Future e-Mobility: Safe, Affordable and Sustainable

AVL Japan and WASEDA University Symposium

December 14th, 2023

G Meister

We are in the Middle of a Transformation

We strive for two Goals: Climate-Neutrality and Energy Security

EU wants to become the 1st carbon neutral continent by 2050

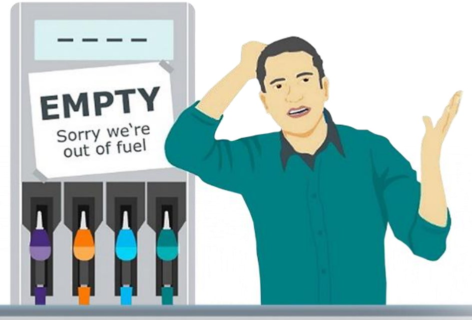
United States to achieve a 50-52 percent reduction from 2005 GHG levels in 2030, net zero by 2050

China will peak emissions before 2030 and aims to achieve carbon neutrality before 2060

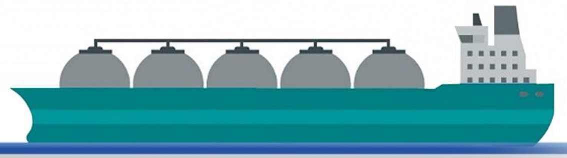
Japan aims for zero emissions, carbon neutral society by 2050

Net zero by 2070

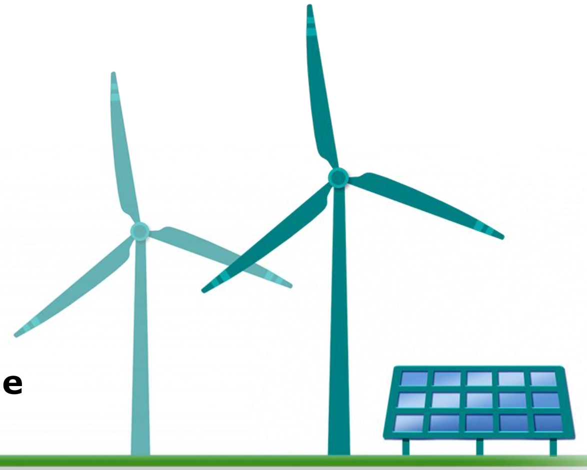
Energy Security



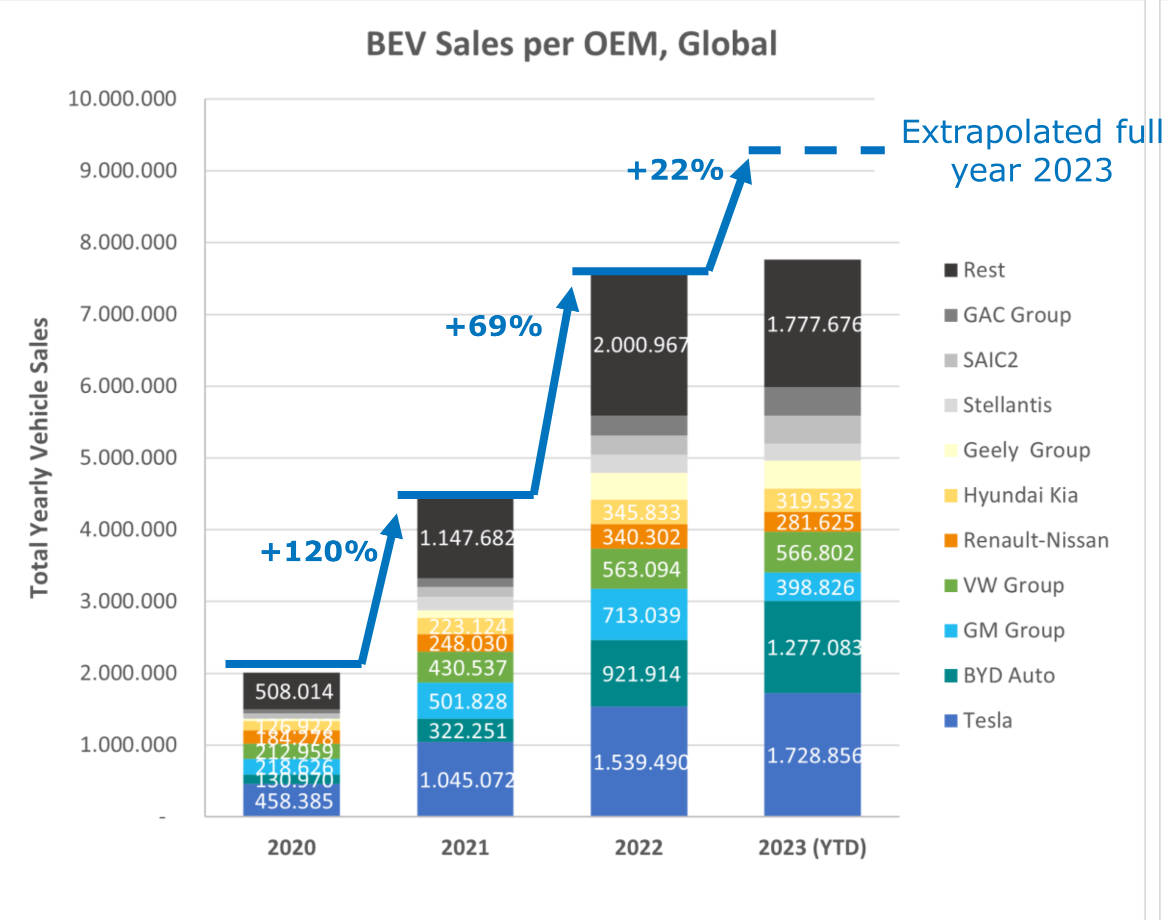
Energy Trade

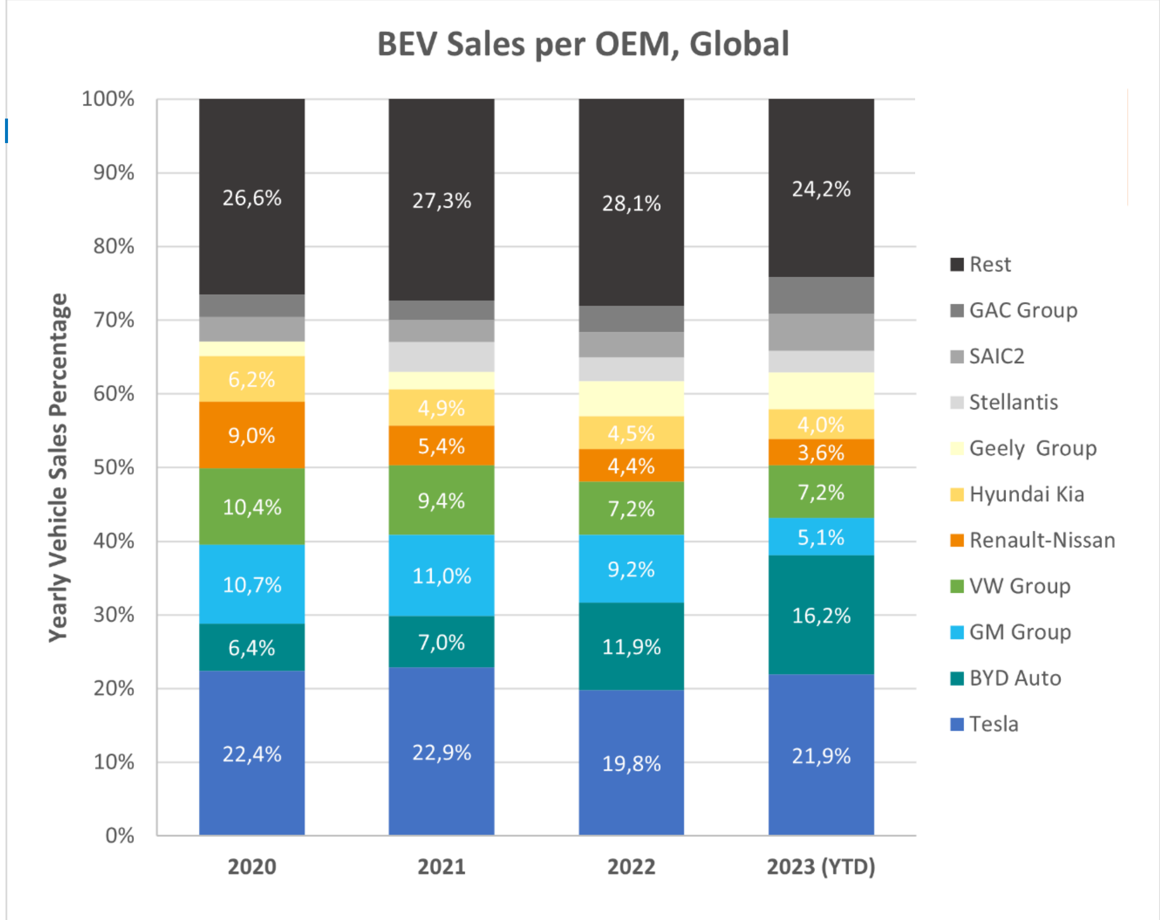


Sustainable Energy



Reality Check - Status September 2023
EV Passenger Car and LDV Sales, OEM share - global





