

Fuel Cell System Simulation for Heavy Duty Application

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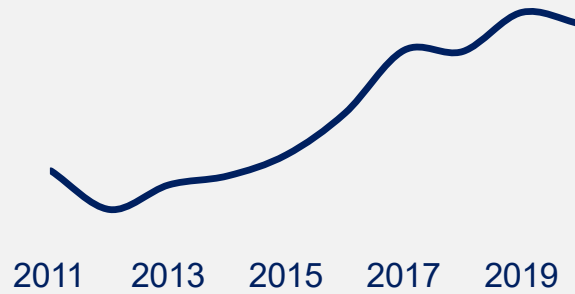
WE SHAPE
FUTURE
MOBILITY



MAHLE

H₂ for Truck Mobility of Tomorrow

Transport Performance
Road Freight - EU27

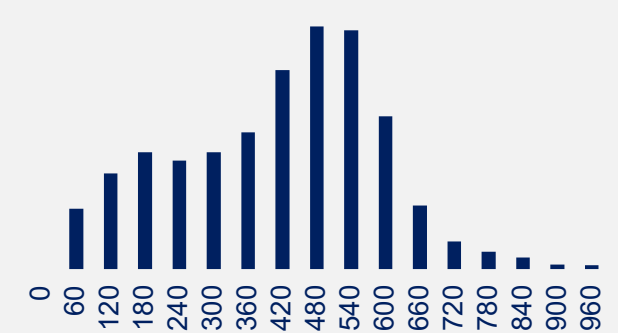


- Steady increase in transport performance
→ Need for fast measures to reduce CO₂



