The AVL Fuel Cell Truck

A Technology Demonstrator Showing Solutions for Future Heavy-Duty Applications

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Today’s Presenters

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Today’s Agenda

1 **About AVL**

2 **Introduction & Target Setting**

3 **System Development**

- AVL FC System
- AVL HD E-Axle

4 **System Integration**

- EE System
- Thermal System
- Geometrical Integration

5 **Advanced Energy Management**

6 **Q&A**

AVL Fuel Cell Truck – A Technology Demonstrator

About 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

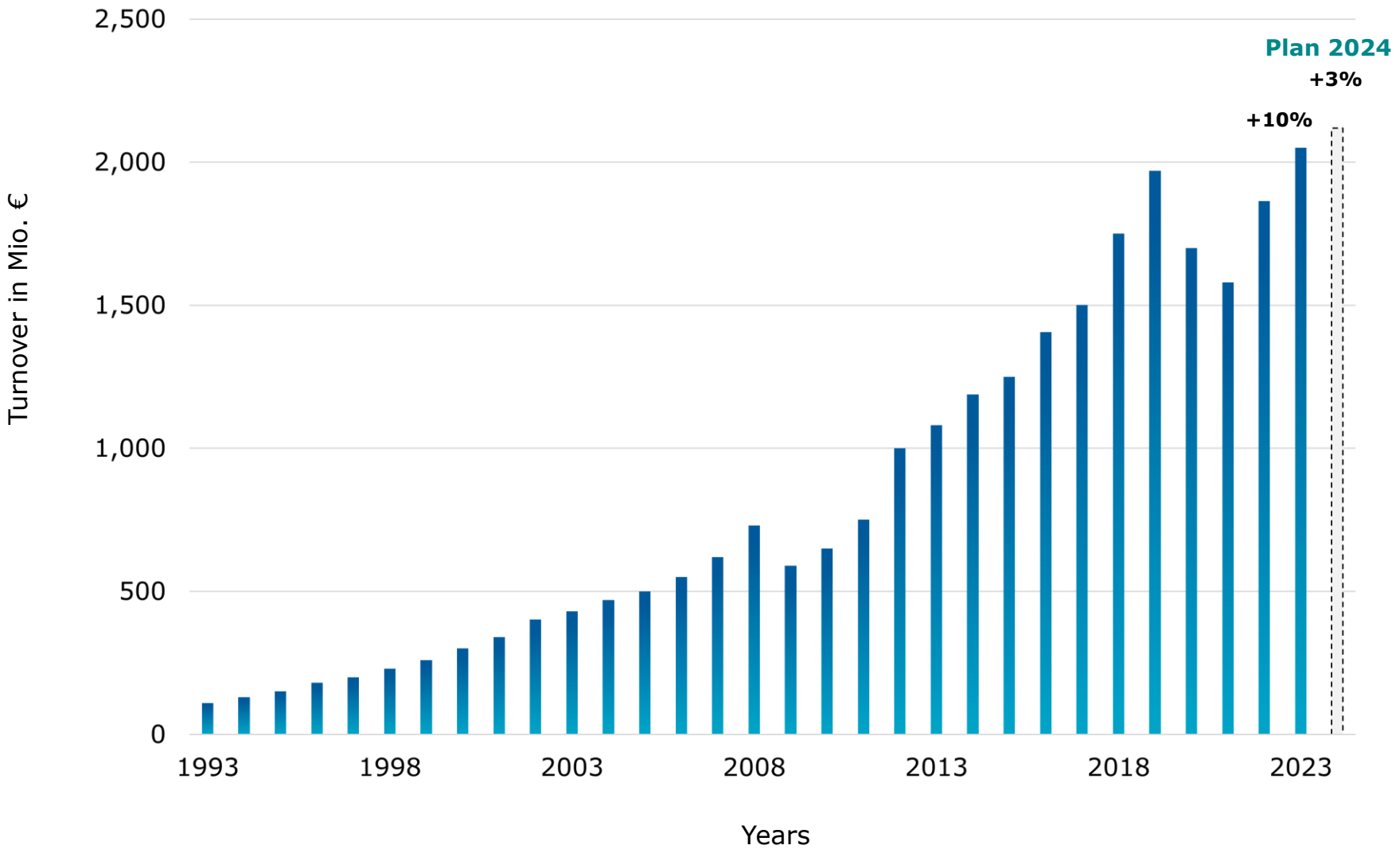
10 %
Of Turnover Invested in Inhouse R&D

2,200
Granted Patents in Force

Our Turnover

2.05 Bn €
Turnover in 2023

97 %
Export Quota



Industry-Wide Value Creation

With future-proven tools, products and systems, augmented by our global network of experts and facilities, we support OEMs and Tier1s to shape current and future technologies for all industries.

Passenger Cars

Commercial Vehicles

Racing

Agriculture

2 and 3-Wheelers

Power Plants

Marine

Engineering a Better Future

Next Generation Vehicles

With our comprehensive technological know-how in all vehicle systems and functions, and our many years of experience in the implementation and use of virtual development methods, we support our customers in managing complexity.

- Development, engineering, services and products
- Vehicle and vehicle systems
- Vehicle functions
- Vehicle development targets and attributes

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

5
Fuel Cell Tech Centers

450+
Fuel Cell Engineers

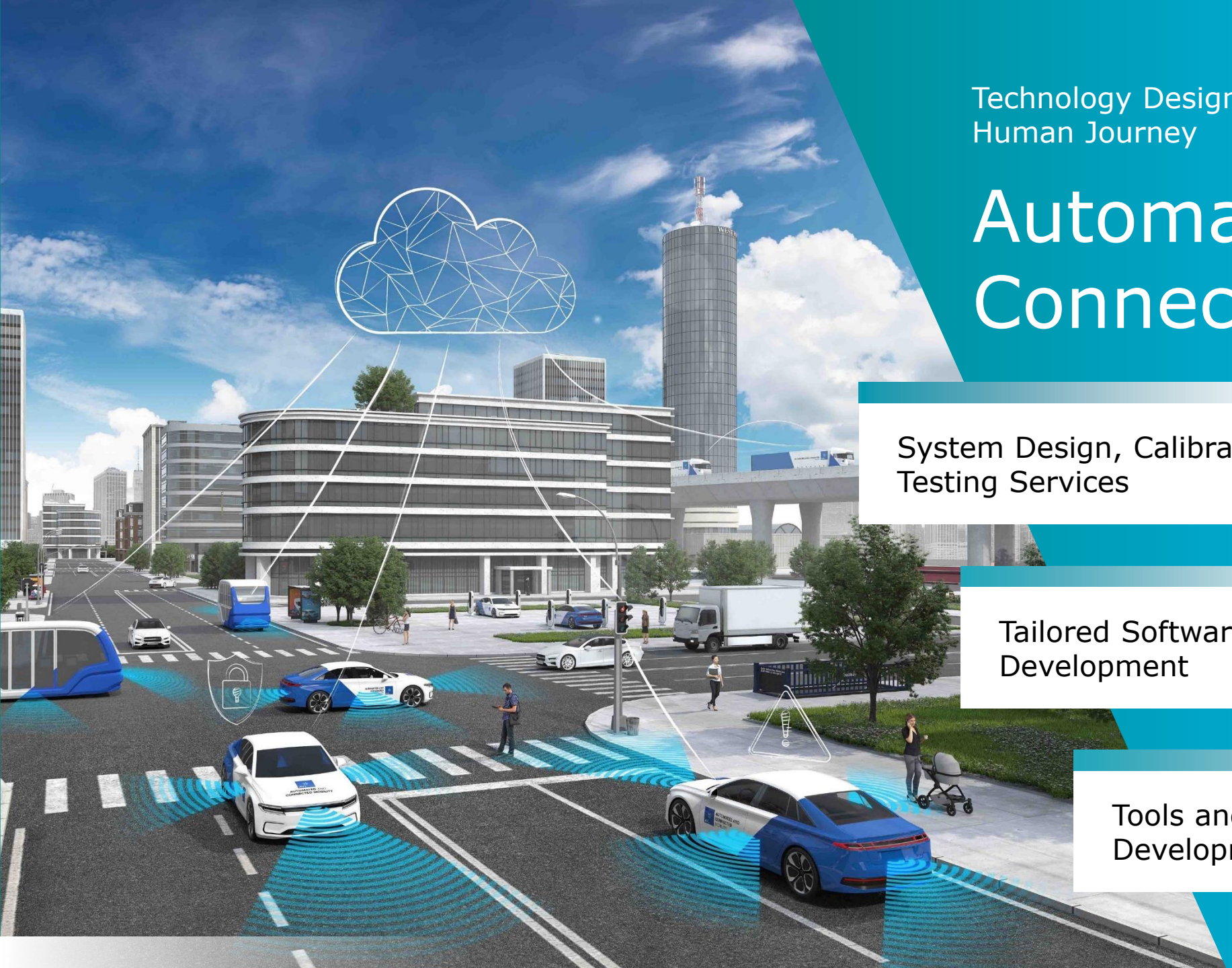
E-Mobility - Highlights

Battery Innovation Center

Our center of excellence at our headquarters in Graz focuses on the development, implementation and validation of new, highly efficient battery production processes.