- BEV sales growth significantly outpaces the total market, slowing in %
- It is getting crowded in the BEV market

Data source: Marklines Oct 2023

Main Factors Influencing BEV Deployment

Range

Carbon neutral electricity

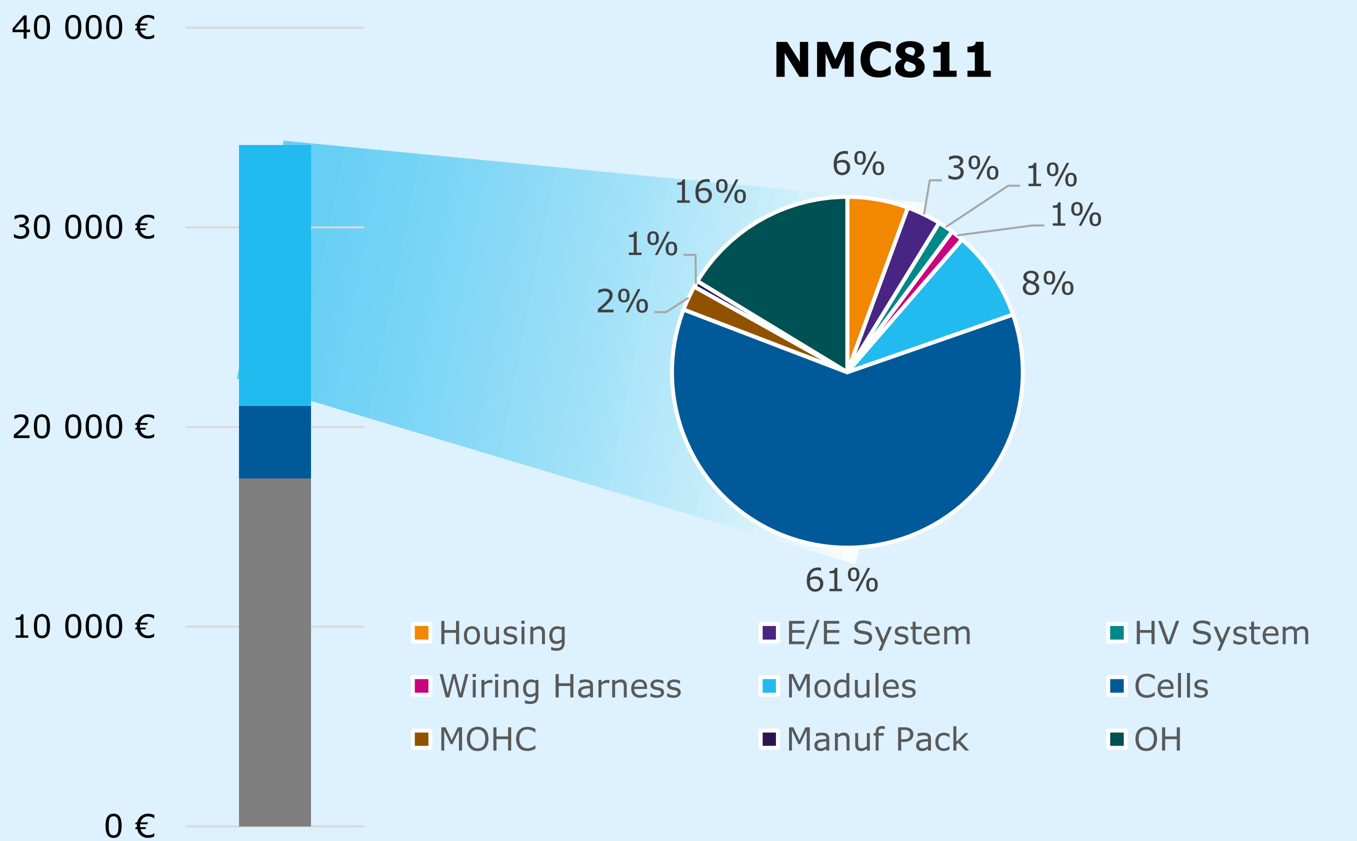
Infrastructure

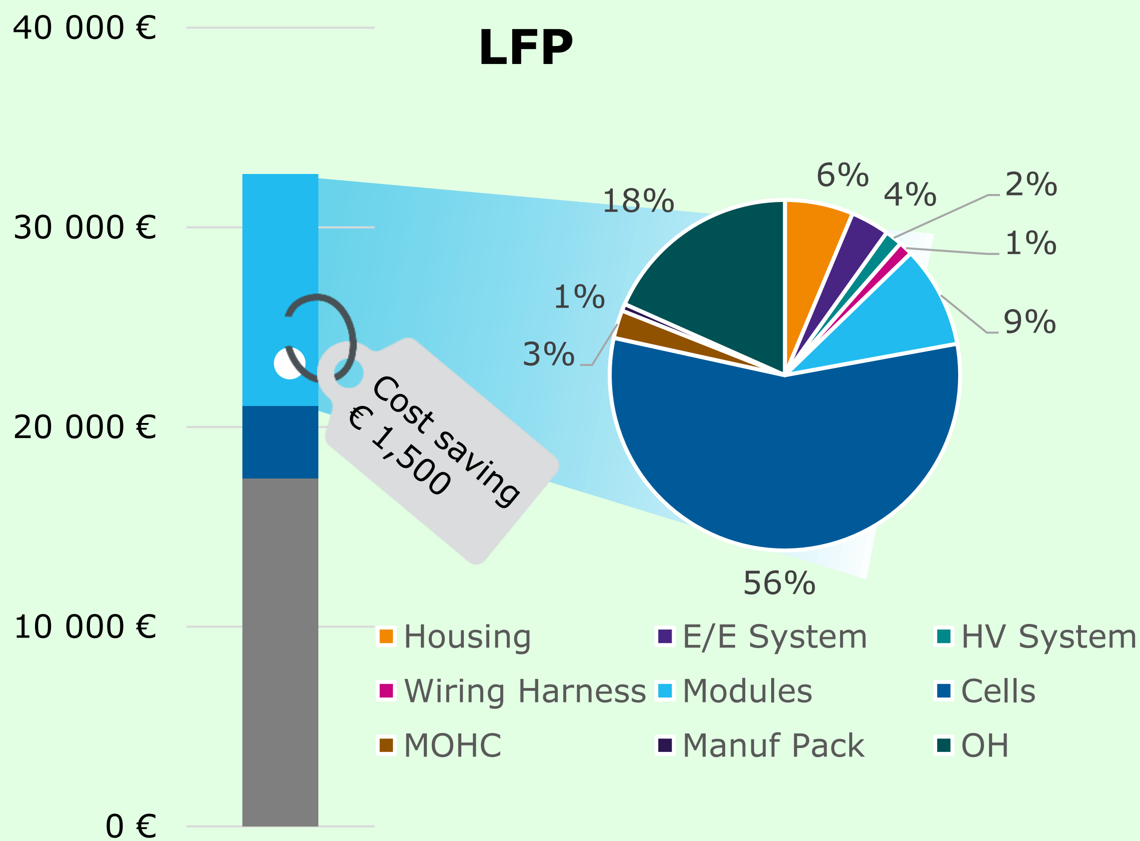
Vehicle Price

Image sources:
- https://blog.evbox.com/far-electric-car-range
- https://www.generalkinematics.com/blog/what-is-green-power/
- https://techcrunch.com/2021/07/13/
- https://insideevs.com/news/565883/electric-car-prices-us/

Cost Effective e-PT Solutions

Passenger Car BEV Product Cost Break-Down
Share of Battery and e-PT of Total Vehicle Cost





- Battery
- PT Others
- Body (incl. BiW, Chassis, ..)

