



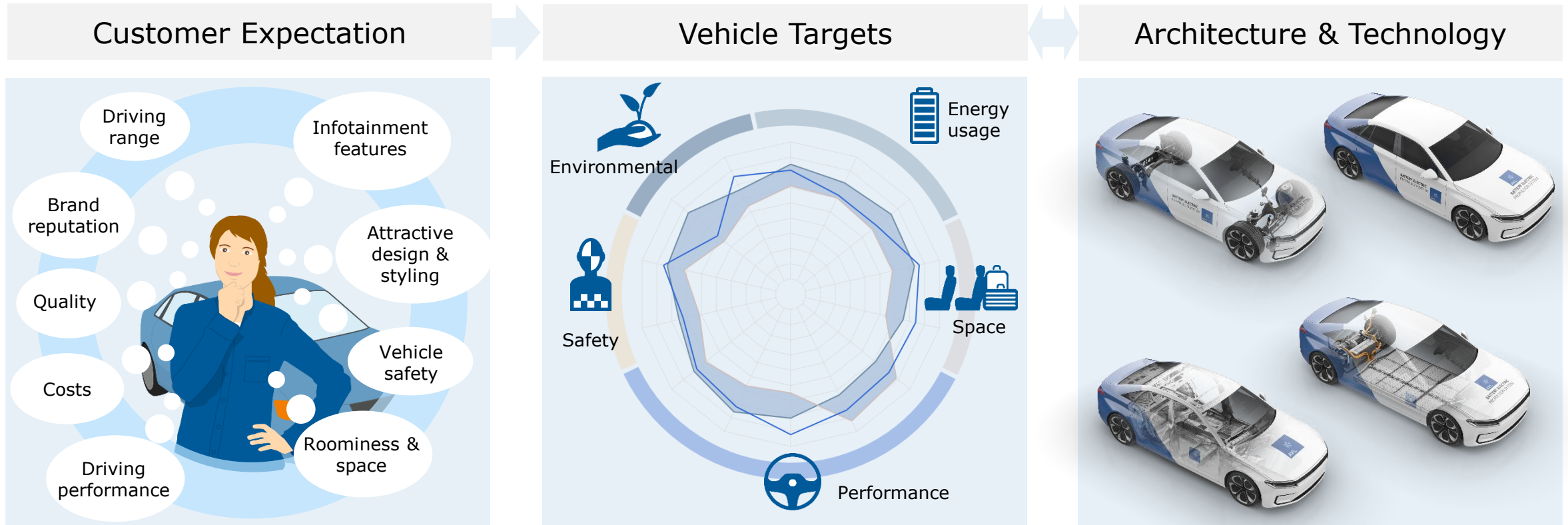
Carbon Neutral Vehicles

developed with Attribute Engineering

Prof. Dr. Uwe D. Grebe









AVL List GmbH

From Customer Expectation to Targets & Architecture



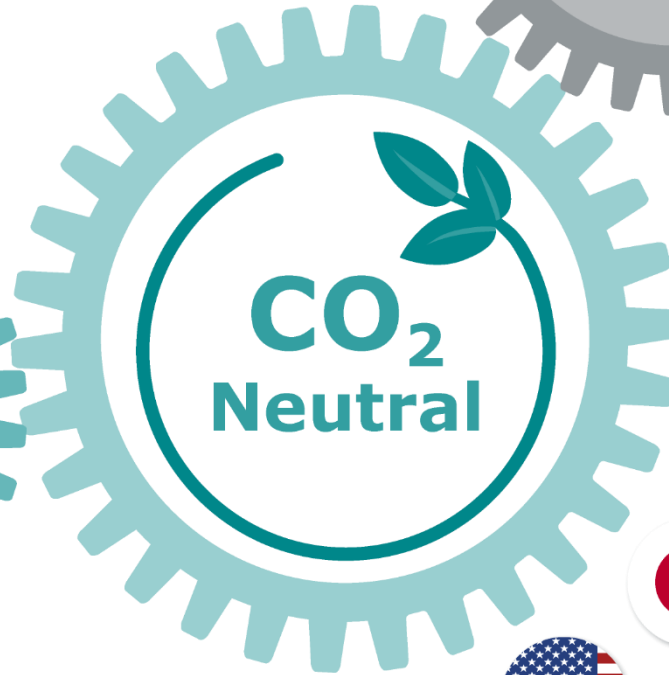
6 to 9 months from Start of Feasibility to Target Agreement / Concept Agreement are state-of-the-art
How to shorten it? How to manage complexity?

Flashlight on Passenger Car Regulations and Market Requirements

	EUROPE 	CHINA 	US 	Japan 
SAFETY 	Legal: Similar requirements, differences in collision speed, dummies and biomechanical limits			
	NCAP worldwide: mainly driven by Euro NCAP 			
NET-ZERO EMISSIONS 	Specific consumer test: Small overlap crash Battery protection vs. weight increase			
	Tank to Wheel CO ₂ legislation	TtW, "Well To Wheel" proposed	Tank to Wheel CO ₂ legislation	Well to Wheel CO ₂ legislation
	ICE _{fossil} ban: 2035	2035: new ICE → Hybrid	ICE ban in some states	mid 2030s: new ICE → Hybrid
	Limits: THC, NMHC, NO _x , (NH ₃)	Limits: THC, NMHC, NO _x	Limits: NMOG, NO _x	Limits: THC, NMHC, NO _x
MOBILITY ECOSYSTEM 	Limits: Particulate Number (PN)			
	Limits: Particulate Matter (PM)			
	2030: 15 Mio. charging stations	2030: 14 Mio. charging stations	2030: 13 Mio. charging stations	2030: 150,000 charging stations
	2031: H ₂ refueling stations every 200km	2030: 1000 H ₂ refueling stations planned	2030: 4300 H ₂ refueling stations planned	2030: 1000 H ₂ refueling stations planned
	246 Mio. vehicles in use	273 Mio. vehicles in use	116 Mio. vehicles in use	62 Mio. vehicles in use

Differentiation in Vehicle Architecture per Region

On the Roadmap to Carbon Neutrality



EU 2050



China 2060



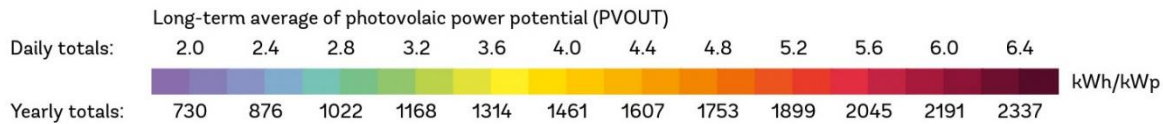
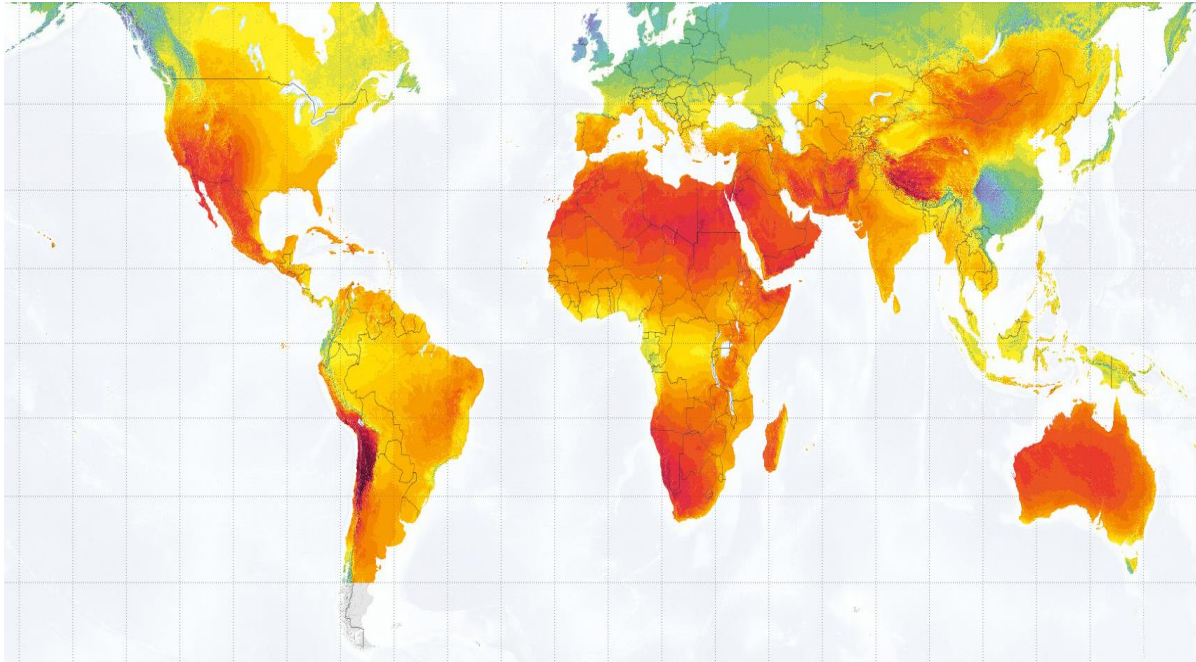
Japan 2050