Hydrogen and Fuel Cell Test Center

The new center in Graz is one of the largest and most advanced test sites for fuel cells and electrolysis systems in the world.



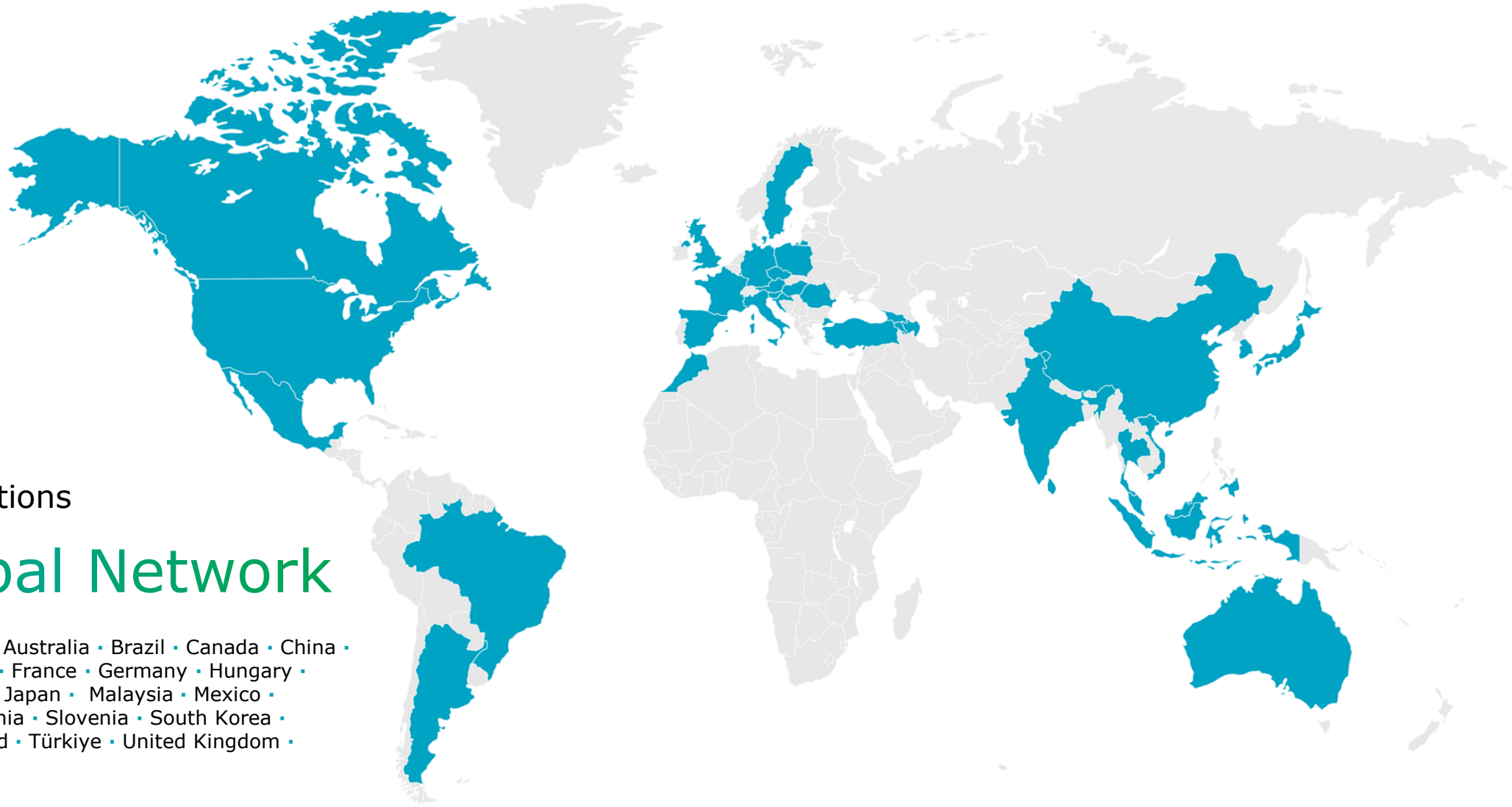
Technology Designed for the Human Journey

Automated and Connected Mobility

System Design, Calibration and Testing Services

Tailored Software and Controls Development

Tools and Methods for Development and Testing



Worldwide Locations

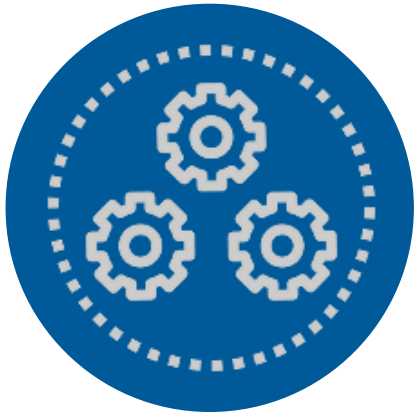
Our Global Network

Austria, HQ | Argentina · Australia · Brazil · Canada · China · Croatia · Czech Republic · France · Germany · Hungary · India · Indonesia · Italy · Japan · Malaysia · Mexico · Morocco · Poland · Romania · Slovenia · South Korea · Spain · Sweden · Thailand · Türkiye · United Kingdom · United States · Vietnam

Introduction & Target Setting

Introduction

High Range and low overall costs when operating a fuel cell truck require an optimal system architecture. Electrified rear axles (eAxles) as well as powerful Fuel Cells are building the basis.



The integration of all single components to an optimized system is key.

Above all, the thermal and electrical system of an FCEV represent the greatest challenge for engineers around the world. Predictive operating strategies are helping to increase efficiency and durability at the same time.

Diesel Trucks to Be Challenged

State-of-the-art Diesel long-haul Truck in Europe

+ around 450 hp
+ up to 4.500 km range, refill < 15 min
+ low TCO → low cost of transport
+ highly efficient
+ maximum transport volume and payload
+ universal application (-30 °C … +45 °C ambient)

but

- CO_2 emissions 33 g CO_2/ton-km payload
  (32 t comb. weight, 21,6 l/100 km, 17,5 t payload *)
- Euro VI → Euro VII emissions

Diesel trucks are highly efficient, but not Zero Emission.

How to combine leading edge performance and zero emission?

→ A solution can be Fuel Cell Electric Drive.