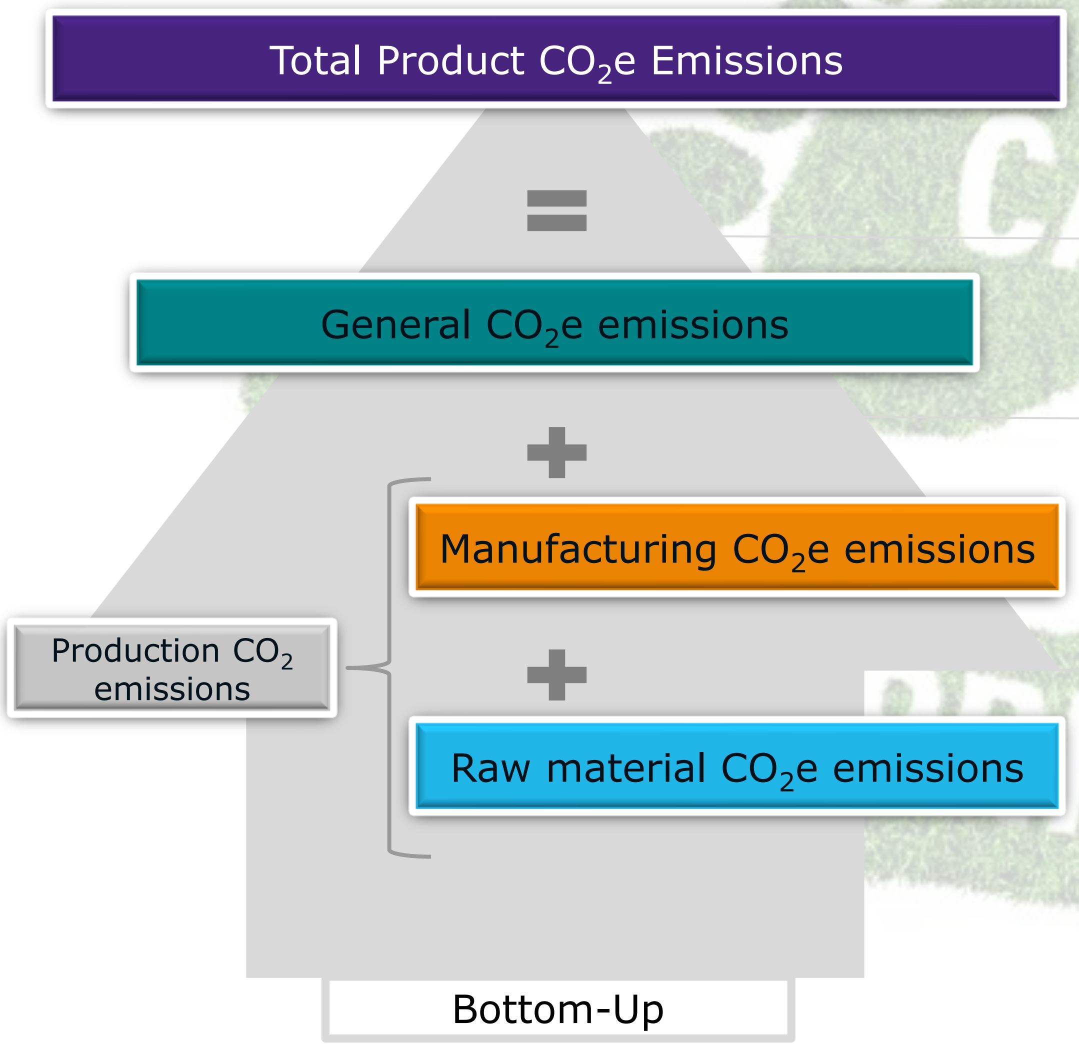
Cell Design	Prismatic	**Annual Output (both)**	20 GWh
Cathode Type	NMC811	**Cells per Year (both)**	70 Mio. pcs.
Segment	D	**Battery size (both)**	73kWh

- Battery
- PT Others
- Body (incl. BiW, Chassis, ..)

Cell Design	Prismatic
Cathode Type	LFP
Segment	D

Sustainability - Design for CO_2, Bottom-Up Calculation

Supply Chain Environmental Impact Analysis focusing on Carbon Footprint [kg CO_2e]

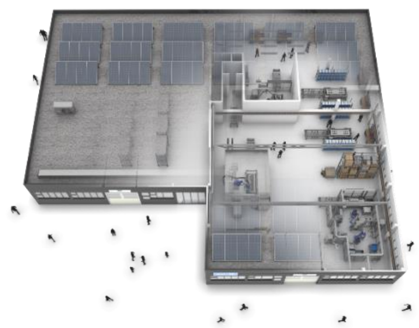


Emissions during production of one product / assembly according to standards:

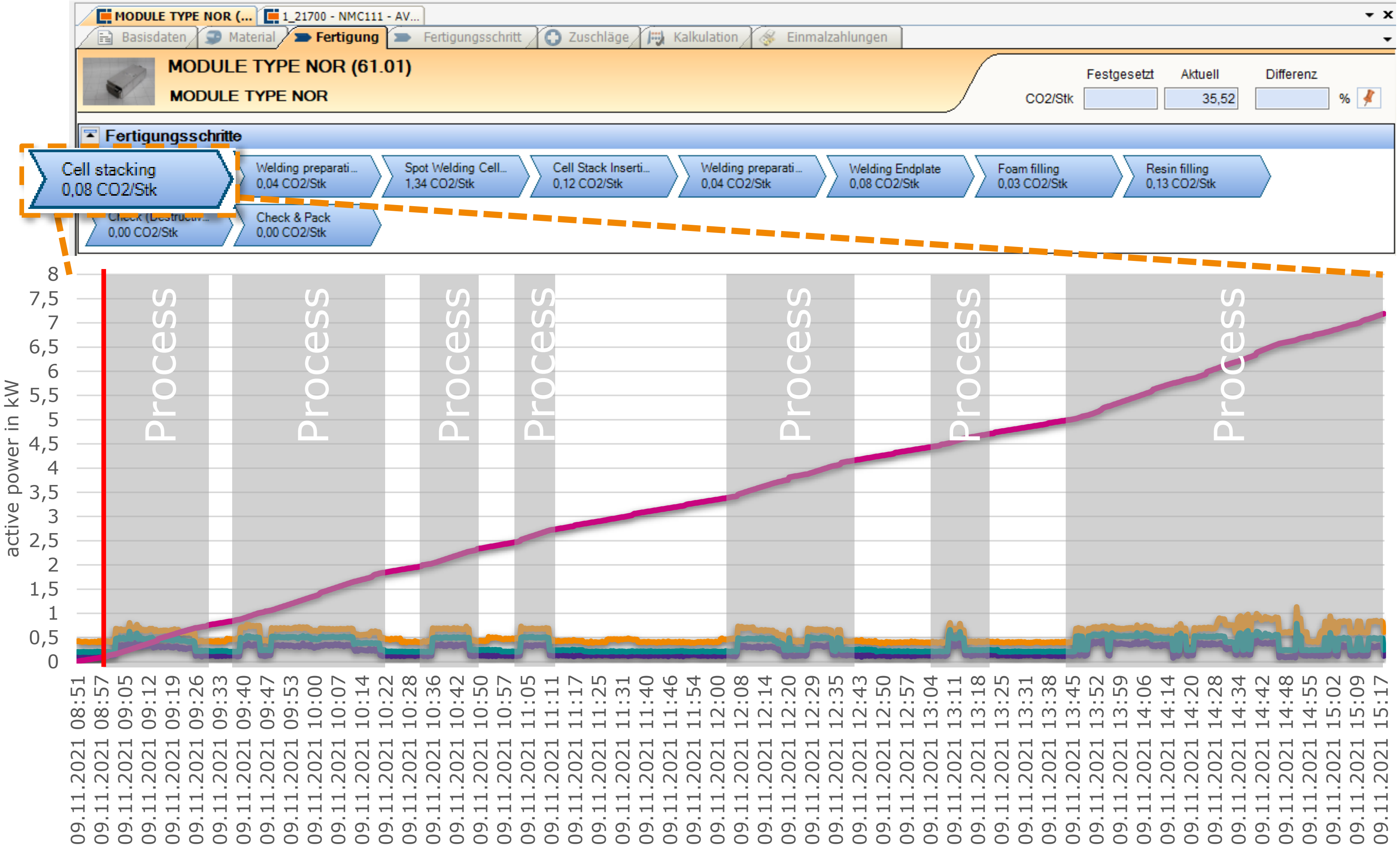
ISO 14067 · Carbon Neutral PAS 2060 · European Commission