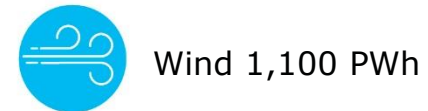
United States
50% reduction in 2030

Renewable Energy – Distribution of Harvest Potential

Harvesting Potential – Example: Solar Power



Annual Global Energy Potentials



- Biomass 53 PWh
- Hydro 35 PWh
- Geothermal 26 PWh
- Wave 17.5 PWh
- Tidal 2.7 PWh

World Energy Consumption

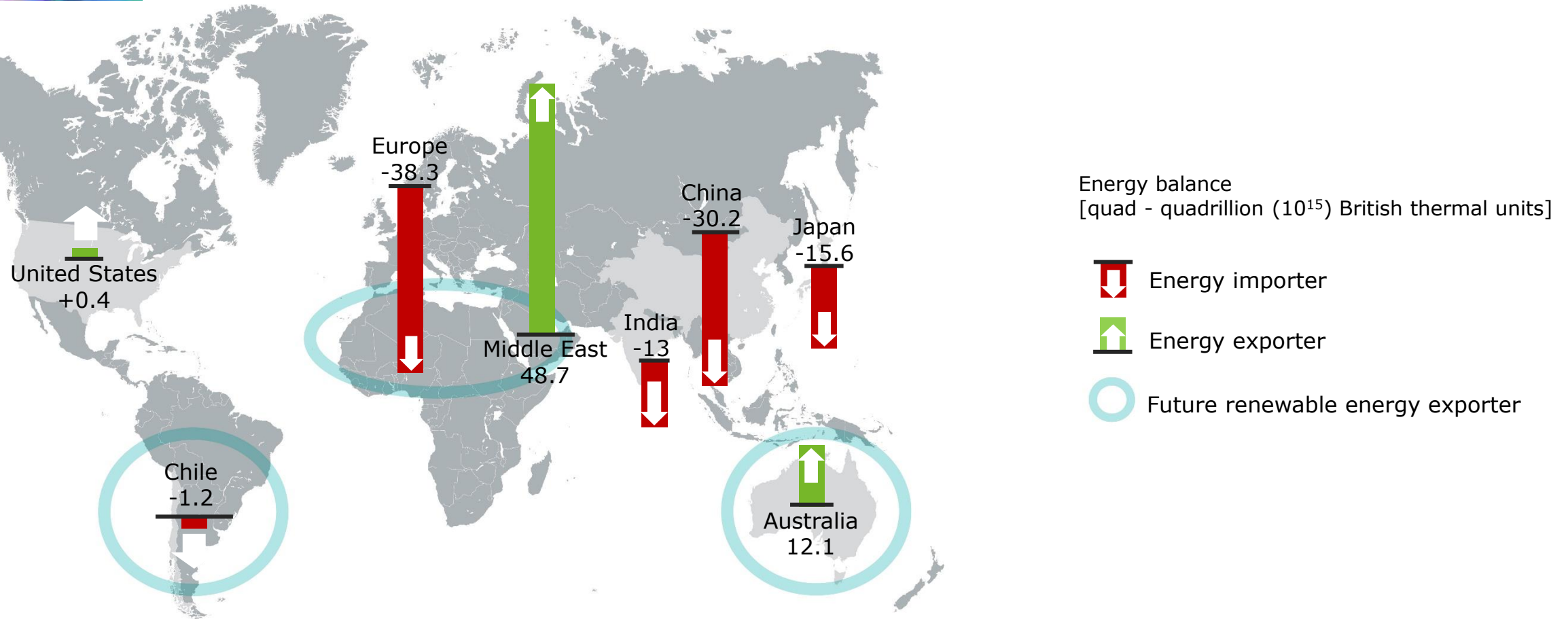
●
162 PWh

PWh ... Peta Watt hours = 10^{15} Watt hours

More than sufficient energy – but usually in the wrong place at the wrong time...

Primary Energy – Net Importer and Net Exporter

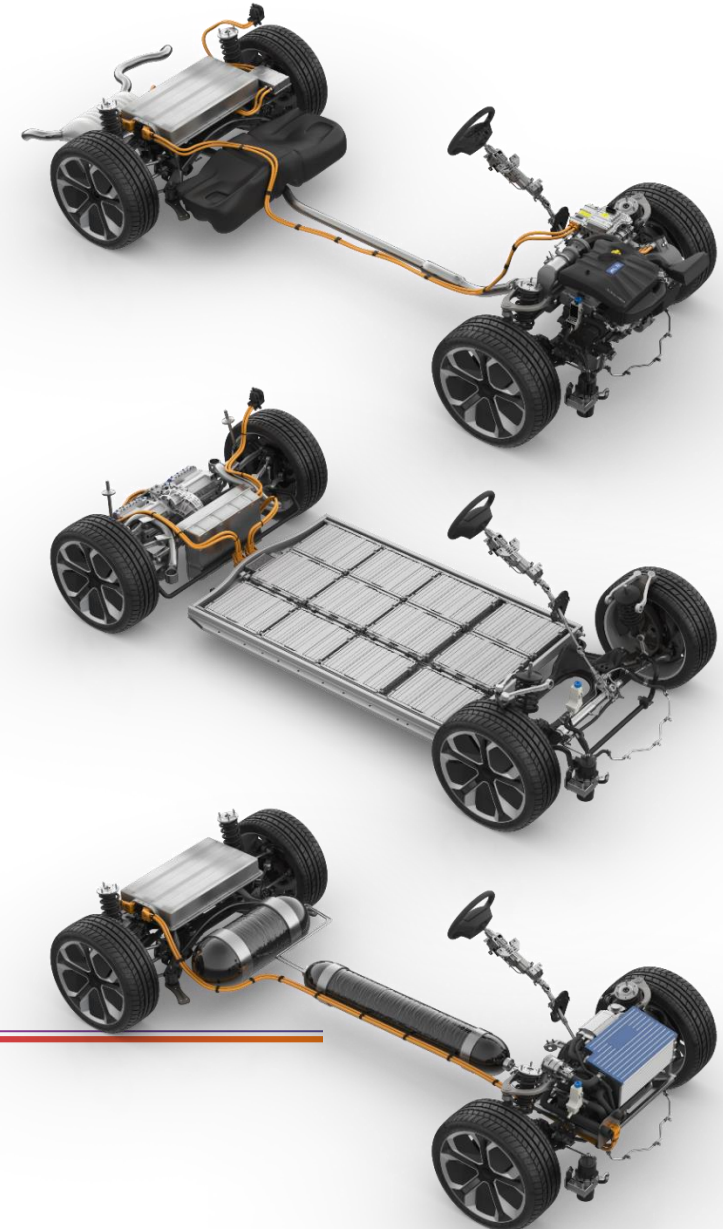
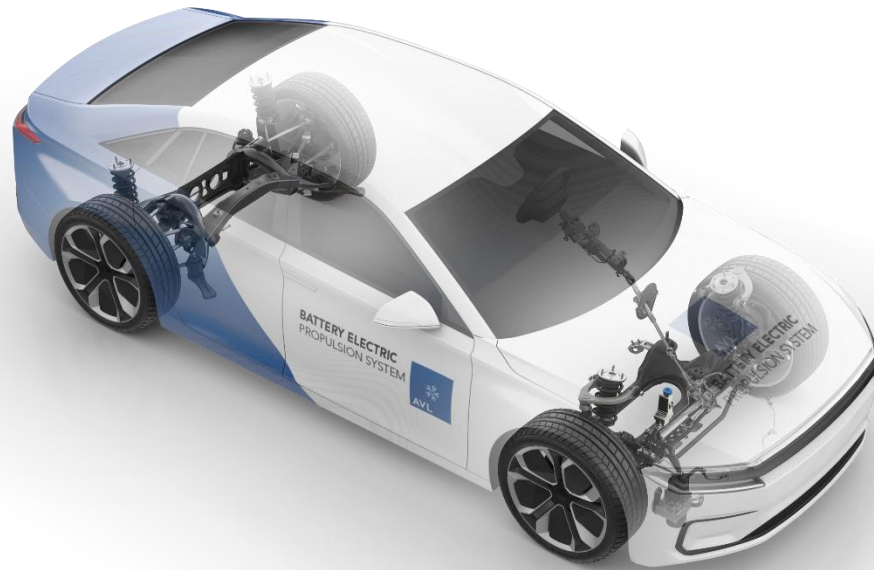
(selected countries, calendar year 2021)



