MAHLE Hydrogen Technologies
FUEL CELL COOLING CIRCUITS
Requirements – Challenges & Solutions

MAHLE Multi-Path Approach

BEV

Fuel Cell

H_2 ICE

Hybrids/Renewable Fuels

MAHLE

Hydrogen Test Center at MAHLE Stuttgart

New test center for hydrogen applications

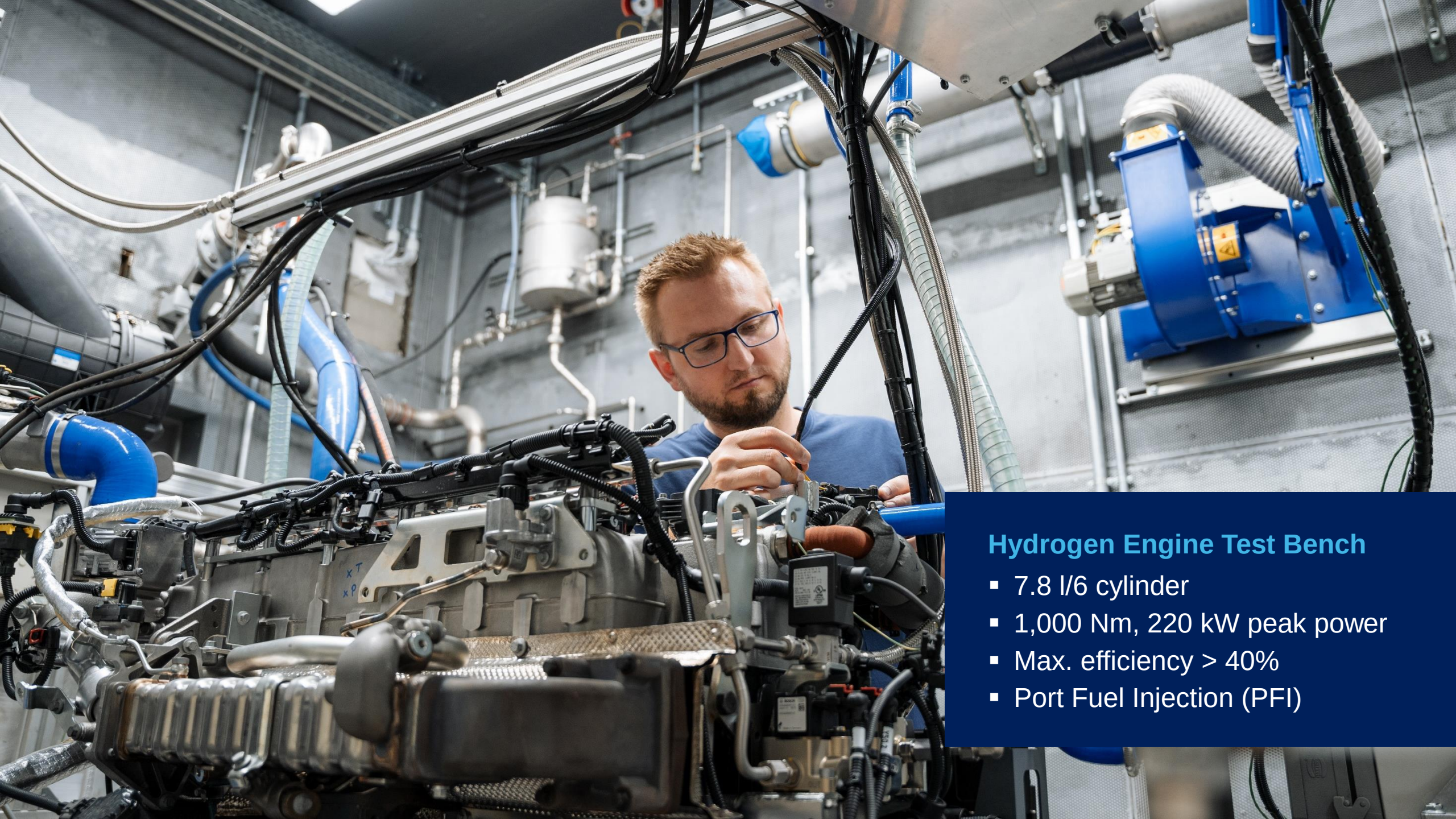
Further expansion planned.