Examples	Sources	Tools
Country-specific overheads, warehouse, logistics	Customer input, AVL Assumption	SIEMENS, iPoint
Emissions from energy consumption	Customer input, AVL measurement data and simulation	SIEMENS, iPoint
Raw material usage and srap	Supplier database, purchased databases, public databases	ecoinvent

Primary Energy Consumption and Emission Measurement at AVL BIC for Carbon Footprint Assessment [kg CO_2e]

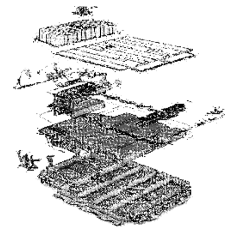


- Integration of measured values in CO_2e modeling
- Digital-twin for energy-based control & scheduling of production



Cost Optimization by Higher Level of Integration

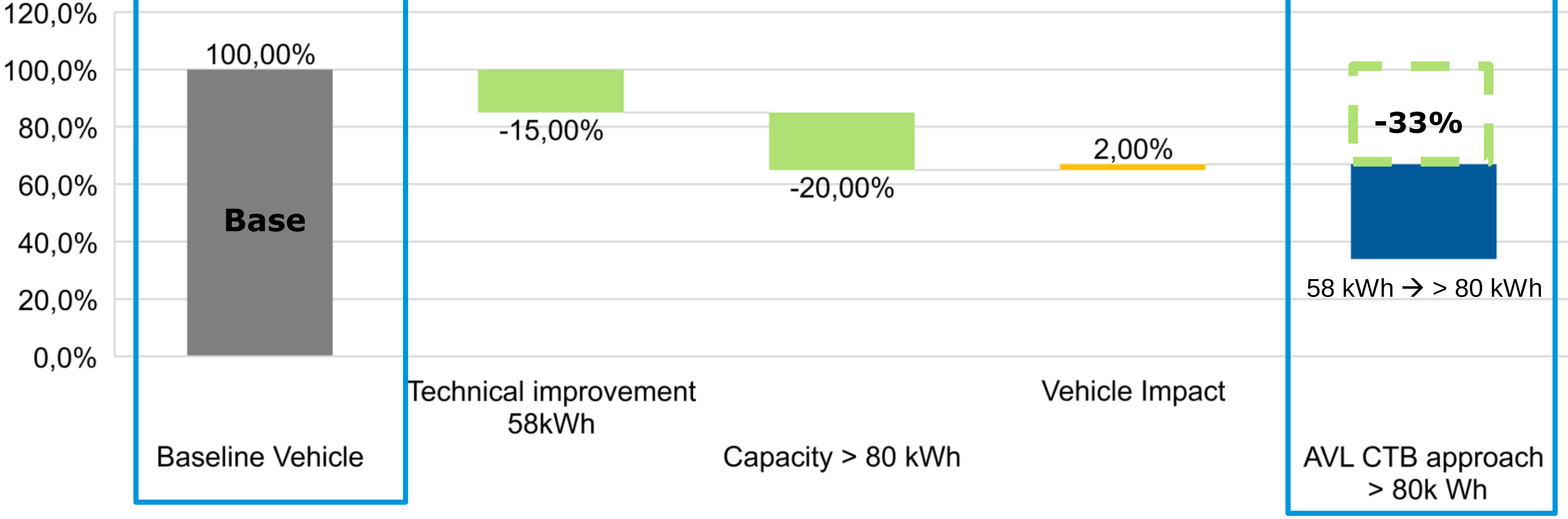
Battery Pack – **Focused Cost Down** Approach, Impact of CMP to CTC



Evaluation is on €/kWh base, presented in percentage.

The presented values are only valid with unified commercial boundary conditions, **without cell costs.**

Base: C-segment CUV battery pack in €/kWh



Baseline Vehicle	Technical improvement 58kWh	Capacity > 80 kWh	Vehicle Impact	AVL CTB approach > 80k Wh
Baseline C-segment crossover battery pack was provided as an input	Cell2Body layout with new cell arrangement, integrated controller, new cooling and EE unit	Due to the optimized battery pack structure additional capacity can be implemented	Add-on costs are considered: Increased stiffness and sealing for BIW structure	Significant cost reduction by higher level of integration in EUR/kWh

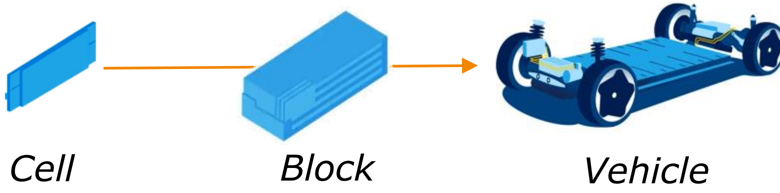
Increase

Decrease

Conventional battery cell integration

Cell-to-pack integration

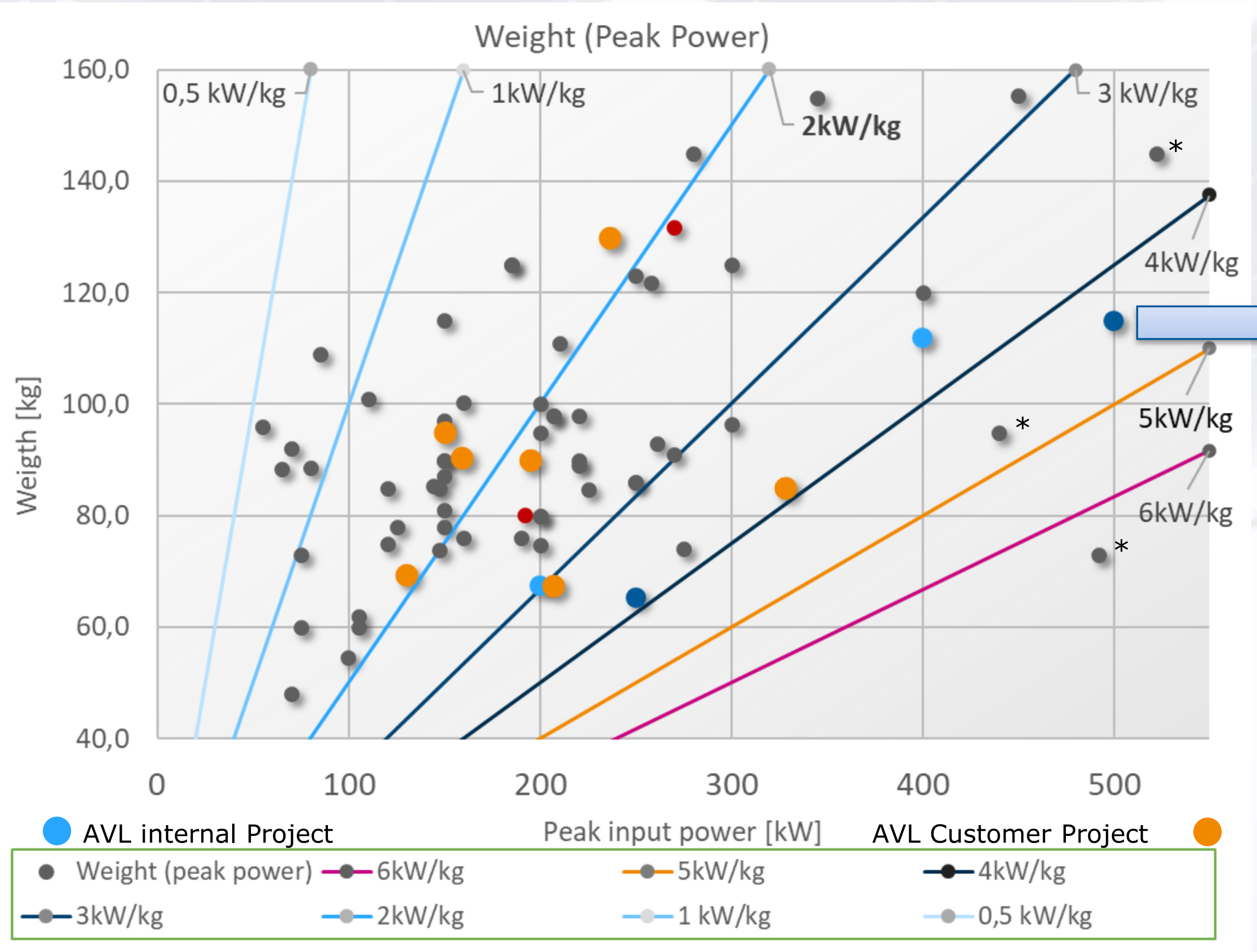
Cell-to-chassis integration



Remarks:
- Values and comments are neutralized
- Baseline values are from AVL benchmark activity