Future national or regional energy independence is highly unlikely.

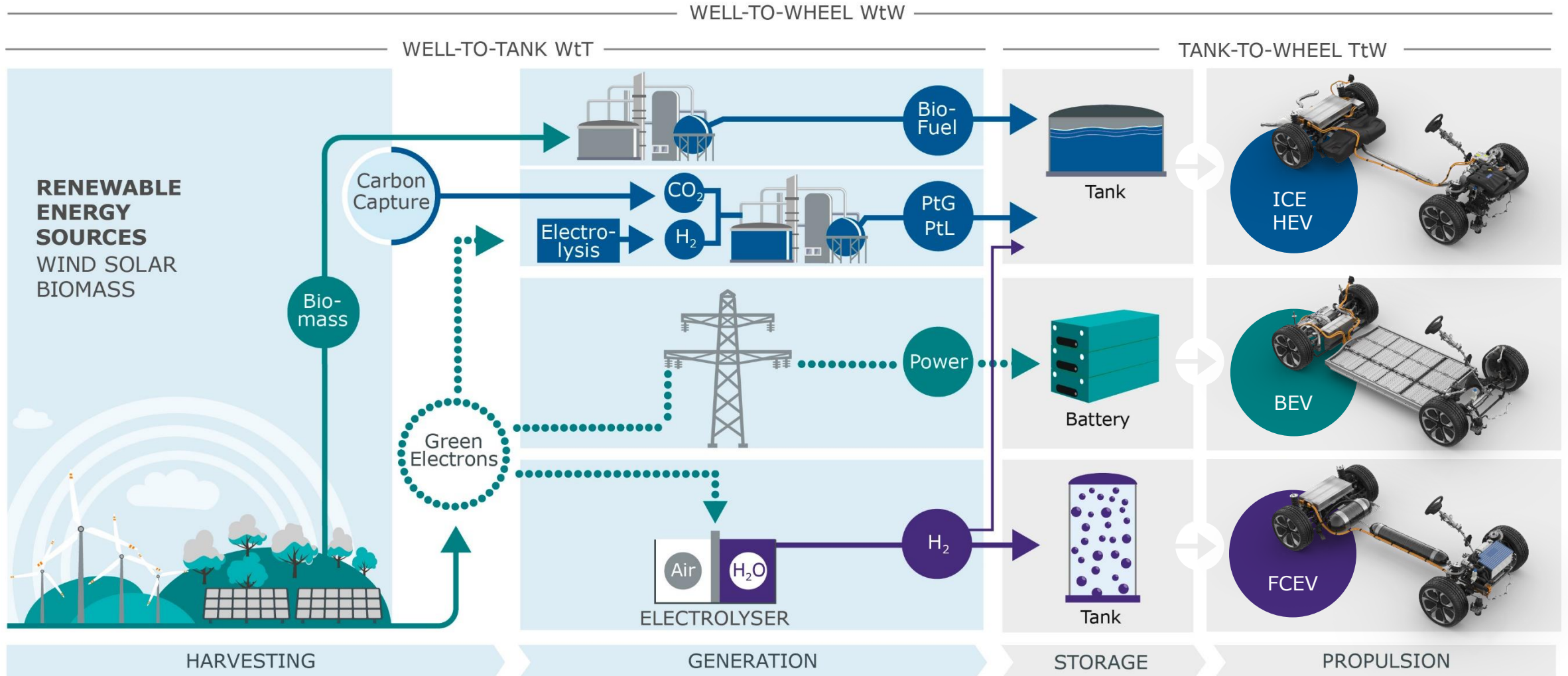
Major energy demand centers will remain – Global trade with renewable energy will be established.

