Battery Solutions for Electric Truck and Bus Applications

Dedicated solutions by AVL

June 4, 2024

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Today’s Presenters

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Today's Agenda

AVL

Reimagining Motion

"We are driven by a **passion** to examine the science, mechanics and philosophy of movement. To help create a world that is climate-neutral and one that makes **safe, comfortable, green mobility** a reality for everyone."

Helmut O. List

Chairman and CEO

AVL List GmbH

AVL at a Glance

1948
Founded

75+
Years of Experience

26
Countries Represented

45
Global Tech and Engineering Centers

12,200
Employees Worldwide

68 %
Engineers and Scientists

10 %
Of Turnover Invested in Inhouse R&D

2,200
Granted Patents in Force

Redrawing the Lines of Electrification

E-Mobility

We are relentlessly striving towards climate-neutral mobility. Not just by increasing the efficiency of multiple propulsion systems, but also by pioneering energy from green resources.

20+

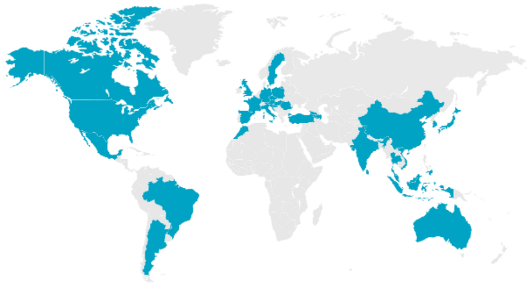
Years of Experience

5,700+

E-Mobility Experts

900+

Executed Battery Projects



15+

Locations for Battery Development

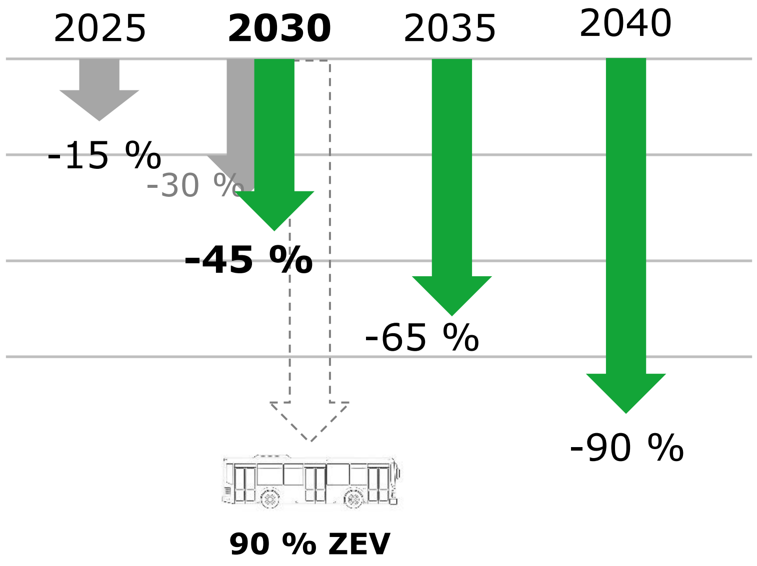
Battery Solutions for Electric Truck and Bus Applications

Introduction and Target Setting

Public

EU HDV CO_2 Standards – Decision and Consequences

EU Parliament and Member State Ministers' Decision as of May 13, 2024



-45 % CO_2 in 2030 requires…

- 420,000 zero-emission vehicles to be in operation within less than six years
- close to 100,000 ZEV to be registered annually from 2030

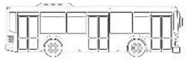
This means around **one third of all new registrations** would have **to be zero-emission** vehicles from 2030.

in case of non-compliance with the CO_2 targets:
penalty of **4,250 € per gCO_2 / t-km** in 2030

Should a manufacturer with a 20 % market share **(~50k vehicles** p.a.) miss its target by **1 g**, the penalty would amount to over **360 million €**.

© ACEA Factsheet CO_2 standards for heavy-duty vehicles, 17.02.2023, www.acea.auto

Grey: targets in previous regulation.


City buses

Battery Electric Commercial Vehicles are to become mandatory.

Commercial Vehicles are Dedicated to Its Application

Trucks

- Urban Distribution
- Regional Distribution
- Traction
- Haulage
- Special Vehicles
  (Garbage Trucks, Fire Brigades, …)

Buses

- City Bus – low floor
- Regional City Bus – low entry
- Coach
- Special Vehicles
  (Bus-Train, Convertible Bus, BRT, …)

© pictures MAN Truck & Bus SE

Key Challenges Truck and Bus Batteries

- No thermal propagation
- High voltage safety

- Modularity and scalability
- Serviceability for modules

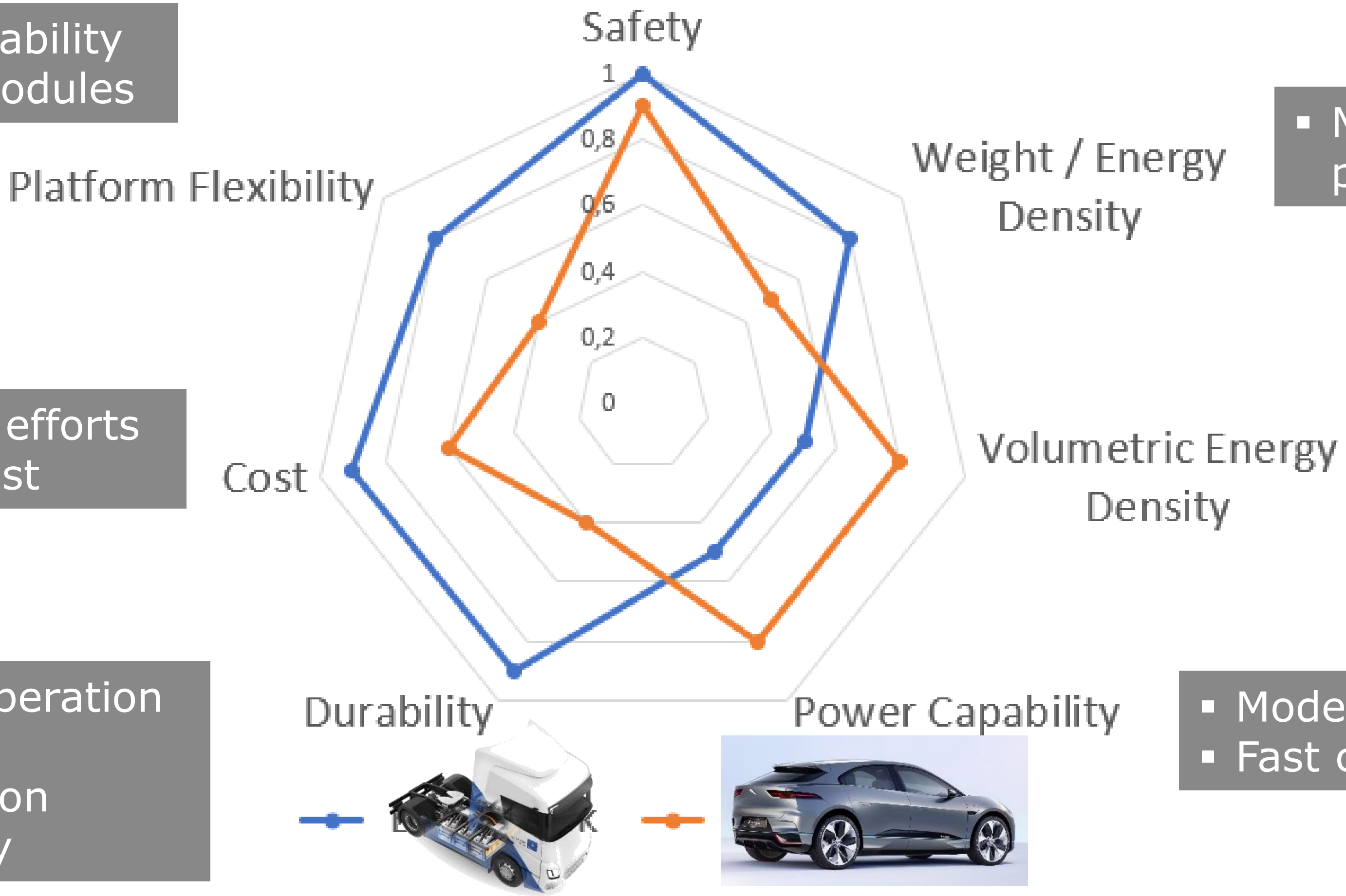
- Max. freight and passenger weight

- Lean development efforts
- Optimized piece cost

- Max. freight volume
- Max. number of passengers

- Ready for 24/7 operation
- High lifetime
- Tightness/corrosion
- 100 % availability

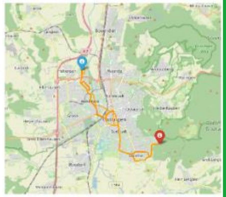
- Moderate drive cycles
- Fast charge capability



EV City Bus Key Requirements

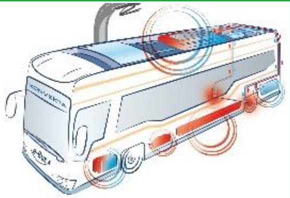
Geometrical
- Step height, kneeling, floor, seats, etc. (R107)
- Approach, departure and ramp-over angles

Drive cycle
- 200-300 km mileage per day
- 2-3 stops/km
- 5-25 km/h average speed, 60-80 km/h maximum speed.