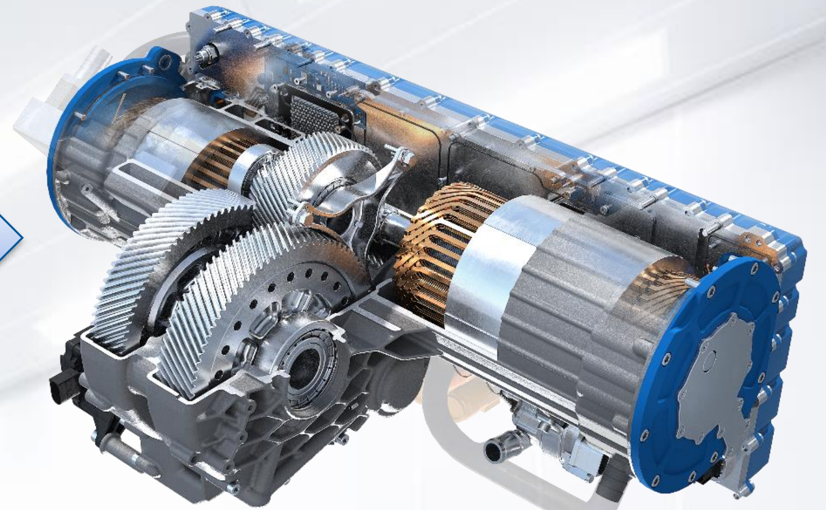
Cost Effective High-Performance EDU

AVL High-Speed Electric Drive Unit – Main Properties



* Information based on benchmark data

AVL High-Speed EDU – GEN 2



EDU Weight
116Kg

Max Speed
30000rpm

Peak Power
500 kW (250 kW/EM)

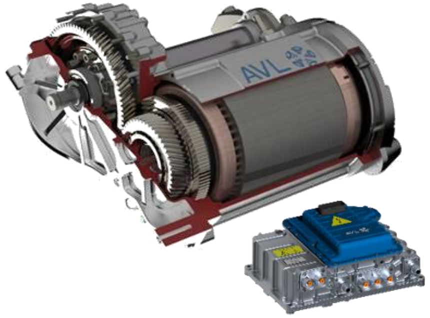
Power Density
4,31 kW/Kg

Demo Vehicle
Test drive possible on request

Cost Effective High-Performance EDU

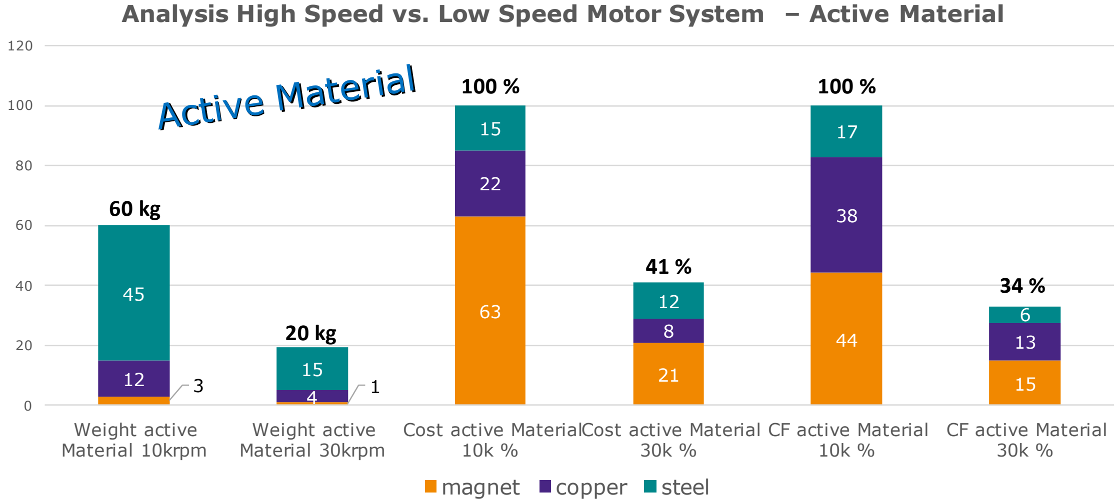
Standard-Speed vs High-Speed Approach

High Torque Motor vs **High Speed Motor**



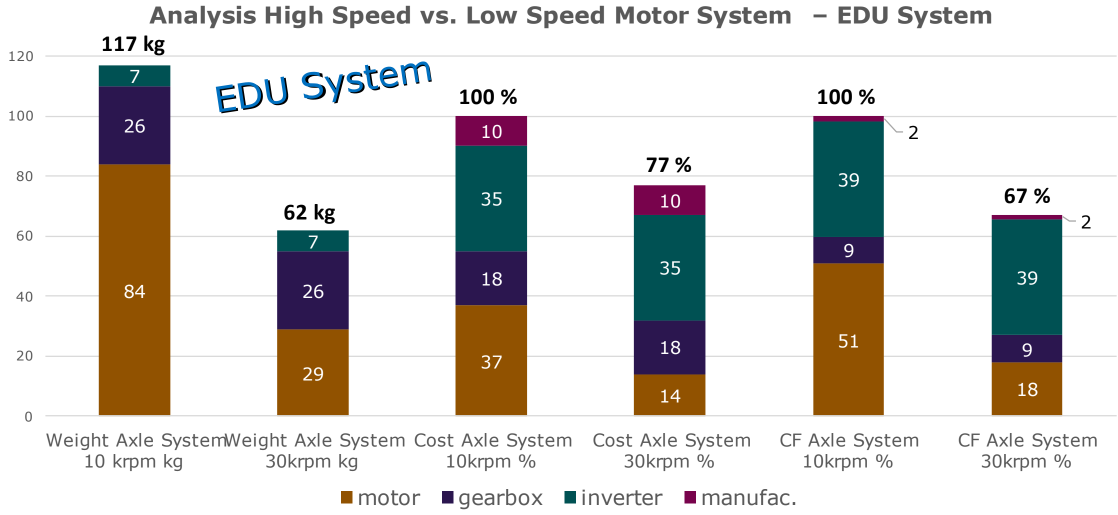
System HM132
- 250 kWpk
- 10000 rpm
- 4800 Nm
- 800 V
- 117 kg

System High Speed
- 250 kWpk
- 30000 rpm
- 3100 Nm
- 800 V
- 62 kg



Speed increase

-59% cost
-40 kg weight
-66% CO_2e



Speed increase

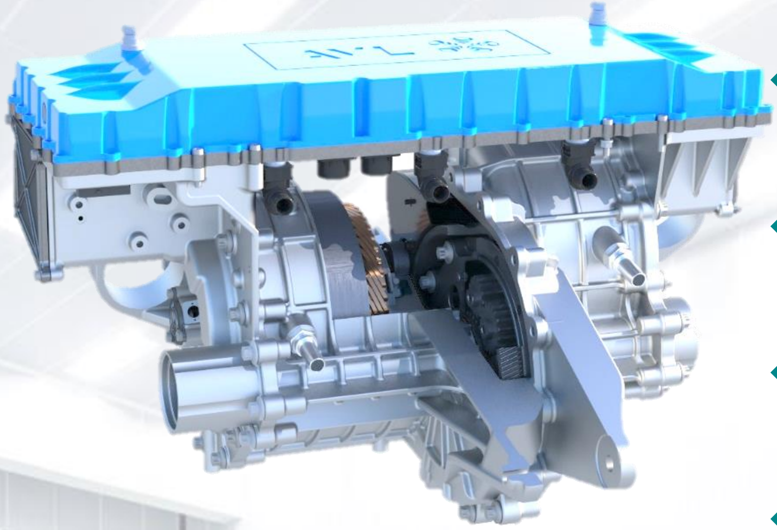
-23% cost
-55kg weight
-33% CO_2e

AVL High-Efficiency BEV Project

Dual Drive High-Efficiency EDU - Design Concept and Features

Main Design Features

- 2 EM concept for max. efficiency
- Decoupling of booster E-Motor
- Dual inverter based on AVL PI850e
- Loss optimized Transmission