- EU's "Fit for 55" accelerates transformation in road transport

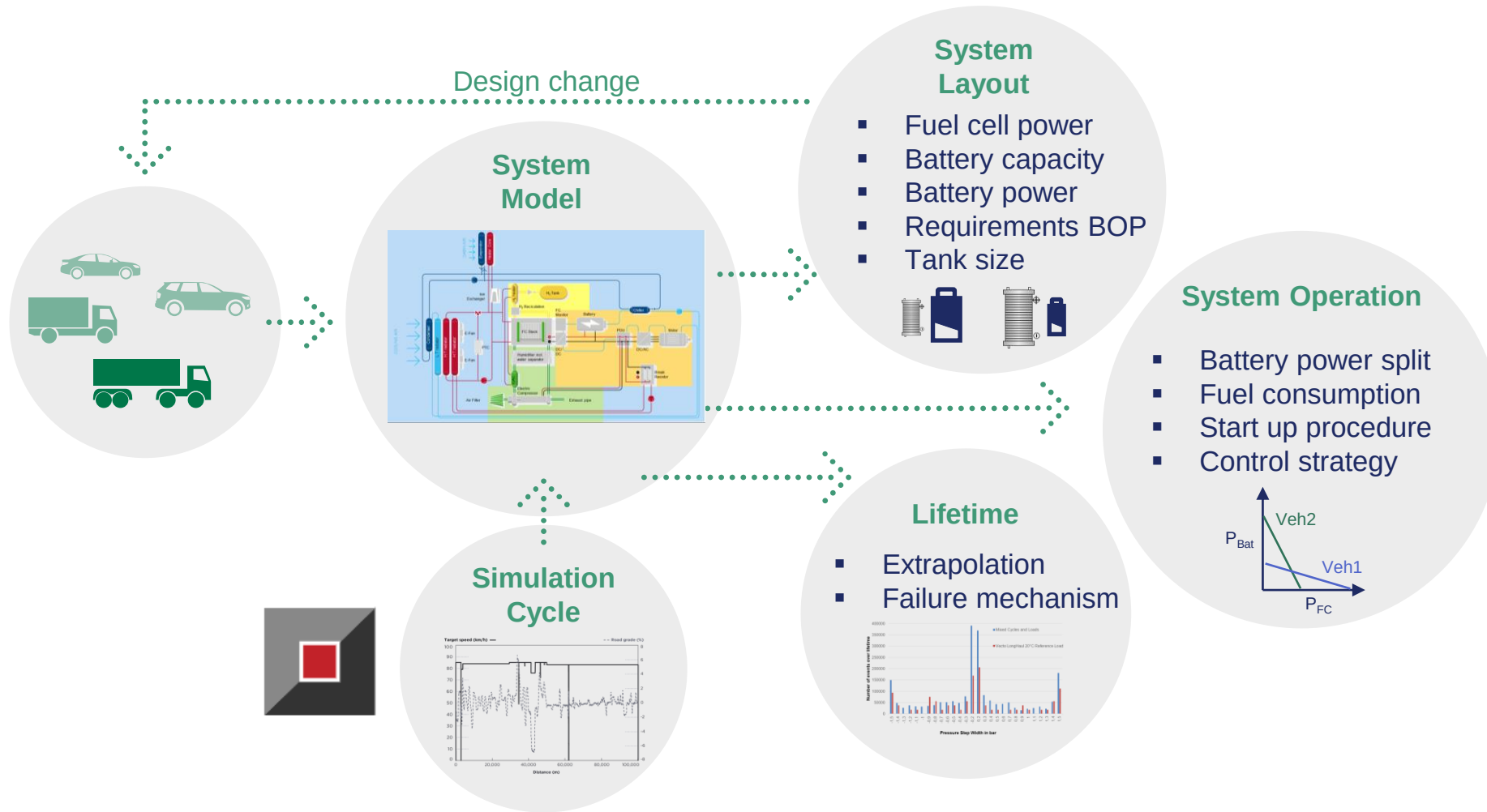
Daily Mileage / km



- Daily mileage peaks at 500 km/d
→ Defossilisation of long haul trucks

H₂ enables carbon free transport, especially for long ranges and non-road application

System Simulation: A Way to Address the Targets

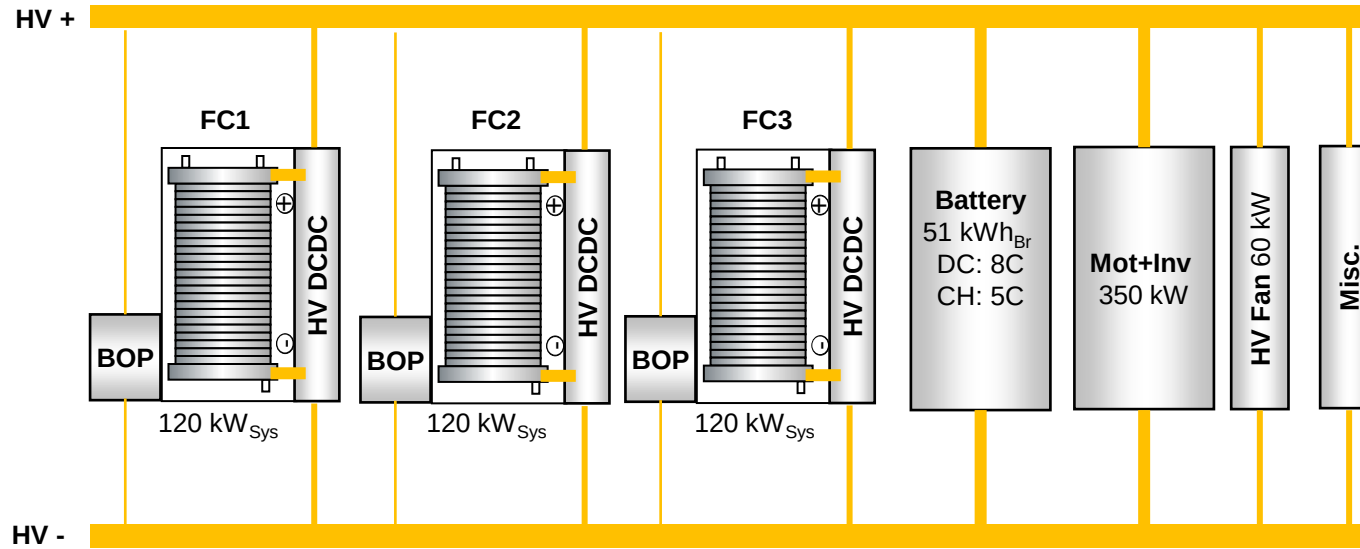


Simulation to determine optimal system & component specification

Model Layout



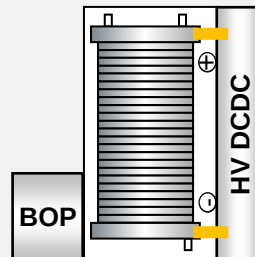
Model Layout



Generic HV Layout for a FC Truck

Fast Running Fuel Cell Truck Model:

- Single FC System calculated
- Uniform power distribution
- *Next Step:* Module-wise optimization



× 3



- Class 5 Long Haul Truck
- Fuel Cell 3x 120 kW (EOL)
- Battery 51 kWh_{Br}
- Motor 350 kW_{el}



- Low load 2600 kg
- Reference load 19300 kg
- Max load 24300 kg
- Ambient: 15, 25, 35°C