Energy Storage System and charging
- Up to 420 kWh for 12 m, up to 640 kWh for 18 m bus
- Opportunity and depot charging

Thermal conditioning
- The ambient temperature requirement is between -30 °C and +65 °C for both cabin and battery



State-of-the-art BEV City Bus
Battery Placement on the Roof

PROs

+ **Easy to package** due to available free space on the roof
+ Possibility to implement various **off the shelf battery** packs from the market
+ **More space** at the back of the bus for other power electronics
+ **Safety** against venting gases in the event of battery failure

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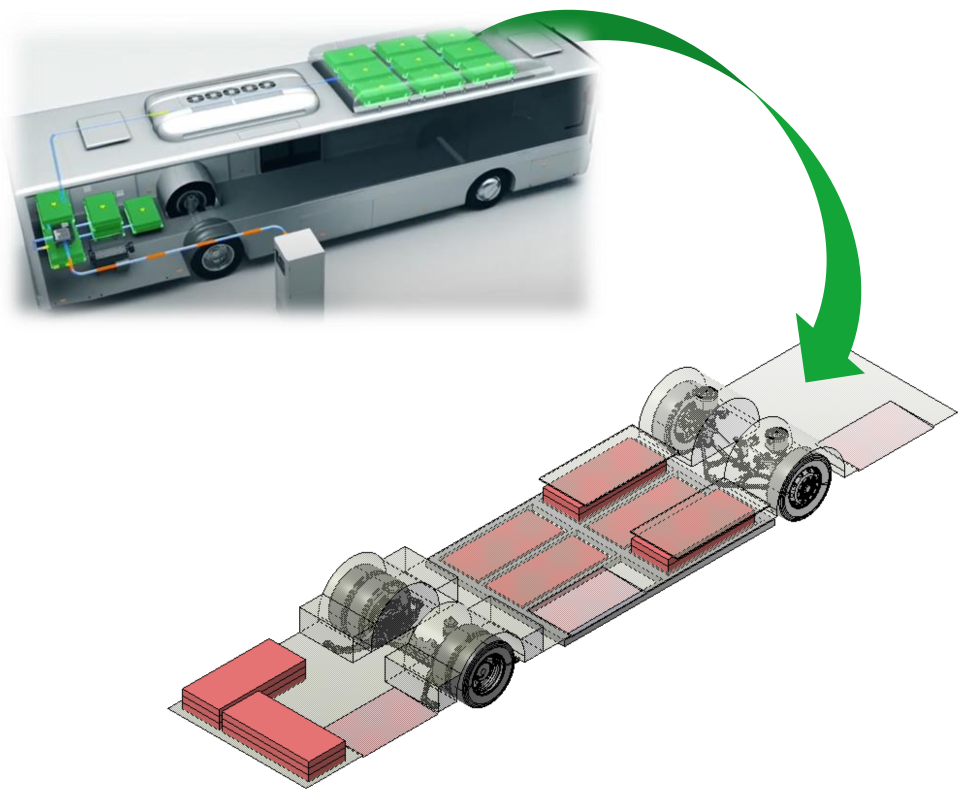
CONs

- Higher **Center of Gravity**
- Reduced lateral and longitudinal **handling** performance
- Worse **tilting** performance
- Need for heavier, more complex and robust **roof structure**
- Longer **cooling** lines
- Longer HV harness cause **voltage drop**
- Need for additional **protective cover** against external factors
- Difficult to **maintain** and access

The Challenge

Low Floor Battery Integration



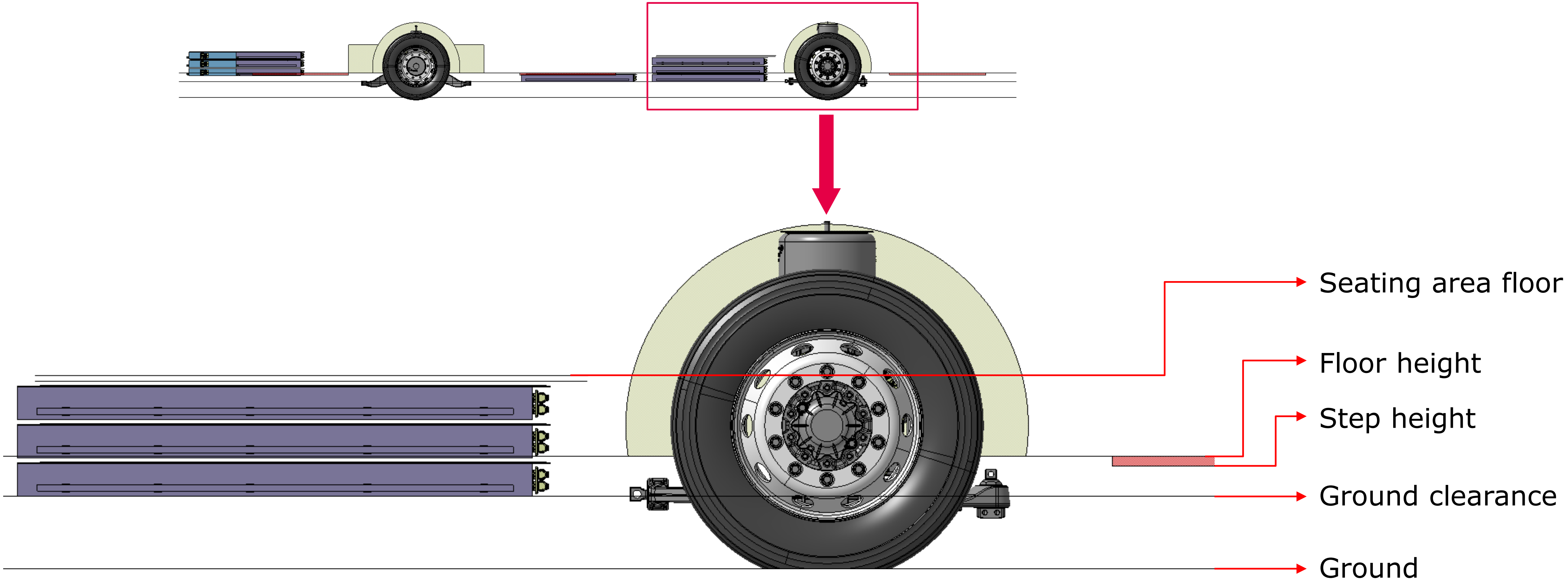
AVL R&D Project

Integration of the Battery into the Low Floor of a City Bus:

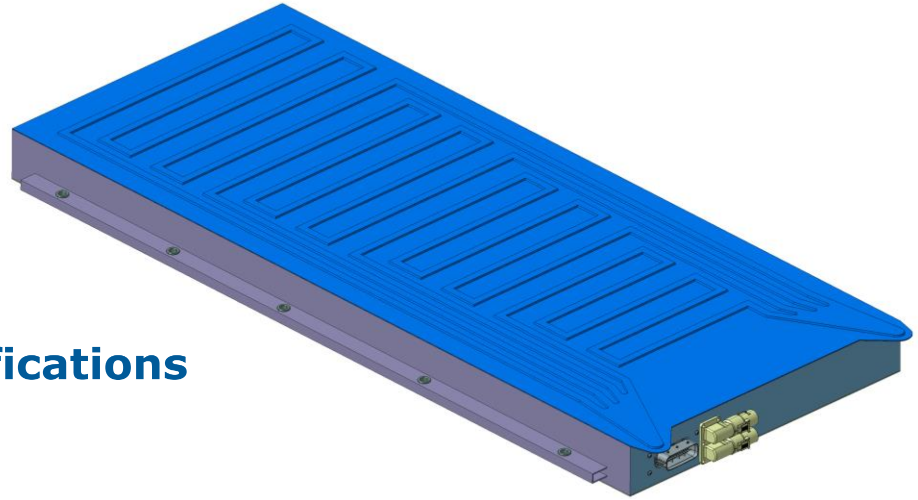
- Battery capacity
- 12 m and 18 m City Bus
- **Modular Battery System**, applicable to other bus types as well (low entry, coach, …)
- Safety and Durability
- Passenger capacity

AVL Battery Integration into City Bus

Geometrical Boundaries



AVL Battery Pack – City Bus Underfloor Placement



KPIs

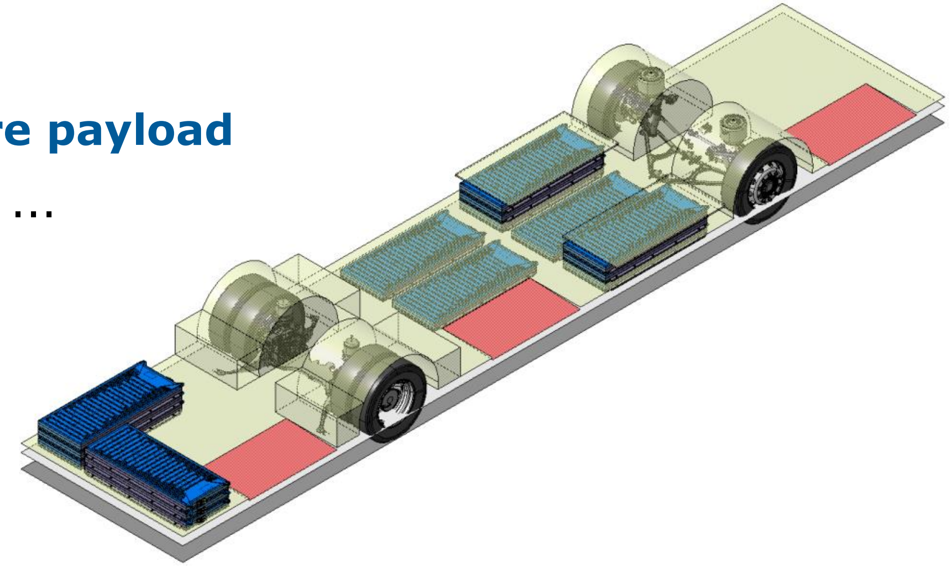
- Optimized outer dimensions for maximum energy capacity
- **Energy capacity ~35 kWh/pack**

Achievements / Requirements

- Ability to package underfloor structure **without extensive modifications**
- **No compromise** on legal requirements
- Better handling performance due to **lower Center of Gravity**
- Shorter **cooling lines** and **HV harness**
- Lighter by using similar existing floor structure, that means **more payload**
- Possible to implement for **other bus types**, coaches, low-entry, ...

