Electrification Trends vs Global Demand

Waseda University - AVL Japan Joint Symposium

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G. Meister

AVL List GmbH

EV Market

Primary Factors Influencing BEV Adoption

Range & Charging Anxiety

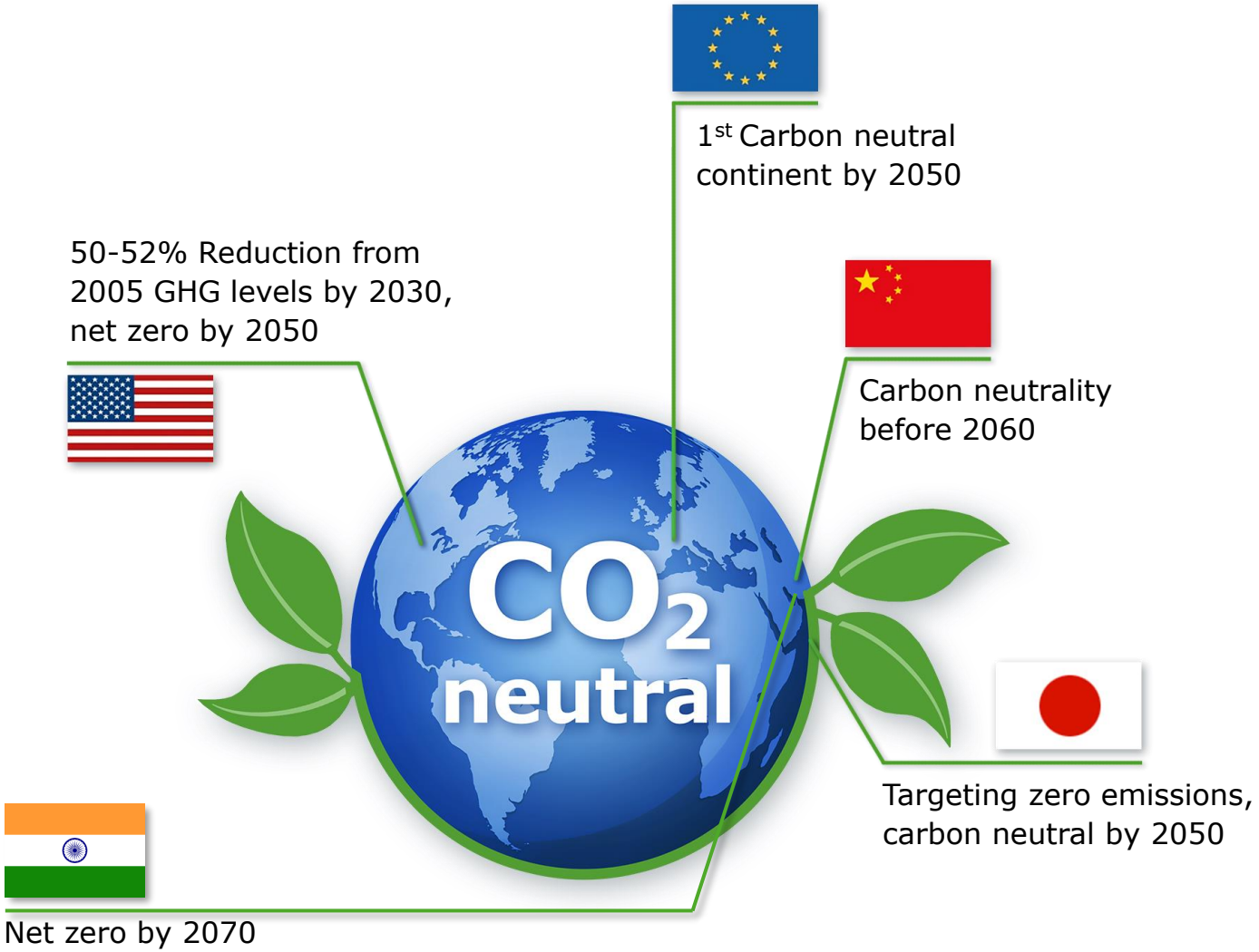
Carbon Neutral Electricity

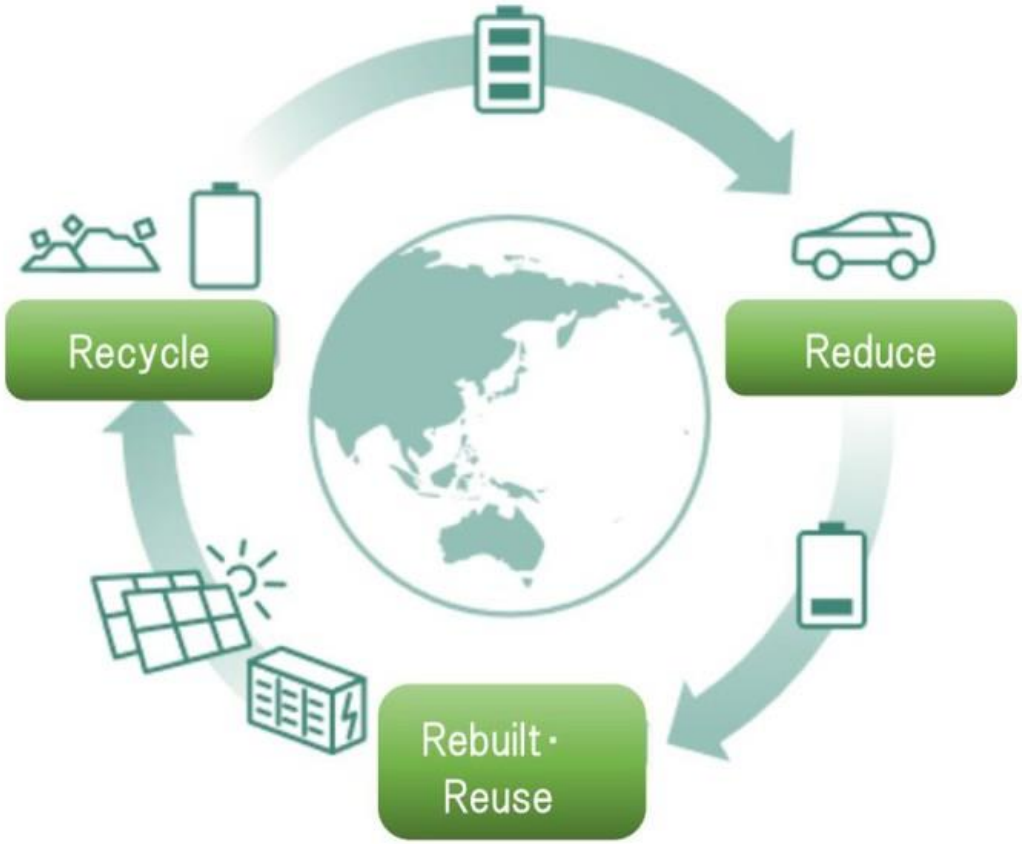
Vehicle Value - Price, Incentives, Residual Value