* reference: trucker 01/2023, SuperTest DAF XF 450

Target Setting

Achieve Industry Ready Vehicle Usage

- 42 t Gross Combination Weight
- Real World Operation demonstrated with reference trip: Graz – Wiener Neudorf – Graz
- Range: 400 km
- Re-fueling time: < 15 min.
- Highway uphill driving w/o vehicle performance reduction

Main System & Integration Areas

+ Single Type Approval

- FC System Integration — 310 kW
- Battery System Integration — 72 kWh
- Tank System Integration — 700 bar / 32 kg
- eDrive Integration — 400 kW / 540 kWp
- Cooling System Integration — 30 °C ambient
- EEA, FuSa, Security, EMC, ECE R100, ECE R134 … — 800 V
- Energy Management/ Controls — @40 t GCW: <8 kg H_2 / 100 km

+ Prototype Safety

System Development

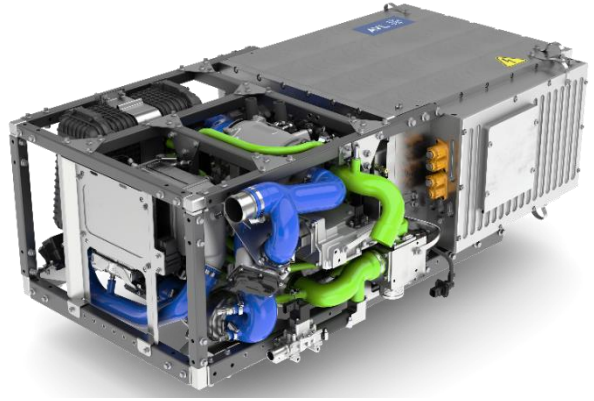
AVL Fuel Cell Technology Demonstrator Truck
From Stack Components to Fuel Cell Electric Vehicle

Fuel Cell Stack

Note: AVL offers only stack engineering services, AVL will not produce and sell stacks

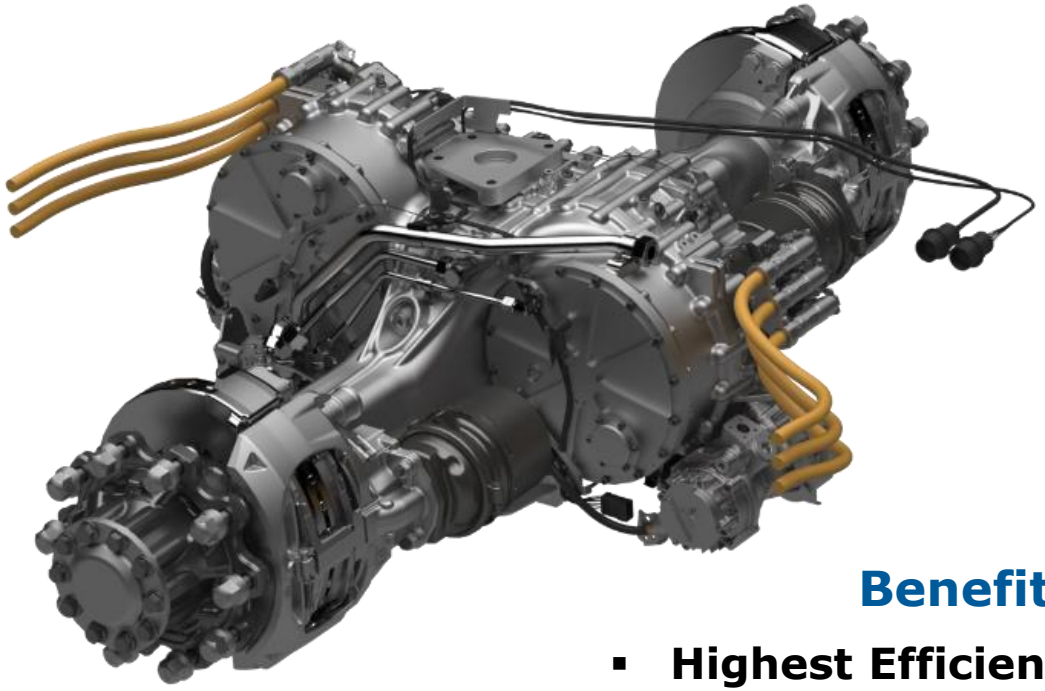
- Power (modular): 30 – 150 kW
- Power Density: 4.1 kW/L
- Lifetime: > 25,000 h
- Efficiency: 48 % (@ 0.6 V)
- Freeze Start Up: -30 °C
- Single cell row, carbon plates

Fuel Cell System



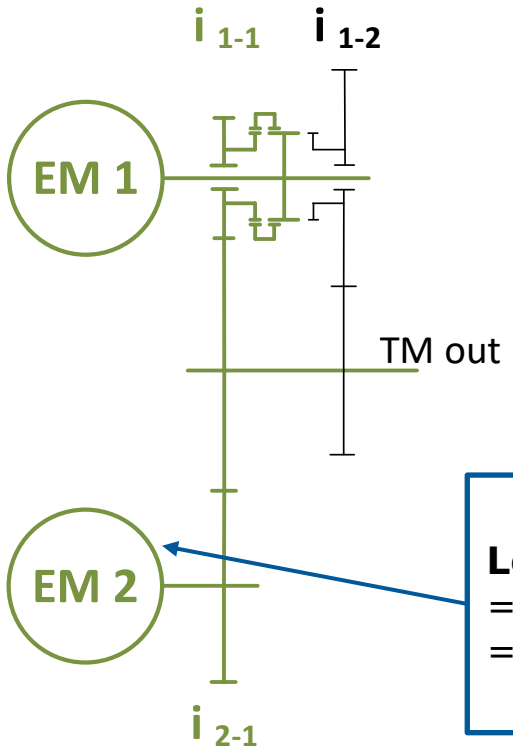
- Rated Power (per module): 155 kW
- Power Density: 0.33 kW/L
- Lifetime: > 15,000 h
- Efficiency: 45 % (@ Rated Power)
- Freeze Start Up: -30 °C

AVL Fuel Cell Technology Demonstrator Truck
Heavy Duty e-Axle



* without brakes

E-motors (PSM)
- 2 x 270 kW peak power
- 2 x 200 kW continuous power
- 9.000 rpm max. rotational speed
- Direct oil cooling for highest torque density



Long Haul Drive Cycle
=> 70 % EM2
= high efficiency

Benefits:
- **Highest Efficiency**
- **Weight < 1.000 kg***
- **Powershift Functionality**
- **Flexible, Scalable and Modular Architecture**

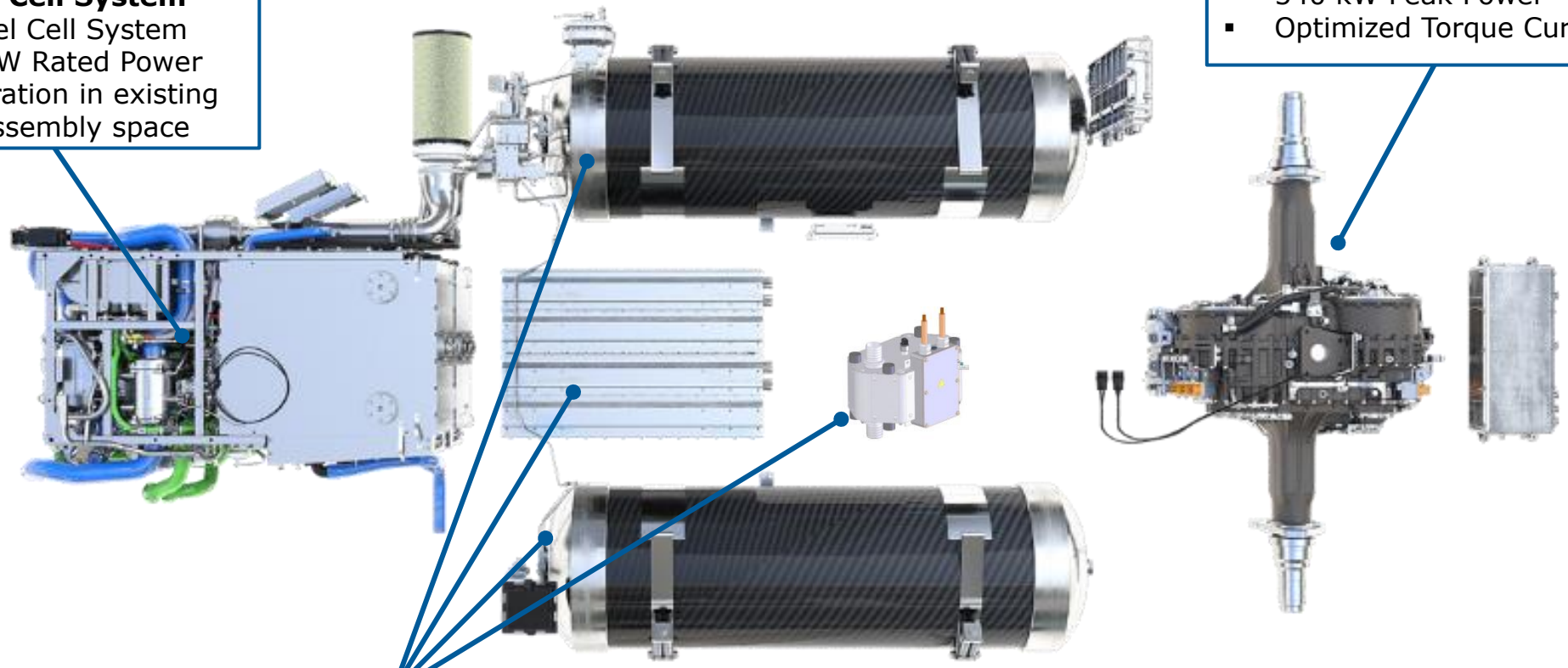
System Integration

AVL Fuel Cell Technology Demonstrator Truck

Main Powertrain Components

AVL Fuel Cell System
- 2x Fuel Cell System
- 310 kW Rated Power
- Integration in existing ICE assembly space