Challenges

- Restrictive **packaging** limits, especially in height
- **Serviceability** / Exchangeability / Replaceability
- **Safety** concept and durability



AVL Battery Pack – Capacity for BEV City Buses

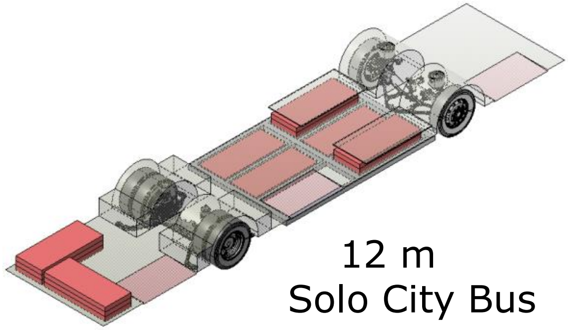
Vehicle integration

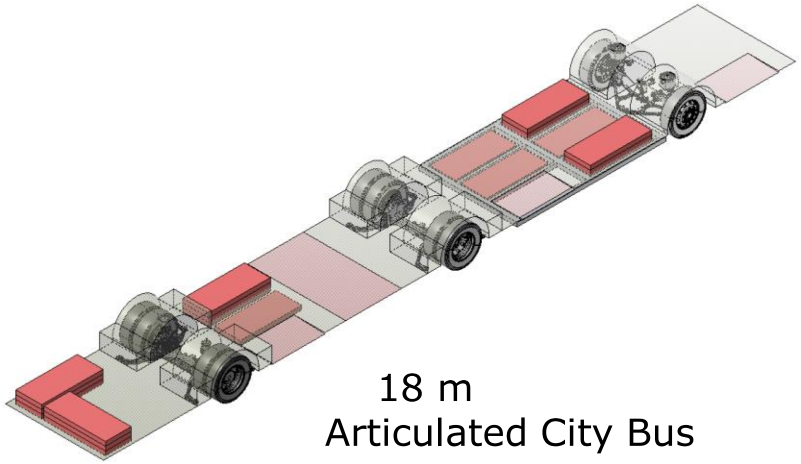
- Maximum battery packs and capacities for both options are
  - **12 m Solo City Bus** → 15 packs → **519 kWh**
  - **18 m Articulated City Bus** → 19 packs → **657 kWh**

- Possible ranges for both options,
  - **12 m Solo City Bus** → up to **470 km** based on SORT-1 Cycle *
  - **18 m Articulated City Bus** → up to **500 km** based on SORT-1 Cycle *

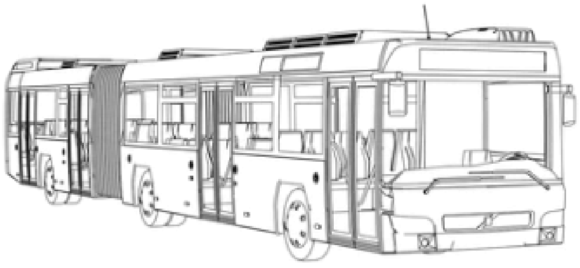
- Packaging in compliance with
  UN Regulation ECE R107

*** SORT** =
Standardized **O**n-**R**oad **T**est Cycles,
an initiative of the UITP Bus Committee





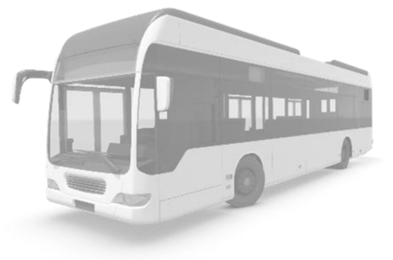
Battery Capacity of City Buses

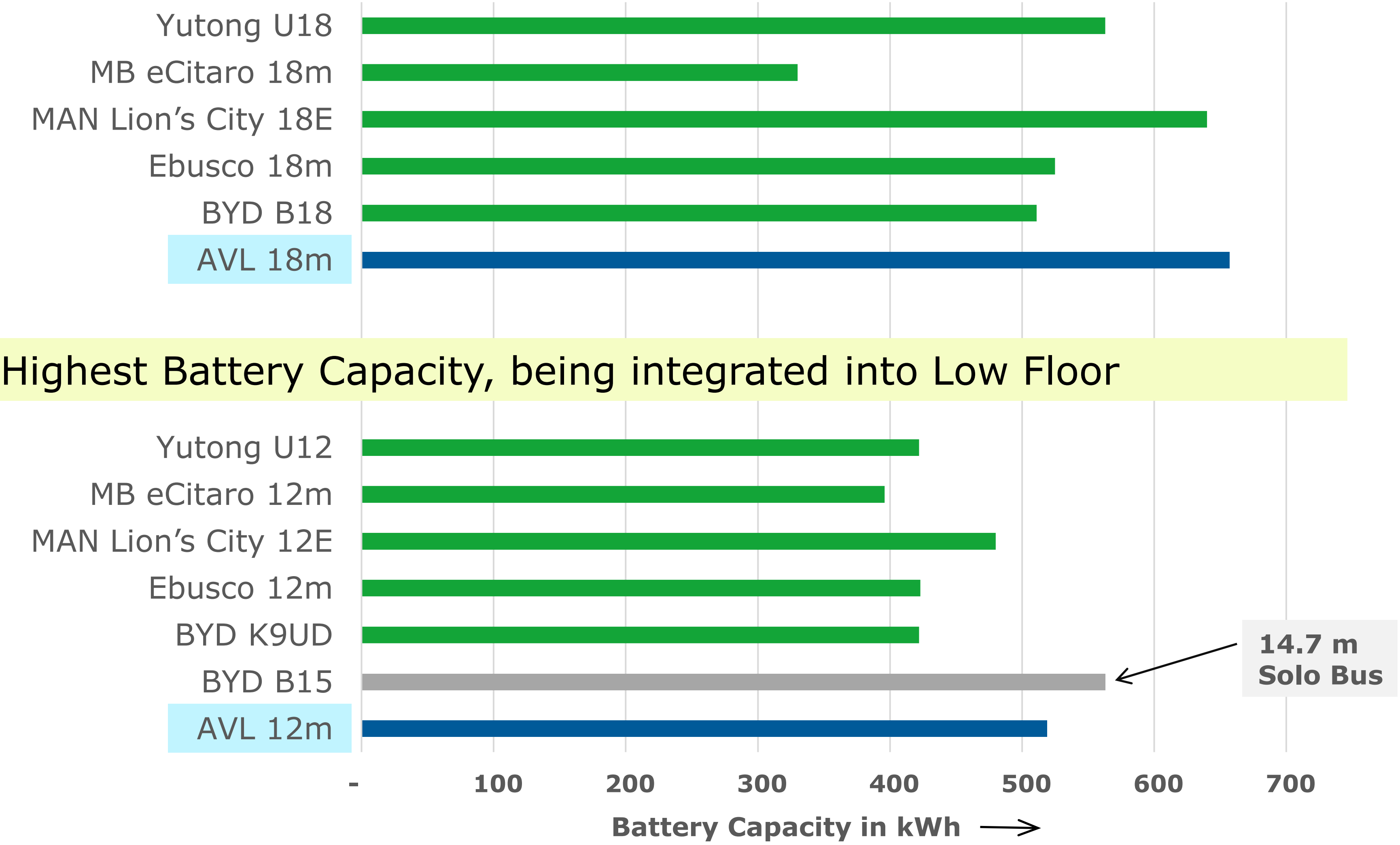


18 m Articulated Bus

AVL Solution: Highest Battery Capacity, being integrated into Low Floor

12 m Solo Bus





How to Solve These Challenges?