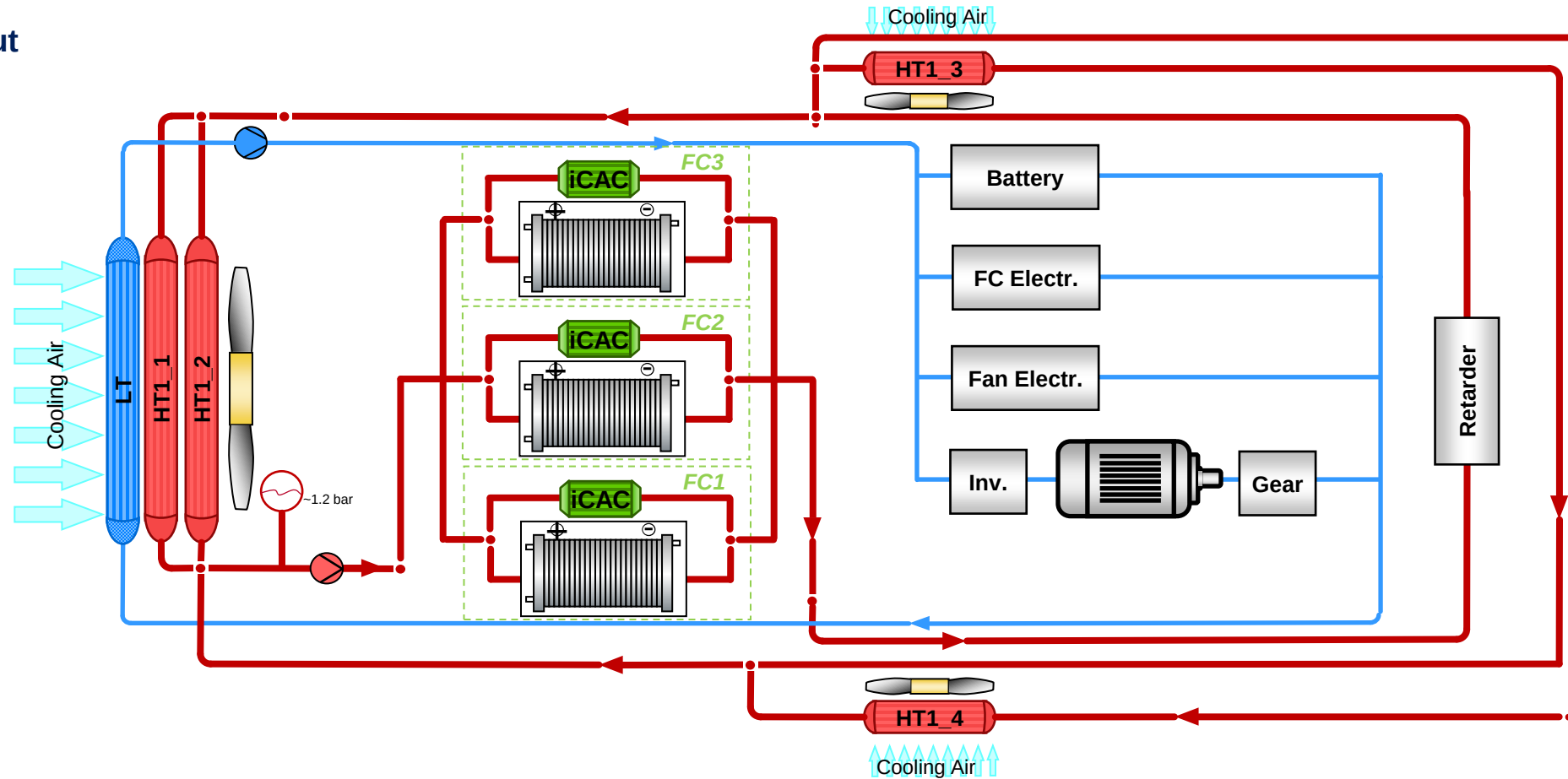


- VECTO Long Haul
- VECTO Regional Delivery
- Real Drive (Brenner pass, Black Forest)