Selection of the Propulsion System



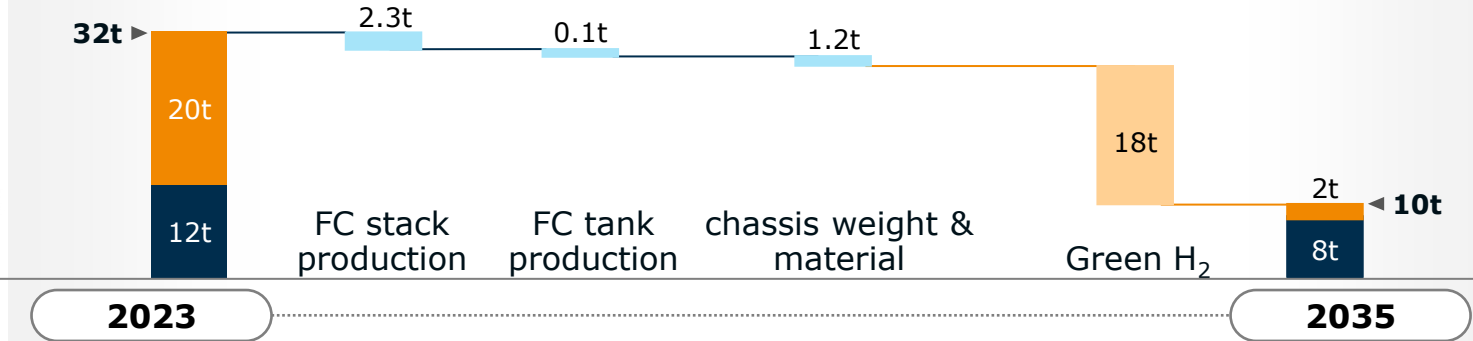
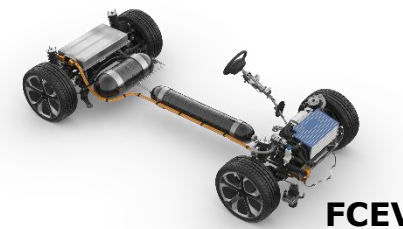
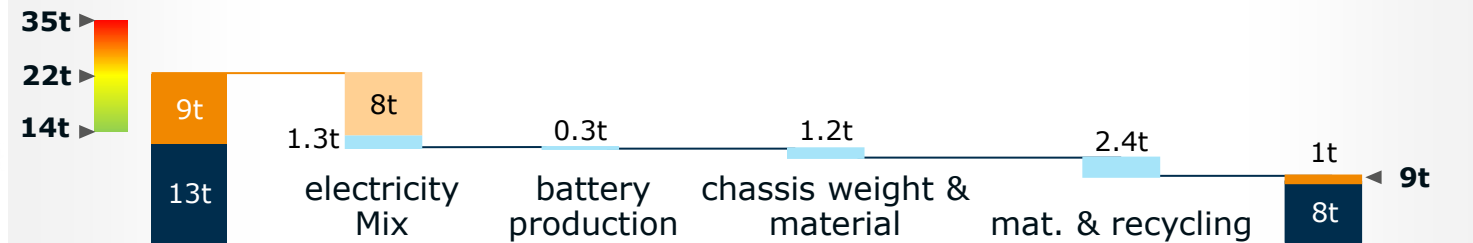
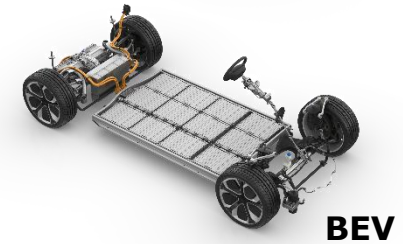
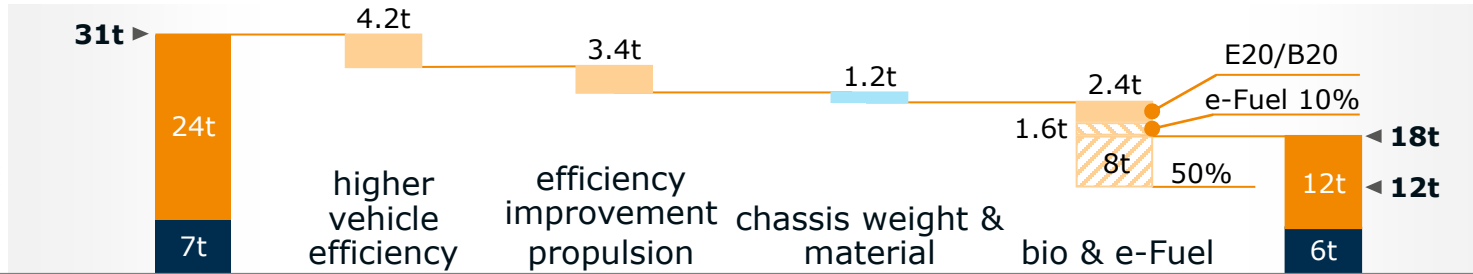
Finding the right composition of propulsion, body in white, chassis system and E/E architecture

Pathways to clean and sustainable Propulsion Systems



ICE ... Internal Combustion Engine | HEV ... Hybrid Electric Vehicle | BEV ... Battery Electric Vehicle | FCEV ... Fuel Cell Electric Vehicle | PtG ... Power to Gas | PtL ... Power to Liquid

Life Cycle CO₂ of Propulsion System Options



C-Segment Vehicles

Hybrid Electric Vehicle (HEV)
Propulsion 110 kW / Fossil Gasoline

Battery Electric Vehicle (BEV)
Propulsion 150 kW / Battery 60 kWh / 330 km range

Fuel Cell Electric Vehicle (FCEV)
Propulsion 110 kW / Fossil Hydrogen

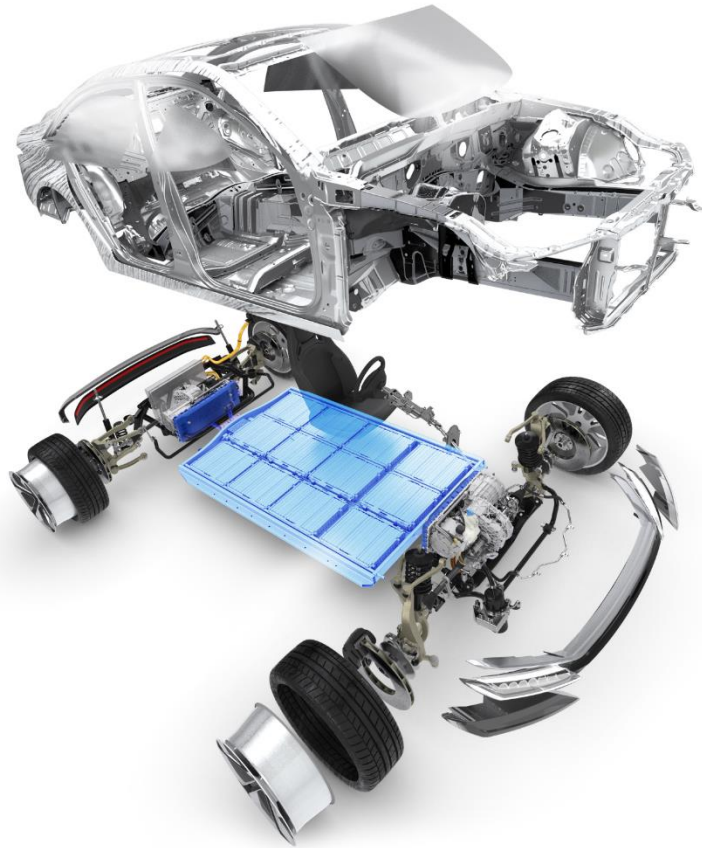
Sources: AVL, EU EEA, IEA WEO 2021, Fraunhofer ISI, ifeu

CO₂ Life Cycle Emission (180 tkm)

Production

In-use

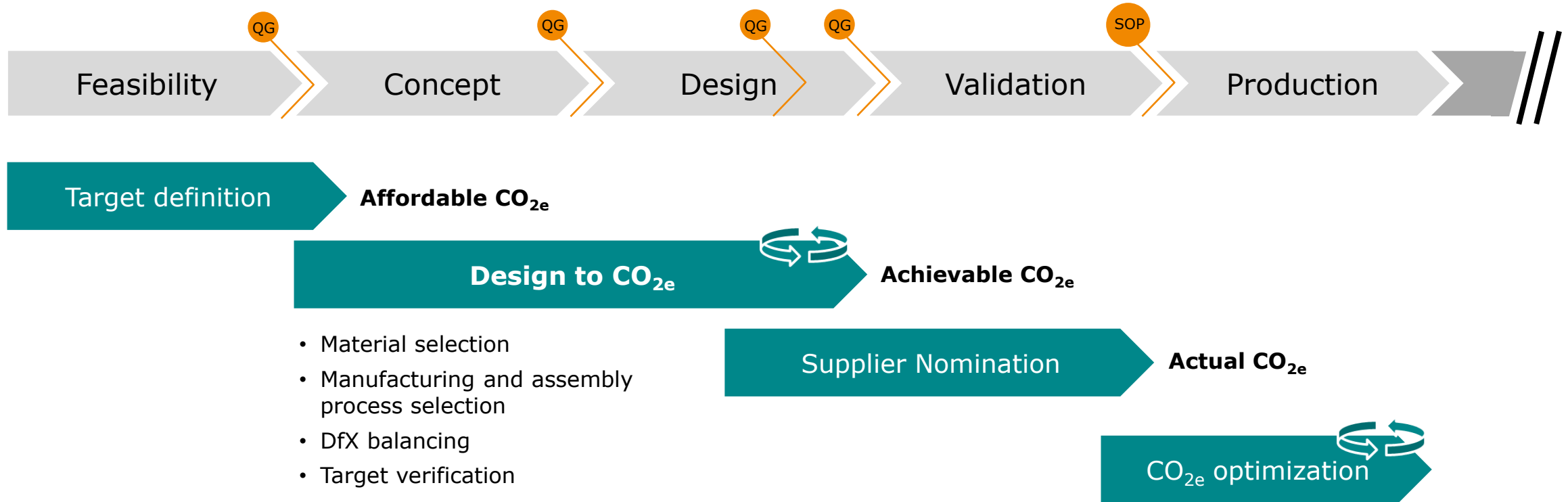
Similar range of Life Cycle CO₂ emissions for all powertrains utilizing all options. High dependency on energy mix, especially for BEV. Hydrogen and ICE fuel need to shift to renewable energy.



