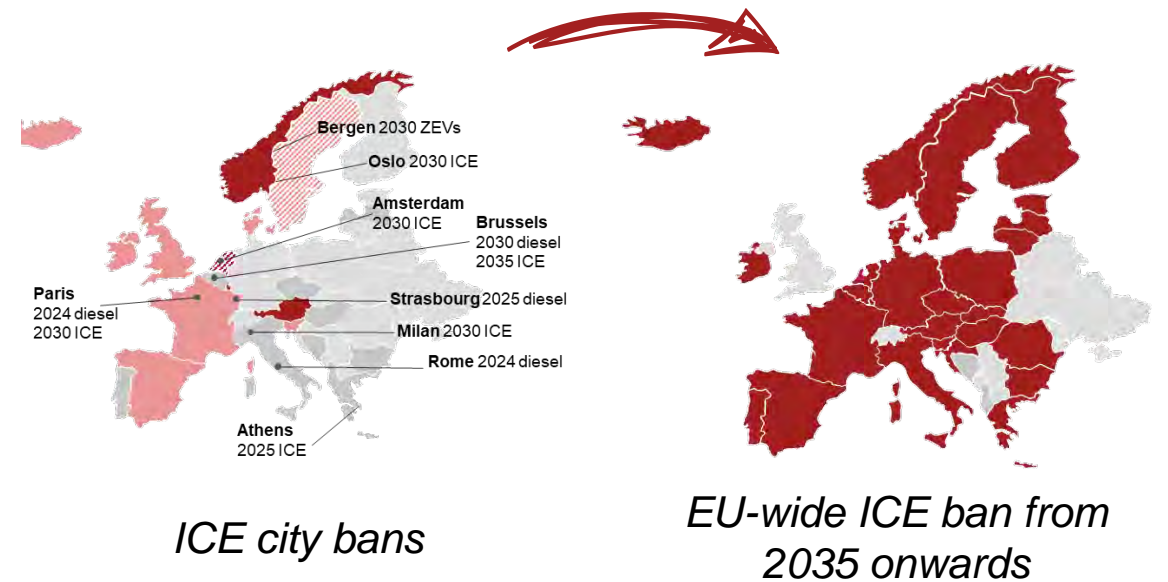
International CO₂ fleet targets



EU (Fit-for-55) & CN regulatory initiatives expected to drive down CO₂ fleet targets further and facilitate OEM fleet electrification

— history △ enacted

From ICE city to EU ban

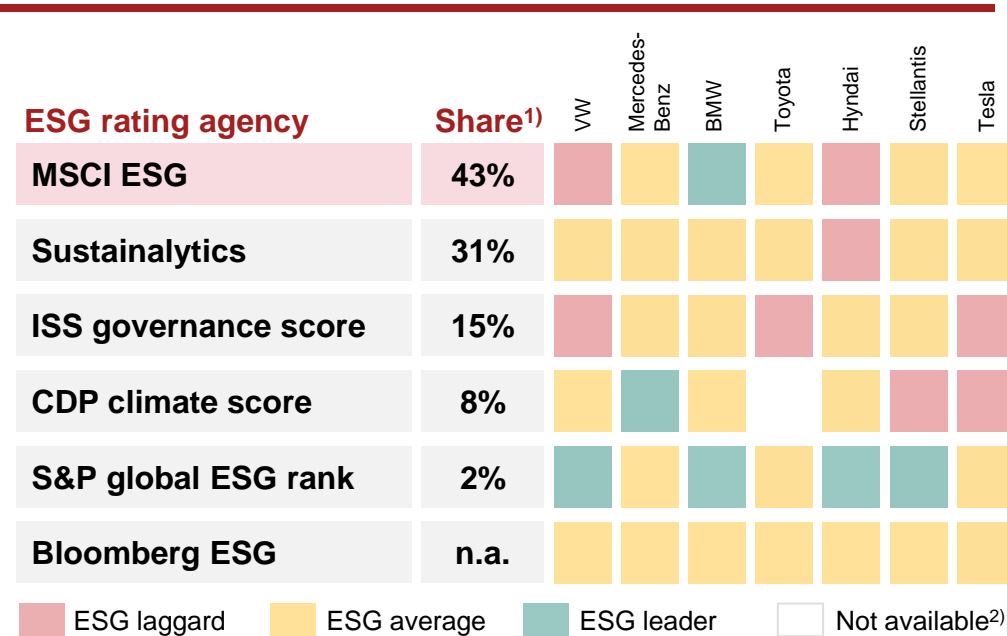


From selective ICE city bans, the EU council confirmed EU-wide ICE ban for cars and vans by 2035 – ICE and syn-fuels no longer an option for road transportation

To raise transformation capital, OEMs, are increasingly focusing on ESG, encouraged by financials markets as a key parameter

ESG Financial Industry

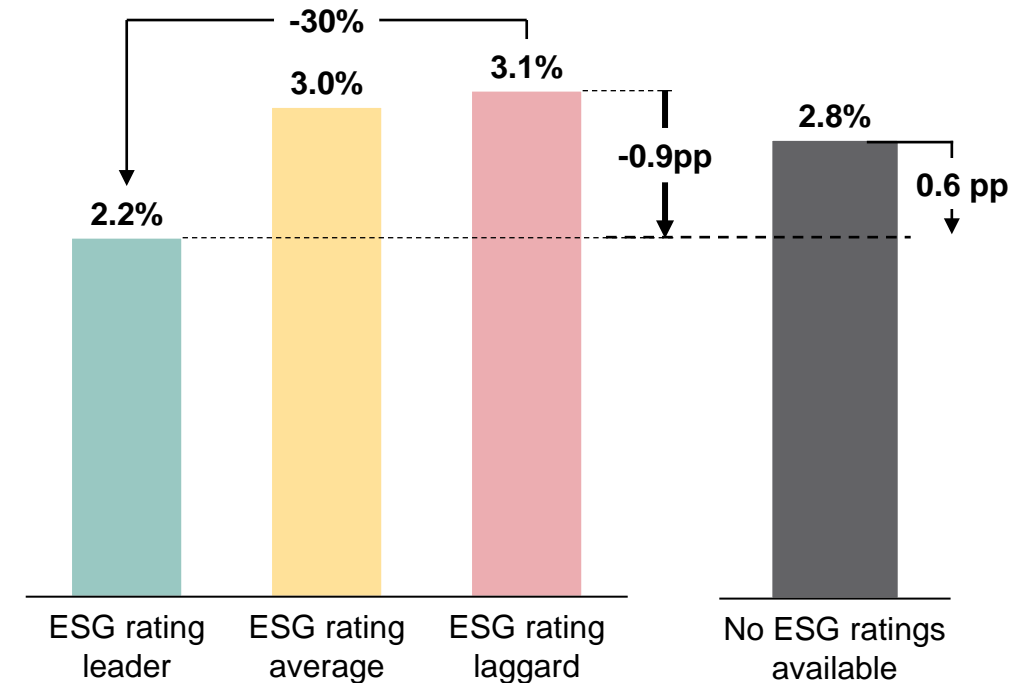
ESG Rating of OEMs



Key drivers of OEM rating performance:

- Automotive OEMs have **high environmental exposure**
- High share of **EVs improves overall rating performance**
- Number of quality-related **vehicle recalls** has a negative impact within the social dimension

Impact on transformation financing (in WACC% of debt)

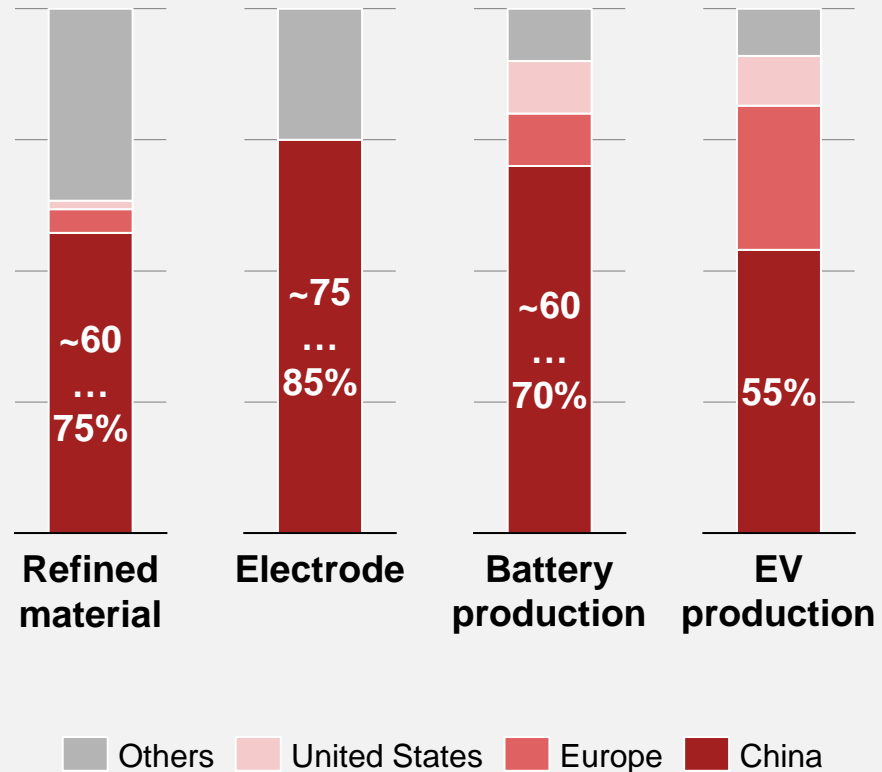


Significant savings in financing the transformation can be made through a clear ESG agenda

Yet the race for the global supply chain for the ePowertrain remains open, with fierce geopolitical competition on future value creation

Geopolitical competition on ePowertrain value chain

2023 regional battery supply chain share



Chinese policies



Bolster market position

- Tax incentives¹
- Improved IP protection²
- Mature EV industry infrastructure³
- Far-sighted EV value chain investments and subsidies³
- Fewer forced JVs with Chinese state-owned companies
- Easing of Covid-related lockdown rules

US policies



Localize supply chain

- **USMCA regulation and inflation reduction act** push for **localization of electric vehicle value chain**
- **Tax credits** for EV companies if majority of **battery components** by value sourced in **US** or **“allied” countries**
- Since minerals are localized worldwide, **localization of refineries** likely to follow

EU policies



Regain value creation

- **EU Green Deal Industrial Plan** to scale value creation of decarbonized industries
- **EU Critical Raw Material Act** aims to build EU extraction, processing and recycling industry
- Multiple strategies for **recovery and resilience** and **temporary aids** for **crisis and transition**

To meet diverse relevant customer needs, future BEV powertrains require differentiated platforms



Evolution of powertrain portfolio

Since 2020, the **powertrain portfolio** has moved from **technology openness** towards a **BEV-centric powertrain portfolio**. **Plug-in hybrid** and **fuel cell** vehicles have **declined in significance**.