AVL e-Axle
- 2x Electric Motors
- 540 kW Peak Power
- Optimized Torque Curve



AVL Energy Storage
- AVL Modular HV Battery
- 2x H_2-Tanks (32 kg @ 700 bar)
- Brake Resistor (180 kW)
- Integration in standard assembly space

Example for Areas of EE Integration

Vehicle Architecture (DMU), Geometric Integration and Packaging

E/E Fusing Concept

Vehicle Safety

Y-capacitance

EMC

Equipotential Bonding

Insulation Resistance

Vehicle Communication Network

VCU development

Functional Safety

Battery System

NVH Activities

Fuel Cell System incl. BOP

Vehicle calibration & testing

Brake chopper

Homologation

Powertrain Systems

Electrical safety

Electrified Auxiliaries

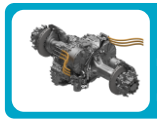
E/E system Architecture

Thermal System

AVL Fuel Cell Technology Demonstrator Truck

Heavy Duty Power Distribution Unit

Connections

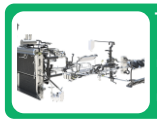


Dual motor e-axle
- 2x 270 kW peak
- 2x 200 kW continuous

Fuel cells
- 2 x 155 kW continuous

Brake chopper
- 250 kW continuous

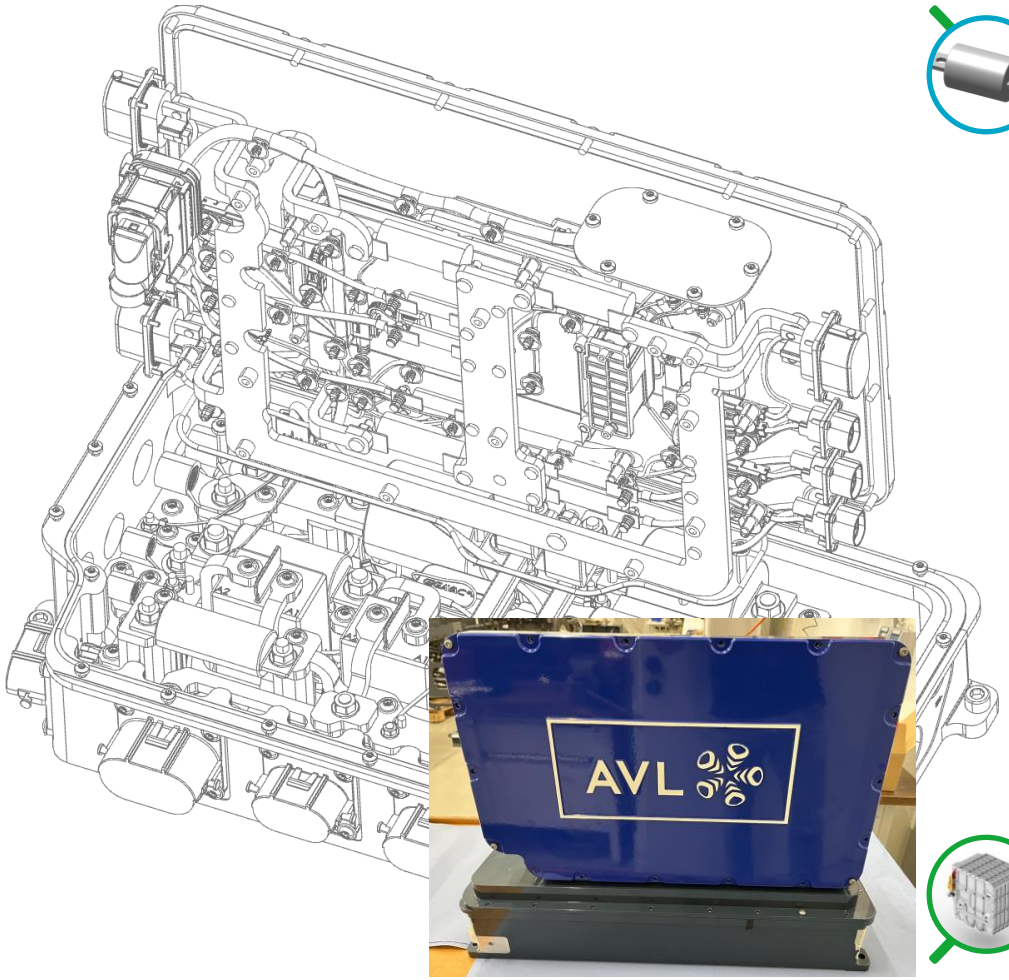
HV voltage battery packs
- 2 packs in series → 800 V
- 190 kW peak, 95kW continuous



Thermal management components
- Main fan (>40kW continuous)
- AC compressor, heater, pumps

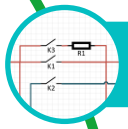
Auxiliary outputs
- Steering pump, air compressor
- HV-LV DCDC

AC & DC charging
- Including DC charging contactors



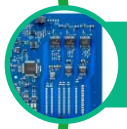
Features

Overcurrent protection

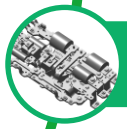


Pre-charging of HV system & monitoring

Contactor control (main contactors, pre-charge and DC charging)



Isolation resistance and voltage monitoring



Current and temperature monitoring

HVIL signal generation and monitoring

Battery multipack control & EVCC*

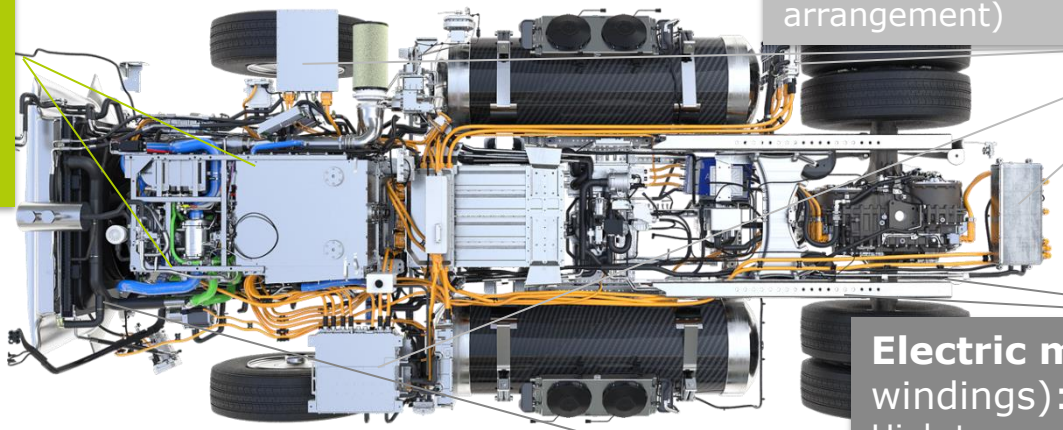
*separate controller, but can be combined on customer request