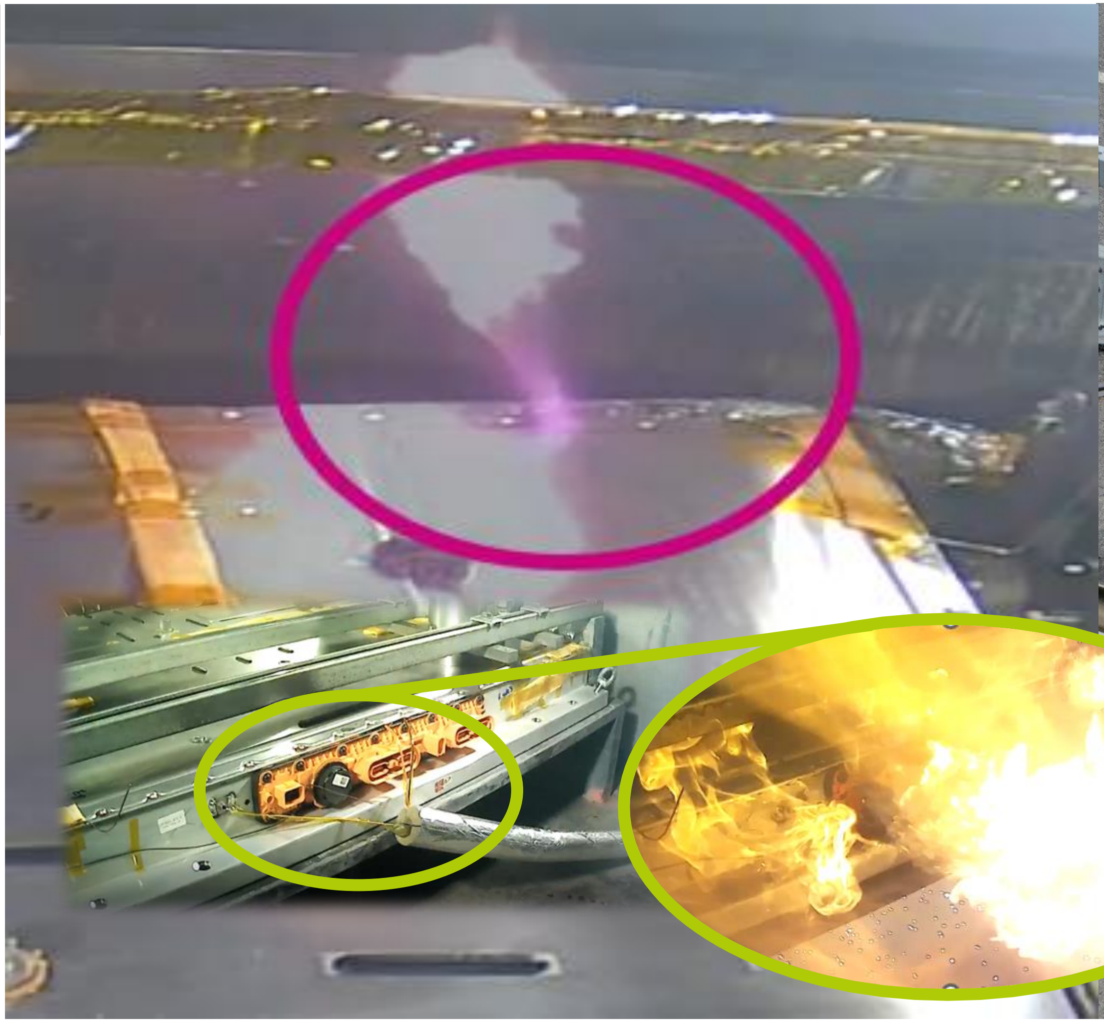
Safety and Durability

Thermal Safety as Key Challenge in Battery Development
Battery Competence in Synergy With Various Skill Sets

Cell

System

Function



Virtual Development	Design & Development	V&V & Testing Efficiency	AI & Data Analysis	PM, Process & Quality

Thermal Safety as Key Challenge in Battery Development

Cell

System

Function

Battery Competence

Cell selection: Safe vs risk cell types and its implications on design:

- Cell type dependent TR behavior
- Cell testing as service

System engineering: ensure TP solution does not violate other targets or functions

- E.g. costs, weight, package space
- E.g. durability, vibration, EMC, thermal performance, etc.

Cont. cell wear monitoring and prediction in BMS **functions**

TR detection and warning

Model-based system engineering (MBSE)

Development Skills

Unique and compete **simulation** workflow for TP considering:

- Cell heat release
- Particle ejection
- Abrasion
- Gas flow
- Mechanical impacts
- Gas ignition risk

Design guidelines, DfM, Cost Optimization

Testing best practice, tear-down manual, RCA

Data Analytics for fleet monitoring

PM, QM and processes

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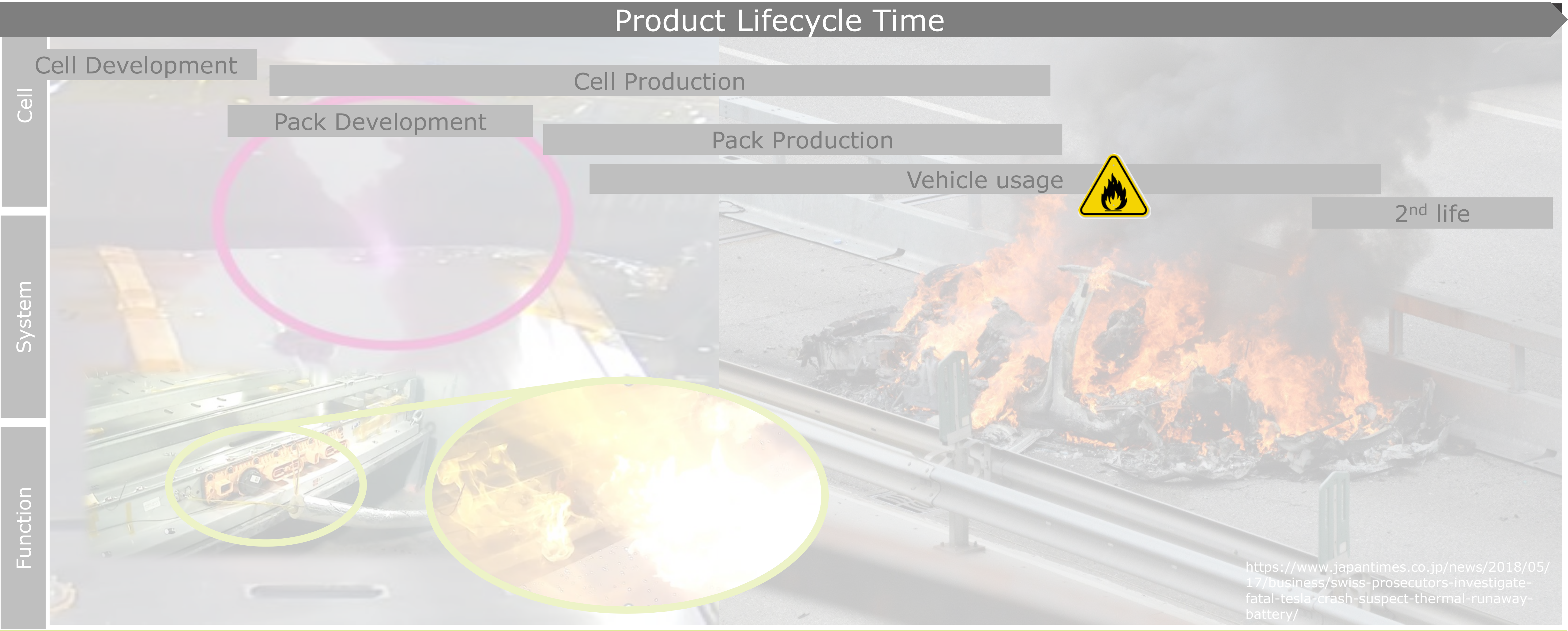
Virtual Development | Design & Development | V&V & Testing Efficiency | AI & Data Analysis | PM, Process & Quality

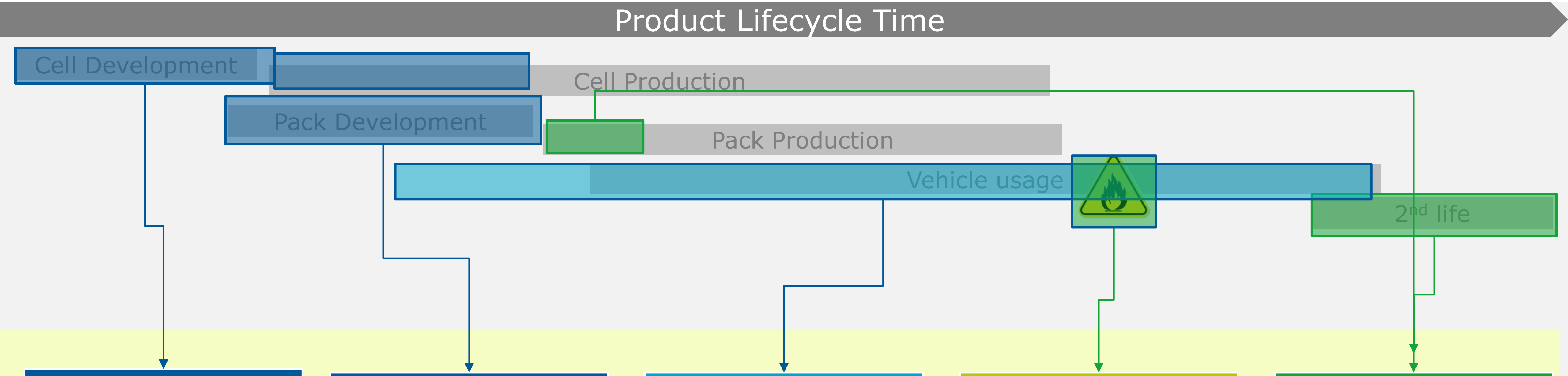
Thermal Safety as Key Challenge in Battery Development



https://www.japantimes.co.jp/news/2018/05/17/business/swiss-prosecutors-investigate-fatal-tesla-crash-suspect-thermal-runaway-battery/