Example 1: CO_{2e} optimization of a battery cover

Battery case study to explore the opportunities for CO_{2e} reduction through material and design decisions.

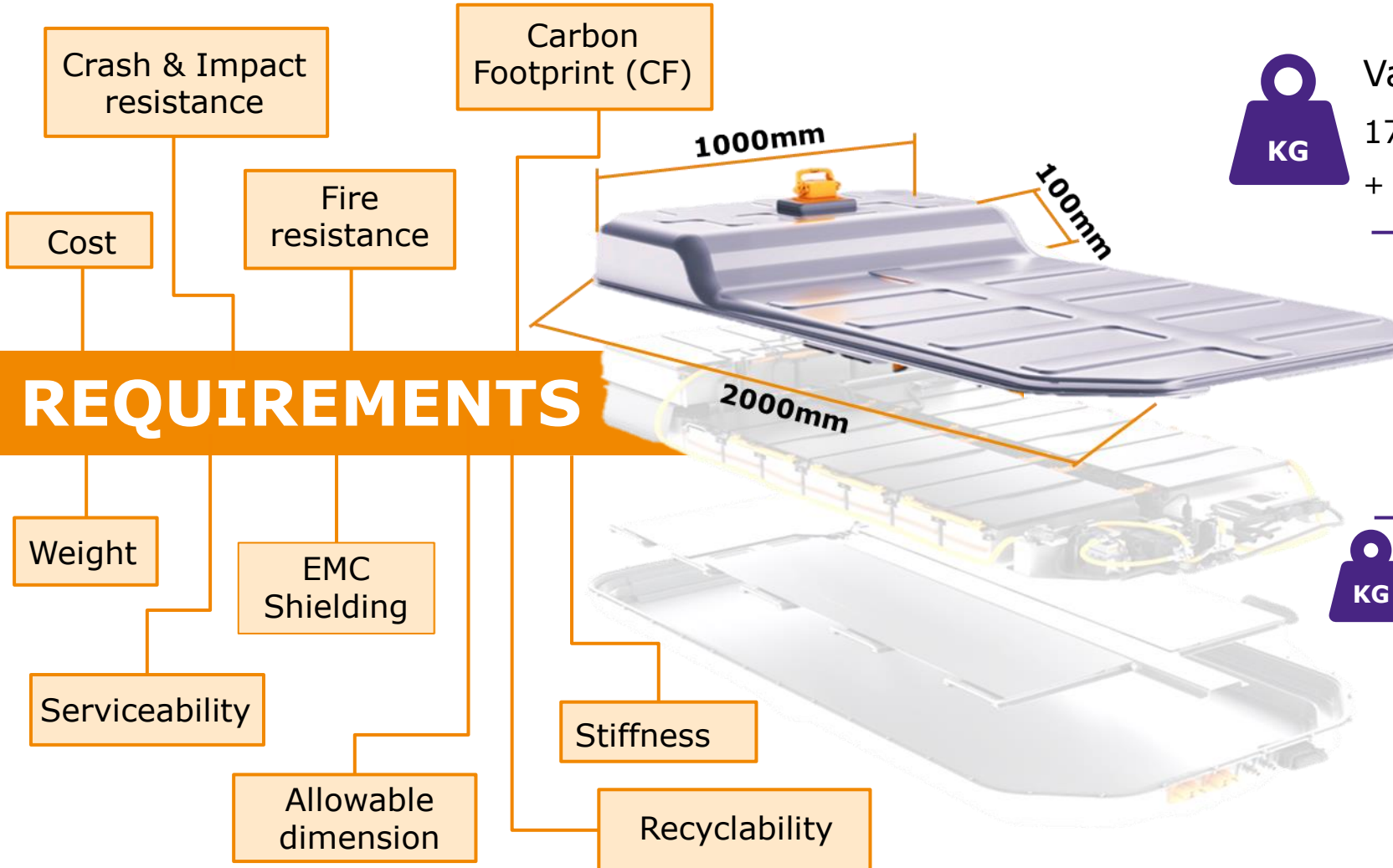
Design to CO_{2e} in Product Development



Consider CO_{2e} as a parameter in the early phase of development

* QG... Quality Gate; ESG... Environmental, Social, Governance; CBAM... Carbon Border Adjustment Mechanism; EHS... Environment, Health, Safety; PLM... Product Lifecycle Management, RFQ... Request for Quotation

Battery Cover – Material selection



Variant 1 **Steel**

17.88 kg (cover only) / 1 mm thickness
+ Bolts and cathoretic coating (KTL)



Variant 2 **Aluminum**

7.26 kg (cover only) / 1.2 mm thickness
+ thermal propagation protection (MICA) and additional bolts

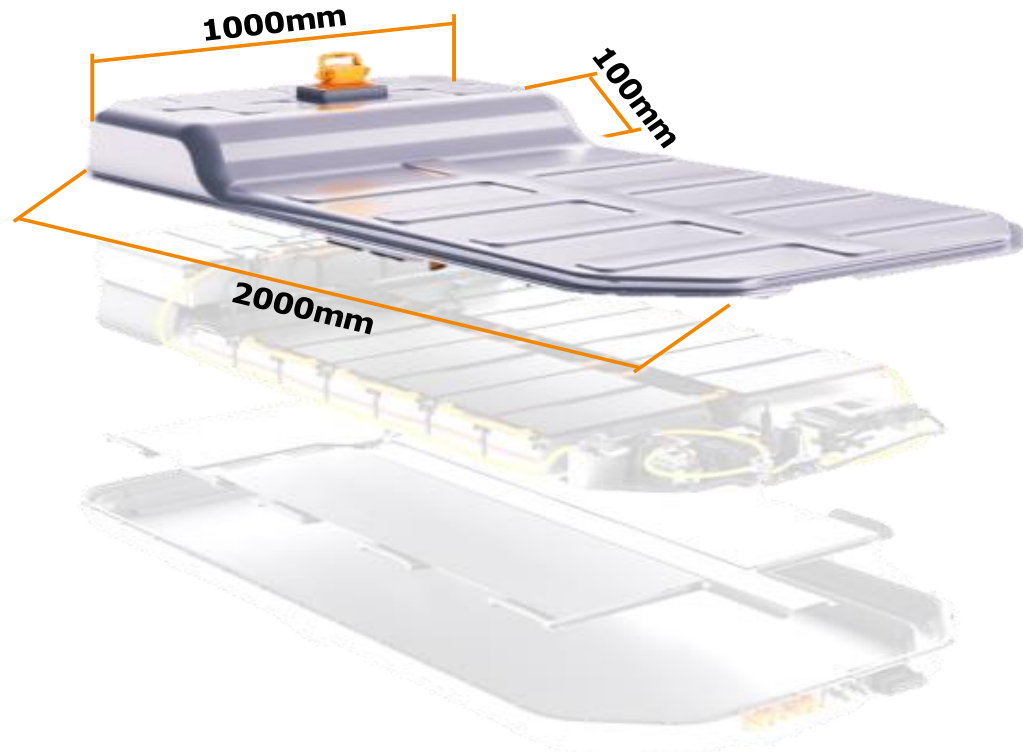


Variant 3 **Sheet Moulding Compound (SMC)**

10.35 kg (cover only) / 2.5 mm thickness
+ thermal propagation protection (MICA), EMC shielding, Paint and Glue