Demanding Challenges for Heavy-Duty Electrification

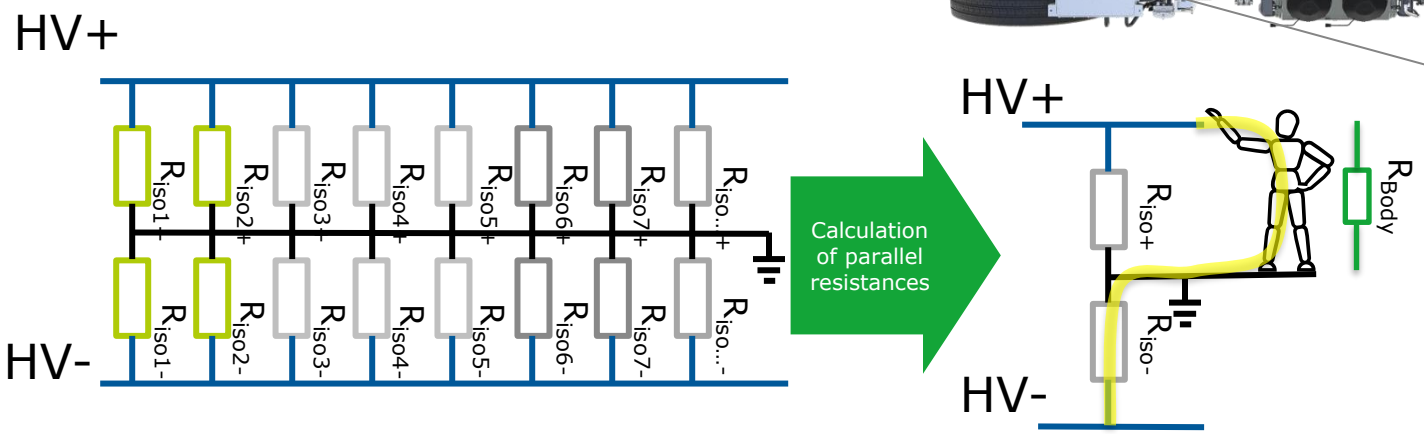
Isolation resistance

Fuel cell system:
Coolant in direct contact with HV in fuel cell stacks → conductivity and paths to ground define Iso-Resistance
Major contributor to total isolation resistance

Power Electronics (DC/AC & DC/DC converters):
High isolation resistance of single components
Large number of components in HV system → **contribution not neglectable** (parallel arrangement)



Electric motors (insulation of windings):
High temperature dependency of isolation resistance (+10 °C → $R_{iso}/2$)
Large number of components in HV system → **significant contribution** (parallel arrangement)



In a system with too low insulation resistance, **a single failure would be hazardous for people**.

Demanding Challenges for Heavy-Duty Electrification

Y-Capacity

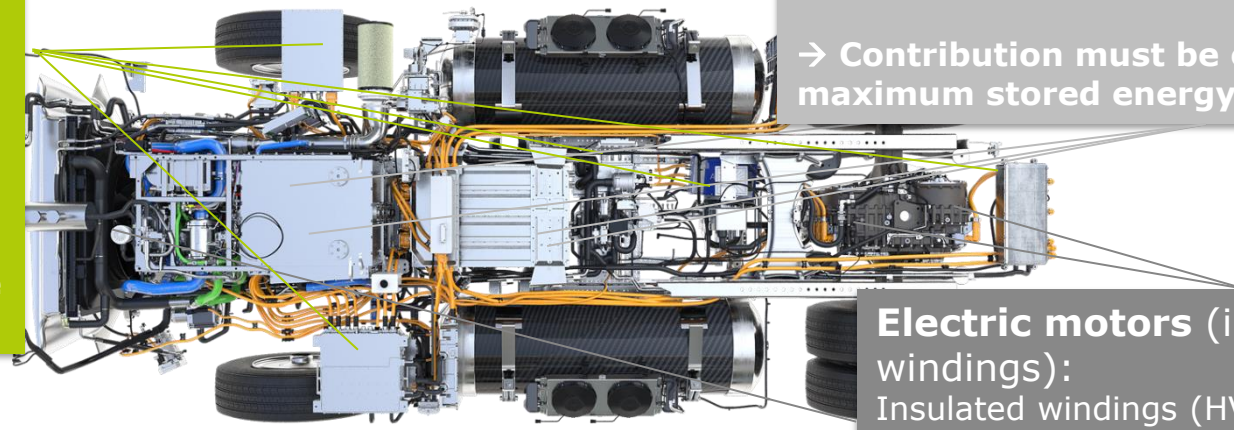
EMC Filters:
EMC filters are part of each HV component with power semiconductor switches

High y-capacities in off-the-shelf components, since it's the easier way to meet EMC targets

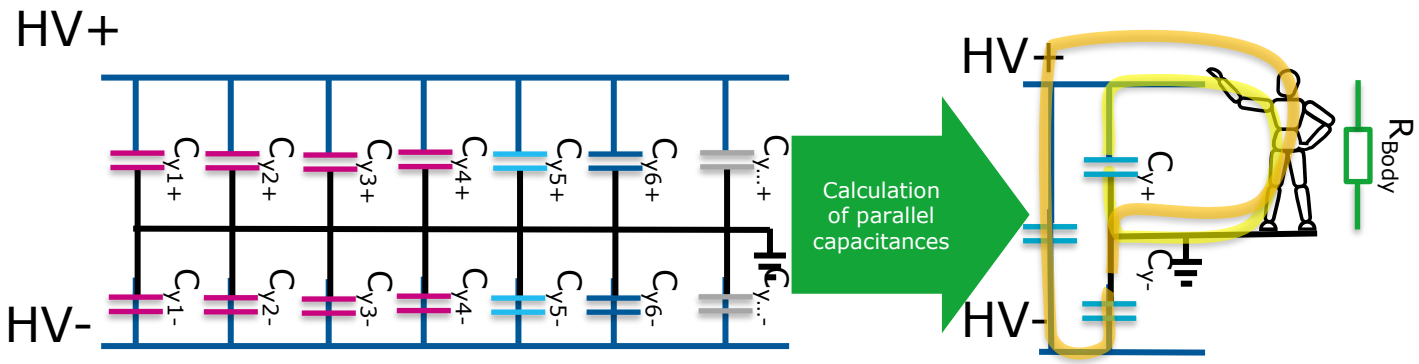
→ Severe impact on total y-capacitance even by low-power HV components

Fuel Cells, and Batteries, brake resistors
Large electrically active surfaces and small distances to ground planes (e.g., battery cell to cooling surface) act as a capacitor

→ Contribution must be considered for maximum stored energy

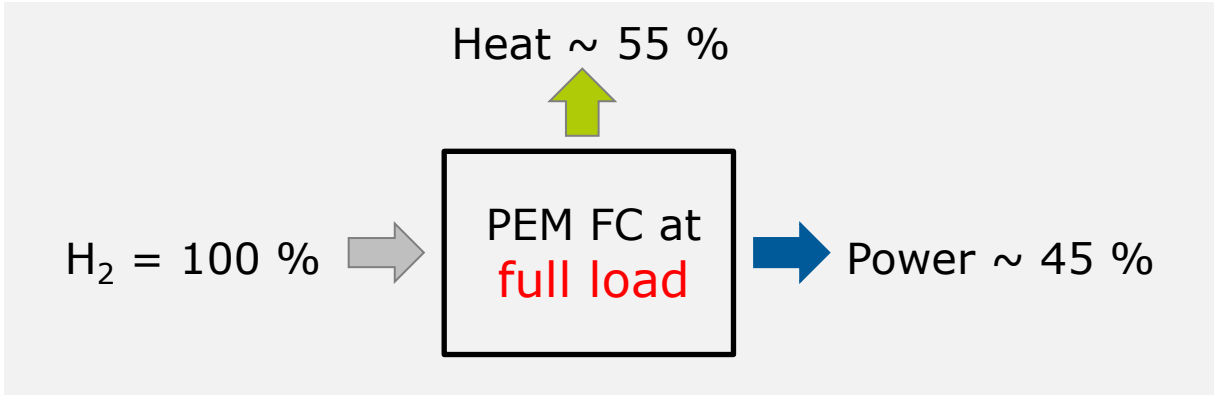


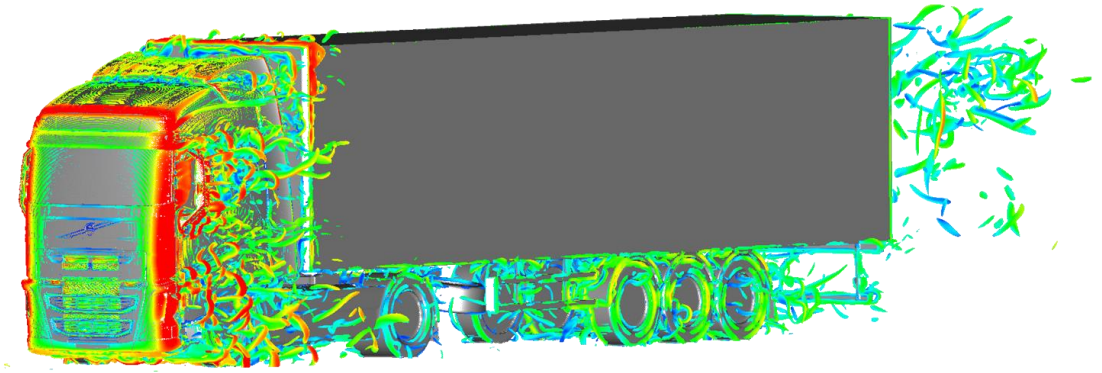
Electric motors (insulation of windings):
Insulated windings (HV) in stator slots (GND) also act as a capacitance
→ small contribution, but needs to be investigated