Research on fuel cells & hydrogen powered engines

Target: develop economical and robust solutions for the automotive industry.

Commitment

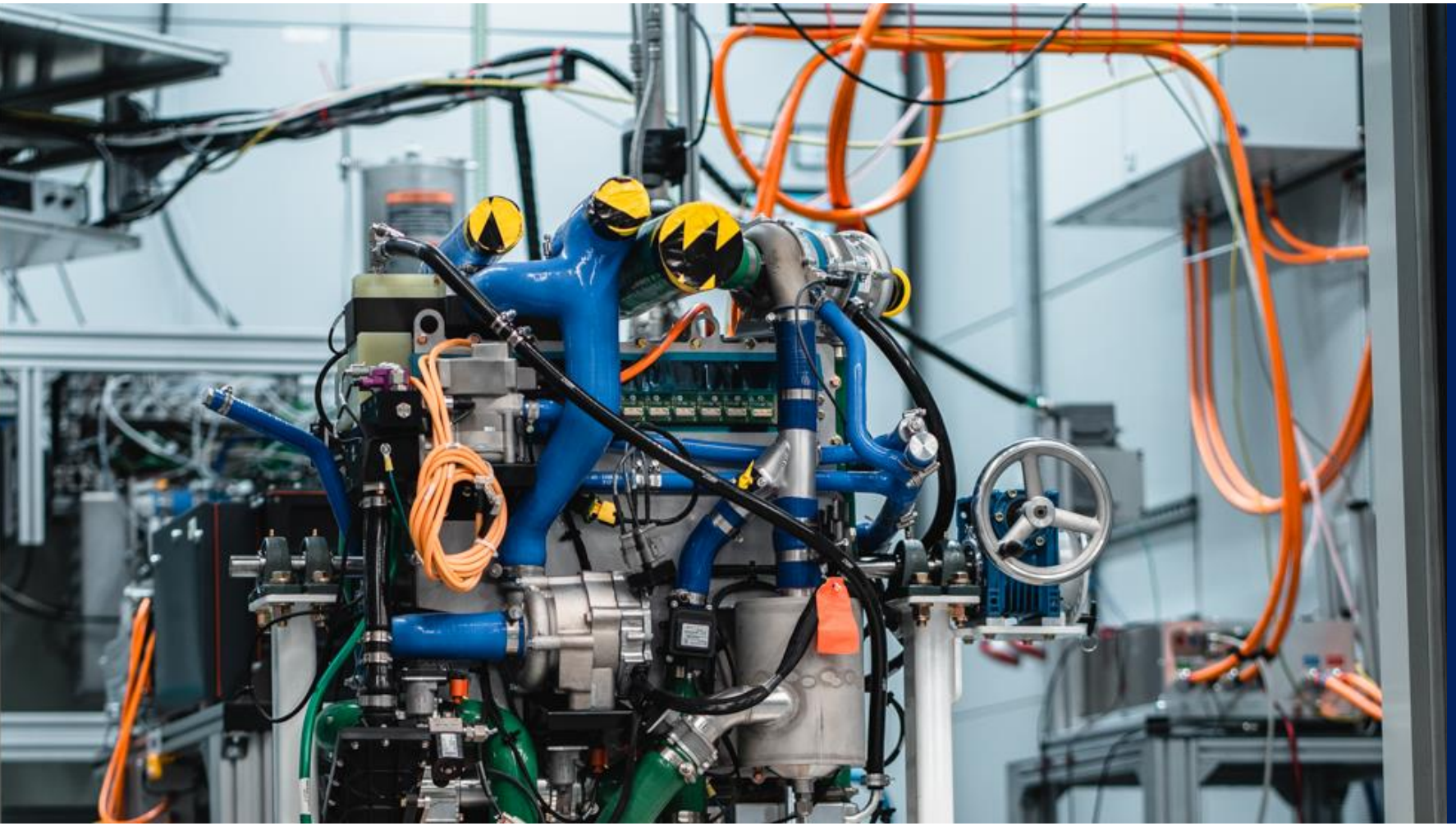
Around 100 employees in Stuttgart are working on solutions for H2 technology.