non-exhaustive list

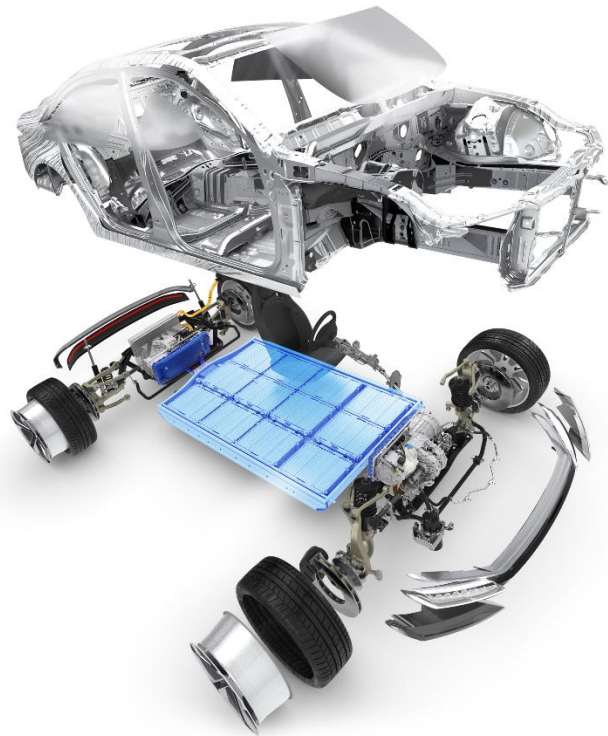
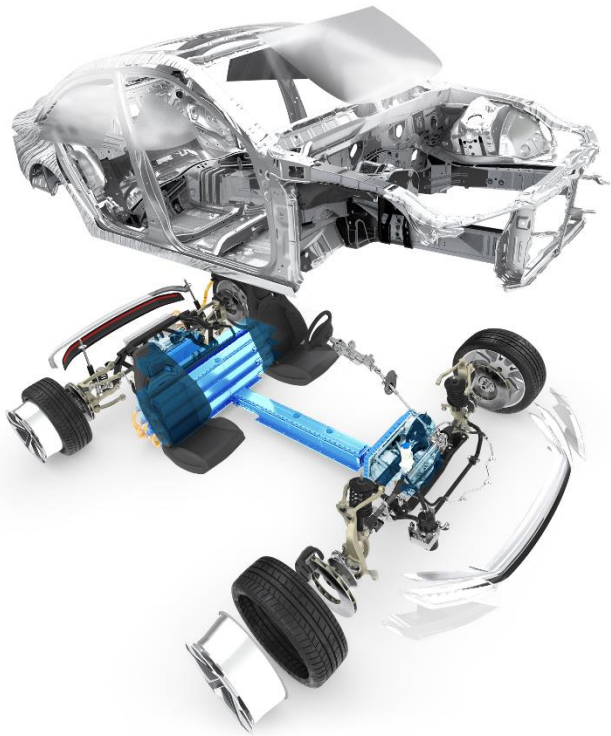
Battery Cover: Production Processes and Results



Variant	Cost [€]	CF [kg CO _{2e}]	Weight [kg]
Steel	70	66	18
Aluminum	117	85	7
SMC	147	67	10

rounded to the nearest whole number

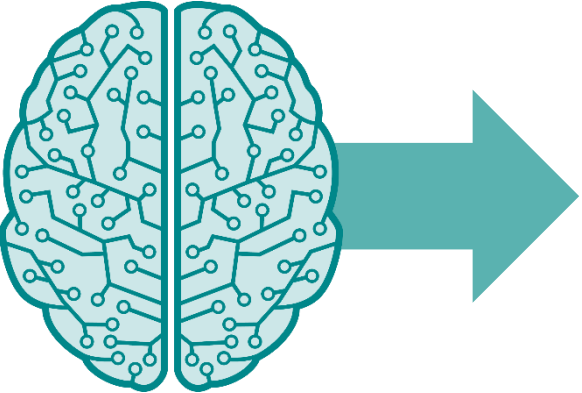
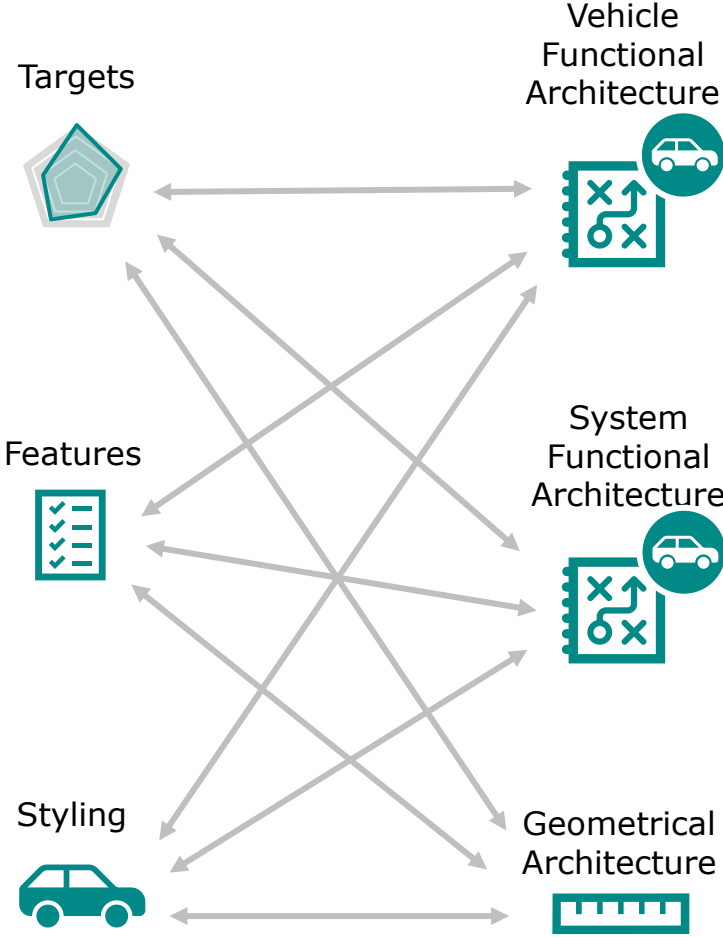
With the view on lifecycle, beyond costs additional parameter need to be balanced.