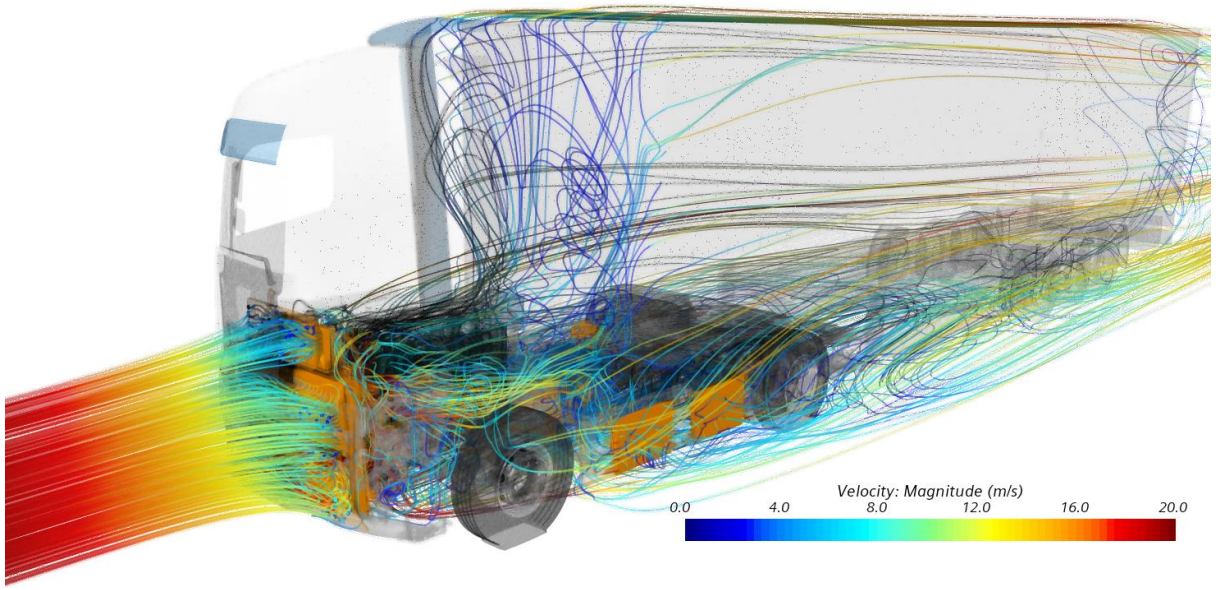


In a system with high Y-capacity,
a single failure would be hazardous for people.

Thermal System
Challenge – not hot Exhaust Gas







- High share of losses into cooling fluid, no hot exhaust gas with high mass flow
- Low temperature level
- De-Ionized coolant in high temperature circuit

→ 3 optimized cooling circuits (LT, MT, HT)

→ High voltage main radiator (30 kW)

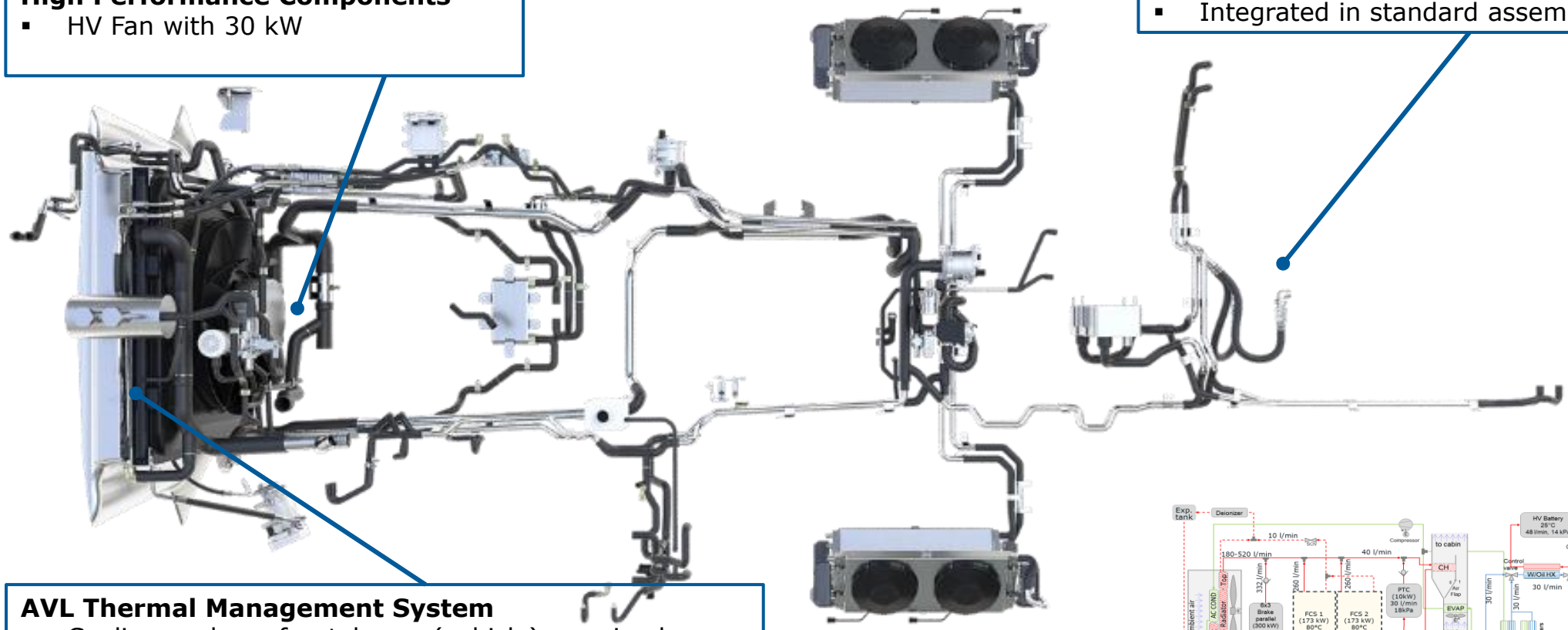
→ Additional low voltage radiators

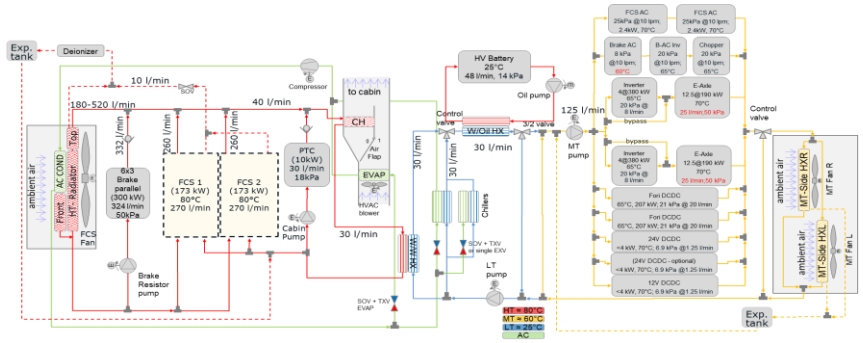
→ Predictive thermal management

AVL Fuel Cell Technology Demonstrator Truck
Thermal System

High Performance Components
- HV Fan with 30 kW

AVL Thermal Management System
- 3 optimized and interconnected cooling circuits (LT, MT, HT)
- Integrated in standard assembly space