Safety

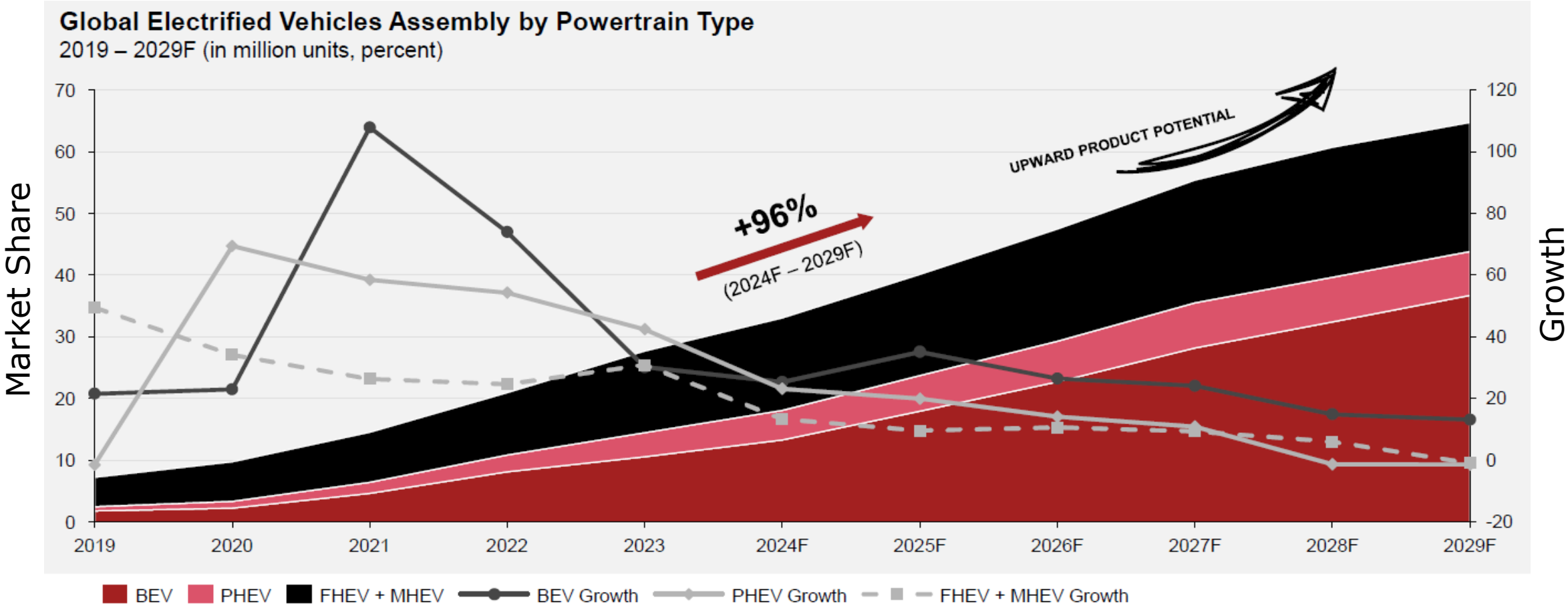
Sources:
- https://blog.evbox.com/far-electric-car-range
- https://www.generalkinematics.com/blog/what-is-green-power/
- https://techcrunch.com/2021/07/13/
- https://insideevs.com/news/565883/electric-car-prices-us/

We are in the Middle of a Transformation
Striving for Climate Neutrality and Material Circularity





Global Electrified Vehicle Assembly
Forecast by Powertrain Type

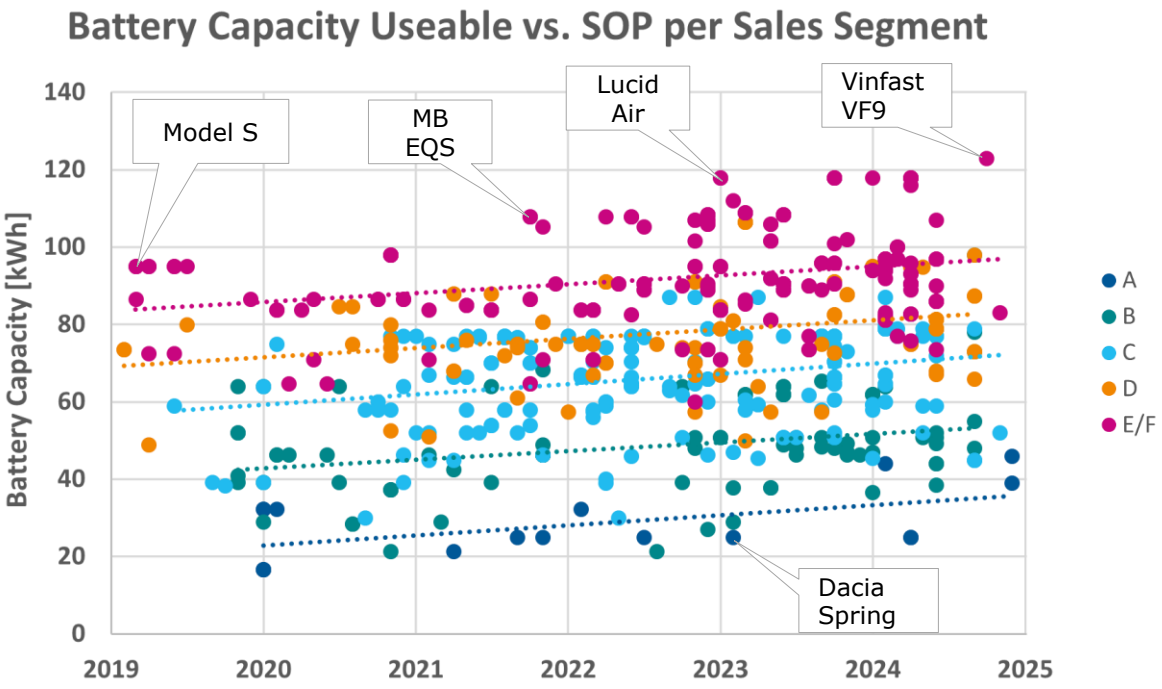


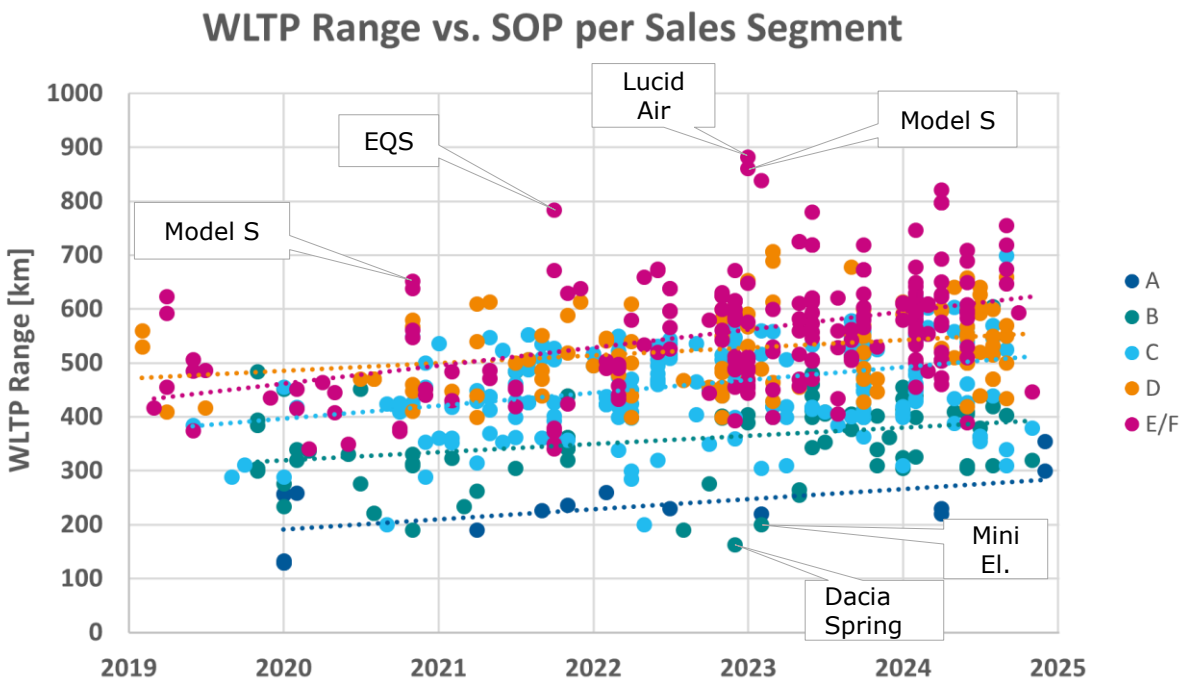
BEV is expected to outperform other powertrain options in the mid-term driven by regulations despite short term slow-down.