Platform characteristics and specifications

To meet differentiated **customer needs**, **tailor-made product platforms** need to be developed. The **differentiation drivers** are still **range**, **power** and **charging speed**. Varying **cell chemistry** and **battery pack architecture** are expected to be **enablers for differentiation**.

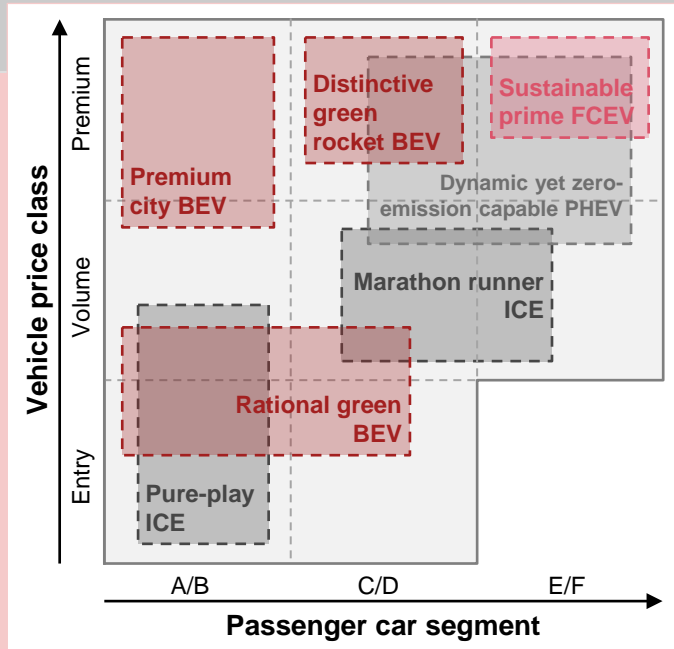


Range still matters

We expect that **range will remain a key factor** within platform specifications, and each will offer **both standard** and **long ranges** to meet differentiated flexibility needs.

Since 2020, the powertrain portfolio emerged from technology openness towards BEV centric powertrain portfolio

Evolution of powertrain portfolio (2030)



2030 Powertrain portfolio (as of 2020)

Back-up powertrain ICE

Remaining platform to address non-BEV markets (e.g. those lacking infrastructure)

Emerging BEV dominance BEV

Differentiated powertrain platform:

- Cost decreases
- Increased energy densities
- Rapid charging capabilities

Deprioritized developments

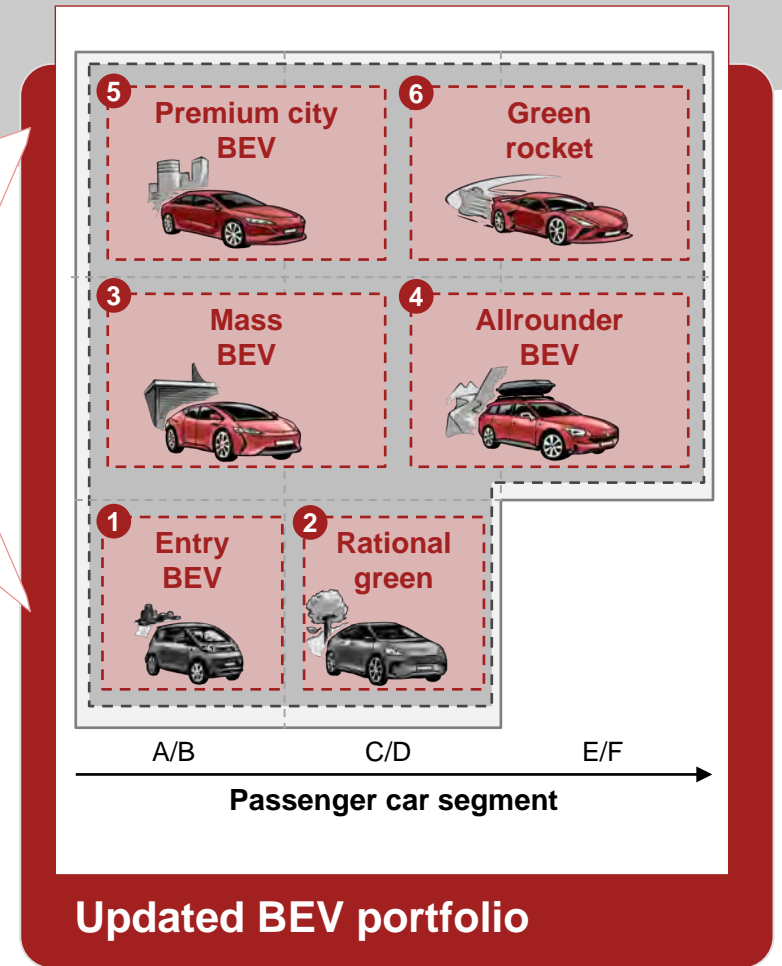
On-hold development PHEV

- Descoped development (ZEV focus, TCO disadvantage)

Deprioritized development FCEV

- Downsized development (shift towards BEV)
- Price development unclear

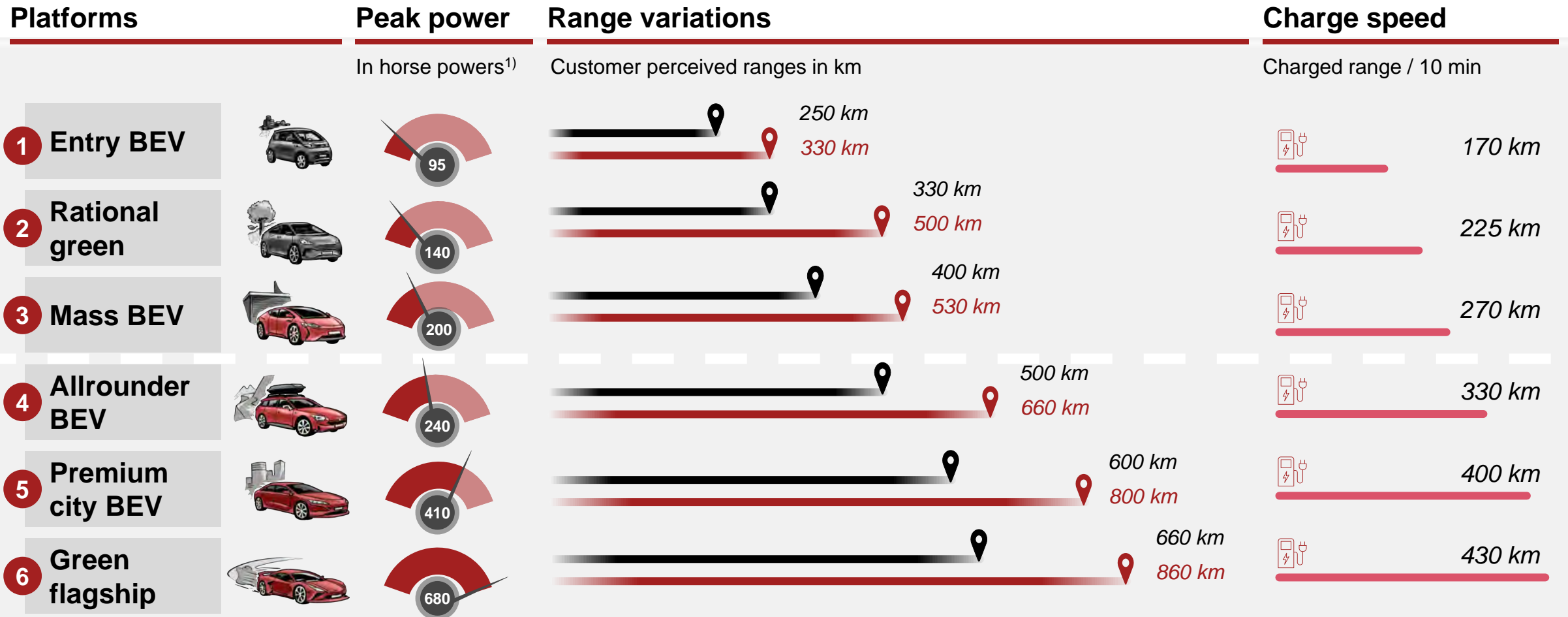
Powertrain developments



Updated BEV portfolio

Across these platforms, standard and long-range variations are expected to be offered to meet customer flexibility requirements

Customer relevant BEV platform specifications (2030)





Cell and eDrive innovations are expected to be competitive brand differentiators and far from a commodity



Technological development until 2030

Battery and **cell chemistry** are expected to be far from a **commodity**, but the **key brand differentiator** and **competitive driver**. **Vehicle range, charging speeds** and **vehicle costs** are key **factors in the differentiation**.



Technology roadmap cell chemistry

Next-generation cell chemistries will enter the market in **waves**. In the first wave, cathodes with **high Ni content** and **olivine blends** will gain importance, as well as **higher SiOx content (anode)**. Going forward, **Si/C** and **LMNO** are positioned for market entry, while **solid-state batteries** are expected to enter **the market with limited size** and **capacity** beyond 2030.



Technology roadmap for electric drive

Technological advancements in the **eDrive system** improve **efficiency** throughout the **drive cycle** and therefore reduce overall operating costs. **Enhanced cooling** allows brand differentiation in fast-charging solutions.