Hydrogen Engine Test Bench

- 7.8 l/6 cylinder
- 1,000 Nm, 220 kW peak power
- Max. efficiency > 40%
- Port Fuel Injection (PFI)

Fuel Cell Test Facilities – Stuttgart



MAHLE testbench for fuel cell stacks and BoP components

Key features

- Up to 250kW net power
- Possibility to test multiple fuel cell modules
- Media conditioning
- Seamless hydrogen supply
- Approved safety concept

Overview MAHLE HYDROGEN Fuel Cell System Approach

Thermal Management

Electric A/C Compressor

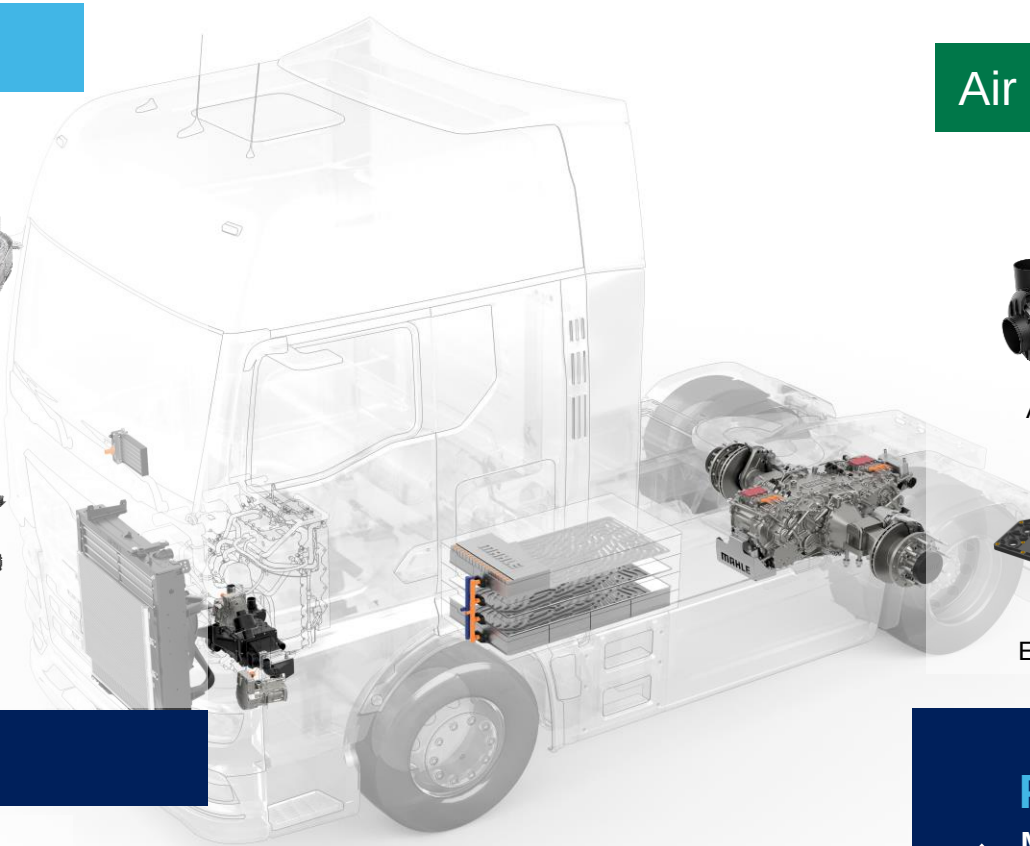
Electric Pump

H_2 HEX

Electric Fan

C2C Heat Exchanger*

Cooling Module

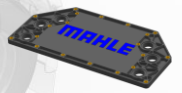


Air Management

Air Filter