AVL Service Portfolio

Service Portfolio in Thermal Safety and Thermal Propagation All Across the Product Lifecycle: Development to 2nd Life



Cell
- Safe cell design
- Cell TR testing
- Vent gas analysis
- Particle characterization

Development
- Full simulation approach
- Design guidelines
- Component & material testing
- Pack testing & tear down
- Trouble shooting

Fleet Operation
- Cell wear monitoring
- Cloud monitoring
- Identification of risky batteries
- Predictive maintenance

Thermal Event
- Trouble shooting support, tear down, RCA
- Fire extinguisher solution
- TR detection & sensor layout in BMS
- Cell failure vs external fire as source of pack fire

Sate of Safety (SoS)
- Algorithm for EoL testing
- Test device + algorithm for SoS charact.
- Battery passport

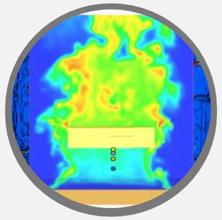
AVL Service Portfolio

Virtual Risk Assessment: **Mechanical Damage** Which Can Lead to Thermal Runaway During Operation

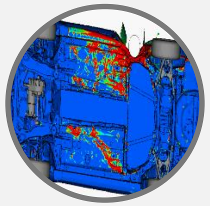
Cell

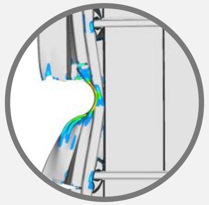
System

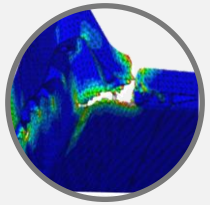
Function


External Fire


Complete Vehicle

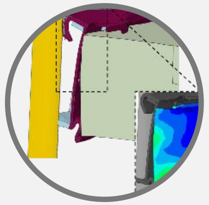

Crash load on battery


Housing rupture

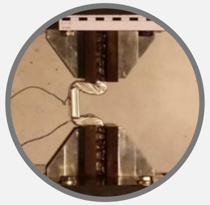

Finger proof protection


Coolant leakage


HV isolation

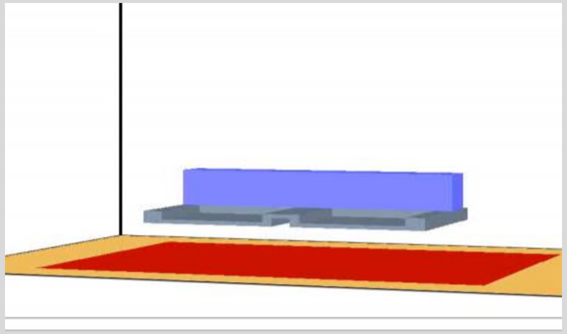

Module contact


Cell defor-mation


Cell hazard prediction

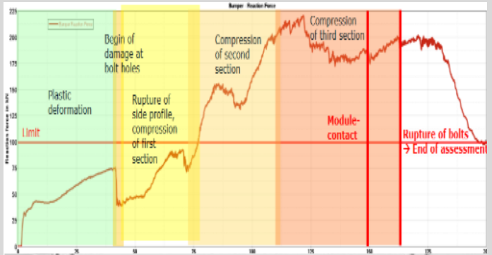
External Fire

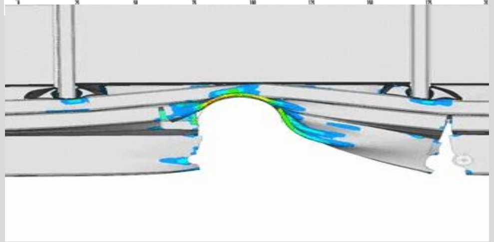
Risk Assessment if external fire can damage and trigger battery to Thermal Propagation



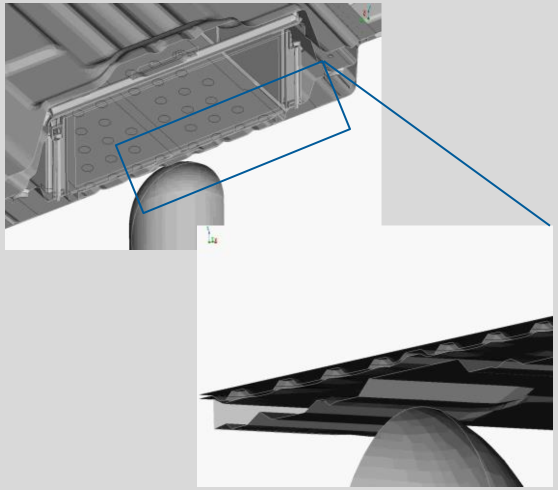
Crush

Assessment if reaction fore in crush case can be achieved without HV failure or cell damage





Bottom/Top Intrusion



Virtual Development | Design & Development | V&V & Testing Efficiency | AI & Data Analysis | PM, Process & Quality

Cell Wear and Failure Prognosis
Thermal Runaway Detection

Cell

System

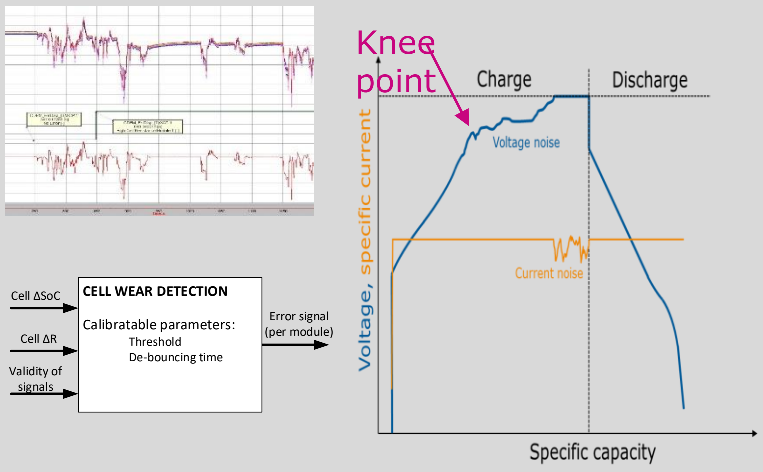
Function

Cell failure/wear/damage prediction

BMS-based Approach (On-board)

Usage of onboard measurements
- High frequency
- Many signals available, voltage for each cell for instance

Limitations in calculational aspects

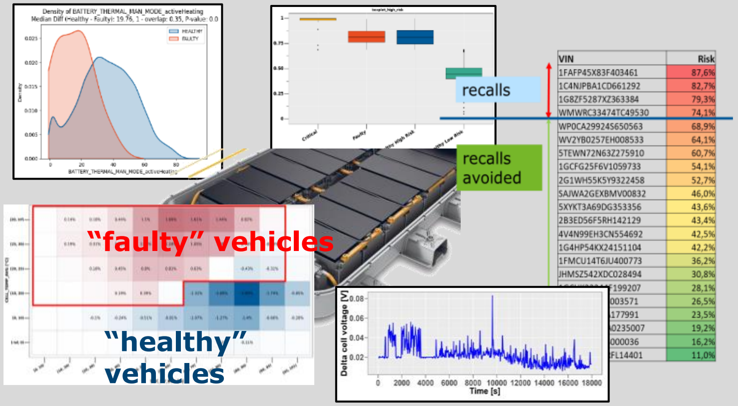


Cloud-based Approach

Telemetry data is used to **re-train an existing empirical model** for thermal runaway prediction. With the model we can assign a risk factor per vehicle for selective technical actions.

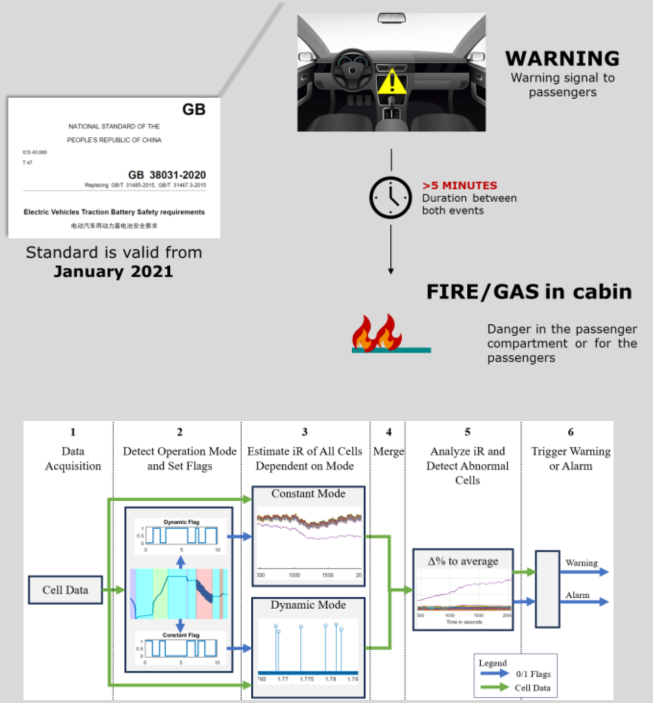
Benefits: only small number of faulty vehicles are required; model was already used for recall actions from European OEM in a worldwide fleet operation