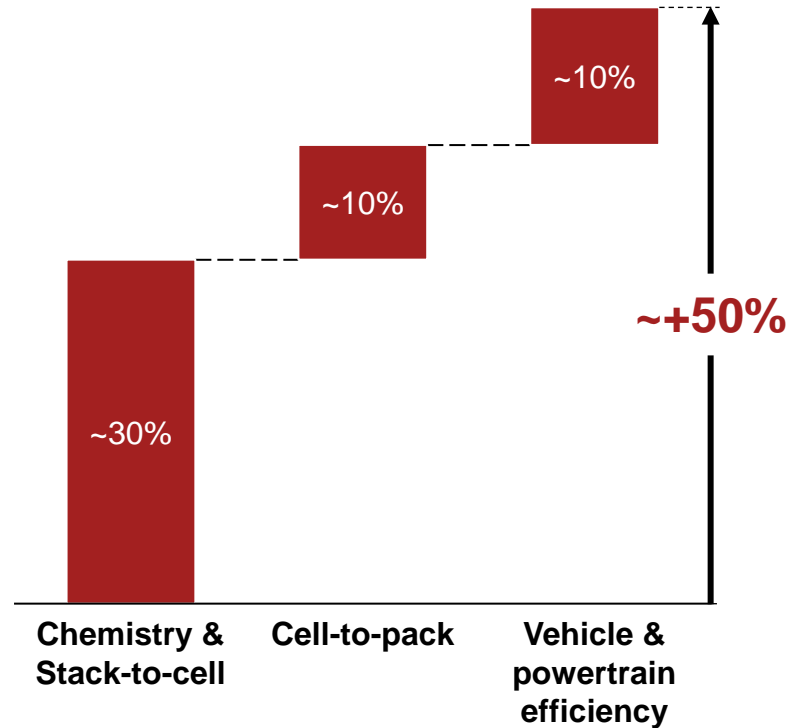
To build differentiated BEV platforms, battery and cell chemistry are expected to be a key brand differentiator and competitive driver

Technological development (2023 vs. 2030)

Vehicle range increase



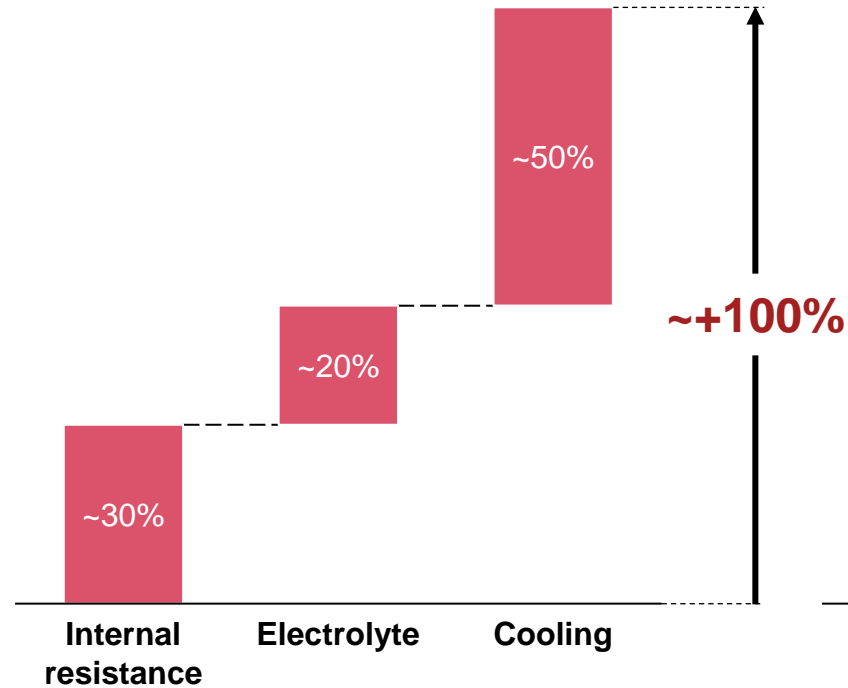
Exemplary for prismatic NMC



Charging speed increase



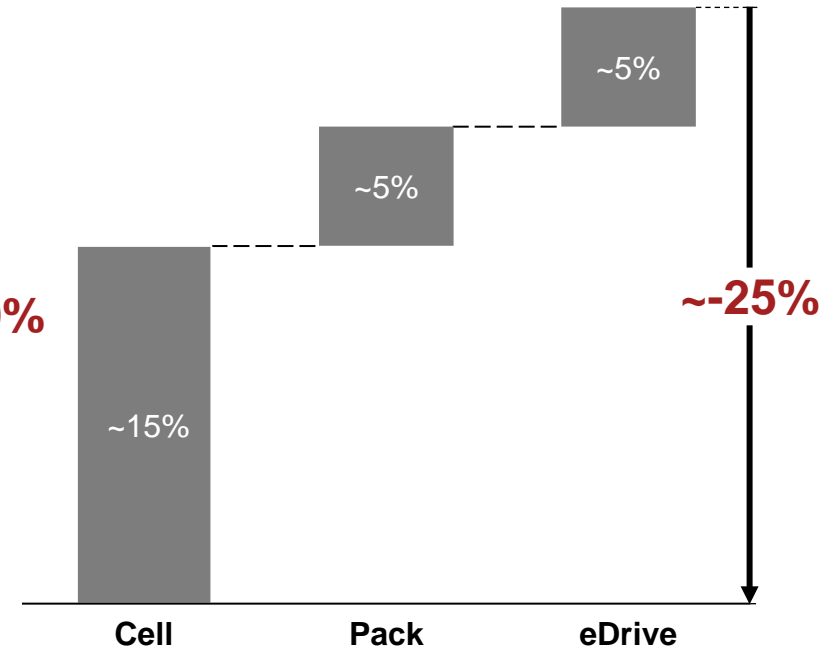
Exemplary for prismatic NMC



ePowertrain cost reduction



Exemplary for prismatic LFP

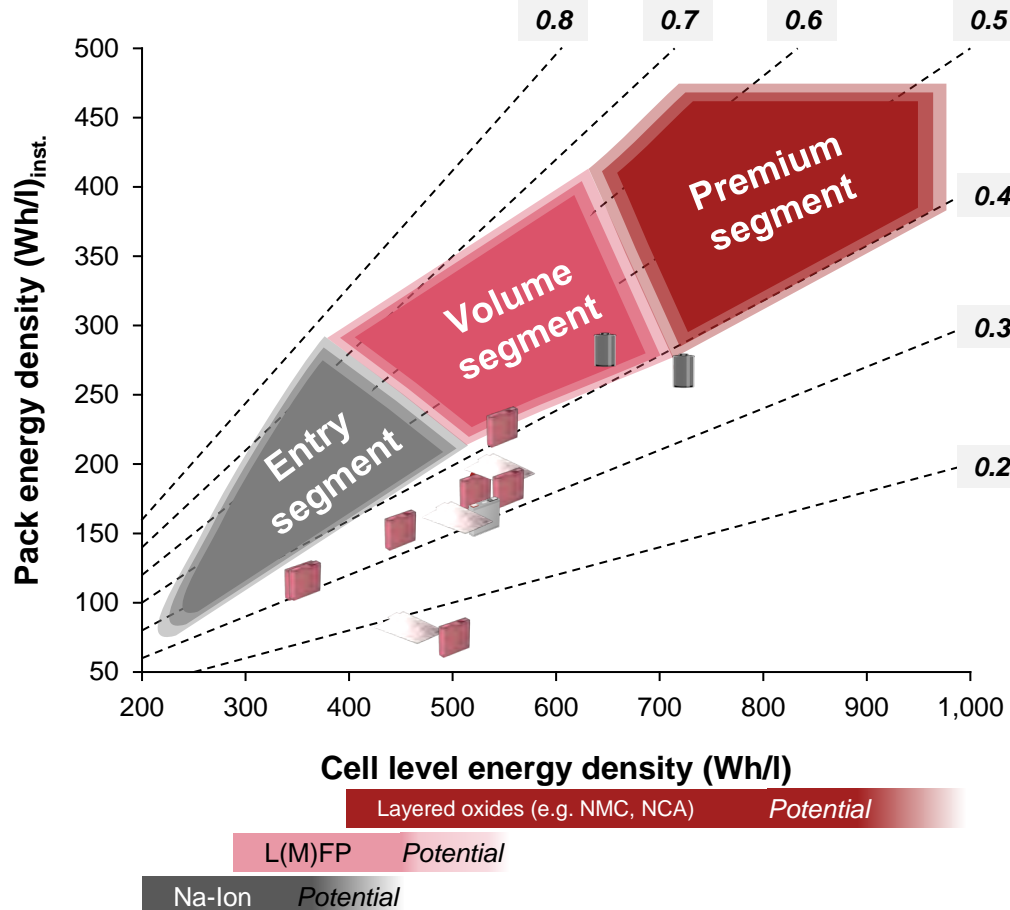


OEMs are able to tailormade batteries to customer demands, by leveraging available cell technology and cell-to-pack efficiency

Pack and cell energy density

Benchmark pack and cell energy density (in Wh/l)

Comments



Entry segment

Entry segment expected to be equipped with cost-efficient LFP cells and, in the future, with cost-efficient Na-Ion cells



Volume segment

LMFP and NMC cells are used in the volume segment due to price, technical properties and energy densities