Humidifier/Cathode Module

Charge Air Cooler



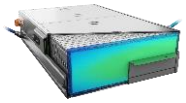
End Plate

Ion Exchanger

Electric Powertrain

Electric Motors

Electric Motor Components



Battery Know-How

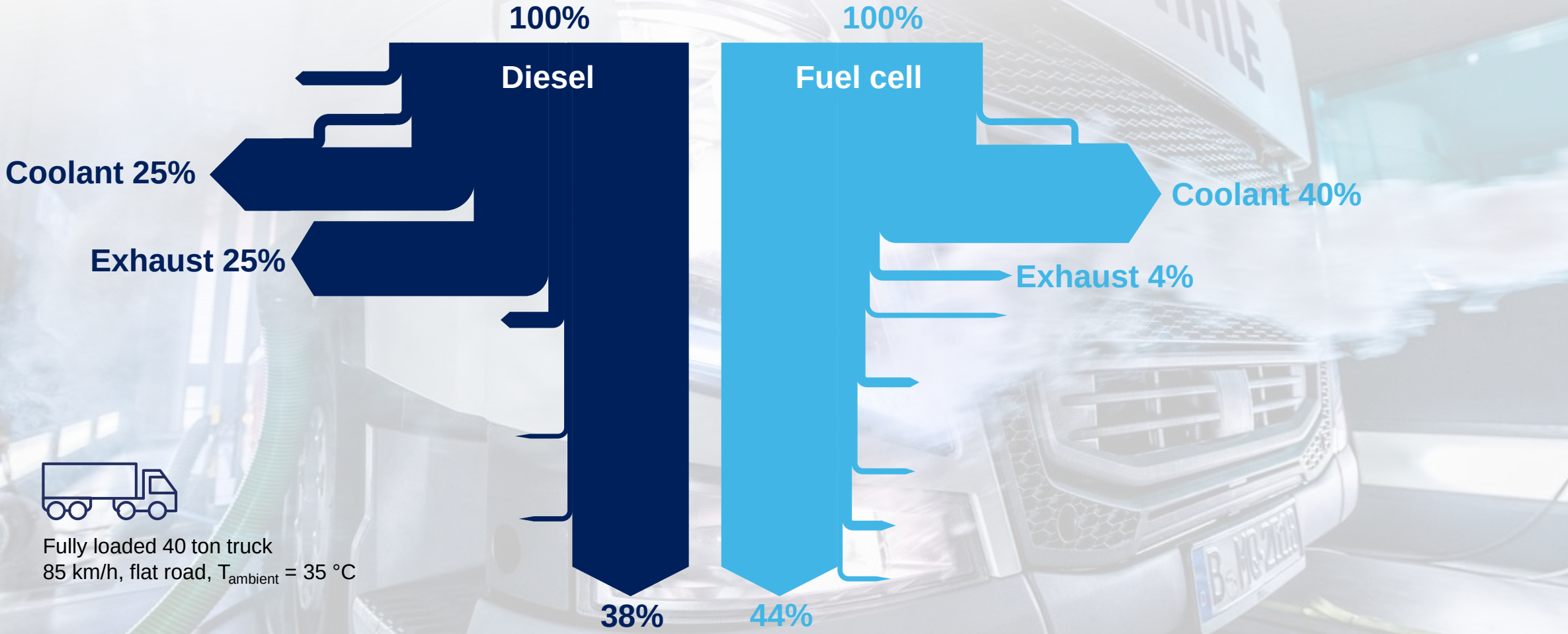
* Coolant-to-Coolant Heat Exchanger

Portfolio System Approach

MAHLE provides balance of plant components embedded in a strong system approach.

MAHLE

Despite Higher Efficiency, Requirements for the Fuel Cell Cooling System Increase



Fully loaded 40 ton truck
85 km/h, flat road, $T_{ambient}$ = 35 °C

Cooling Module

Fuel Cell
Project House

Complete cooling modules will provide thermal stability to FC Systems up to heavy duty sizes