Source: S&P Global Mobility Light Vehicle Production Powertrain forecast, April 2024 Review Market: Global

EV Technology

EU Market Data
Tech Trends – Battery Capacity and WLTP Range

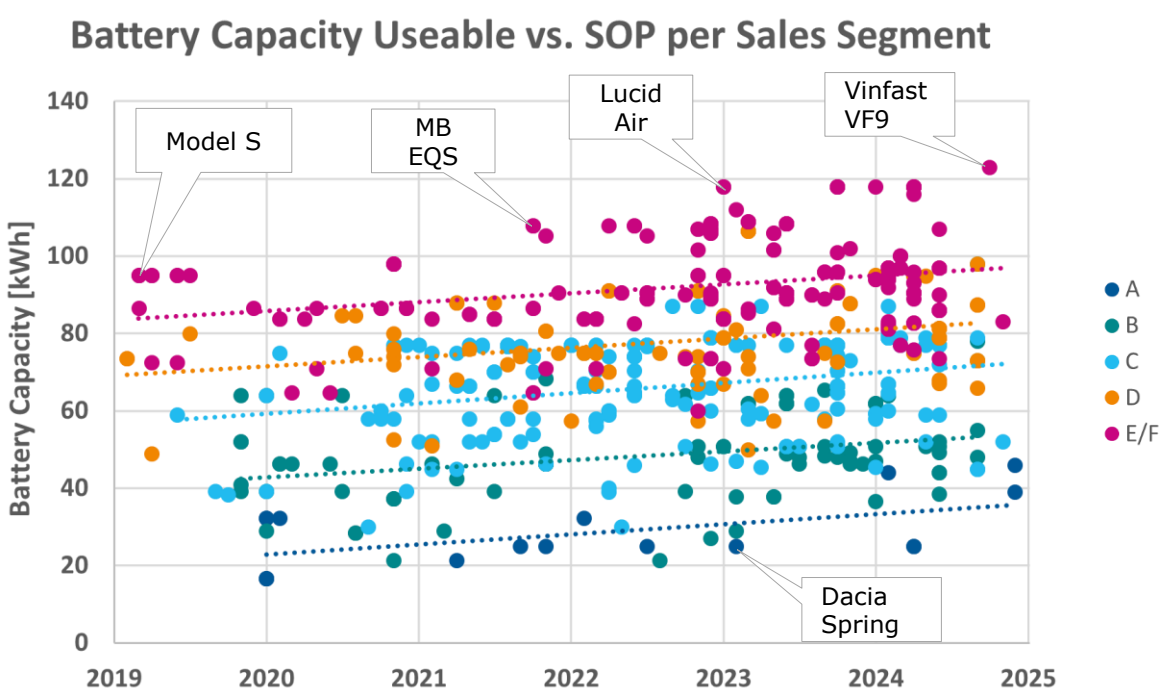


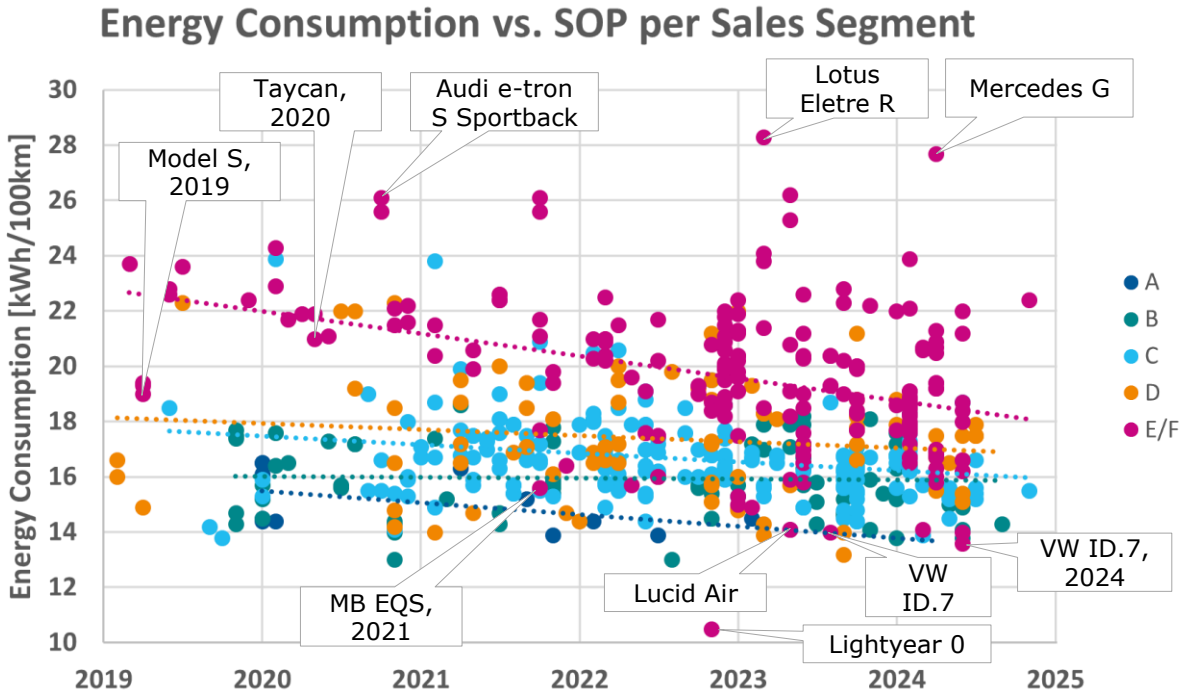


Trend: Capacity / Range Increases to address Range Anxiety
Latest Concern: Increased Anxiety of Charging Time and Availability