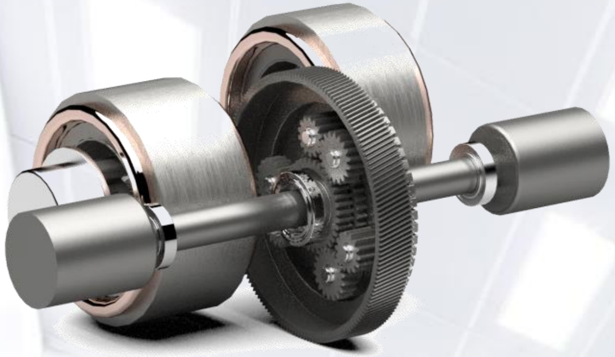


Special Design Features

- Special Gear Setup
- Passive Dry Oil Sump
- Advanced Hairpin Windings
- Compact Differential

AVL High-Efficiency BEV Project

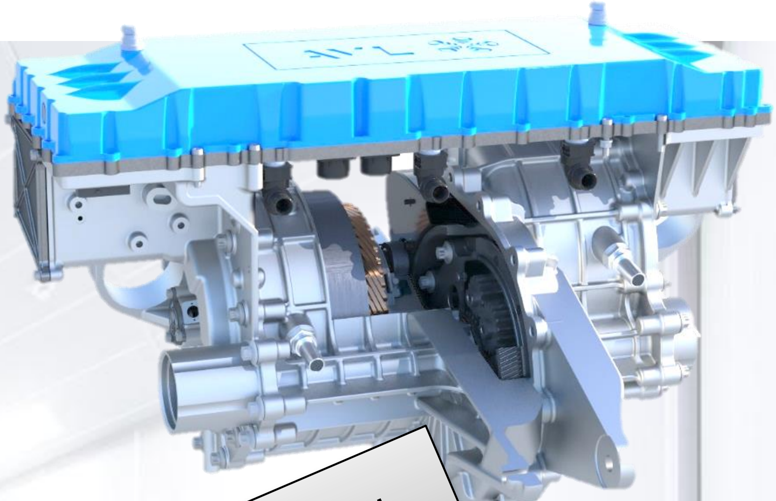
Dual Drive High-Efficiency EDU – Operating Strategy and Efficiency in WLTP

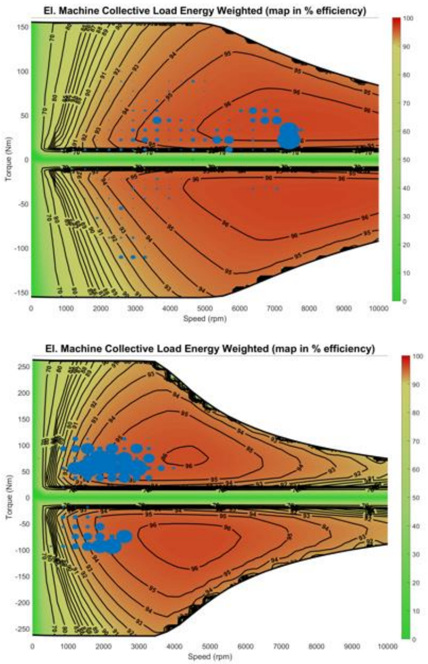


WLTC 94,1%

RLC 93,9%

System optimizer



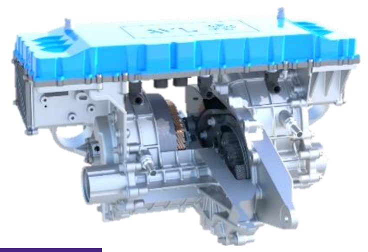


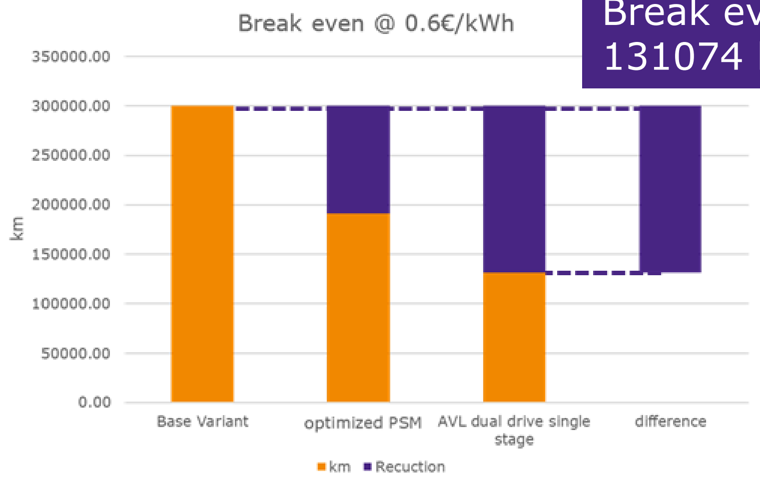
Validation on test bed in Q2/2024

Baseline EDU (single speed EESM) WLTP efficiency 88%
=> 6% efficincy gain

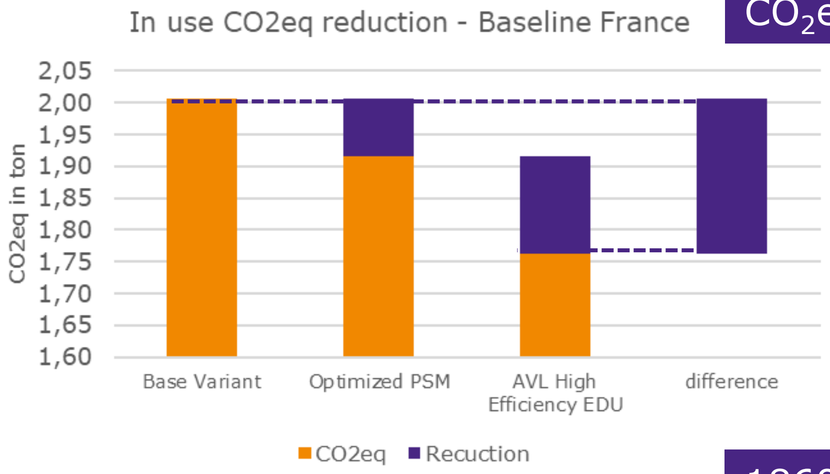
AVL High-Efficiency BEV Project

Dual Drive High-Efficiency EDU – ROI and CO2 Impact In-Use

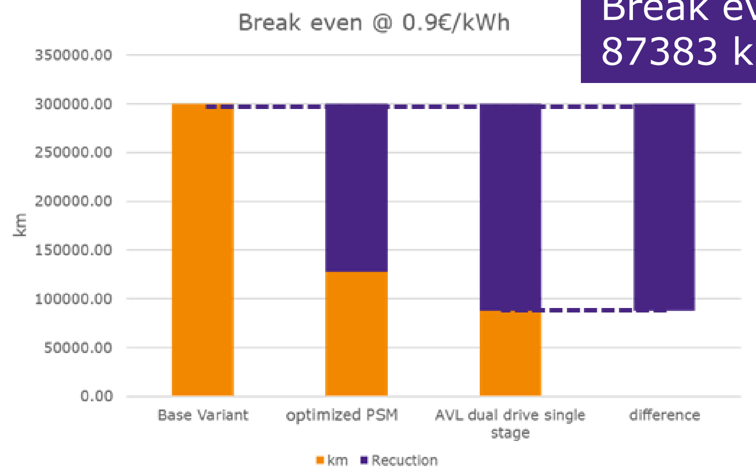




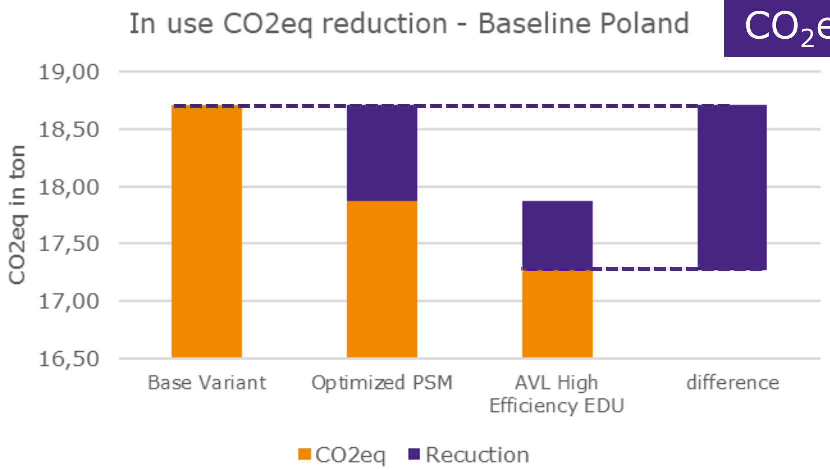
Break even after 131074 km



240 kg CO_2eq reduction



Break even after 87383 km



1860 kg CO_2eq reduction

Assumptions: C-segment | BEV: Propulsion 150 kW, Battery 60 kWh (330 km range) | lifetime 300,000 km