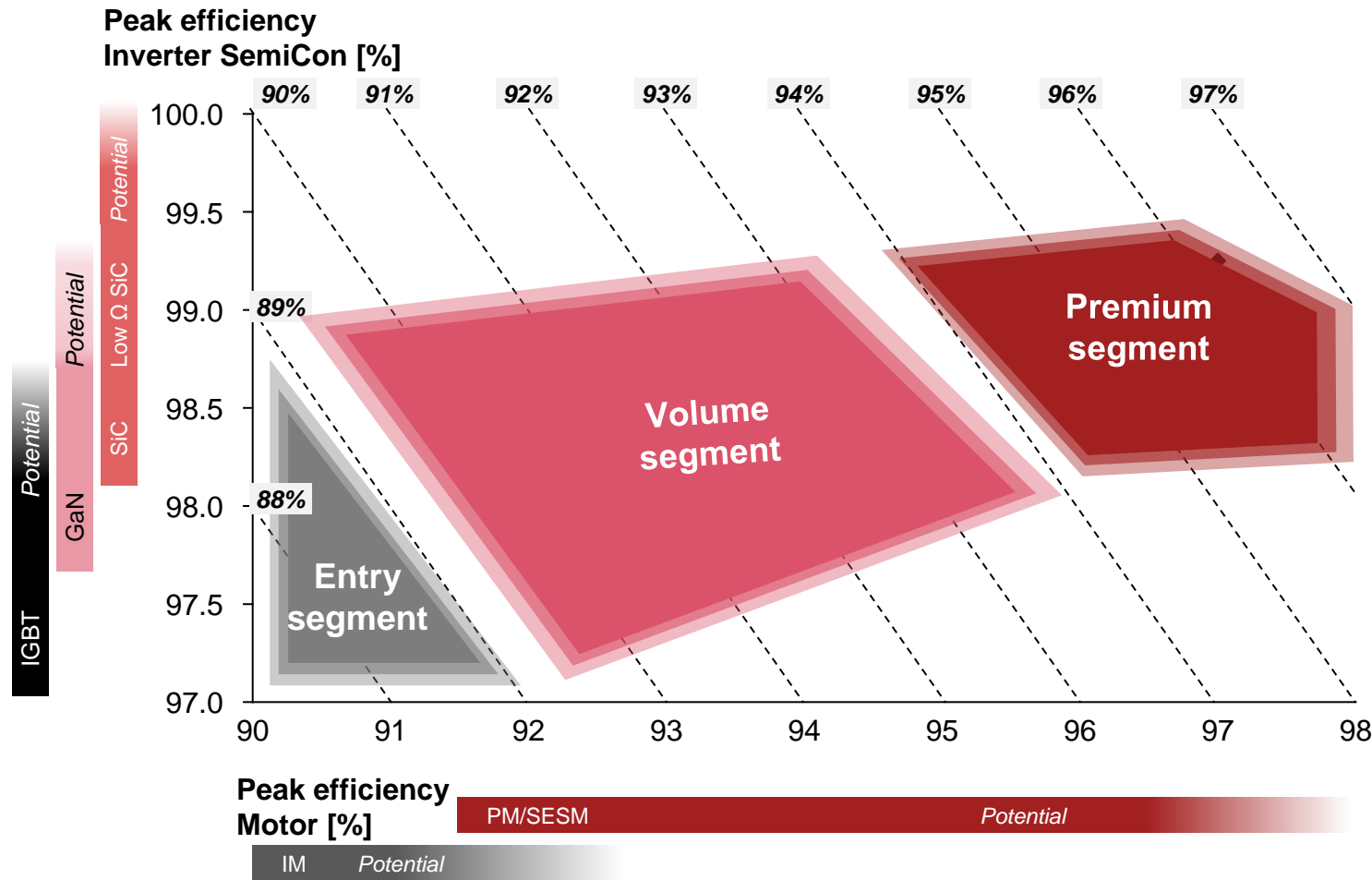
Premium segment

NMC cells are used - high pack energy density is achieved through thermo-management technologies and structural integration



Similarly, eDrive configurations allow differentiated platform efficiencies and power by motor and inverter combinations

eDrive efficiency



Comments

Entry segment



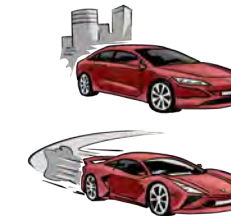
Entry segment equipped with separately excited synchronous motors (SESM) for medium range, or induction machines for inner-city applications and IGBT-based inverters for smaller power ranges

Volume segment



Permanent magnet motors (PM) or (SESM) In combination with GaN based inverters

Premium segment



Premium segment with double PM or SESM and efficient SiC- based inverters and low ohm SiC-based inverters for highest power & efficiency range

Battery cells to remain key cost driver of the electric powertrain, heavily affected by raw material prices



Battery as key powertrain cost driver

Battery costs likely to remain main cost driver for future powertrains across all platforms. Especially cells comprise majority of material costs.



Upstream costs have high impact on cell costs

Costs of raw and active materials constitute up to more than 50% of total battery costs. After price peaks in the early part of the decade, largely caused by undersupply, investment are expected to ease this issue and level prices for the remainder of the decade.



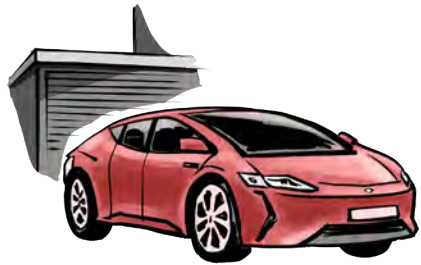
Cell costs across segments to decrease

Owing to technological and commercial factors, cell prices will probably decrease over the coming years and facilitate diversified BEV powertrains across the market.

Within the BEV powertrain, the battery constitutes the largest cost component, heavily affected by cell prices and relevant materials

Price breakdown of BEV (exemplary for Mass BEV, standard range)

Mass BEV platform






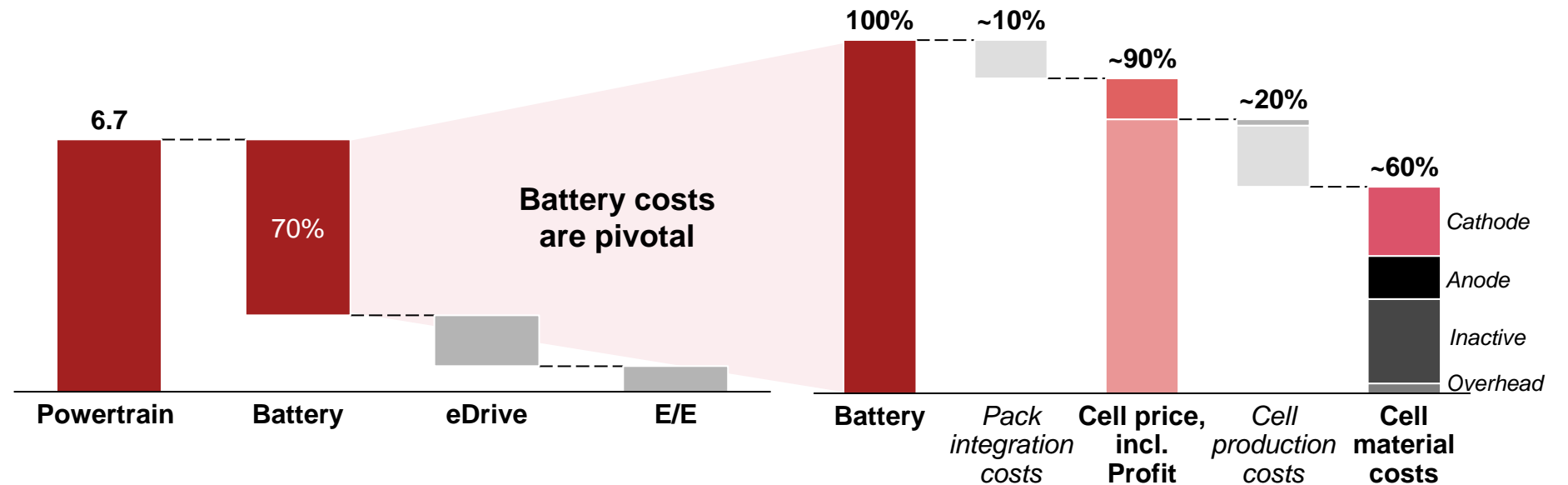
Powertrain cost split (in k€)

~70% of the powertrain are comprised of battery costs

Battery cost split (in %)

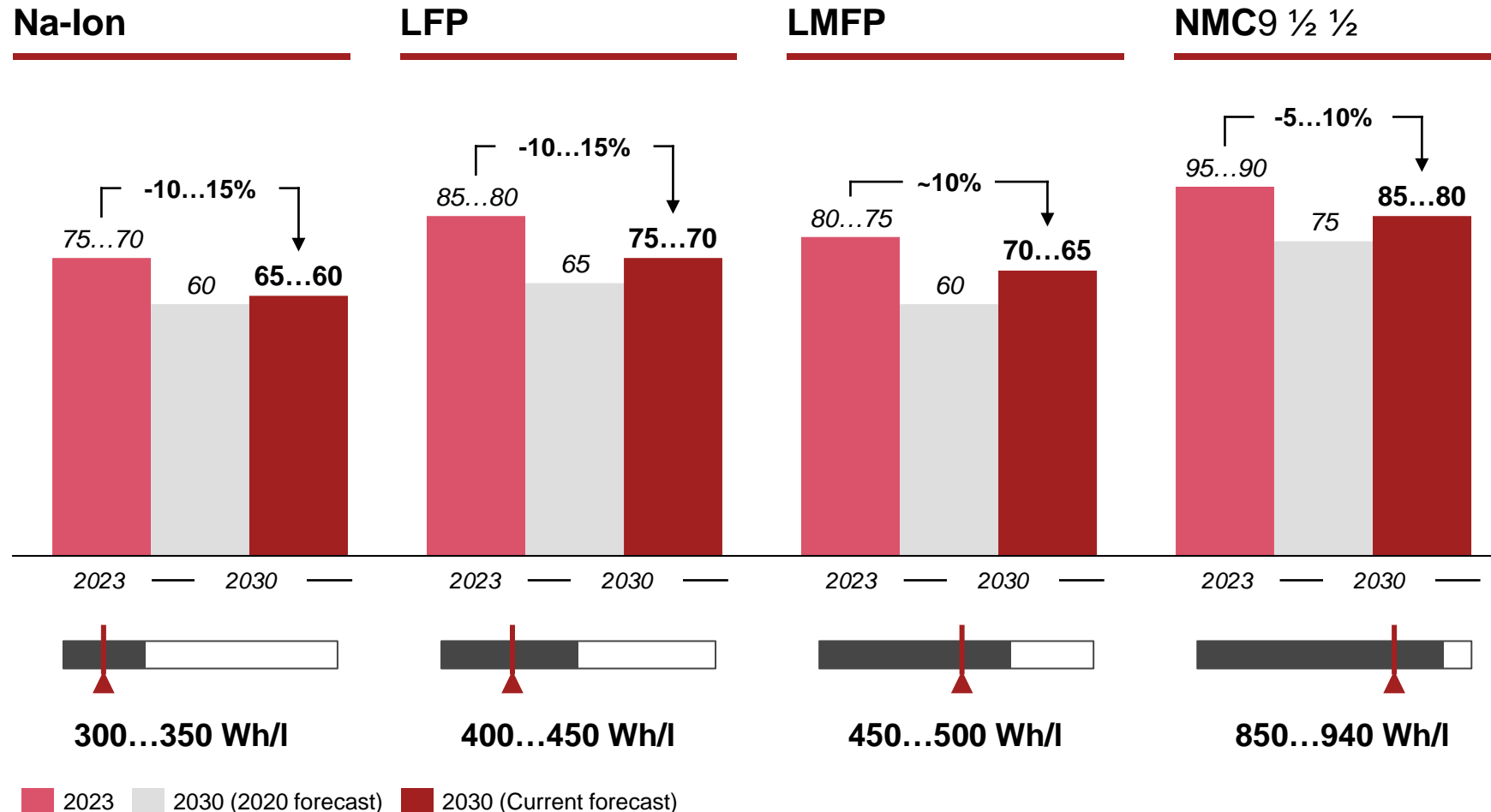
Battery materials constitute ~60% of total battery price

-  **Technology specs** ~60 kWh
150 kW
-  **Chemistry** LMFP
-  **Range** ~400 km



Cell prices will likely fall by 2030, with Na-Ion and LMFP cells dominating LFP, while NMC remains attractive for premium segments