Sources: 7-2024 ev-database.org/

EU Market Data
Tech Trends – Battery Capacity and Energy Consumption

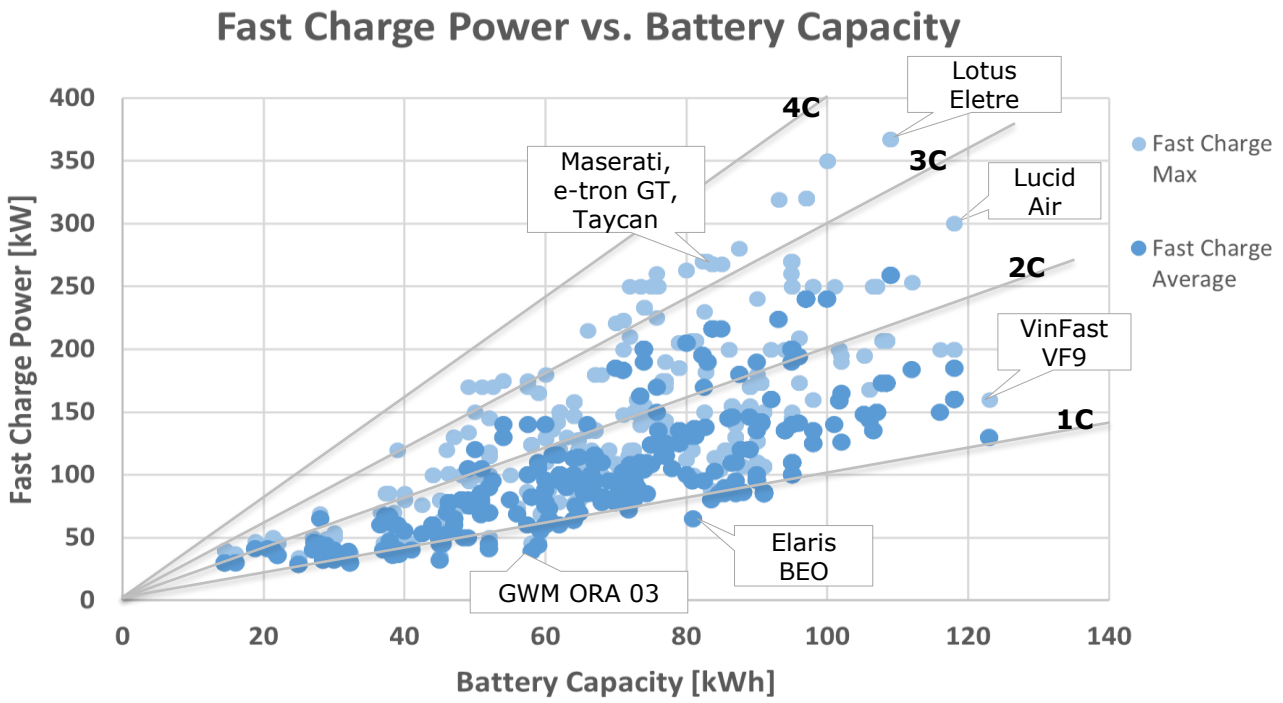


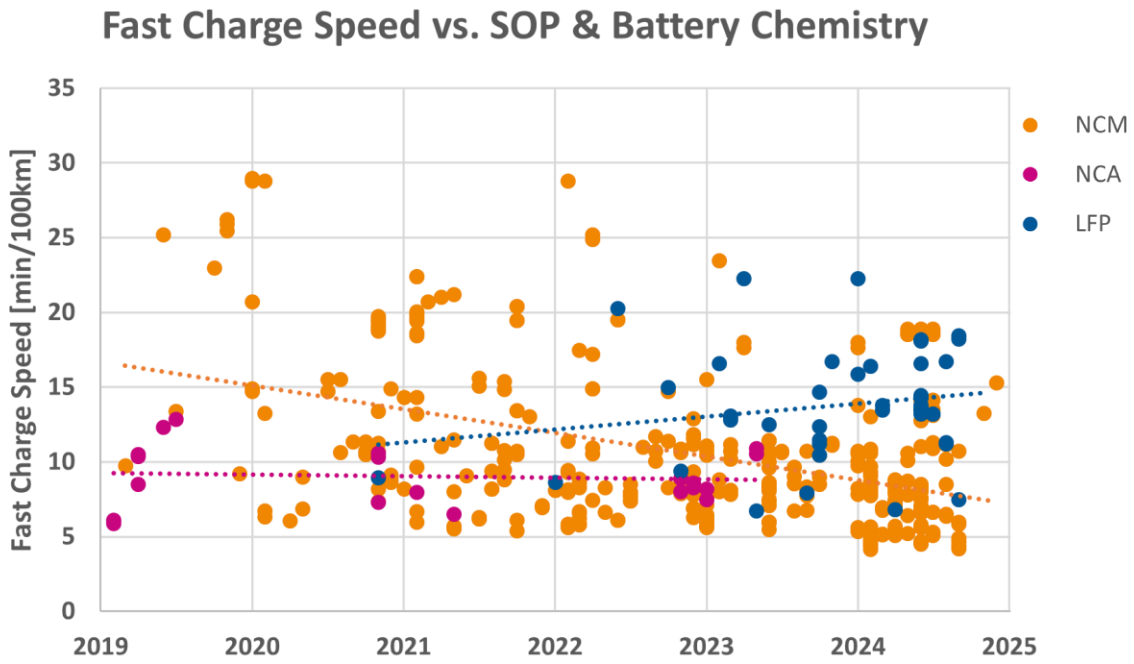


Trend: Capacity / Range Increases to address Range Anxiety
Battery capacity can be reduced when energy efficiency is improved