Battery Safety

Public

Thermal Runaway vs. Thermal Propagation

- **Thermal Runaway**

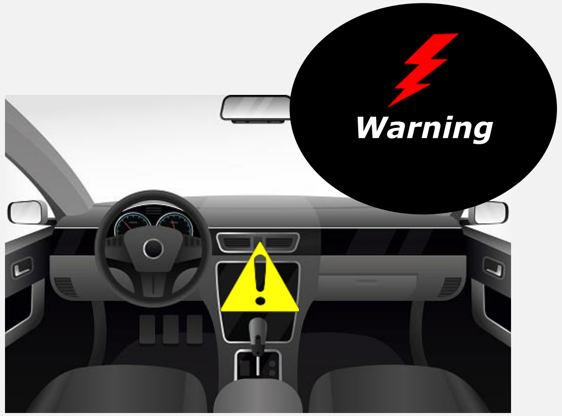
The phenomenon of uncontrollable rapid rise of the cell temperature.

- **Thermal Propagation**

Phenomenon of thermal runaway of adjacent remaining cells in succession, caused by the thermal runaway of an individual cell or cell group in the battery pack or system.

Single Cell Failure

Event Detection



Hazard Event

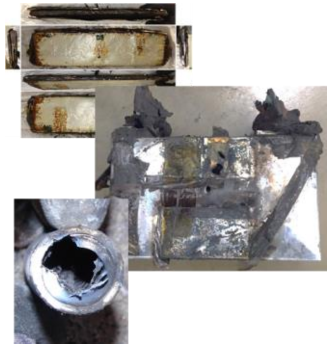
No Propagation Design

The Only Way to Ensure Safety in Every Circumstance

No Propagation **Requires**

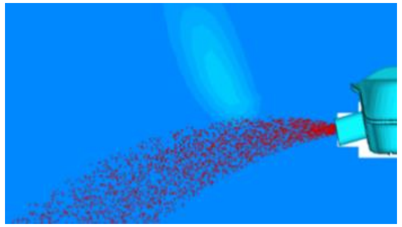
Right chemistry & cell packaging

- Cell tests and benchmarking
- Cell selection studies



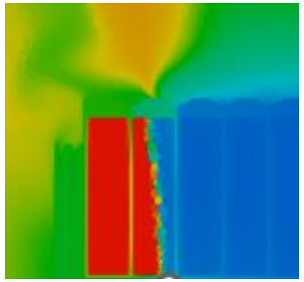
Avoiding ignition

- Gas guidance
- Gas cool-down within venting path
- Trapping ejected particles



Stop cell-to-cell propagation

- Proper energy balance
- Mix of insulating cells and distributing heat

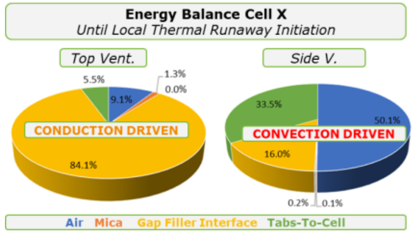


No arcing and no short-circuiting

- Separation of HV and venting path
- Consider particle ejection areas

Heat sink

- Distributing heat and releasing energy
- Increased time allows for event area cooling



Designing “No Propagation” requires **key** design principles

AVL BSCG Graz | AVL Simulation and Design Methodology

Thermal Runaway Tests – Immersion Cooled Battery
Impact of Dielectric Fluid on TP Behavior

Variant 1 Medium Reaction	Variant 2 Severe Reaction	Variant 3 Safe Reaction
		

Right fluid selection for safe battery design

AVL Software and Simulation Methods for Designing No-Propagation Battery Packs

Challenges:

Cell Thermal Runaway

Cell2Cell Propagation

Cover Deformation

Sealing, Tightness

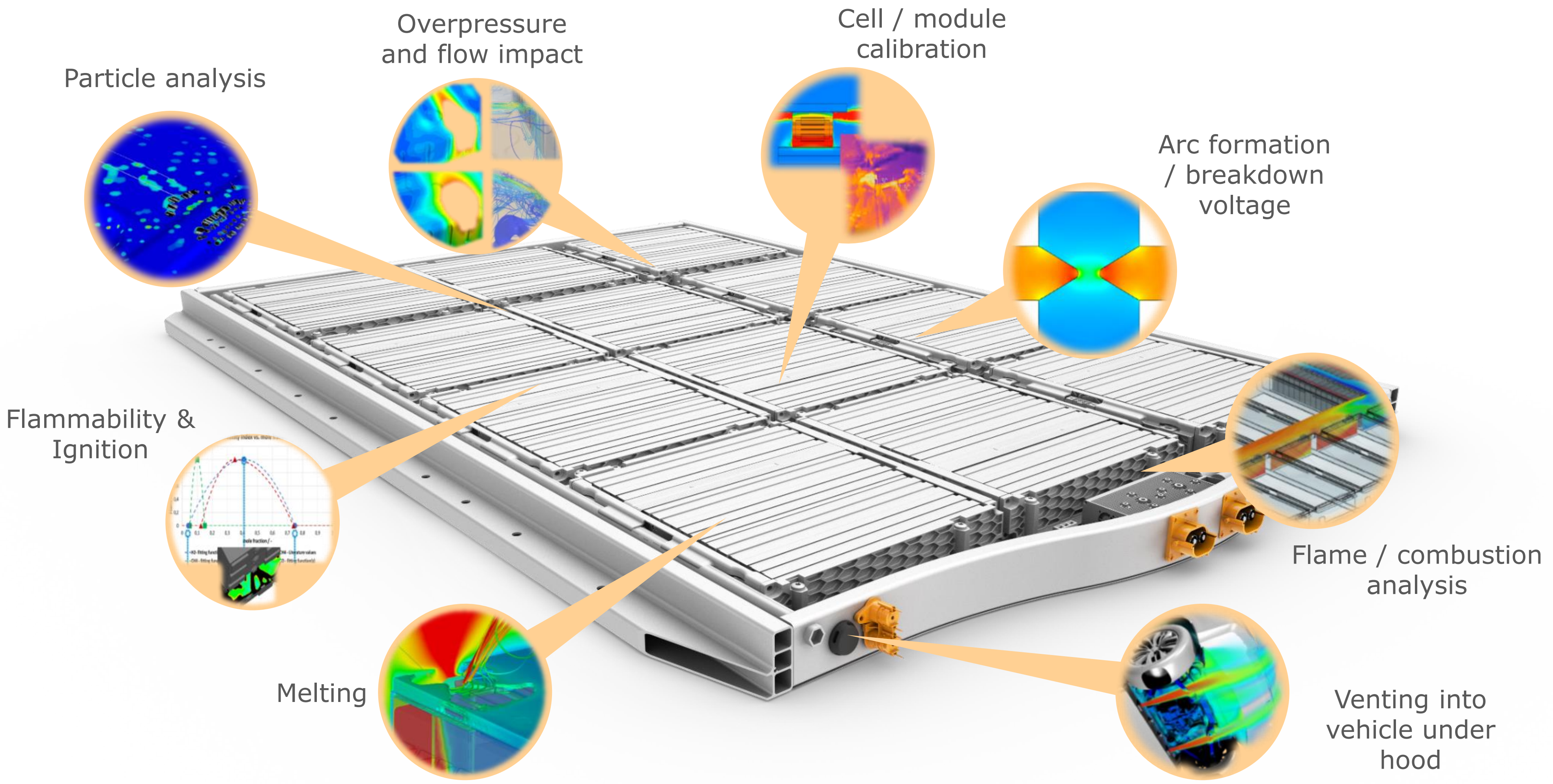
Venting device

Gas Ignition

Material melting

Particle Abrasion

Arcing & breakdown voltage

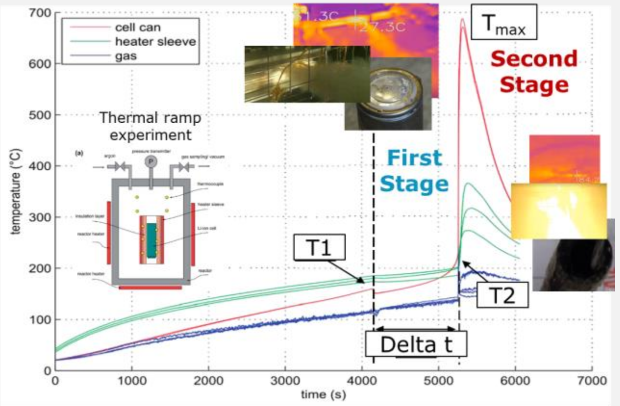


Cell Thermal Runaway as Driver of Thermal Propagation Modeling of Fast Heat Release, Gas & Particle flow

Electro-Chemical Cell Abuse Behavior

Exothermic reaction that is accelerated by temperature rise in 2 phases:

- 1st: slow temperature rise
- 2nd: very fast & severe



- **T1** = first onset T
- **T2** = second onset T
- **T max** = maximum T
- **Delta t** = time between T1 & T2

Cell Characterization Testing

Standard test program

- 3-4 tests
- Thermally triggered event

Measured quantities

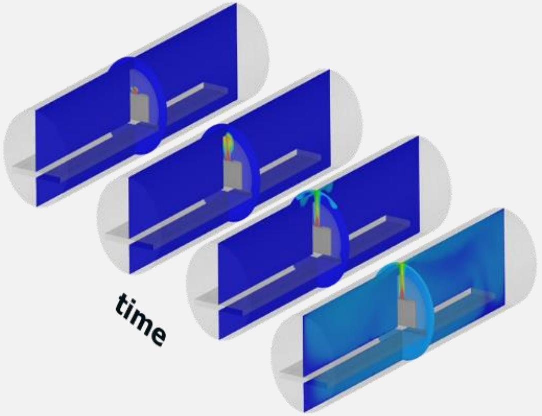
- Heat release
- Gas temperature & pressure
- Gas volume & composition
- Particle traces & composition

Gas & Heat Release Model

Modeling of

- Gas release
- Temperature dependent heat release
- Gas composition after venting event
- Cell expansion
- Particle flow

Model validation

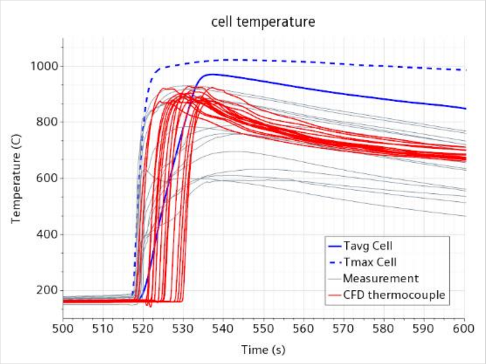


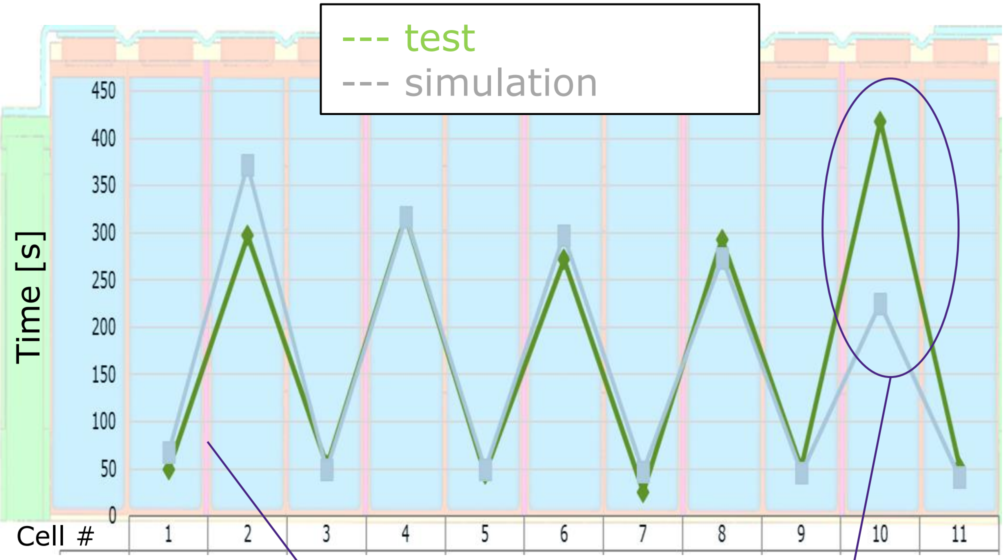
Verification of Simulation with Physical Testing

Good Correlation of Propagation Time Prediction Considering all Involved Phenomena

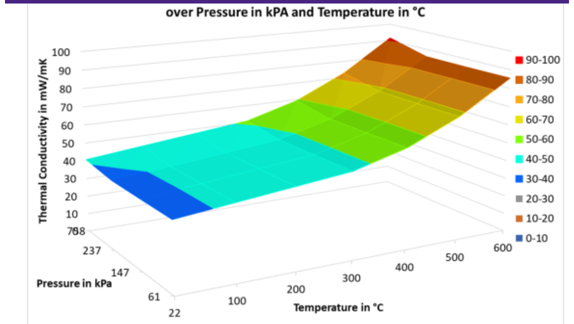
Relevant Input Values

- Cell heat release
- Cell venting gas release
- Cell particle ejection
  - Rate
  - Distribution
  - Material composition
- Cell trigger influence
- Cell expansion during TR
- Thermal resistance
  - Jelly roll to housing
  - Thermal barrier
    - Temperature influence
    - Compression influence

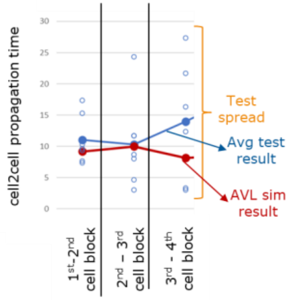




Thermal barrier function vs compression and temp level



Stochastics in TR/TP behavior



Relevant Phenomena

- Cell trigger characteristic
- Heat path
- Coupled gas side
- Mass loss of cell
- Mechanical deformation
- Mechanical particle impact
- thermal particle impact
- Material melting
- Electrical failures & short circuits
- Module environment (gas side)
- Venting gas release
- Oxygen availability
- Stochastics in behavior at all

From 5min Warning to Safe Batteries

Current and Future Acceptance Criteria

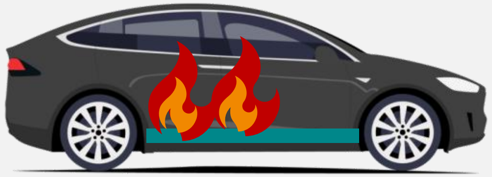
SOP launch

Today → 2026 → 2028

WARNING
Warning signal to passengers

>5 MINUTES
Duration between TP events

Potential FIRE/GAS in cabin

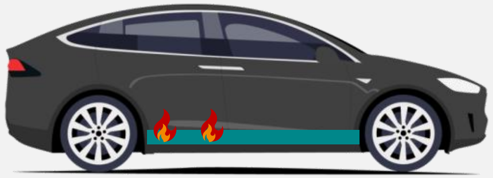


Danger in the passenger compartment or for the passengers

WARNING
Warning signal to passengers

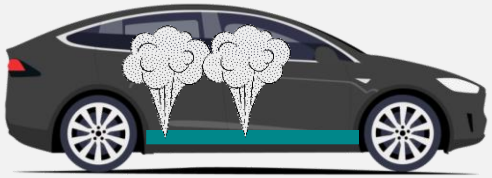
Never
Ignition of exhausted gases

"No Flame Out"



Never
Gas exhausted from the vehicle

"No Gas Out"



Thank you

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