Identification of critical operating conditions



TR detection

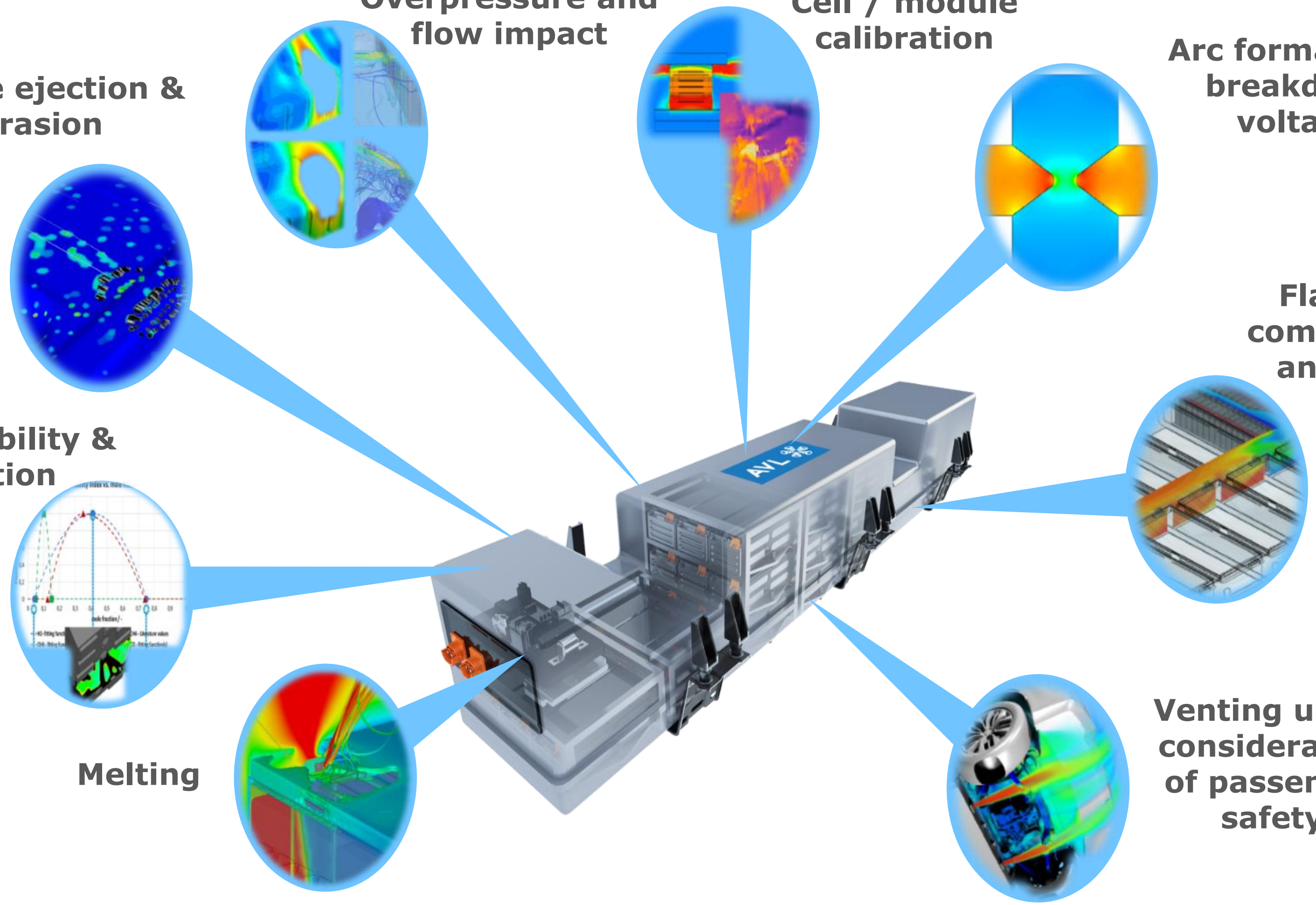
Implemented in BMS
TR detection for Warning signals to the driver accord. to GB requirements



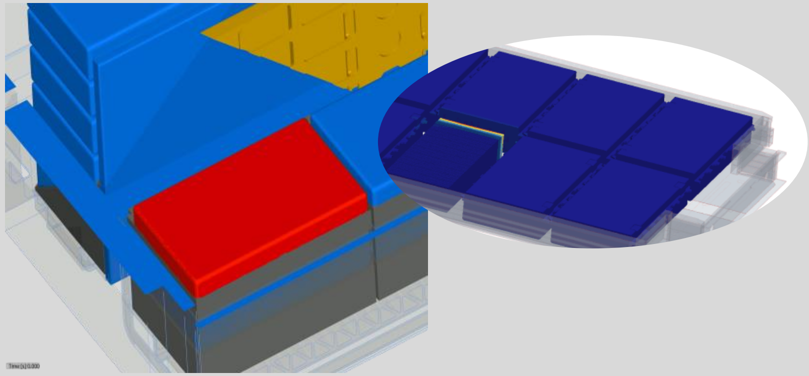
Virtual Development | Design & Development | V&V & Testing Efficiency | AI & Data Analysis | PM, Process & Quality

Thermal Propagation
Multi-Physical Side Phenomena

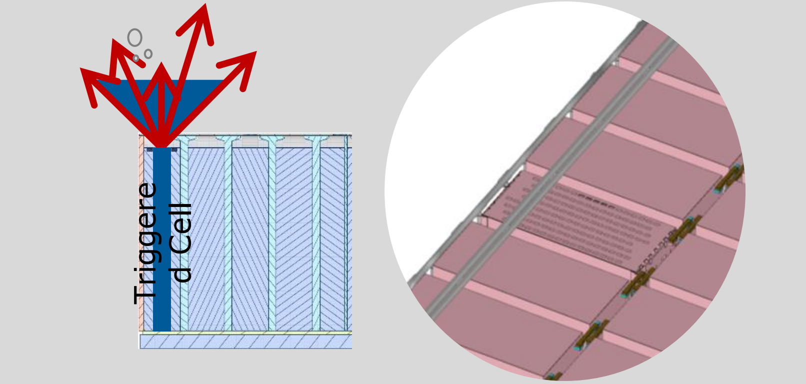
Multiphysics simulation coupling structural and gas side



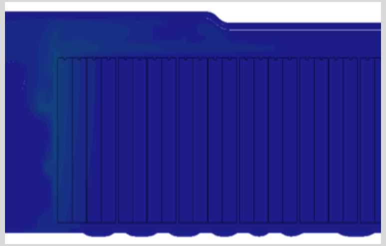
Venting flow



particle flow



Cell2cell propagation



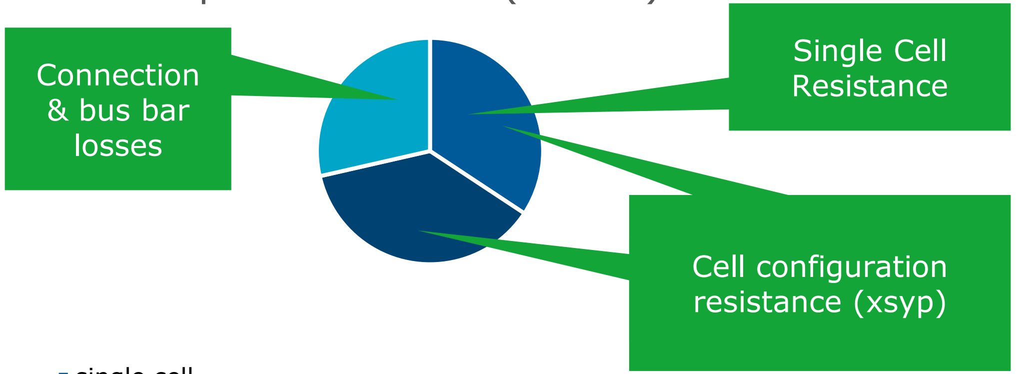
How to Solve These Challenges?

Lifetime

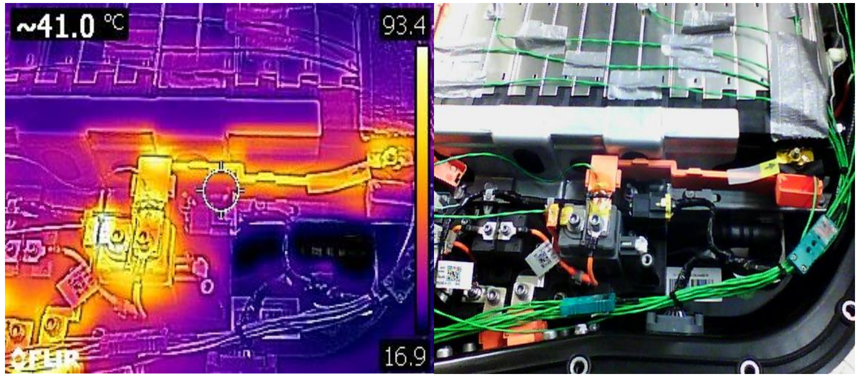
Lifetime Optimization

It‘s Not „Just“ Cell Aging but Much More …

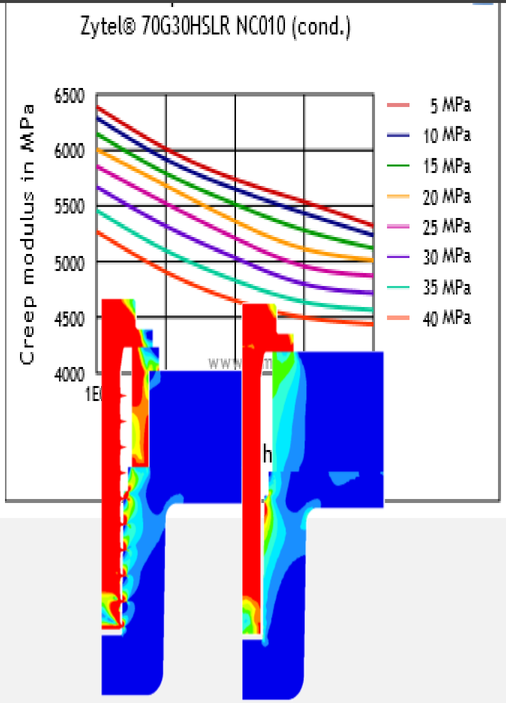
pack resistance (mOhm)