Sources: 7-2024 ev-database.org/

EU Market Data - Comparison of Fast Charging Capability





Fast Charging Capabilities are strongly improved for NCM Chemistries

Source: 7-2024 ev-database.org/ Market: Europe

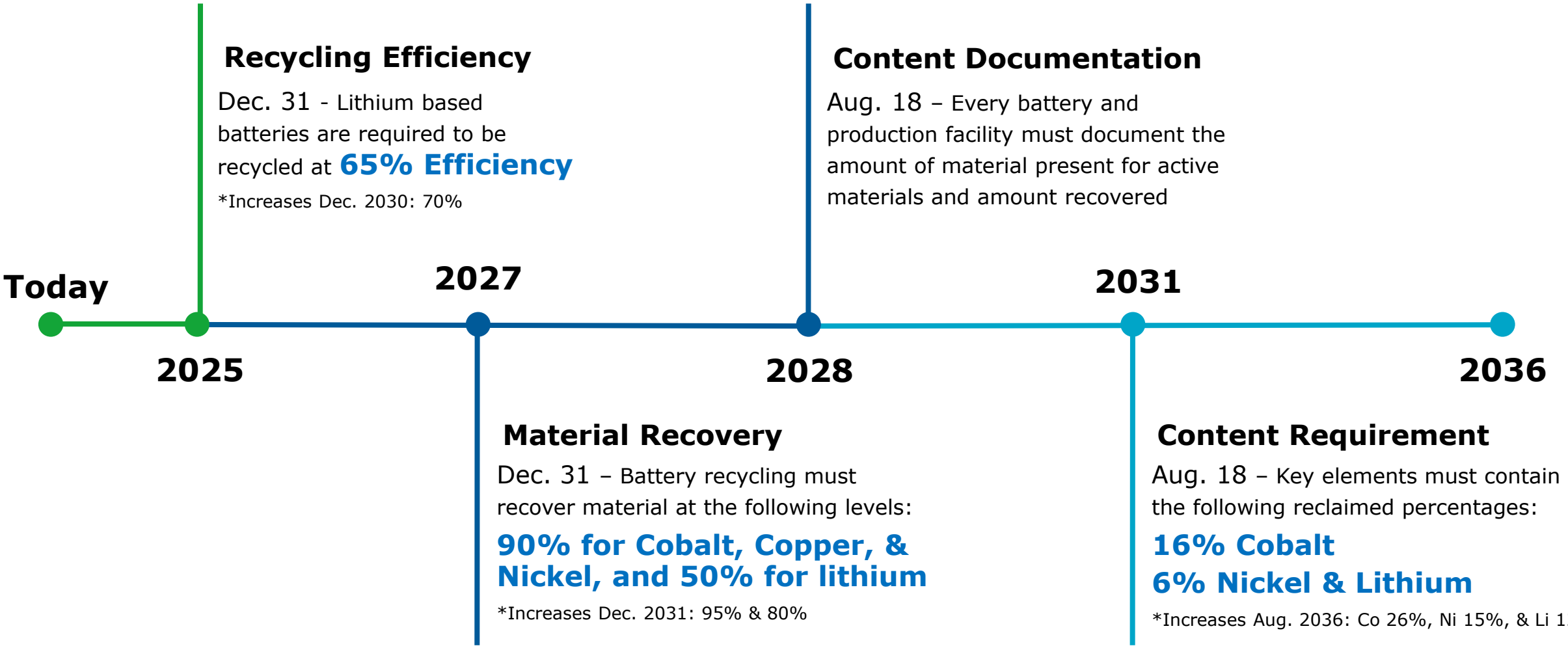
1 BEV Market and Technical Trends

2 **Sustainability Targets vs Current State of The Art Battery Design**

3 Battery Safety

Key Milestones for Battery Recycling Regulations in Europe

Articles 8 and 71 of the 2023/1542



Benchmarking of Battery Concepts

Evaluating Mainstream Design with Regards to Serviceability and Recyclability

C2P – Cell to Pack

Nio ET 7

Battery Data	
Energy Content (usable)	70.5 kWh
Energy Density	131Wh/kg
Voltage nominal	386 V
Cell number	118
Cell type	NMC & LFP
Configuration	118S1P
Cooling	liquid
Weight	535 kg

C2C – Cell to Chassis

BYD Seal

Battery Data	
Energy Content (usable)	82.5 kWh
Energy Density	142Wh/kg
Voltage nominal	550V
Cell number	172
Cell type	LFP
Configuration	172S1P
Cooling	refrigerant
Weight	581 kg

C2M – Cell to Module

VW ID3

Battery Data	
Energy Content (usable)	58 kWh
Energy Density	154Wh/kg
Voltage nominal	396 V
Cell number	216
Cell type	NMC
Configuration	108S2P
Cooling	liquid
Weight	376 kg

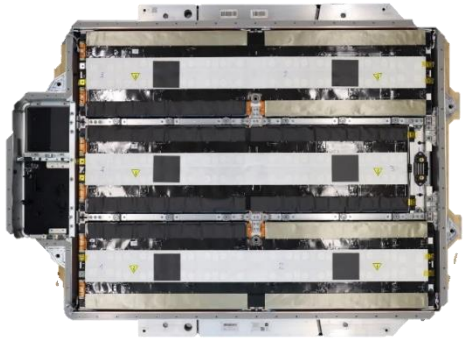
Benchmarking Battery Design

Are Today's Batteries Aligned to Regulation and Efficient Sustainability?

C2P – Cell to Pack

Nio ET 7 (75kWh Prismatic LFP & NMC)

- Cells are retained by bottom plate bonding
- Serviceability is limited
- Recycling via shredding or labor-intensive disassembly process

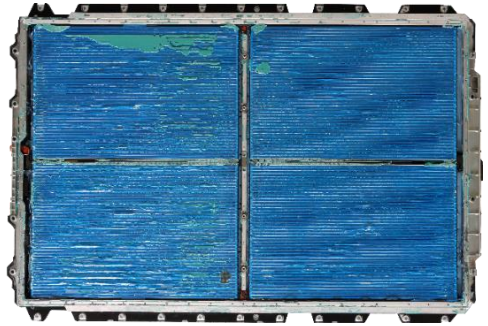


Max. Service Level:
Module Controller

C2C – Cell to Chassis

BYD Seal (82,5kWH Prismatic LFP)

- Cells are retained by bottom plate and top cover bonding
- Recycling likely only possible via full pack shredding



Max. Service Level:
Service Lid EE System Only

C2M – Cell to Module

VW ID3 (58kWh Pouch NMC)

- Modules are serviceable with thermal gap filler to the bottom plate
- Modules or potentially even cells directly input to the recycling process

Max. Service Level:
Cell-Modules

Full Pack Shredding vs. Disassembly to Cell Level

Comparing Recycling Processes

+ Shredding accepts "everything"
  - End of Life batteries
  - Damaged batteries
  - Partial batteries
+ Design agnostic

– Highly heterogeneous product
– Significant refining effort
– Probable aluminum contamination

+ Disassembly to the cell offers recycling process **cost savings of up to 40%** and ~**50% CO_2 emissions reduction**
+ Provides higher purity of "black mass" material
  - Reduced shredder wear
  - Less refinement