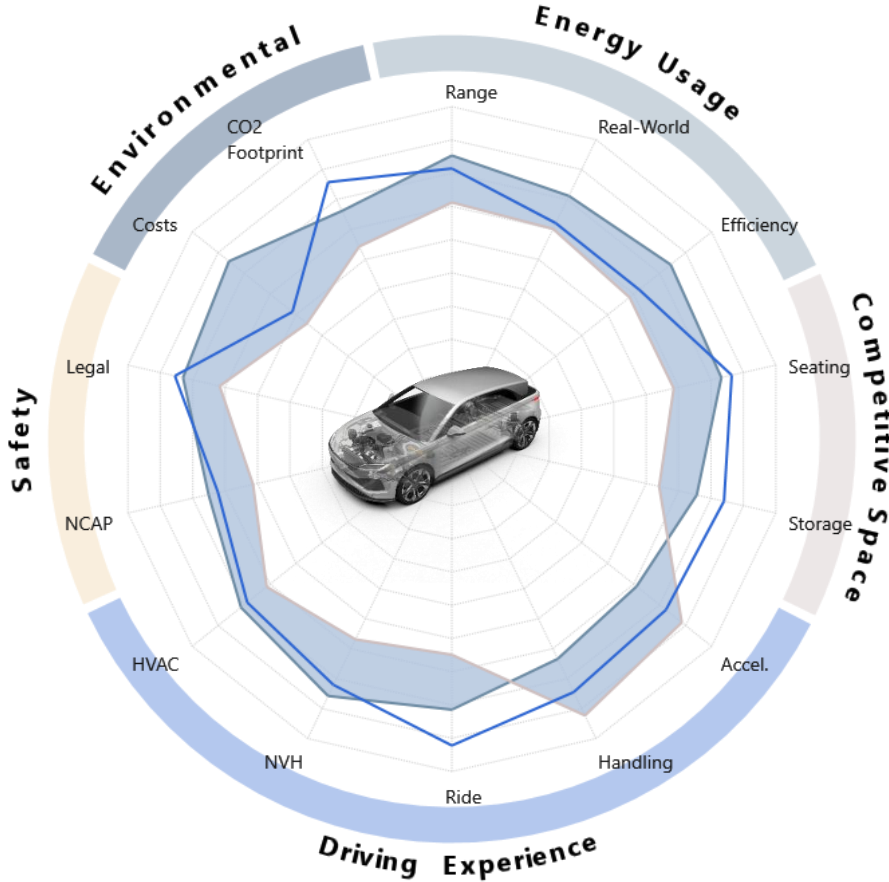
Example 2: Driving dynamics influence of battery topologies

Comparison of two battery topologies in the virtual optimization with artificial intelligence

AI Powered Attribute Engineering



AI Powered Attribute Engineering



Virtual Optimization of all functional vehicle development areas

Technical Specification

Powertrain

Thermal & HVAC

Chassis

Body

E/E & ADAS/AD

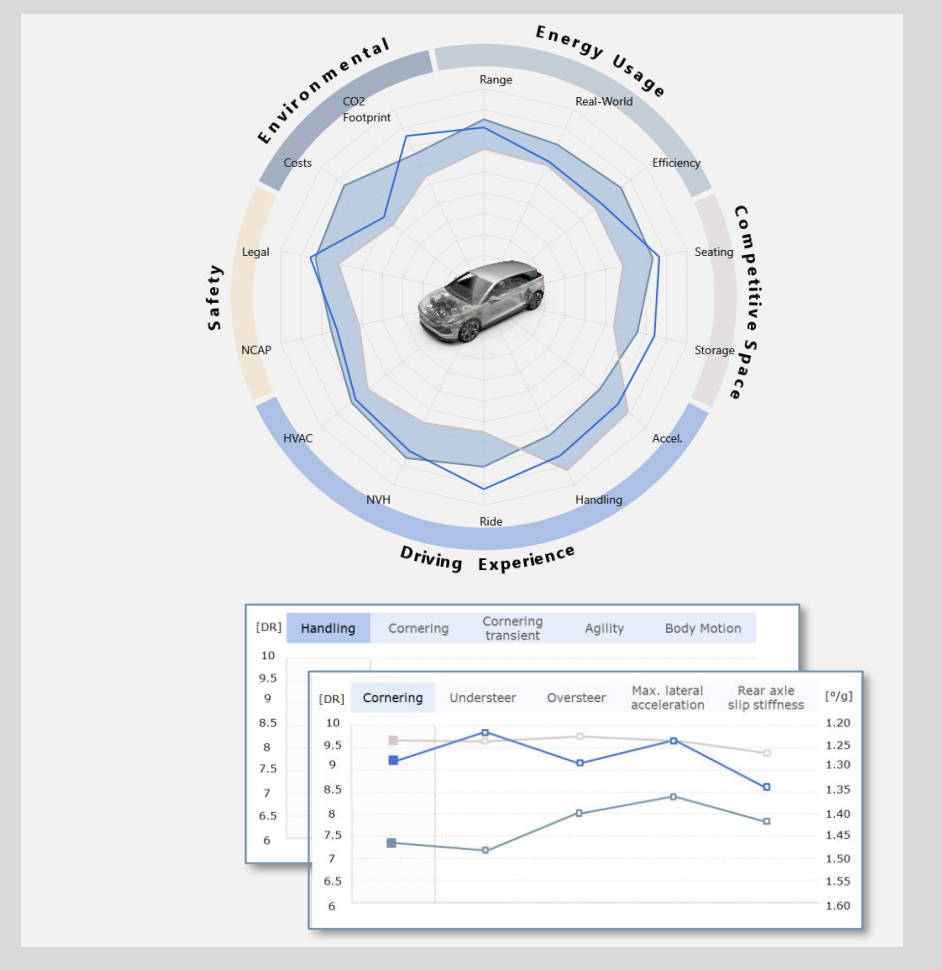
Generation of Predictive Models

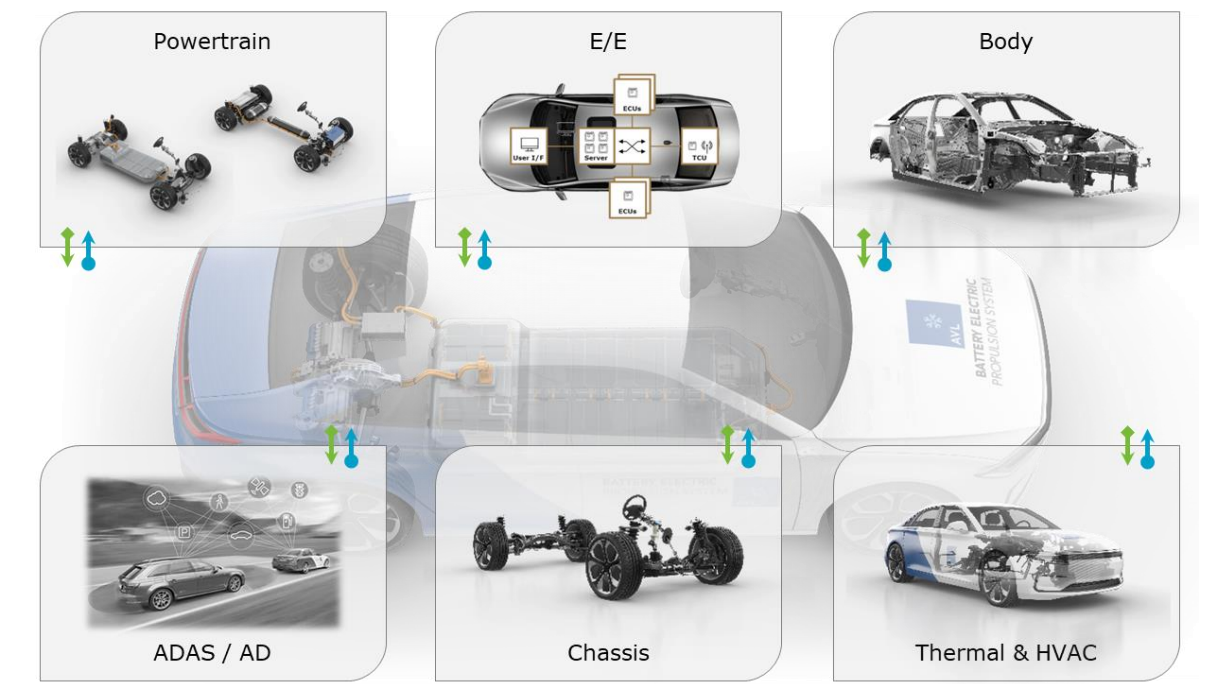
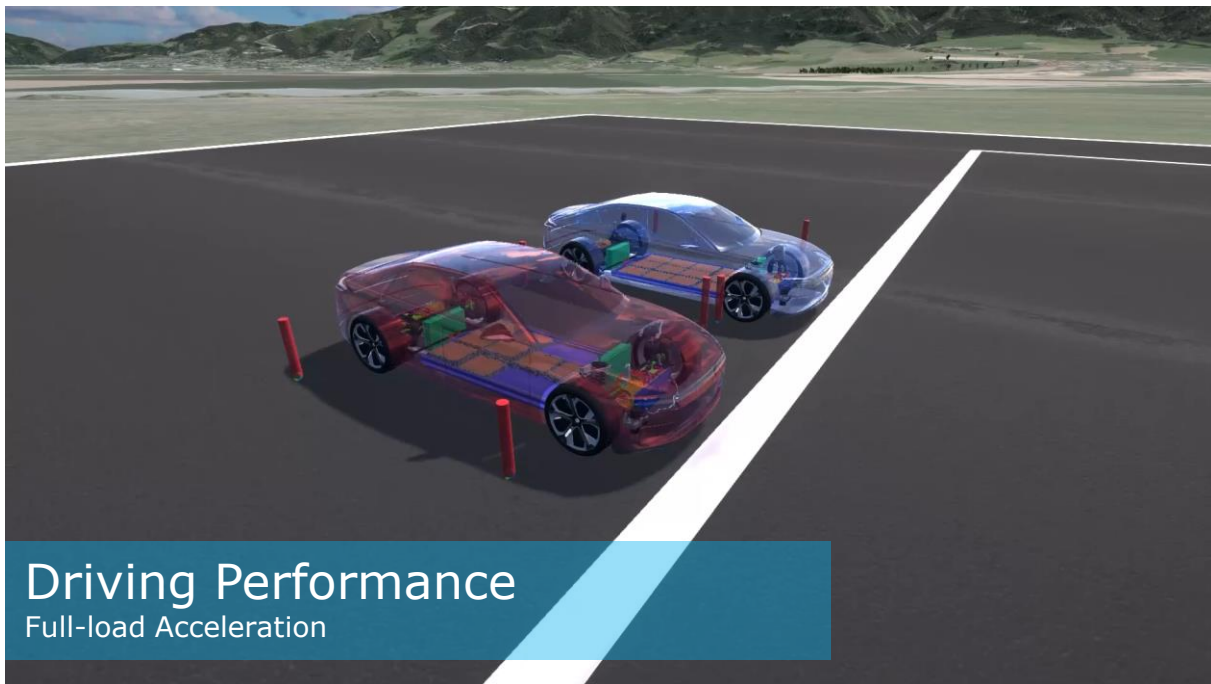
Simulation models of vehicle components and systems.