- single cell
- cell configuration delta
- System Losses (bus bar, connection, welding, bonding losses)

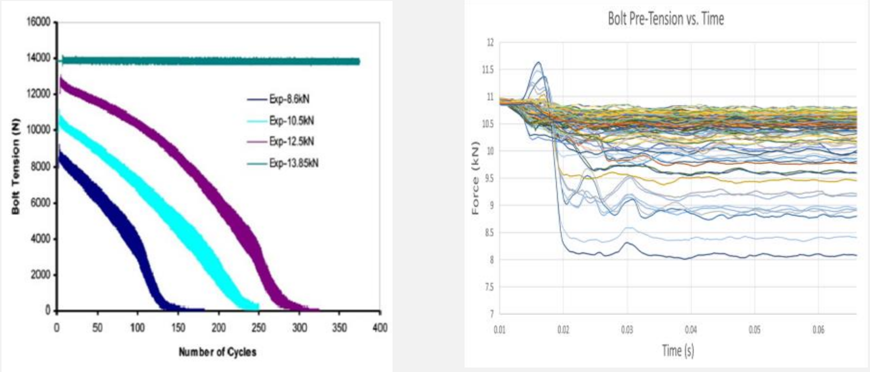


Bolt layout

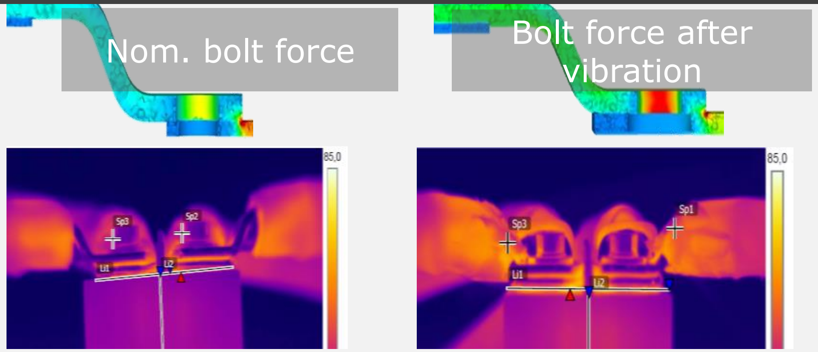


According VDI & FE simulation
- Considering creep strains
- surface roughness
- process quality
- etc.

Mechanical load simulation Vibration and mechanical shock



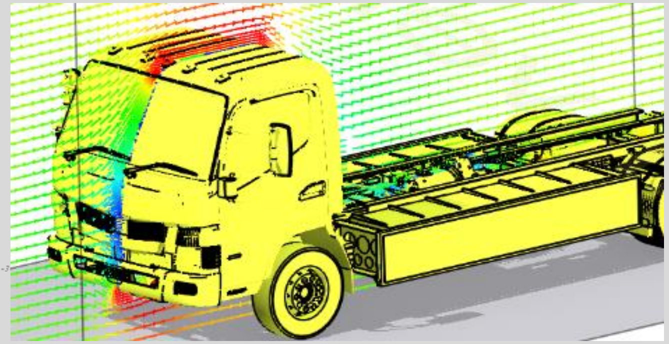
Electro-thermal analysis of EE connections

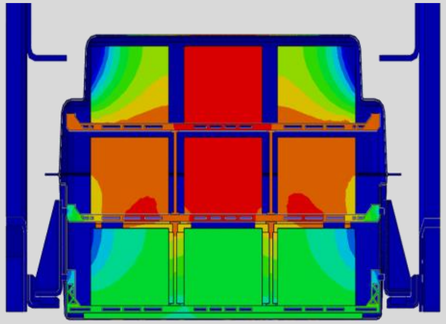


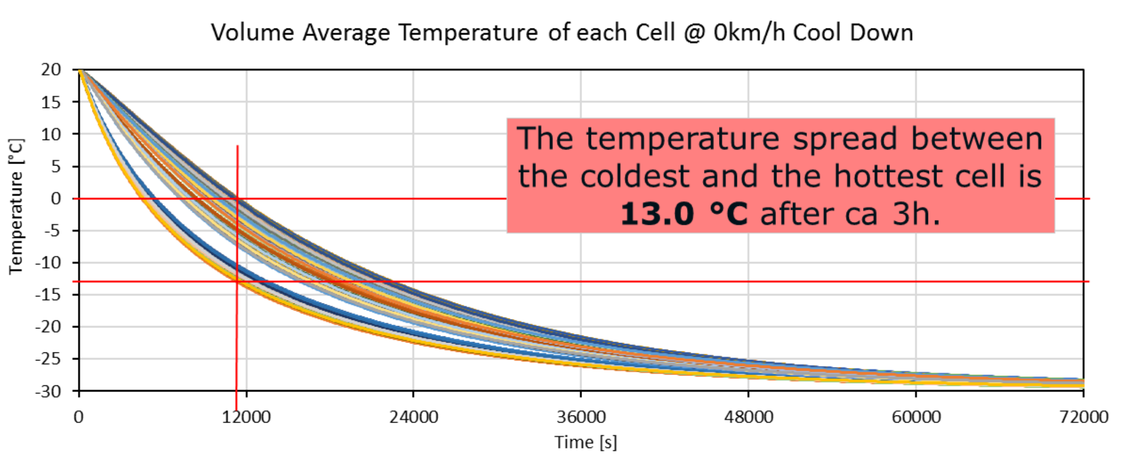
Bolt force influence over lifetime on temperature

Challenge in Thermal Conditioning

Passive cool-down / heat-up

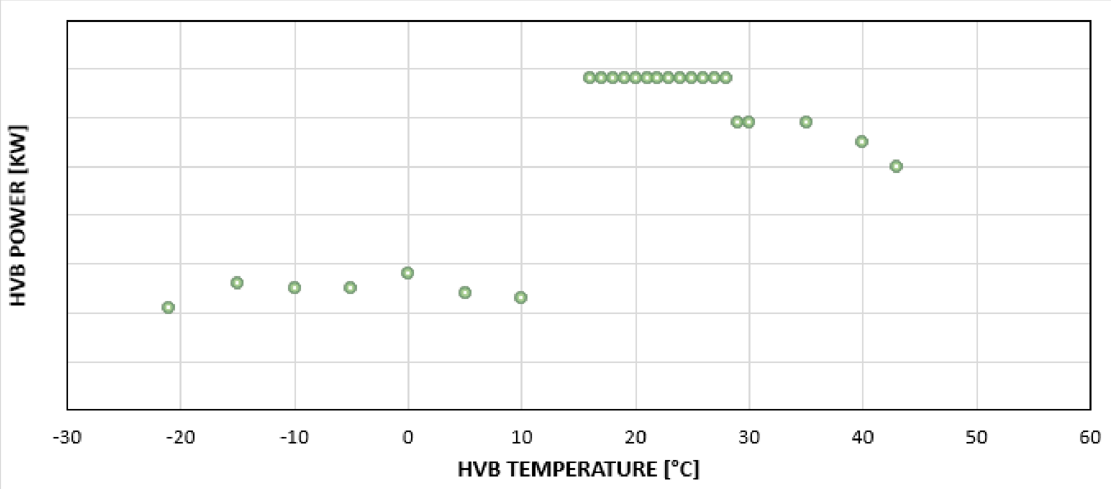






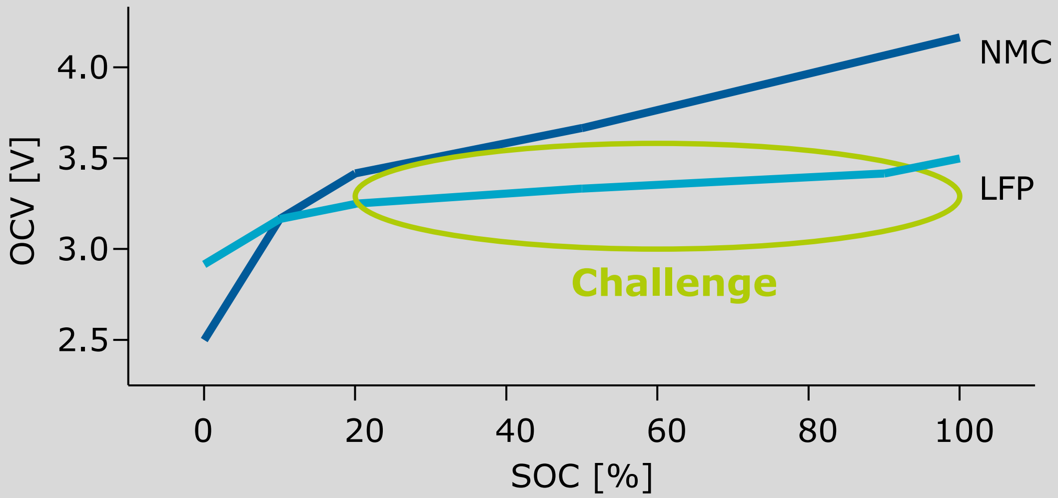
Challenge

High cell temperature influence on performance, charging limits and lifetime

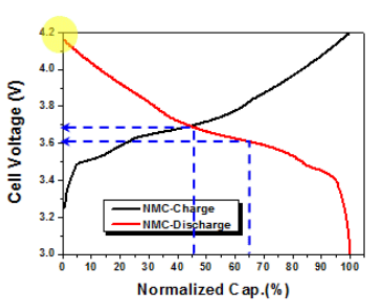


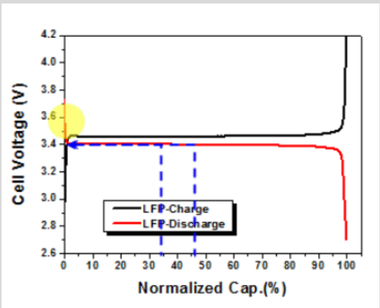
Challenge in estimating SoC for LFP impact on SoX accuracy, SoH prediction