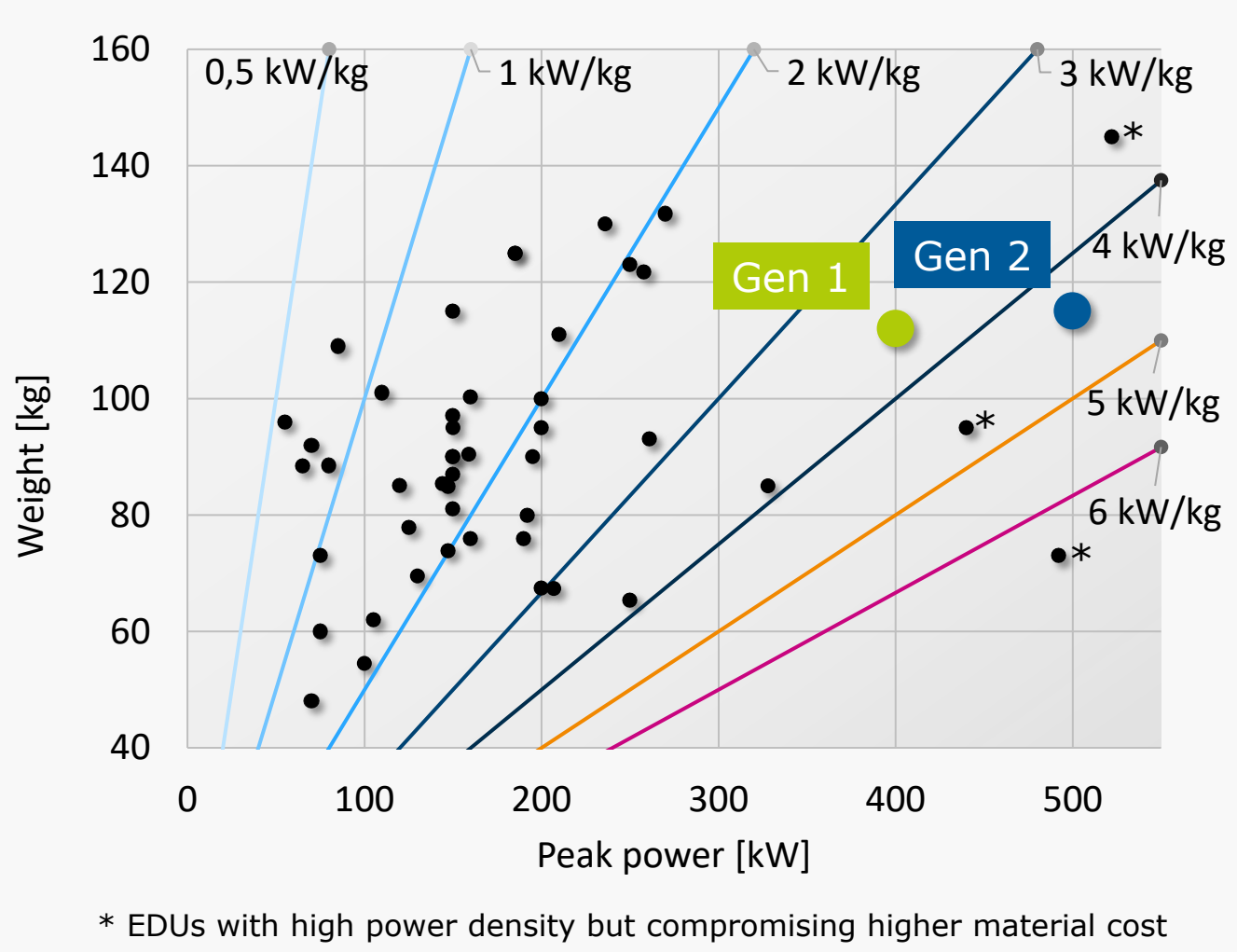
– Increased disassembly effort (today)

Disassembly to the Cell Level is only Possible with Design for Recycling (DfR)

Enabling Cost Savings, Material Circularity, and CO_2 Reduction

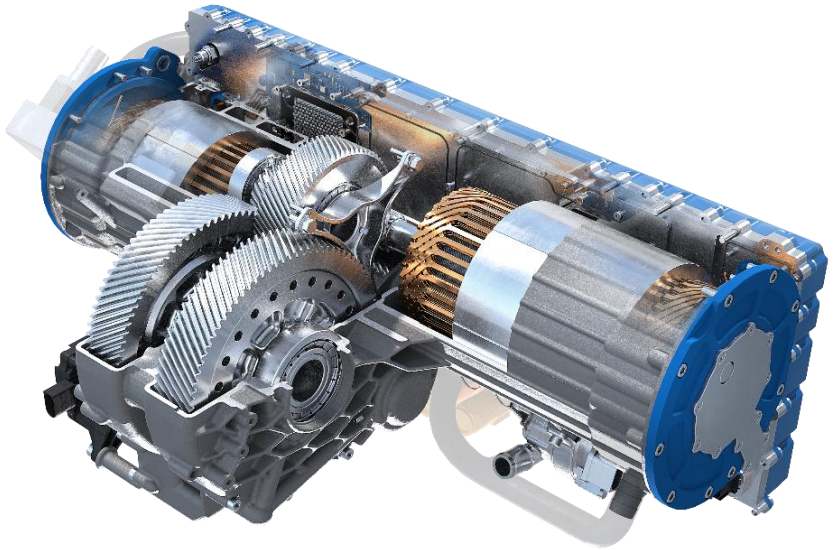
Source: To shred or not to shred, Thompson et. al., 2021; Financial viability of electric vehicle lithium-ion battery recycling, Lander et. al., 2021; The importance of design in lithium-ion battery recycling – a critical review, Thompson et. al., 2020; Reclaimed and Up-Cycled cathodes for Lithium-Ion batteries, Gastol et. al., 2022; A Systematic Review on Lithium-Ion Battery Disassembly Processes for Efficient Recycling, Wu et. al., 2023.

AVL 30.000 rpm EDU development
Key facts and comparison



* EDUs with high power density but compromising higher material cost

AVL high-speed EDU Gen 2 (30.000 rpm)



EDU weight
116 kg

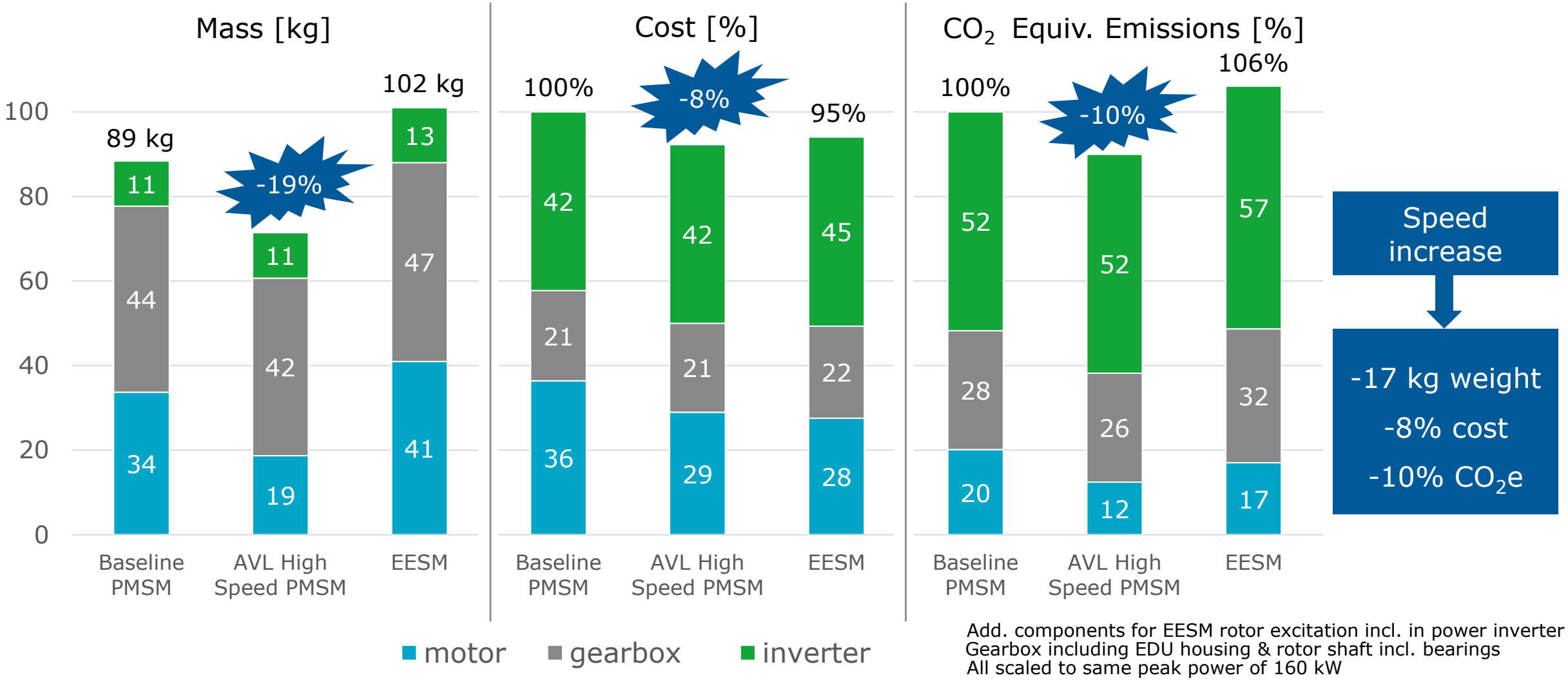
Peak power
500 kW (250 kW/EM)