Strategy & cell price forecast 2030 (in €/kWh)



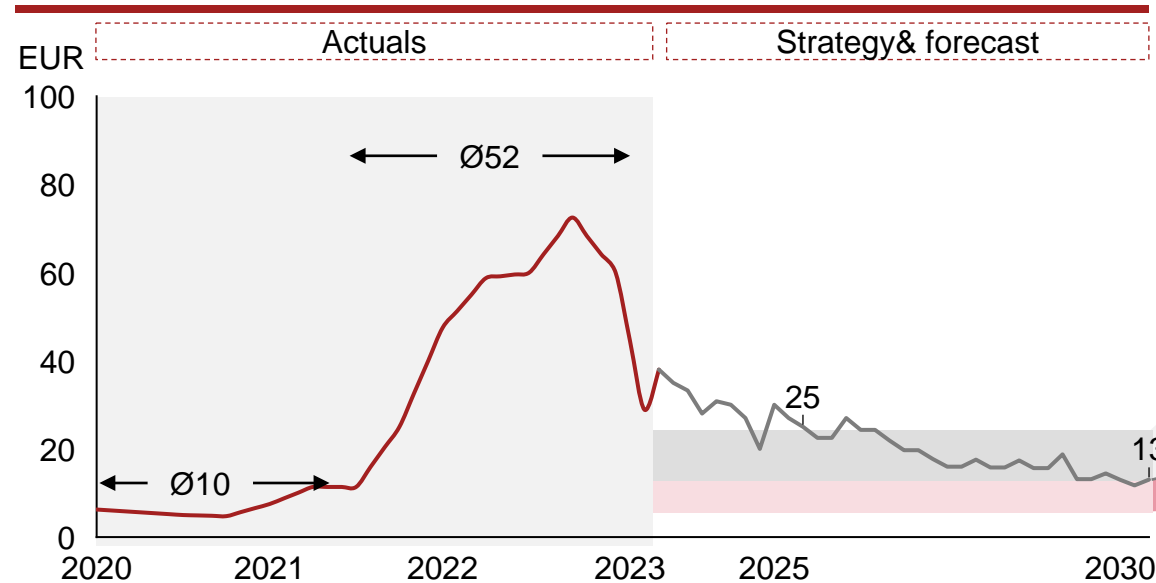
Comments

- By 2030, cell prices are expected to fall by about 10-15% compared with 2023
- Increased raw material prices act as a brake on the 2020 anticipated cell price reduction
- Na-Ions to compete for LFP segment and LMFP to compete for NMC segments

Raw material cost fluctuations impose cell price uncertainties – with Lithium at 20€/kg cell prices are likely to exceed 80€/kWh for LiB

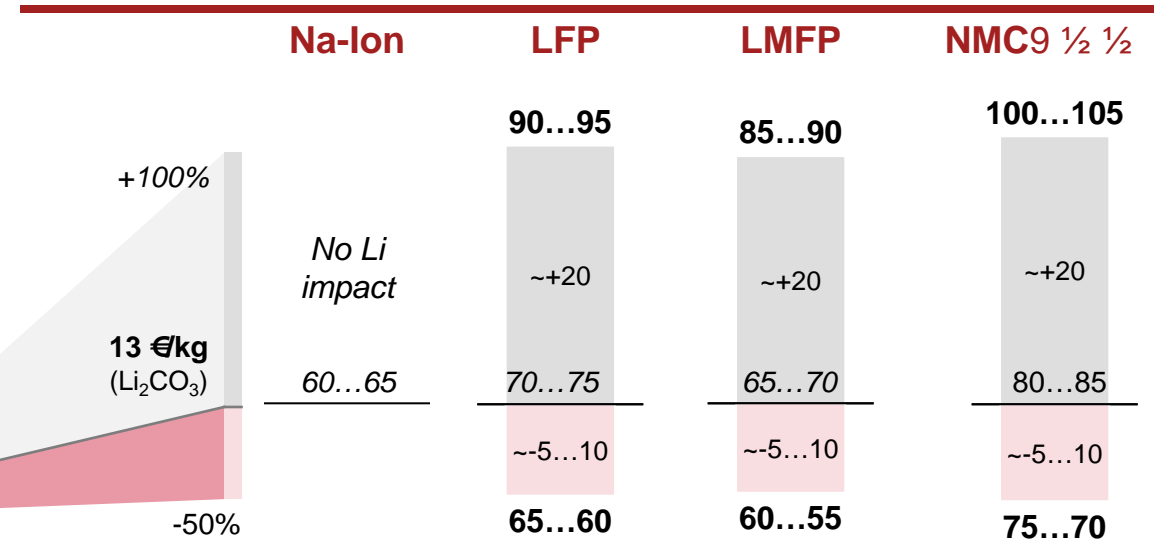
Lithium price forecast and cell price sensitivity

Lithium price forecast (in EUR/kg LCE)



- In the long term we expect LCE prices of ~13€/kg
- Short-term price peaks to be leveled through supply gap closing as a result of investment
- Pre-crisis levels not expected to be realized, due to shift towards hard-rock mining

Sensitivity on Lithium price on cell prices (in €/kWh)



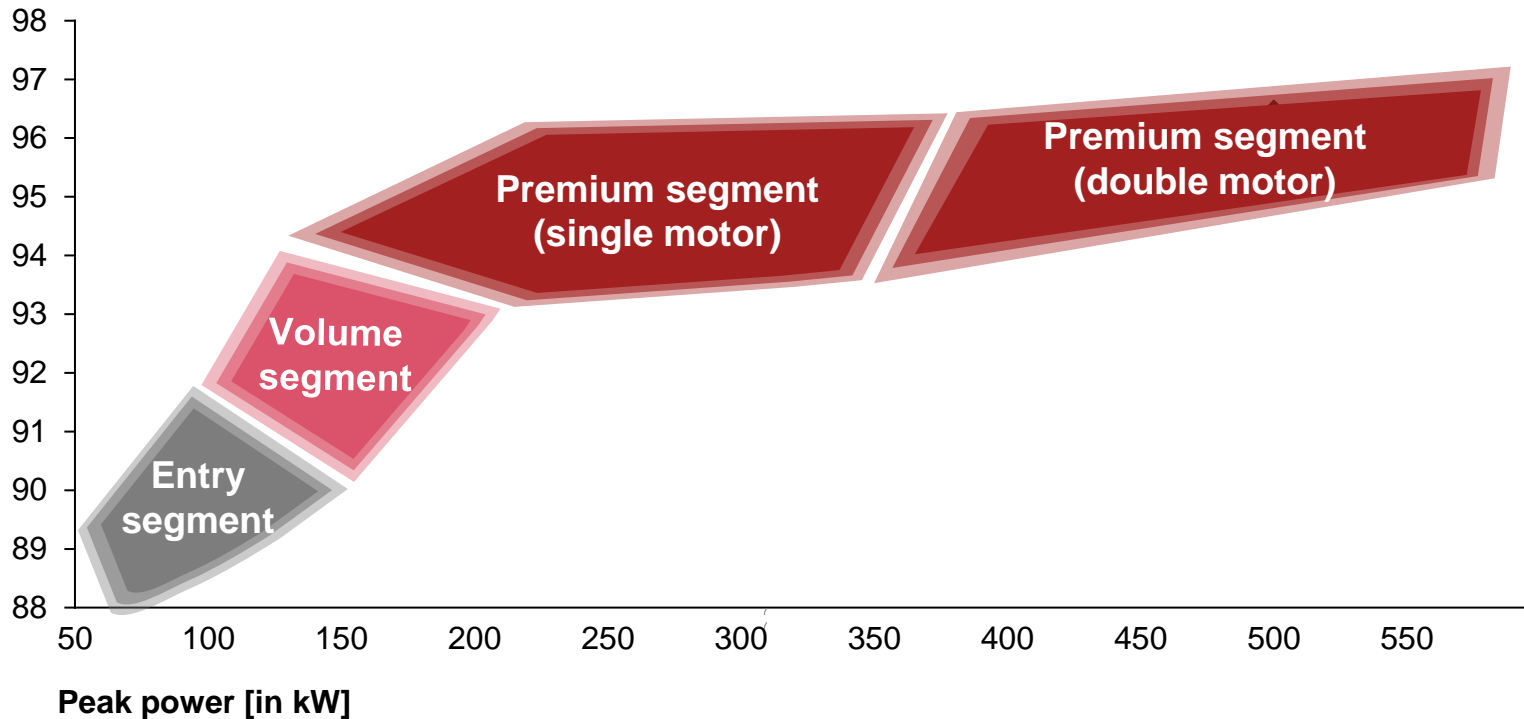
- With LCE beyond 20 €/kg, cell prices below 80 €/kWh are not expected to be realized for L(M)FP & NMC chemistries
- Full independence and resilience of Na-Ion batteries are key advantages in comparison with L(M)FP & NMC
- Change of 1 €/kg LCE translates to 1.5 €/kWh in cell costs

Looking at eDrive costs, relative power boost is cheaper than efficiency optimizations across segments

eDrive costs forecast across segments (2030)

Power / Efficiency plot across vehicle segments

Peak efficiency
[in %]

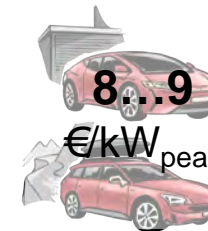


Comments



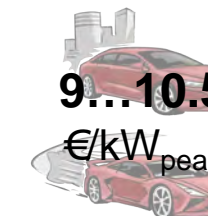
Entry segment

Induction machines & IGBTs enable relatively low costs for power increase



Volume segment

Next leap forward in eMotor and inverter technology yields minor cost increase



Premium segment

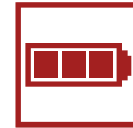
Leverage of double motors and most efficient inverters lead to increases costs for higher power applications

While we expect total cost of ownership parity across segments by 2025, powertrain cost parity will be reached from 2030



Diverse BEV customer criteria

Across the differentiated BEV platforms, customers have diverse buying criteria with regard to flexibility, dynamics, sustainability and operating costs



Technology enables BEV diversification

Diversified technological development in the ePowertrain of the future will probably enable OEMs to satisfy customer segments with diversified powertrains, enabling large-scale market diffusion