Data plots and graphs showing simulation results.

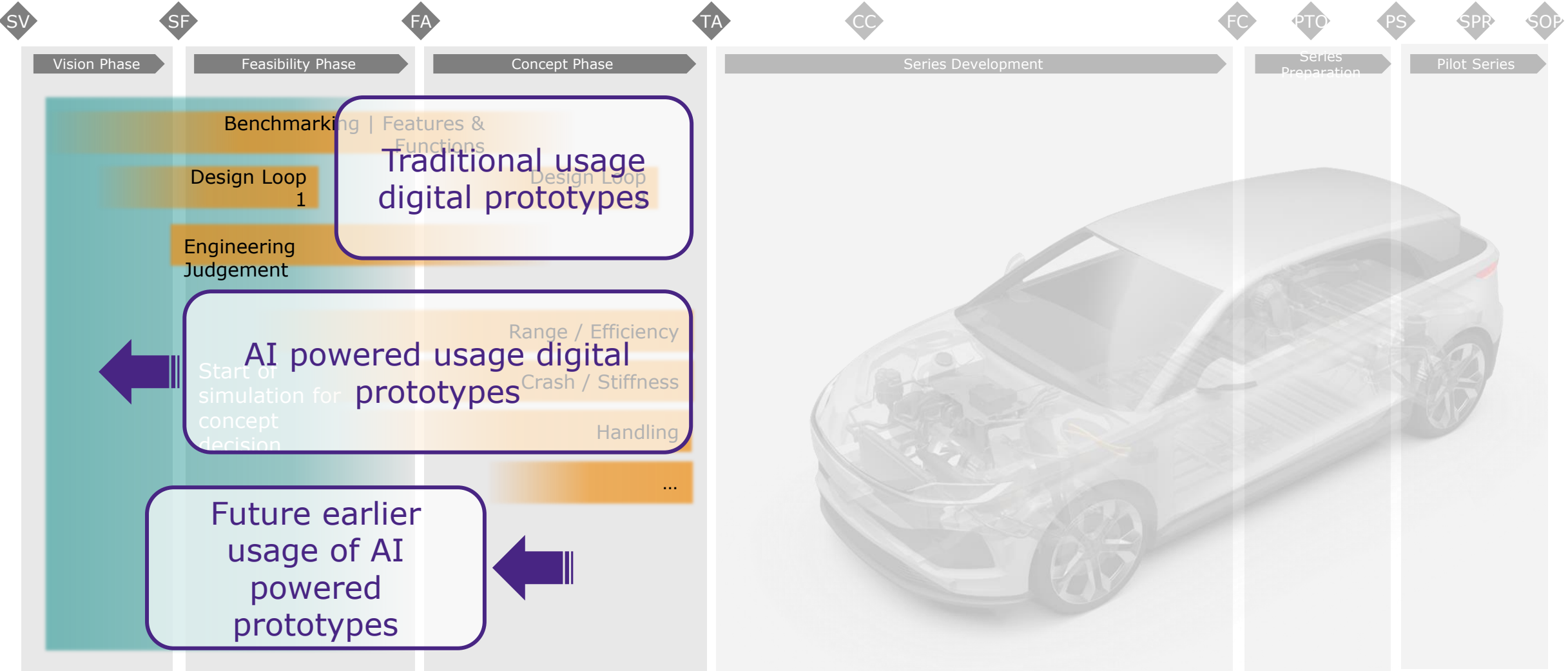
3D models of vehicle chassis and body.

Attribute Optimization & Balancing

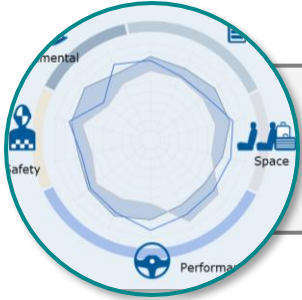




Advance Usage of Digital Prototypes to Define Vehicle Architecture

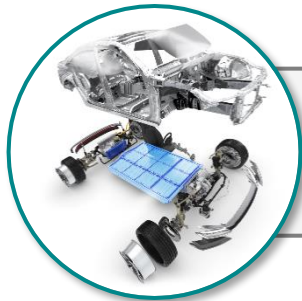
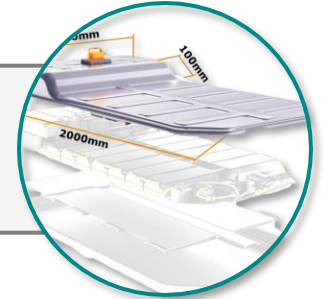


Summary



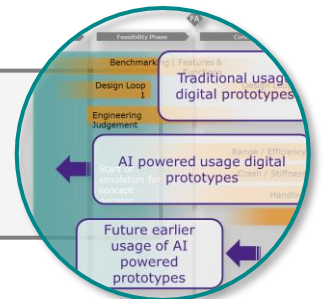
Complexity and speed in functional vehicle development increases

Need for Design-to-CO_{2e} in the lifecycle adds new parameter to vehicle development process.



Usage of digital prototypes in the feasibility phase allows for reductions in development time and better concept decisions

AI-powered attribute optimization will advance and shorten virtual and physical development.



Thank you



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