Power density
4,35 kW/kg

Voltage
800 V

Dual drive
Torque vectoring

EDU System Comparison – High-Speed vs Conventional 160kW Peak, Single E-Motor



Speed increase

-17 kg weight

-8% cost

-10% CO_2e

Add. components for EESM rotor excitation incl. in power inverter
Gearbox including EDU housing & rotor shaft incl. bearings
All scaled to same peak power of 160 kW

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3 **Battery Safety**

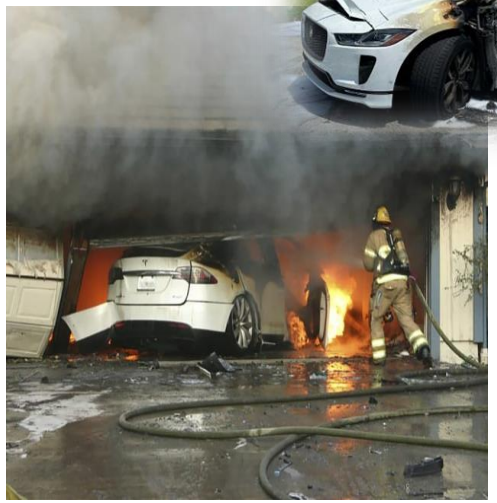
4 Conclusions

Battery Safety - Necessary in all Circumstances

Homologation

Battery Thermal Propagation & Safety

Source: https://electrek.co/2020/10/12/hyundai-recall-77000-kona-electric-cars-risk-battery-fire-lg-chem/



Source: https://www.nbcnews.com/business/autos/federal-regulators-warn-risks-firefighters-electrical-vehicle-fires-n1271084

Transportation & Storage

Birmingham, AL April 2023

EV Battery pack in trailer in TX, Mar 2023

Felicity Ace

From 5min Warning to Safe Batteries

Current and Future Expected Acceptance Criteria

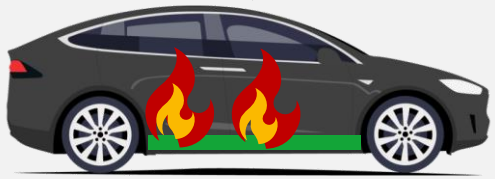
SOP launch

Today | **2026** | **2028**

WARNING
Signal to passengers

>5 MINUTES
Until danger or hazard in cabin

Potential FIRE/GAS in cabin

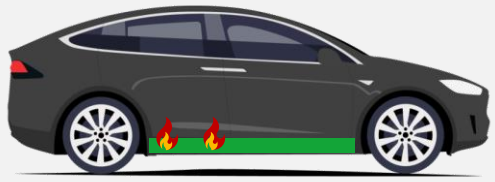


Danger in the passenger compartment or for the passengers

WARNING
Signal to passengers

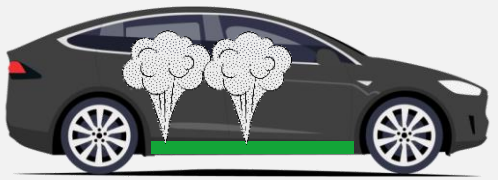
Never
Ignition of exhausted gases (event contained)

"No Flame Out"



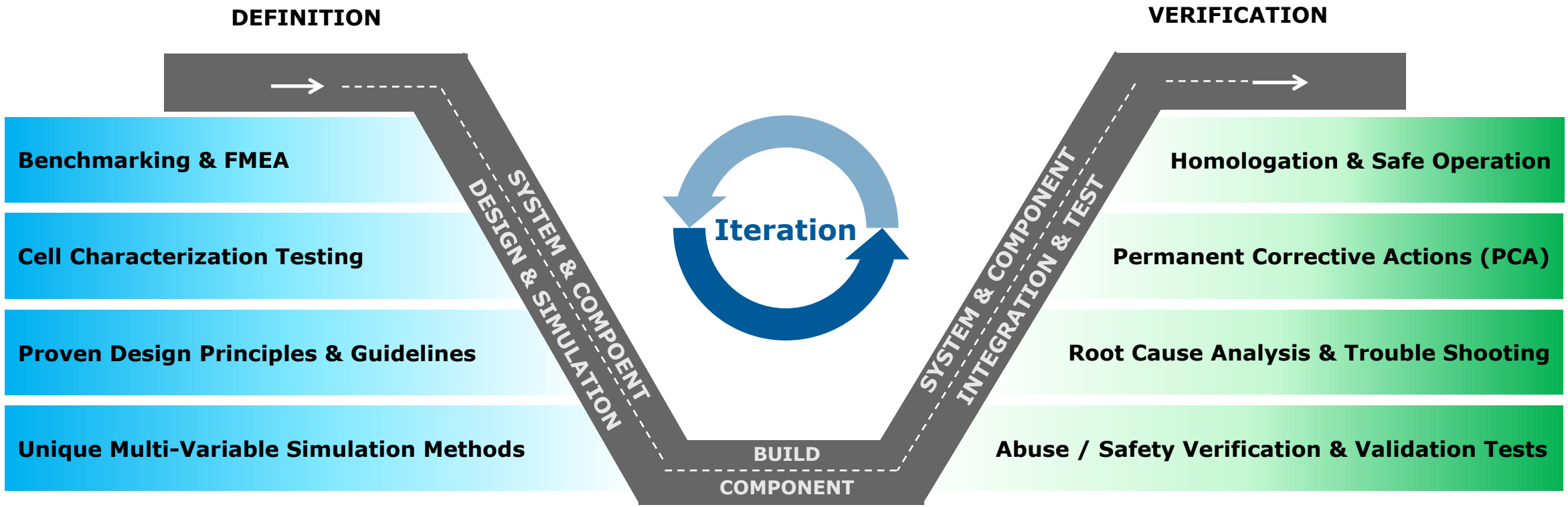
Never
Gas exhausted from the vehicle

"No Gas Out"