Scalable physical fuel cell truck model

Model Layout

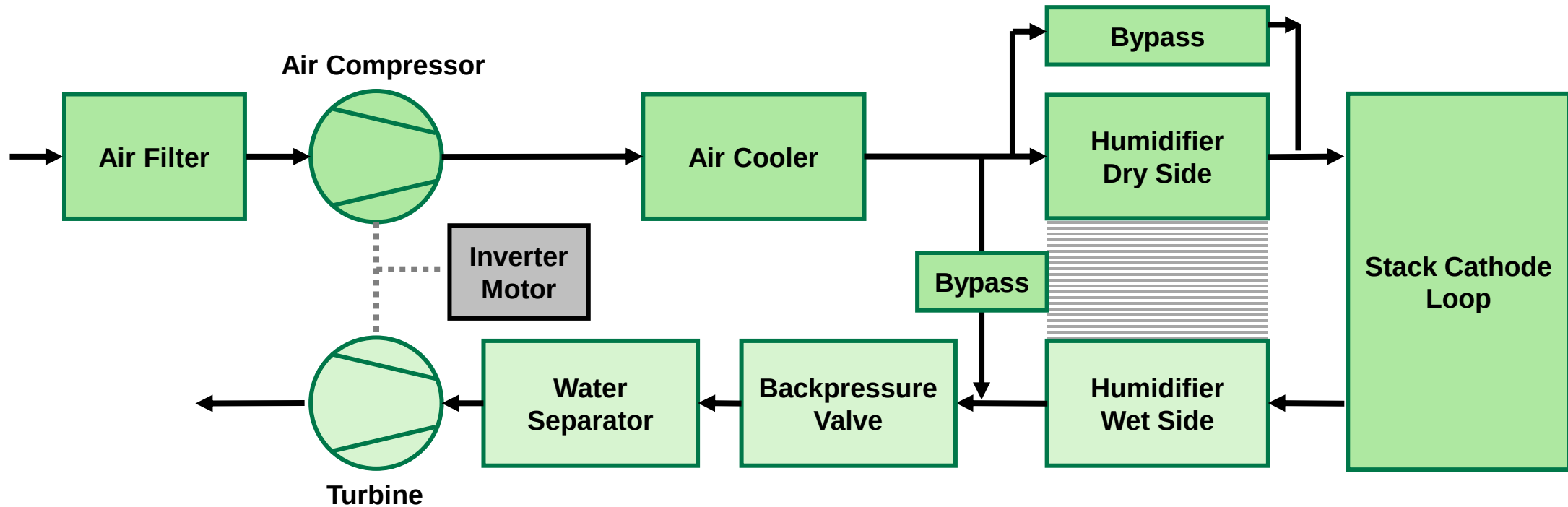
Coolant Layout



Detailed vehicle coolant circuit considering additionally the low temperature circuit

Model Layout

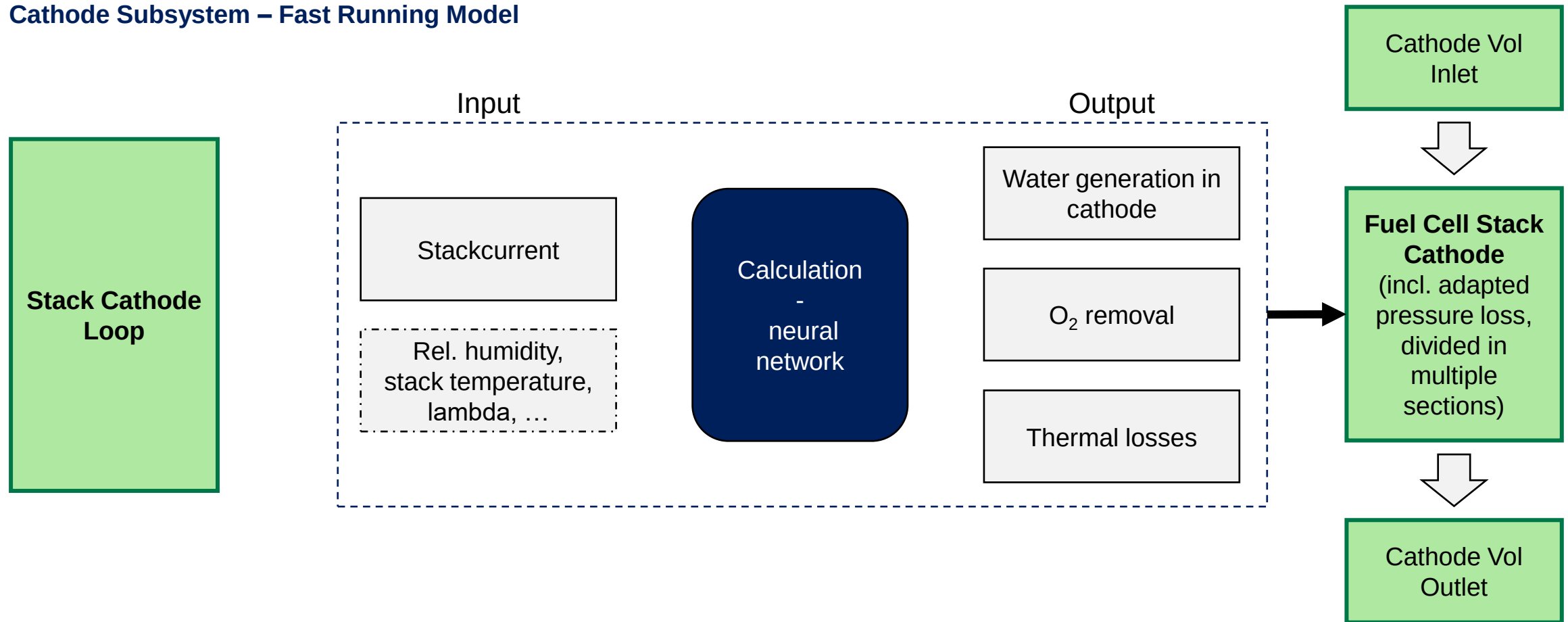
Air Subsystem



FC system model covering all functional components

Model Layout

Cathode Subsystem – Fast Running Model



Reduced complexity for integration into drive cycle simulation

Model Results

Model Results

Lifetime Load Extrapolation



Transient GT Simulation

Evaluation

FC System Requirements

Ambient Temp

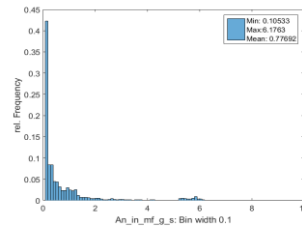
Drive Cycle

Payload

Degradation

Simulation Results:

Histogram
Rainflowcount



Extrapolation:
1.875.000 km

Payload Factor:

Low L	Ref L	Max L
20%	50%	30%

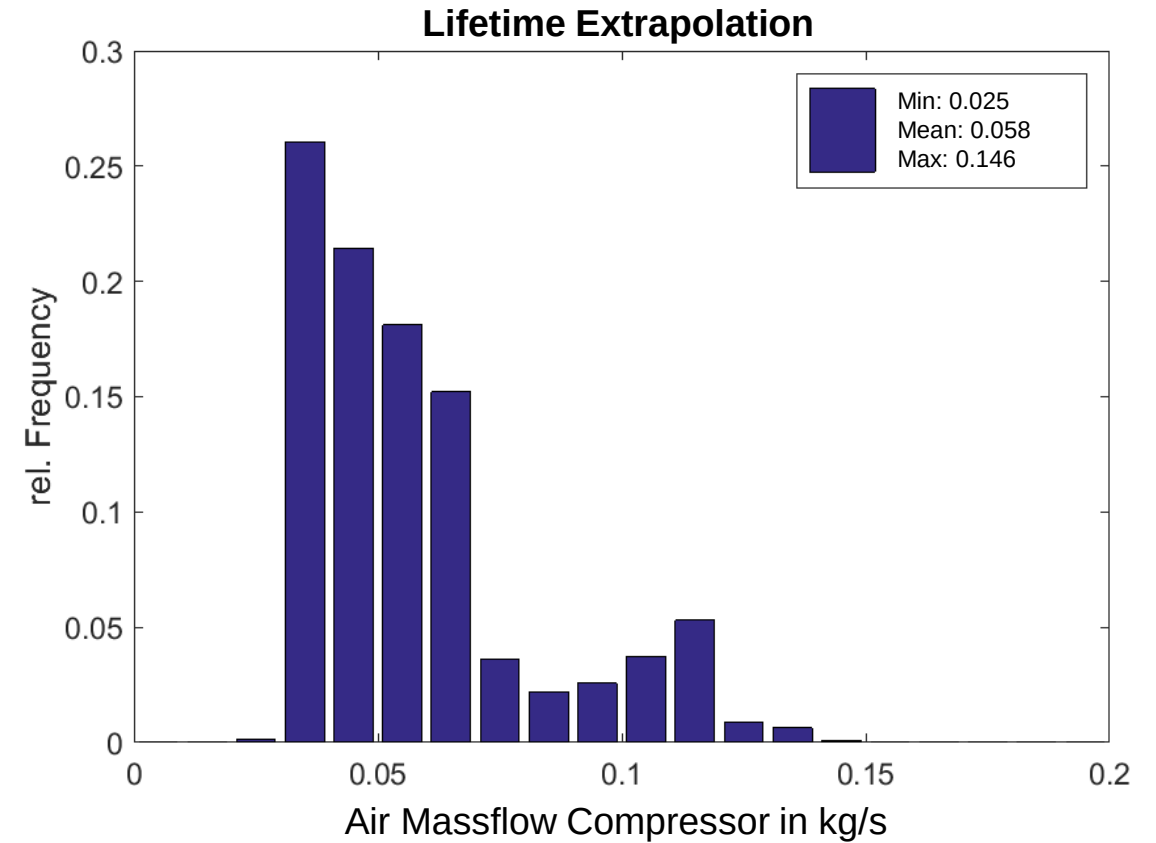
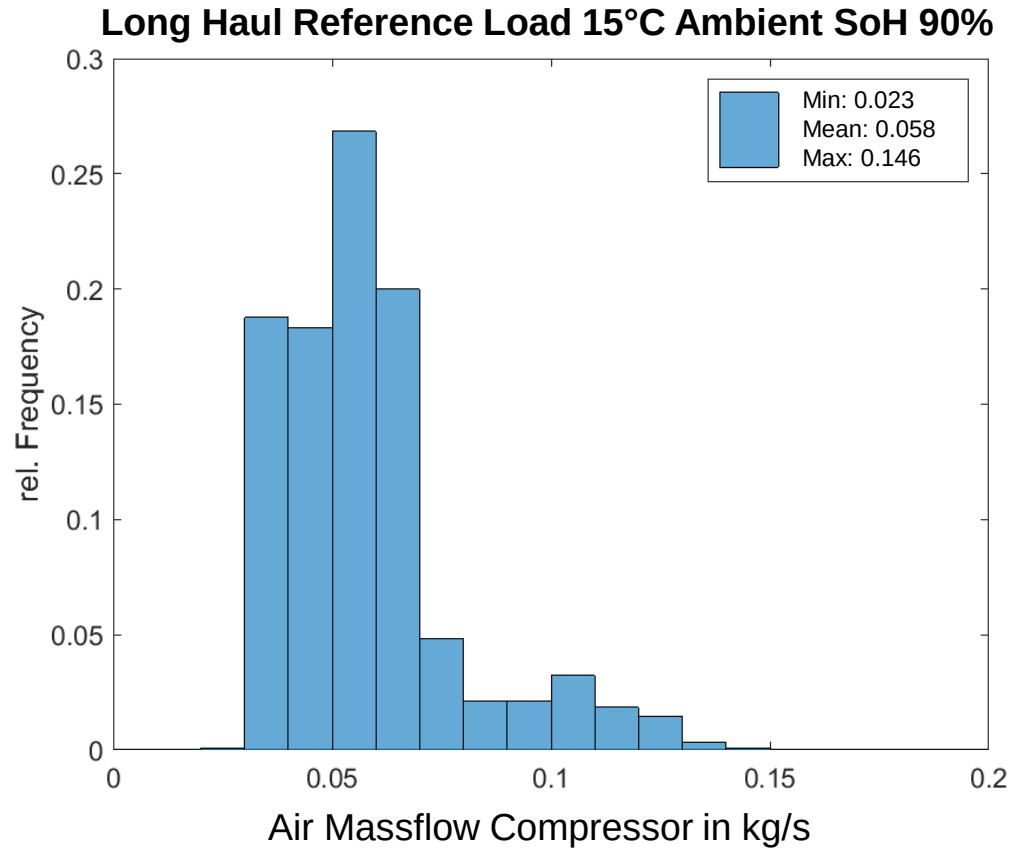
Ambient Temperature:

15°C	25°C	35°C
79%	13%	8%

Evaluation method¹⁾ covers various ambient impacts

Model Results

Air Massflow Compressor (single FC stack)

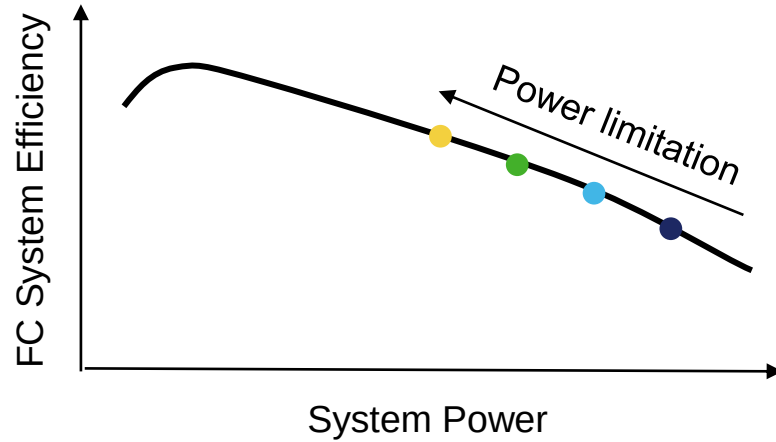


Covering multiple differing drive cycles to estimate component's lifetime loads

Influence of Hybrid Control Strategy

Influence of Hybrid Control Strategy Power Limitation

Efficiency curve

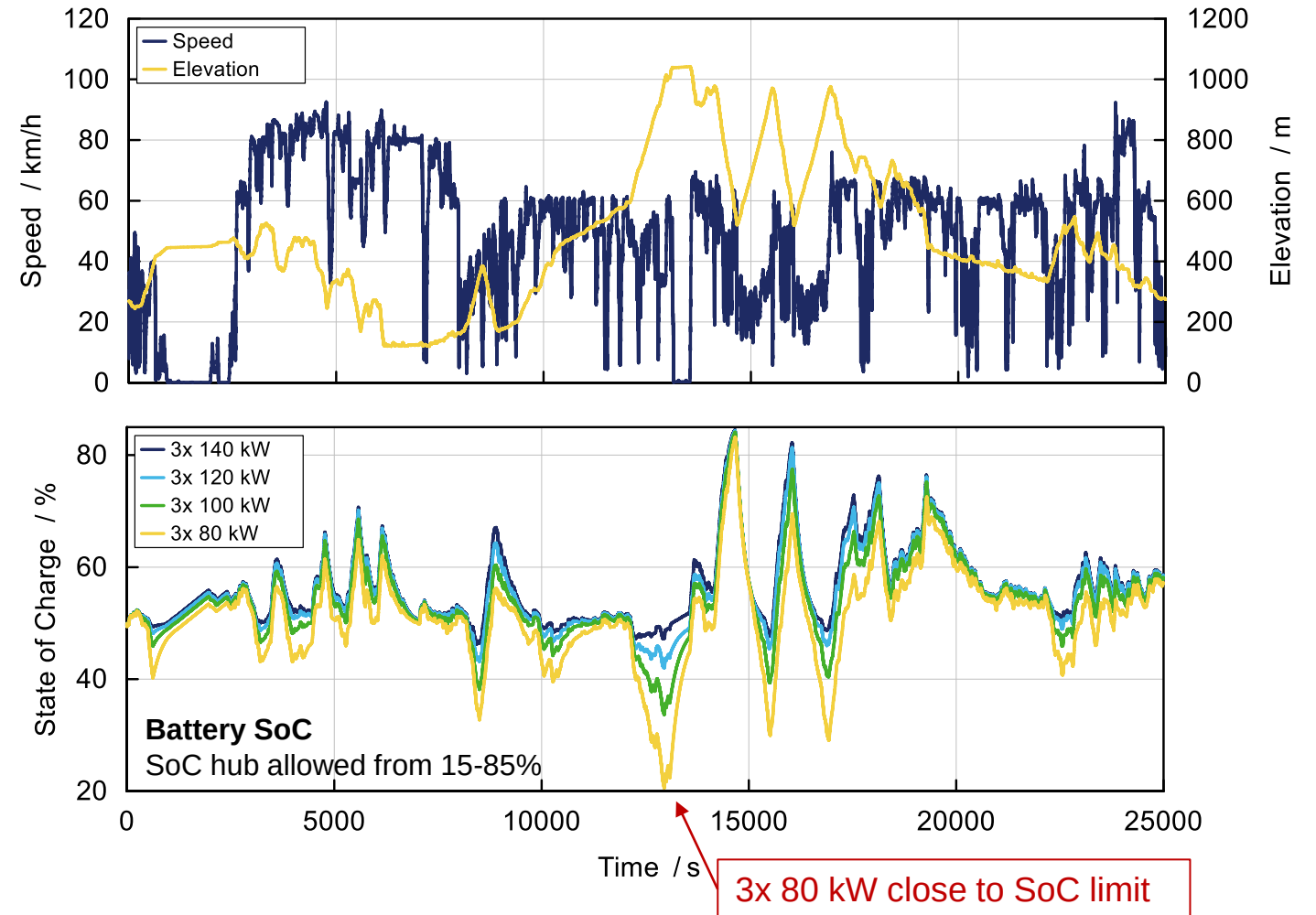