NMC vs LFP



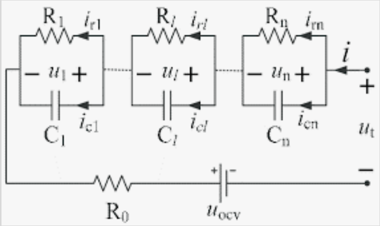
OCV-SOC characteristic LFP vs NMC

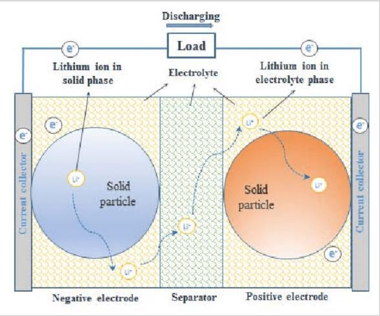


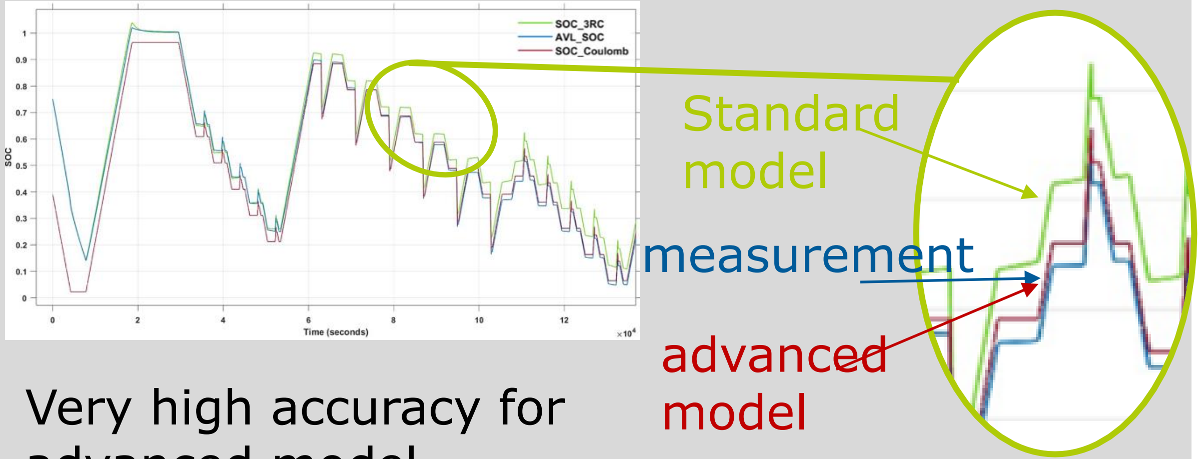


Solution

AVL advanced model

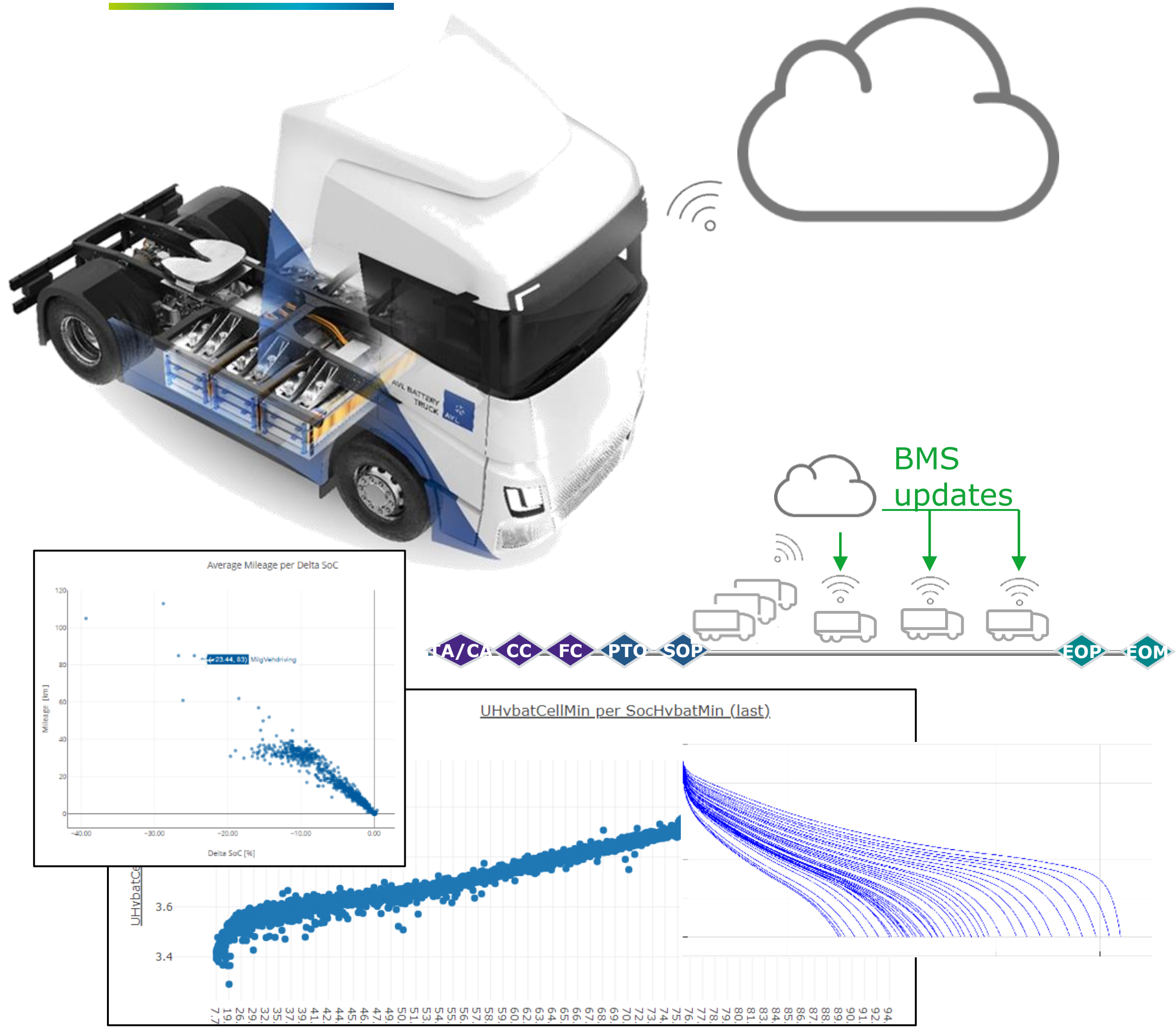






Very high accuracy for advanced model

Cloud BMS and Fleet Monitoring for Improved SoH Modelling and Warranty Cost Reduction



Approach description

Customer Benefits

- Improve SoH estimation precision (abs. max. err <2%)
- Ensure trustworthiness & reliability of vehicle's BMS
- Enable personalized vehicle individual control strategy
- Reduce warranty costs and customer down-time
- Extend battery life-time by 10% and enhance residual value

Challenges

- Connect On-Board BMS with backend cloud algorithms
- Working with huge amount of data from the field
- Bring machine learning models into production

AVL Tasks & Deliverables

- Combine domain and data science expertise for a ML-based SoH modelling
- Identify SoH influencing factors and predict remaining useful life for each vehicle
- Develop model confidence metrics to support the adaptive BMS control strategy
- Design and develop large-scale data processing system for model deployment in AWS
- MLOps to automate training and establish monitoring systems for data and model drift

Conclusion

Battery Concept for City Bus underfloor integration

- Battery concept in underfloor fulfilling package space (height!) requirements
- Very good energy density, Battery capacity exceeding state-of-the-art level
- Realizing system advantages like for thermal conditioning (piping) or electrical function

Thermal Propagation Safe Design

- Full verification methodology with focus on virtual development
- Simulation method considering various physical side phenomena
- Design solutions in place for safe operation and stop TP

Lifetime Optimization

- Battery lifetime consideration beyond cell aging behaviour – including mechanical and performance degradation
- Model approaches for estimation of SoC, SoH, SoF, SoS
- Fleet monitoring in the cloud for lifetime optimization and fleet management

Q&A

Contact

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