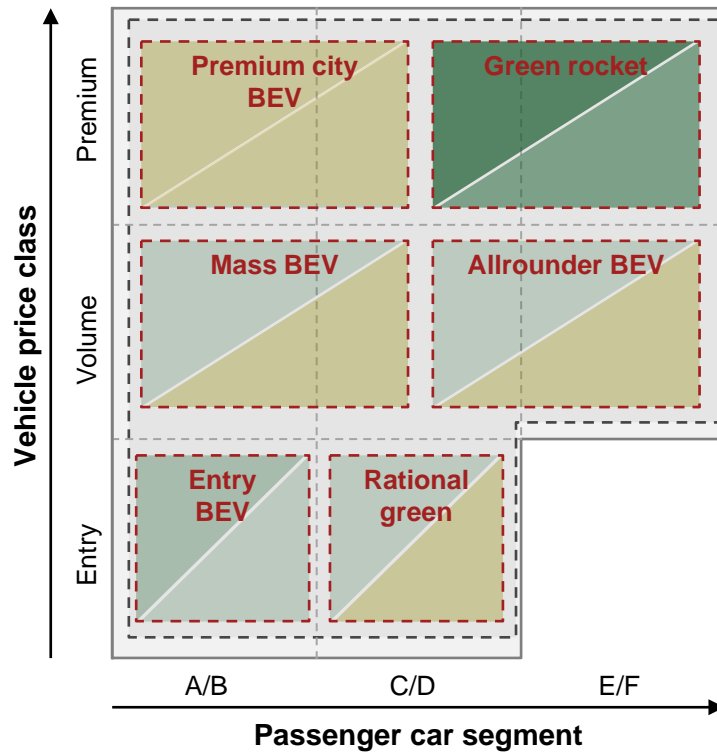
BEVs to reach competitive cost levels

While ICE powertrains face cost pressure due to regulations (e.g. Euro 7), BEV powertrains are expected to become available at competitive costs in comparison with ICE by the end of the decade. Parity of total costs of ownership is already partially achieved and is forecasted to be reached in all segments and ranges by 2025

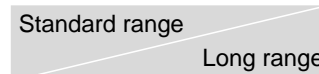
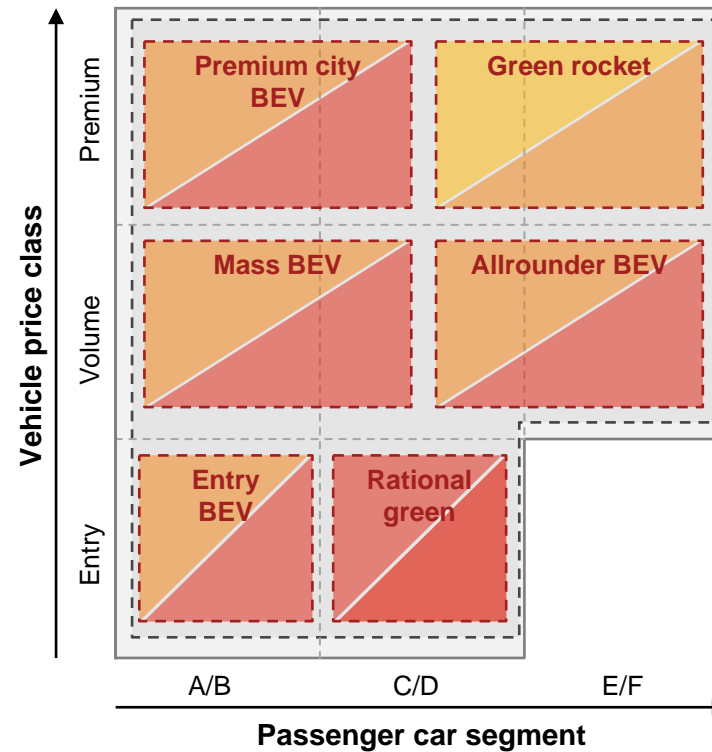
Based on decreasing BEV costs, we expect TCO parity for BEV by 2025 in all classes, but higher total powertrain costs likely until end of decade

Powertrain cost parities (in years)

Total cost of ownership (TCO) parity



Powertrain costs parity



Comments

Total cost of ownership (TCO)

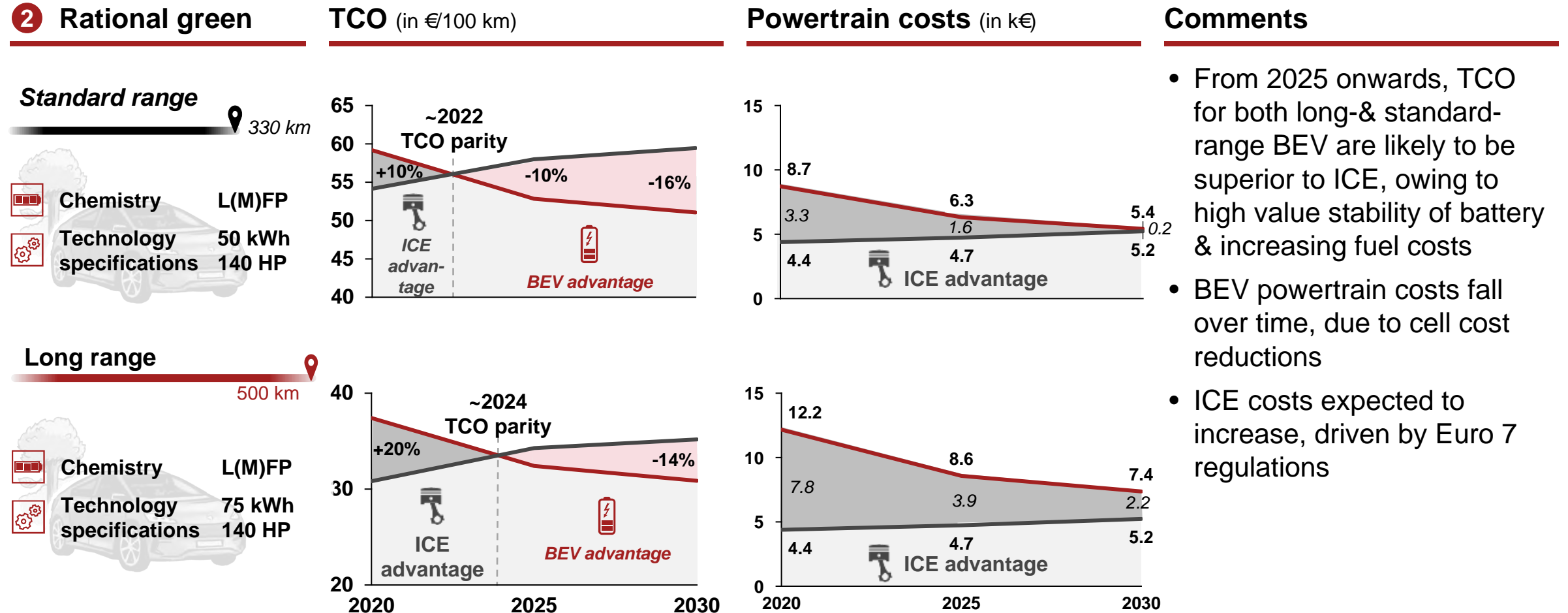
- TCO parity across all segments and ranges expected by 2025, driving premium and volume BEV diffusion
- Premium vehicles to reach earlier TCO parity and powertrain cost parity compared with volume and entry segments
- Shorter-range vehicles reach TCO parity earlier than long-range variants

Powertrain costs

- Parities expected from 2030 onwards, driven by falling battery costs and increasing ICE costs (e.g. due to Euro 7)
- Powertrain costs especially significant for price-sensitive entry class diffusion

Particularly in the entry segment, powertrain parity for both standard and long-range vehicles are not expected to be reached before 2030

Rational green - Powertrain costs and TCO comparison (2030)



By 2030, ~40% BEV vehicle sales share expected, moving towards 70% BEV share in 2040, resulting in ~6.5 TWh battery demand



Diffusion drivers

By 2025, **improved TCO** due to **scale effects** and convenient **charging infrastructure** are likely to lead to BEV diffusion. In 2030, further **TCO improvements** as a result of **enhanced battery technologies** and efficient charging infrastructure are expected to further consolidate the position of **BEVs as the standard choice**.



Regional differences

By 2030, around **40% of light vehicles globally** are forecasted to be based on a BEV platform and a **70% BEV share** expected by 2040. From 2030 to 2040, **global battery demand** will nearly double to **up to 6.5 TWh**.



Market diffusion across segments

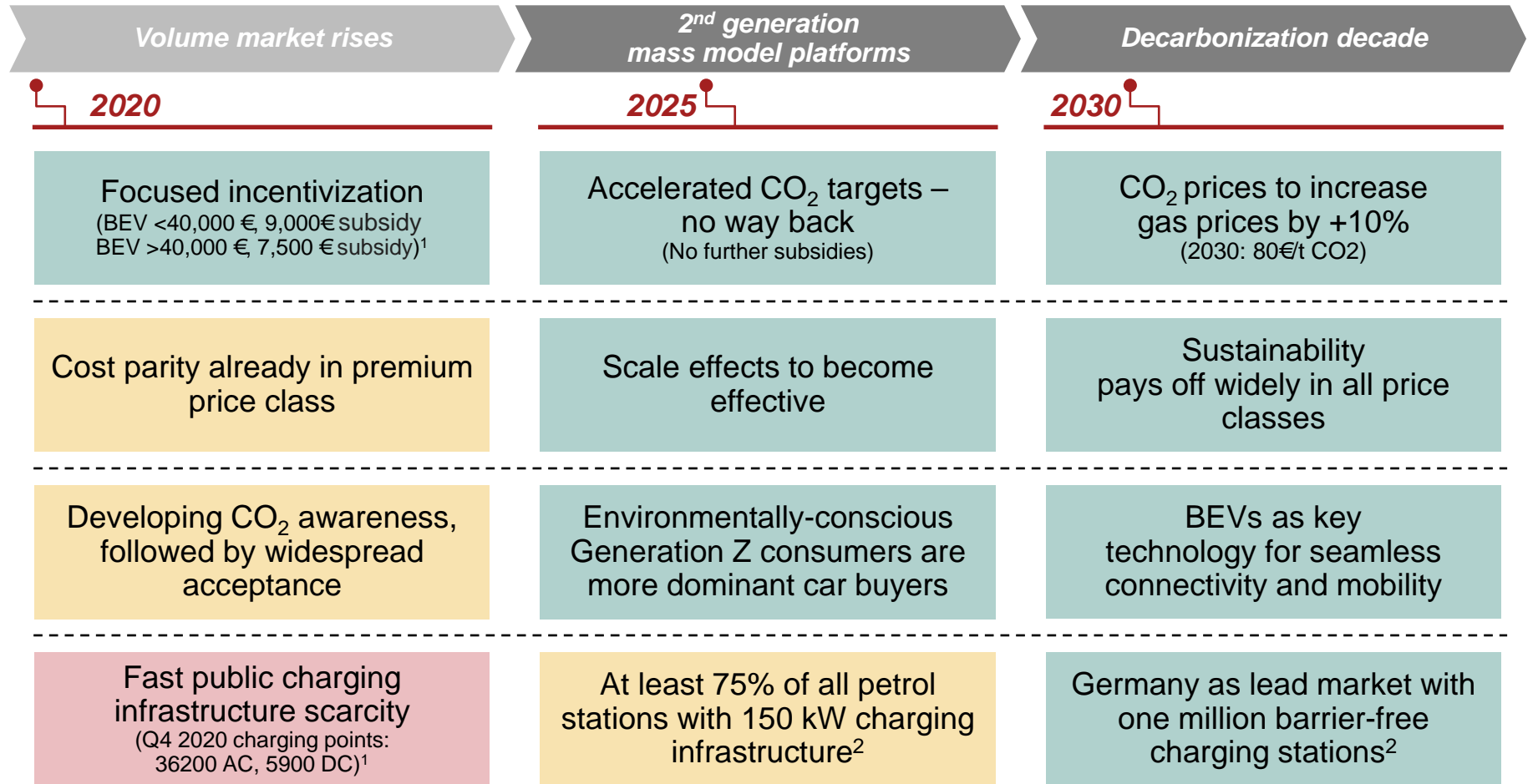
Electrification is moving from premium to entry segments, driven by customer demand. In 2030, a **significant price gap between premium and entry-level BEVs** are expected to remain, with the **middle segment widely adopting electrification**. However, **limited differentiation in electrification rates is anticipated across car segments**.