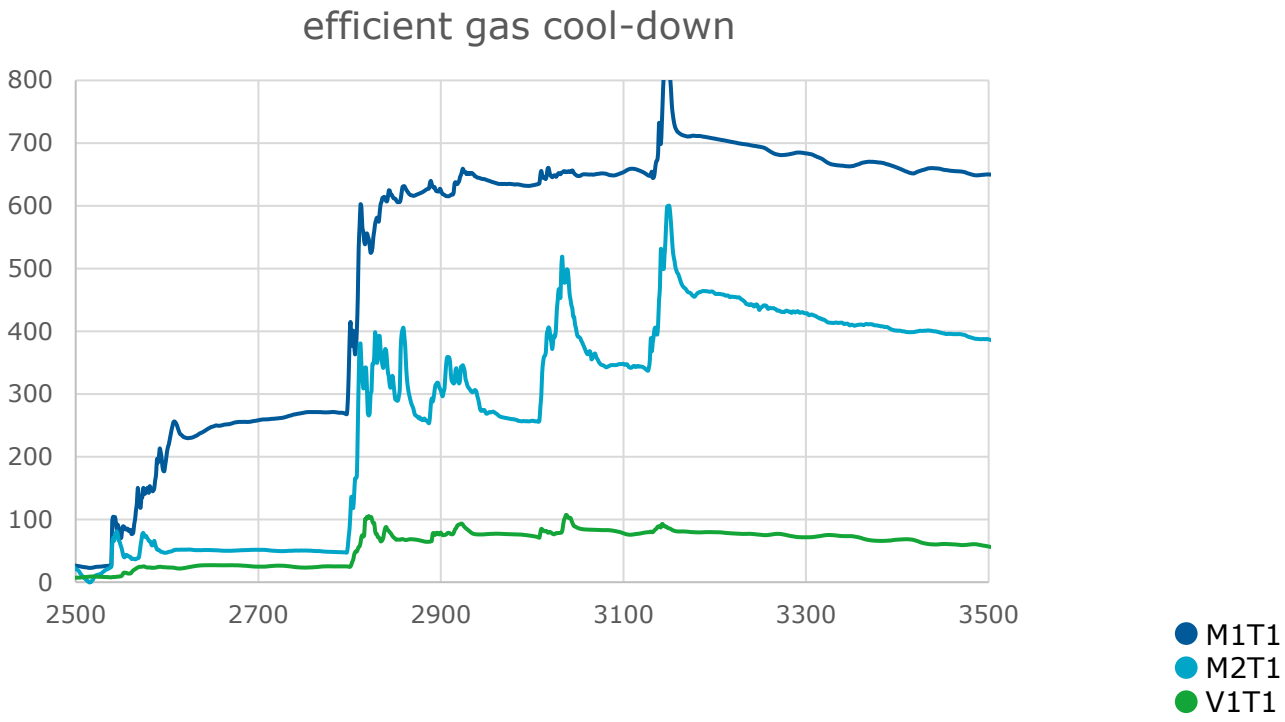
Implementing Battery Safety is an Iterative Process

Safe Battery Design Requires System Engineering Approach:
cell to vehicle, feasibility to after-sales, and HW to SW



AVL No Flame Out (NFO) Battery Design

Efficient gas cool-down and particle stop:
No-flame-out with pouch cell module



With AVL Design Methods

No Flame Out

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Conclusions

- In pursuit of **carbon neutral** transportation **Battery Electric Vehicles** (BEVs) are crucial to achieve set targets
- **Battery-Electric Vehicles** are expected to keep **outgrowing** the average market
- **Current BEVs** do not offer sufficient **value** for mass market acceptance
- **BEV** platform development, build-up of **infrastructure** and **economical stimulus/incentivization** must be defined and timed in **sync** to allow for effective BEV ramp-up as otherwise huge investments by the automotive industry are at **risk**
- Design and integration trends in the market are strongly focused on **cost reduction** and not yet in line with **sustainability**/recycling targets and **consumer expectations** towards vehicle maintenance

Thank you

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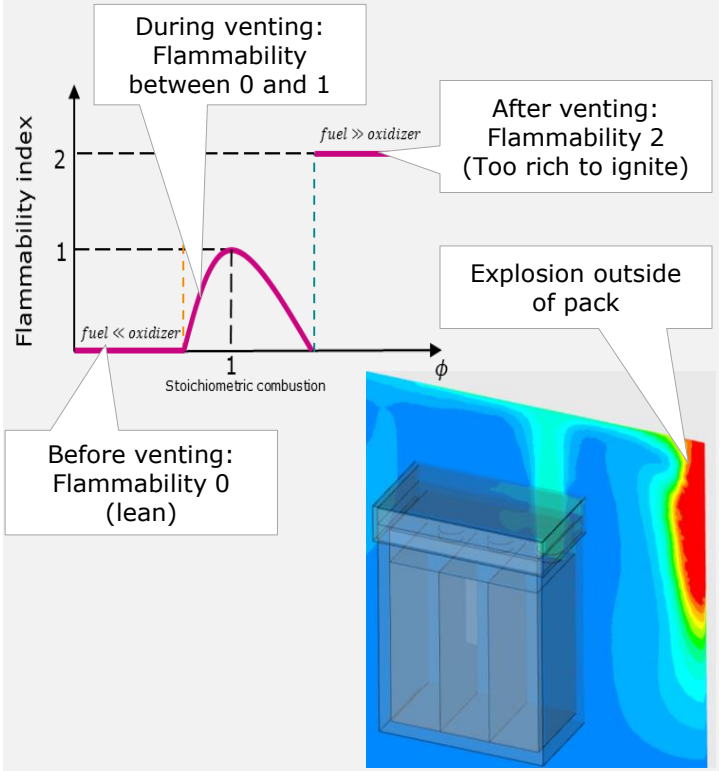
Understanding Flammability and Gas Composition

Designing for Safe Battery Venting

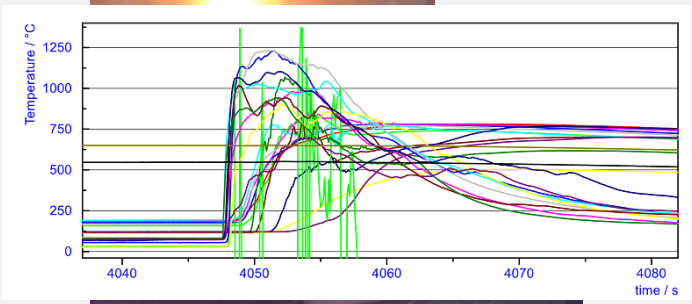
Auto-Ignition

Flammability vs. Stoichiometric Combustion



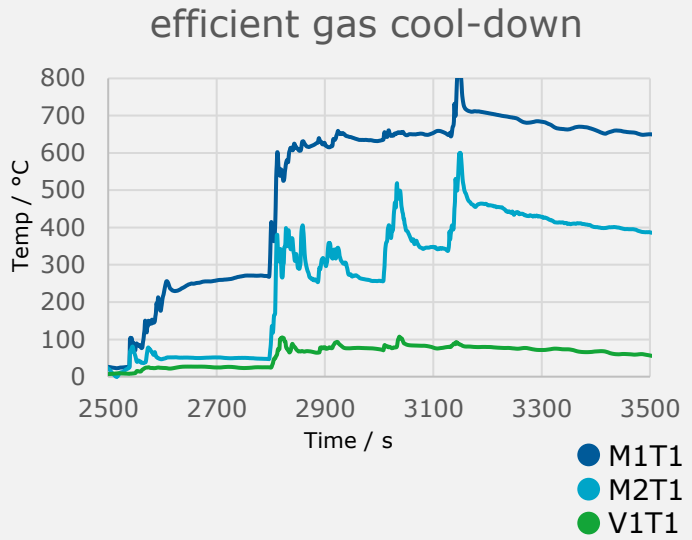
Cell Venting

Up to ~1300 °C gas temp.



Pack Venting Gas Cooled

from ~1300°C to <100°C



Safe vent design must accommodate gas expansion **and** temperature reduction