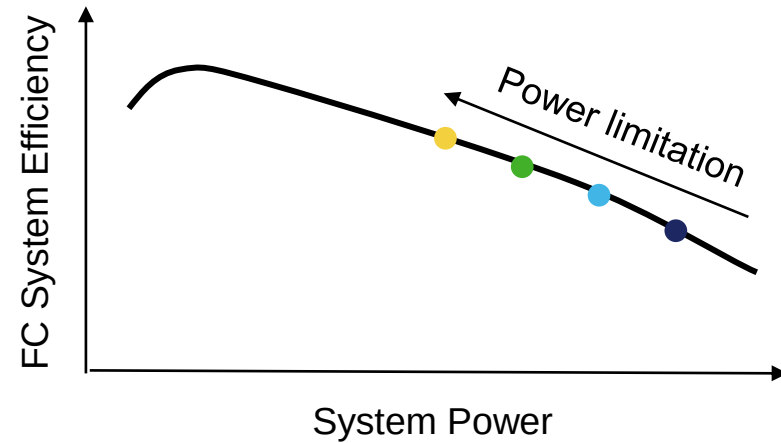


Limitation of output power @ 3x 140 kW Stack

1. 3x **140** kW stack power (100% of installed power)
2. 3x **120** kW stack power (85% of installed power)
3. 3x **100** kW stack power (70% of installed power)
4. 3x **80** kW stack power (55% of installed power)

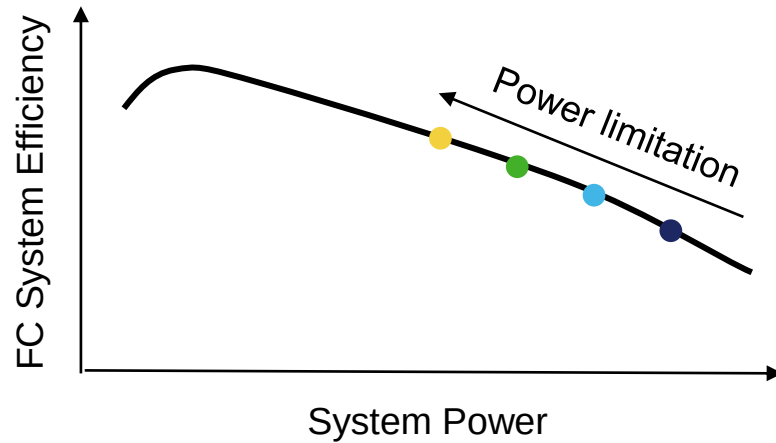
Influence of Hybrid Control Strategy Power Limitation