Looking at BEV diffusion drivers, we see the “decarbonization decade” in full swing – turning market dynamics from market push to pull

BEV diffusion criteria



Example



■ No driver for BEV diffusion
 ■ Moderate driver for BEV diffusion
 ■ Driver for BEV diffusion

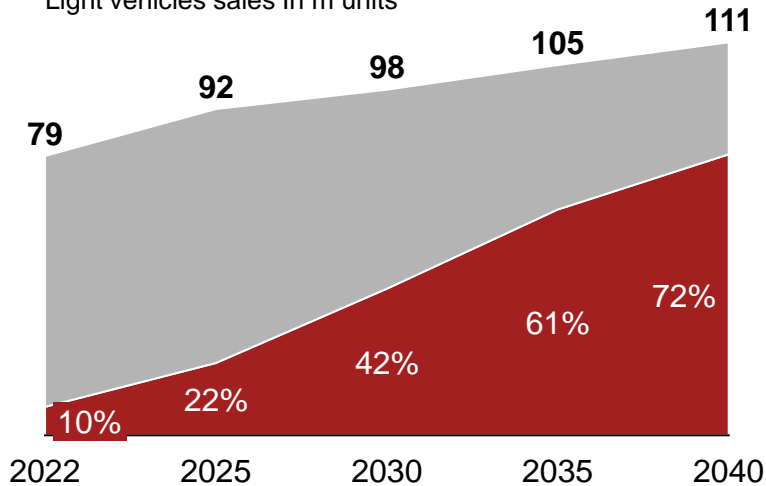
1) For Germany 2) Goal of German government

With market pull in full force towards 2030, 40% of light vehicles sales are likely to have a BEV platform, resulting in 3.4 TWh battery demand

BEV diffusion (Strategy& forecast, as of 2023)

Global BEV diffusion

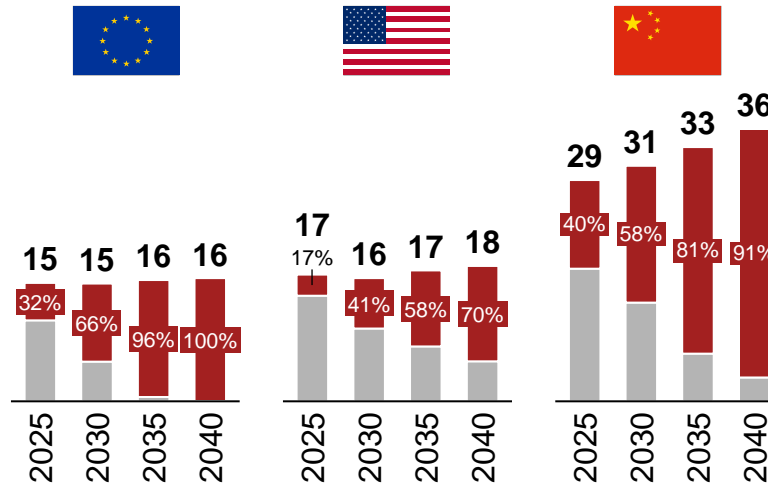
Light vehicles sales in m units



- In 2030, ~40% of all light vehicles are expected to be based on a BEV platform
- By the end of the next decade, at least 70% BEV share expected

Regional BEV diffusion

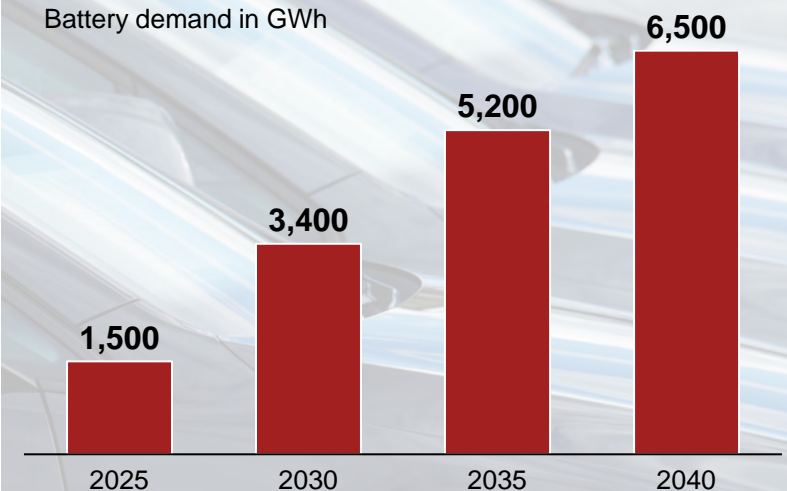
Light vehicle sales in m units



- Across the major three markets, EU and China are expected to be the main drivers of BEV adoption, spurred by regulations, HPC infrastructures and improved economics
- BEV adoption in US expected to accelerate from 2030 onwards

Global battery demand

Battery demand in GWh

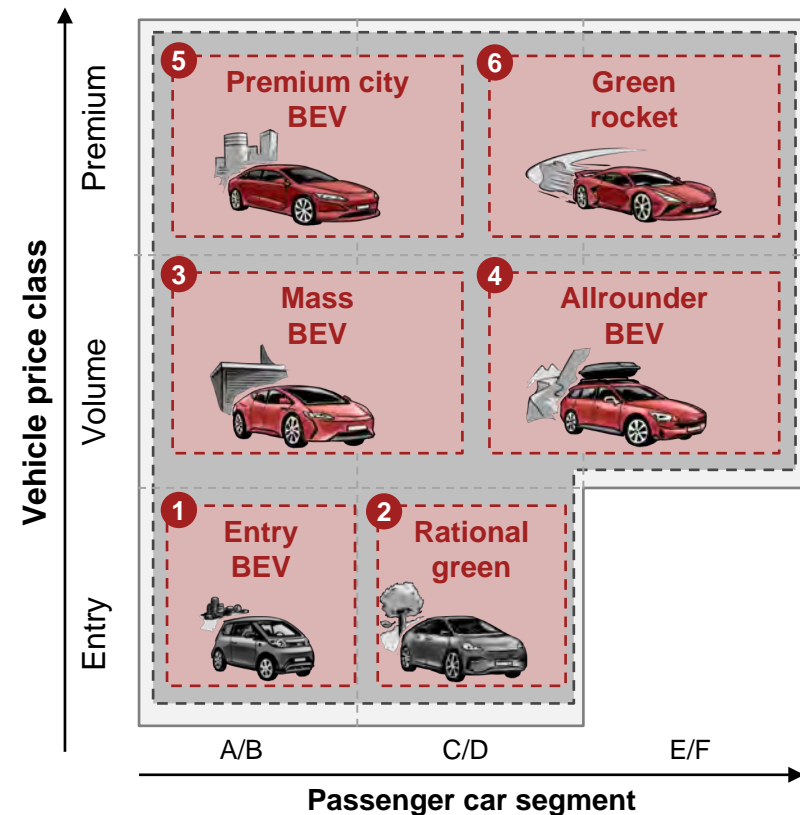


- From 2030 to 2040, global battery demand set to almost double to up to 6.5 TWh
- Market growth driven by vehicle adoption – battery capacities are expected to stay constant from 2030 onwards

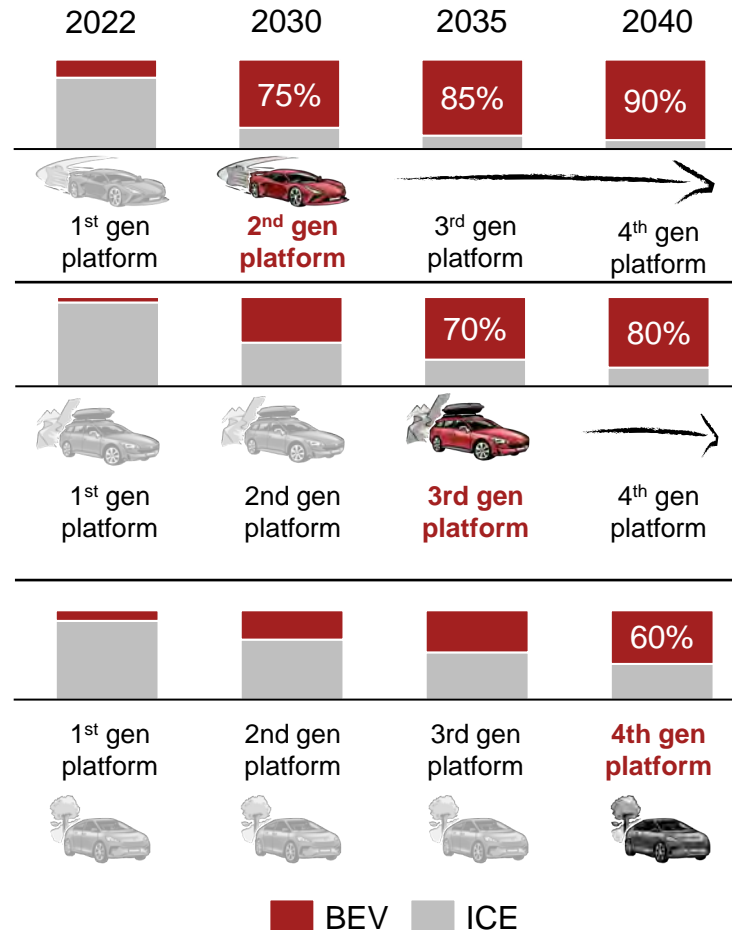
Market diffusion of BEVs likely to move from the premium- towards volume- and entry segments, driven by new platform generations