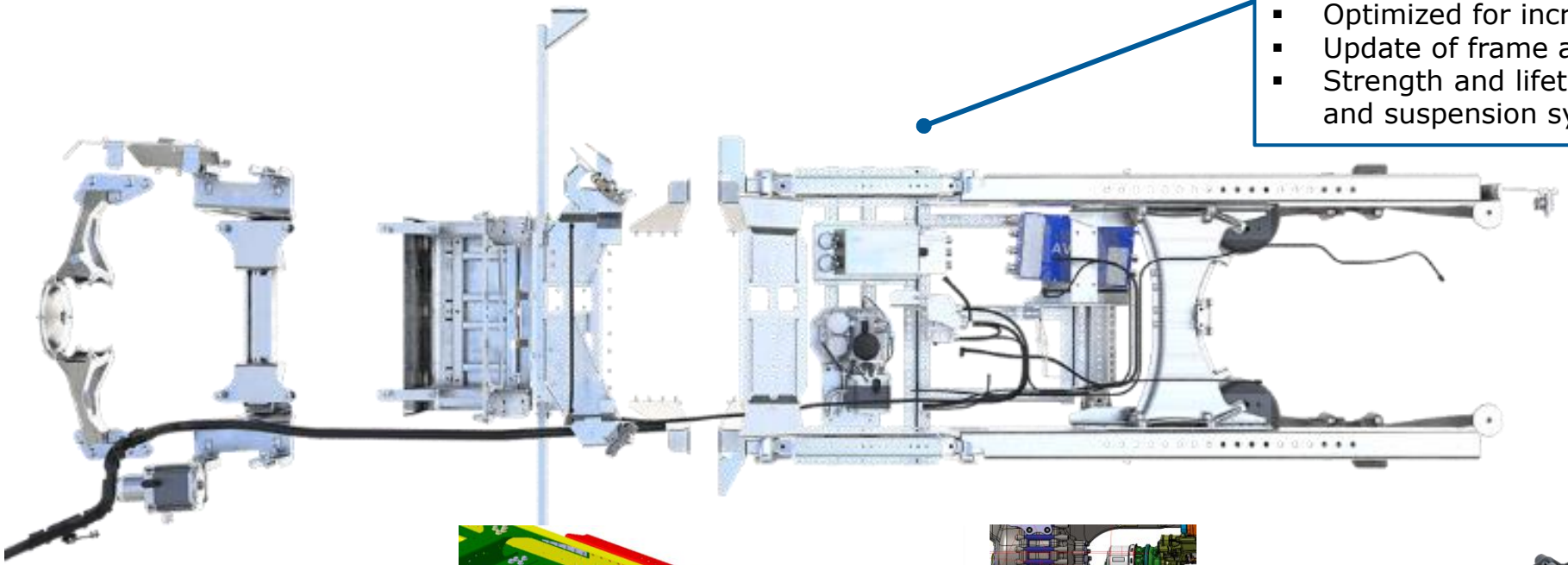
AVL Thermal Management System
- Cooling package frontal area (vehicle) remained unchanged
- Total front radiator surface was increased to 1.8 m² (180 % of initial radiator size)

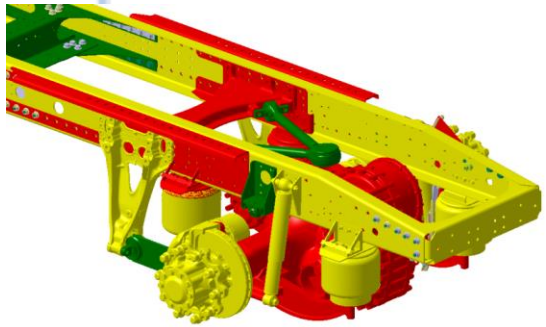
AVL Fuel Cell Technology Demonstrator Truck

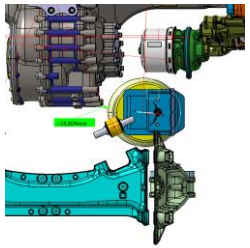
Chassis & Frame

AVL Chassis Development

- Optimized to new geometry of powertrain elements
- Optimized for increased mass of e-axle
- Update of frame and suspension
- Strength and lifetime simulation for complete frame and suspension system (incl. load case definition)







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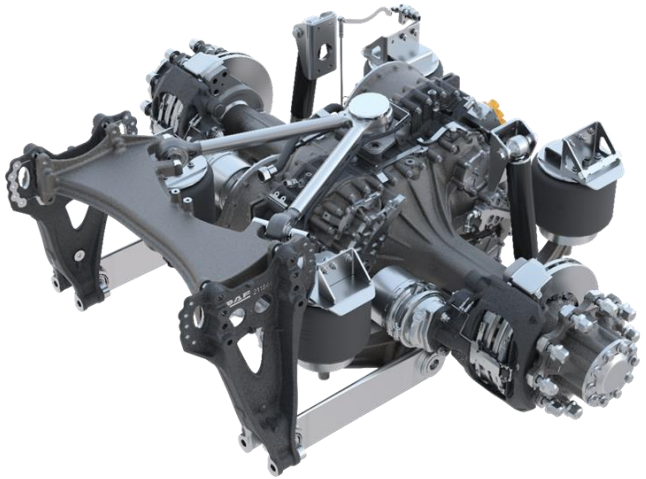
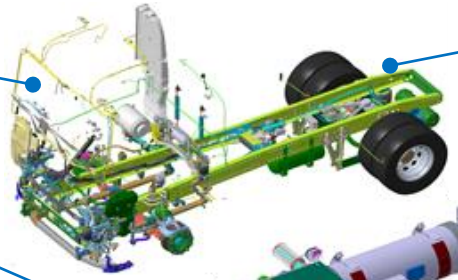
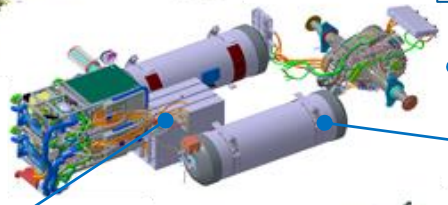


Vehicle Systems Geometrical Integration

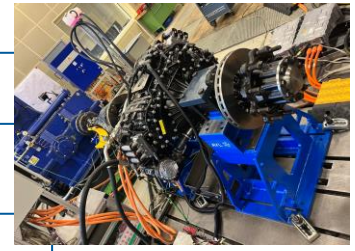
Donor Vehicle (DAF XF, 3.8m wheelbase, Diesel engine)

New HMI



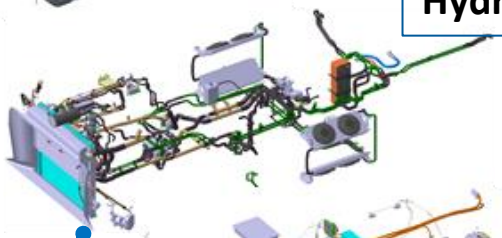


Integration of AVL HD **E-Axle**



AVL **HD FC System**

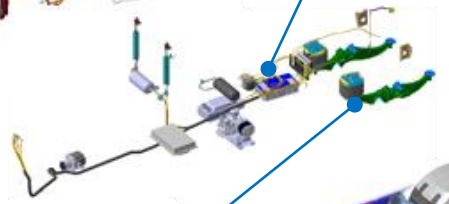
Integration of 700 bar **Hydrogen tanks**



OTS Battery System

Integration of **Brake Chopper/ Resistor**

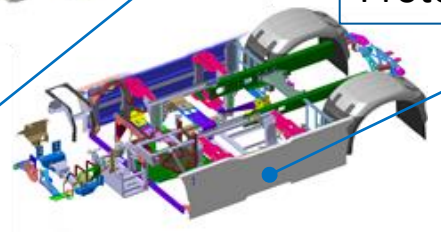
Advanced AVL **Thermal System**



Power Electronics & E/E Integration

Crash Simulation of Side Protection (for H2 Tank)

Adaption of Chassis Components



Advanced Energy Management

AVL Fuel Cell Technology Demonstrator Truck
Advanced Energy Management

A predictive function optimizes system parameters in order to implement the optimal trade-off between