Efficiency curve

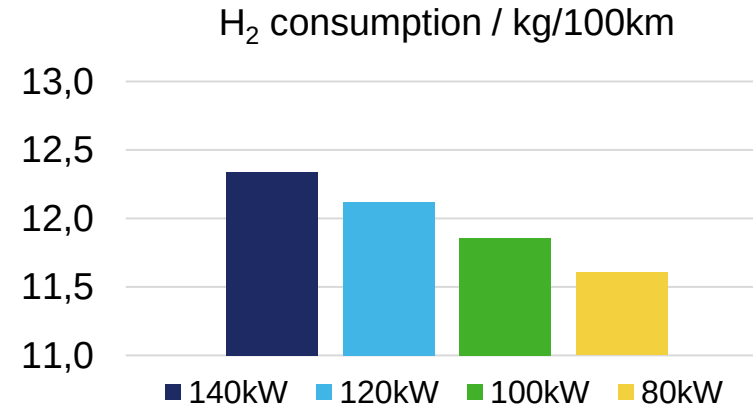


Influence of Hybrid Control Strategy Power Limitation

Efficiency curve



Fuel consumption



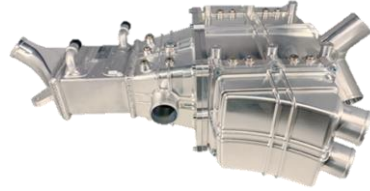
- Oversizing leads to **lower fuel consumption**
- Increased stress for **battery** due lower fuel cell system power output
- Further improvement with stack specific control & ADAS expected

Further improvements & high control complexity expected

Summary



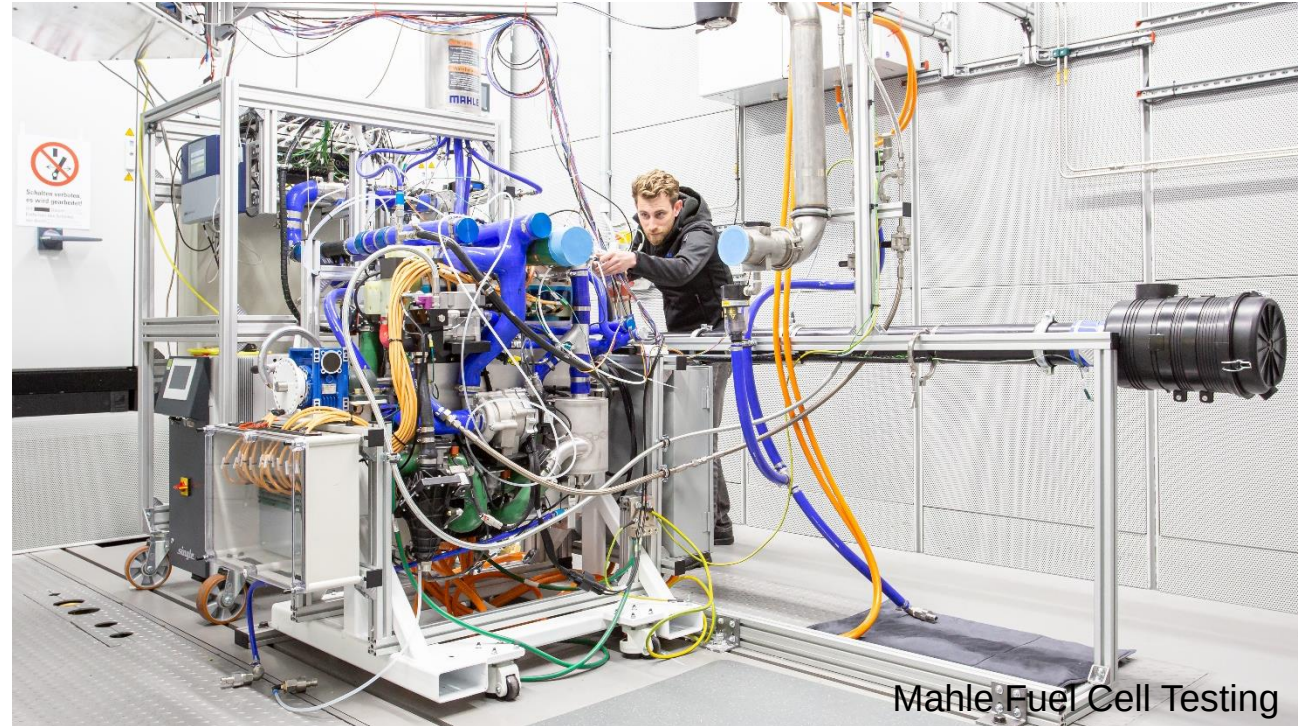
HV DCDC



Cathode Module



HV Coolant Pump



Mahle Fuel Cell Testing

- High complexity in system layout and power management for HD application
- MAHLE's fast running GT-Suite model allows simulation of system and component requirements
- System optimization will lead to further improvement in fuel consumption and range

A nighttime cityscape featuring illuminated skyscrapers. Overlaid on the image are several large, complex geometric shapes composed of blue and white triangles, resembling stylized buildings or abstract structures. The text 'WE SHAPE FUTURE MOBILITY' is positioned in the upper right corner.

WE SHAPE FUTURE MOBILITY

A solid dark blue rectangular box spanning the width of the slide, containing the text 'Thank you for your attention!'.

Thank you for your attention!

A horizontal strip showing light trails from vehicles on a road at night, with green foliage on the left side.

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The MAHLE logo, consisting of the word 'MAHLE' in a bold, blue, sans-serif font.

MAHLE