Market diffusion across segments and price classes (BEV share in %)

2030 powertrain portfolio



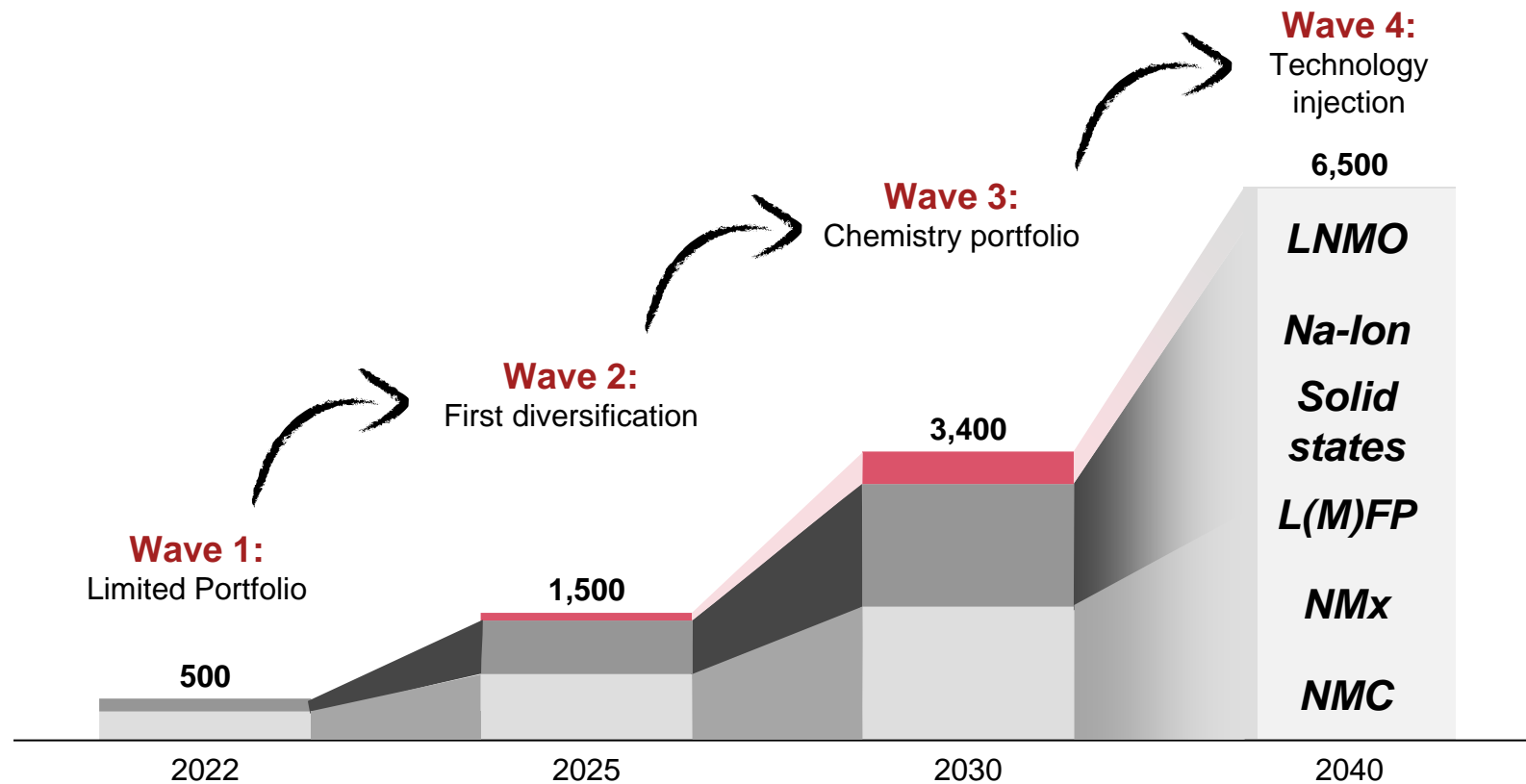
Electrification across classes



- Premium to lead electrification
- Technological and commercial advancement to grow BEV share further
- By 2030, the volume segment expected to be a strong driver for BEV sales and reach brink of large-scale diffusion
- From 2030 onwards, majority of vehicles forecasted to be electric
- Gap between premium and entry electrification expected to persist beyond 2030, owing to price sensitivity
- From 2030 onwards, anticipated cost decreases to facilitate electrification

With these new differentiated platform generations, we expect an multi-chemistry portfolio ramping up to meet the battery demand

Global battery demand – cell chemistry split (in GWh)



Key takeaways

- Wave 1:** Limited portfolio with NMC dominant cell chemistry, driven by the premium segment
- Wave 2:** Diversification driven by entry and volume segment
- Wave 3:** Platform diversification further drives cell chemistry portfolio
- Wave 4:** Future technology injection (e.g. solid-state batteries) results in more diversification of cell portfolio

Companies across sectors should participate in the BEV gold rush, taking advantage of the transformation opportunities



Battery Boom: Transformative Growth

The **battery market** expected to **grow to 6.5 TWh by 2040**, generating **global annual revenues** that will **surpass those of internal combustion engine (ICE) powertrains in the course of this decade**. The scale of this transformation demands **substantial investment**, amounting to nearly twice the GDP of Austria.



Segment-specific BEV Powertrains

BEV diffusion spans various segments, necessitating **tailored powertrain solutions to meet specific needs**. From premium to entry-level vehicles, **customization is vital** in satisfying diverse customer preferences, leading to the widespread adoption of BEVs across the automotive market.

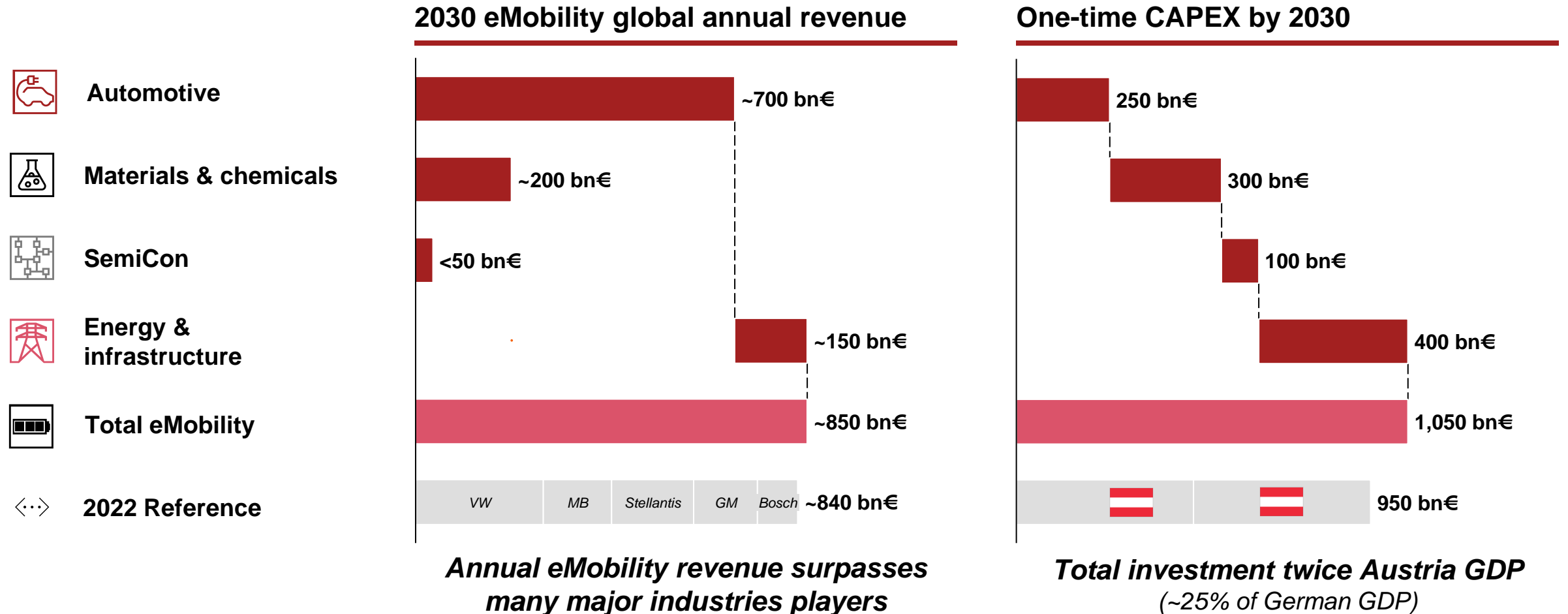


Close collaboration

BEV efficiency **depends on collaboration** and concerted **effort across industries in Europe**. By **fostering partnerships** and collective action, stakeholders can work together to overcome challenges, accelerate innovation, and create a sustainable and effective ecosystem for electric mobility in Europe.

Based on the BEV market pull, we expect transformative growth in the size of multi-corporates revenues and countries GDPs

Global cross industry value pool overview



To participate in the BEV gold rush, cross-industry activities beyond the automotive industry are required and expected

eMobility industry transformation



Automotive

Replace oil with Lithium

- ...changing revenue pools
- ...new required competencies
- ...transforming organizations



Industrial Products

Supply the machine

- ...build regional supply chain
- ...provide equipment to meet demand
- ...develop competitive products



Energy & infrastructure

Power the transformation

- ...build required infrastructure
- ...renewable energy supply
- ...balance and manage grid



Fleet providers

Get it on the road

- ...meet fleet and CO₂ targets
- ...rethink mobility concepts
- ...new investment needs



Public Sector

Set the framework

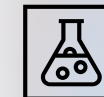
- ...incentivize transformation
- ...align regulation with technology
- ...foster new competencies



Financing & capital markets

Provide the capital

- ...secure financial backing
- ...rethink mobility financing
- ...facilitate new collaborations



Material & chemicals

Mining & refining the new oil

- ...value chain integration
- ...automotive standards
- ...conceptualize recycling

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