Energy/fuel consumption

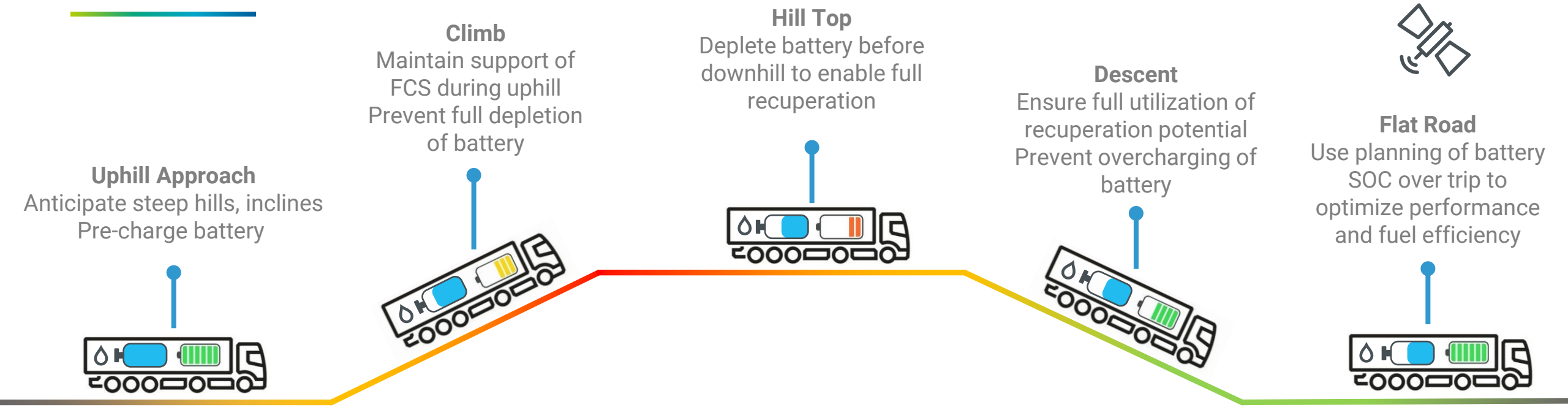
Trip time

System/component lifetime

Optimize TCO

AVL Fuel Cell Technology Demonstrator Truck

Pred. Energy Mgmt. - Use of Digital 3D Road Maps and GPS



Sensors & Actuation

- Preview of route characteristics (altitude, speed limits, curvature, traffic, …)
- Powertrain states (actual gear, torques, battery SoC, etc.)
- Outputs power split between available energy sources (e. g. fuel cell & battery)

Typical PHC Applications

- Applicable to all hybrids, e. g. HEV, REEV, FCEV

Benefits & Tradeoffs

- Up to 5 % energy saving*
- Highest savings on longer routes with mix between urban & highway driving

* expected fuel savings depending on use-case and powertrain specification

AVL Fuel Cell Technology Demonstrator Truck
Targets of Predictive Energy Management

Targets of Energy Management

- **Max. Vehicle performance**
- **Optimize H_2 efficiency / Range**
- **Optimize Component aging**

Integration of Predictive Lifetime Management

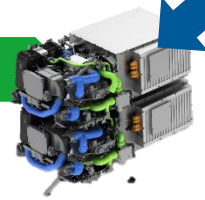
- Integration in energy management
- Optimize component lifetime
- Keep high H_2 efficiency and vehicle performance

→ Reduce TCO for customer

Predictive ENERGY MANAGEMENT

Power split between
- Fuel cell systems
- Battery system

Fuel cell characteristics



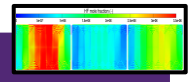
- System efficiency
- Component limits

→ Influenced by aging over lifetime

Battery characteristics

- System efficiency
- Battery capacity
- Component limits

→ Influenced by aging over lifetime



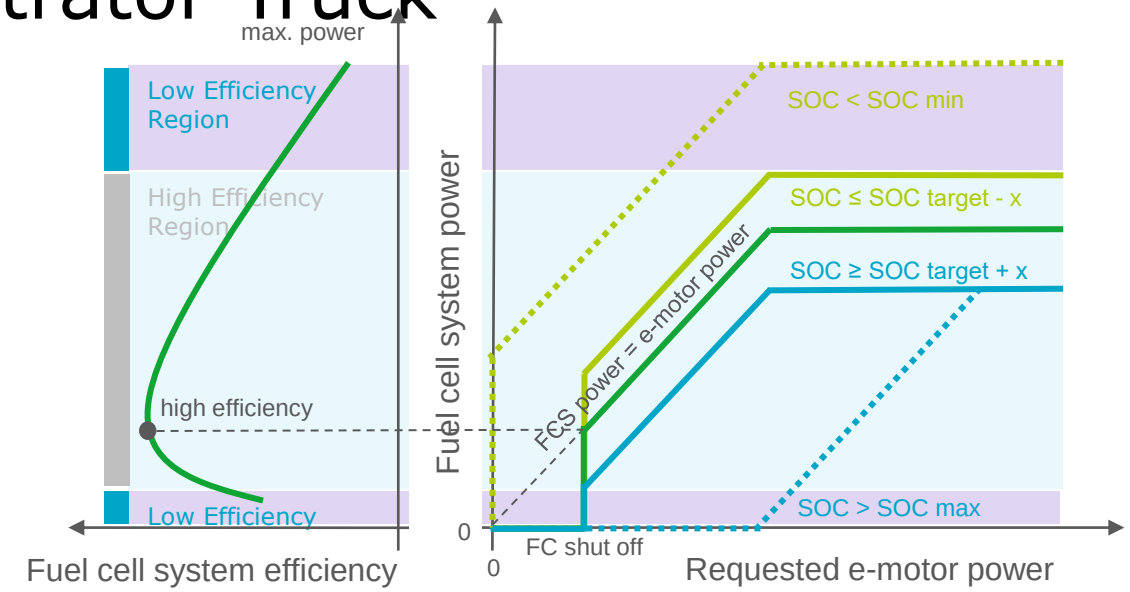
Predictive LIFETIME MANAGEMENT

- Optimization and balancing of component lifetime
- Ensure high H_2 efficiency and vehicle performance
- Optimization of TCO for customer

AVL Fuel Cell Technology Demonstrator Truck

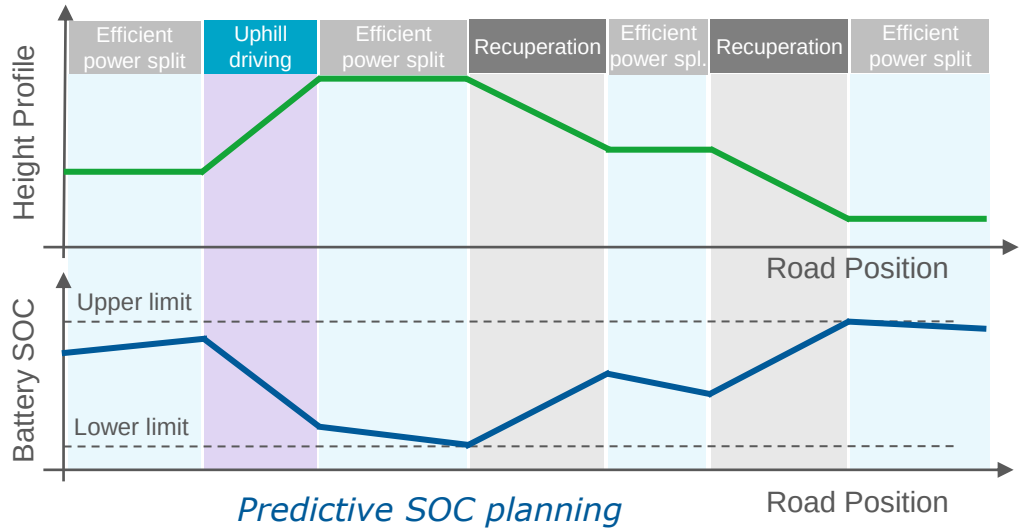
Standard vs. Predictive Energy Management

- **Standard energy management** (without predictive info)
  - Provide requested e-motor power by fuel cell
    - Limited by max. power gradient
    - Remaining e-motor power from battery
  - Control battery SOC to a target value
    - Efficiently adapt fuel cell power
    - Strongly adapt fuel cell power for exceeding SOC limits



Fuel cell system operating strategy

- **Predictive energy management**
  - Optimized SOC planning via road profile & traffic info
    - Efficient power split between FCS and battery
    - Avoid full depletion of battery
    - Utilize whole recuperation potential
    - Reduced component ageing



Predictive SOC planning

Certified and on the Road by **Beginning of 2025**

Q&A

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