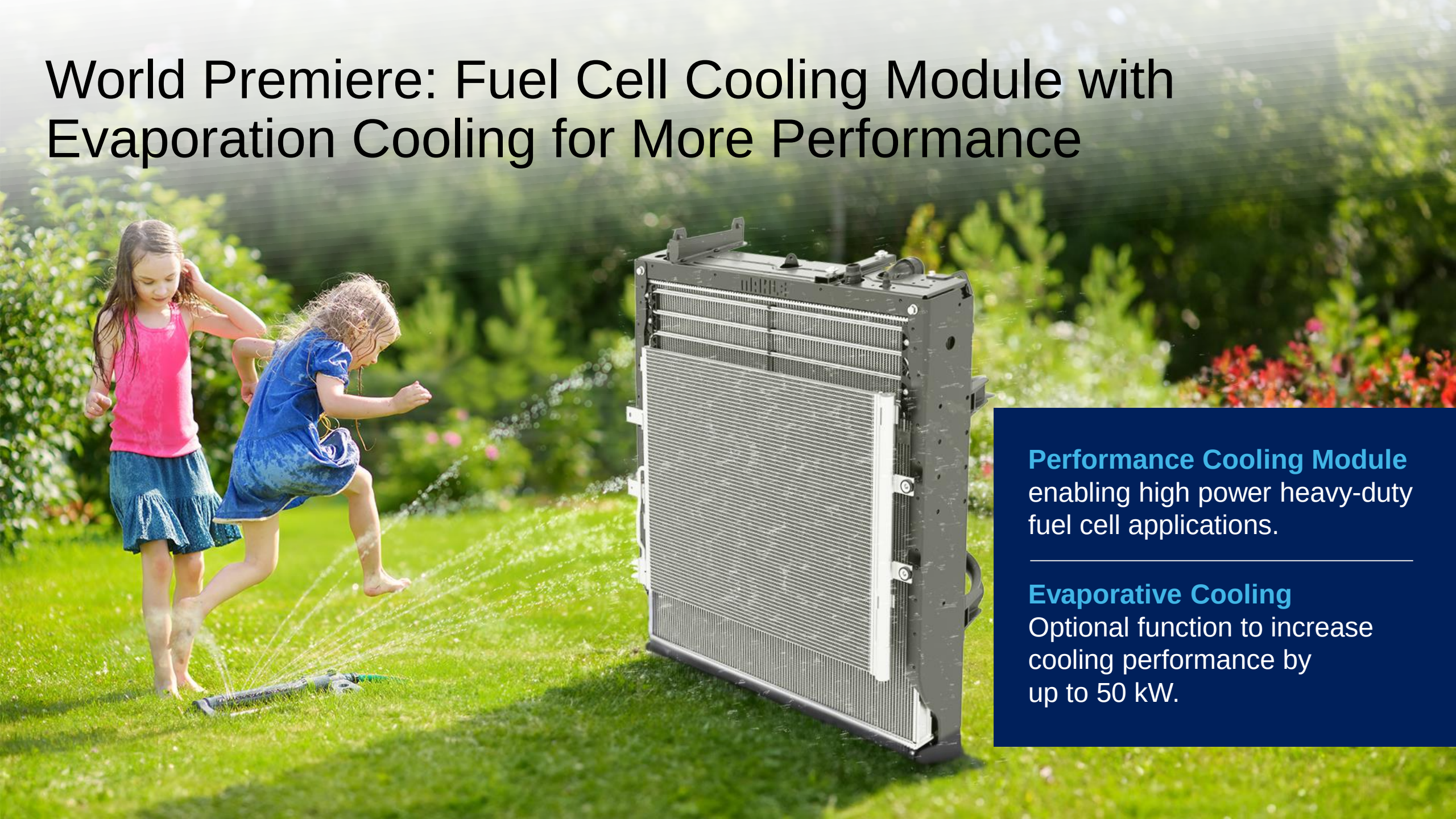
- High maturity level through use of ICE-proven design and components
- Easy to integrate into existing vehicle architecture
- 3 Layer Cooling Module to cool fuel cell stack, E-Powertrain and brake retarder
- Based on existing series components
- Fuel Cell radiator passivated to achieve coolant conductivity requirements
- Specific application for FCEV

Multi-Layer Cooling Module

Modular concept with proven components facilitates the implementation of FC system in existing vehicle platforms

MAHLE

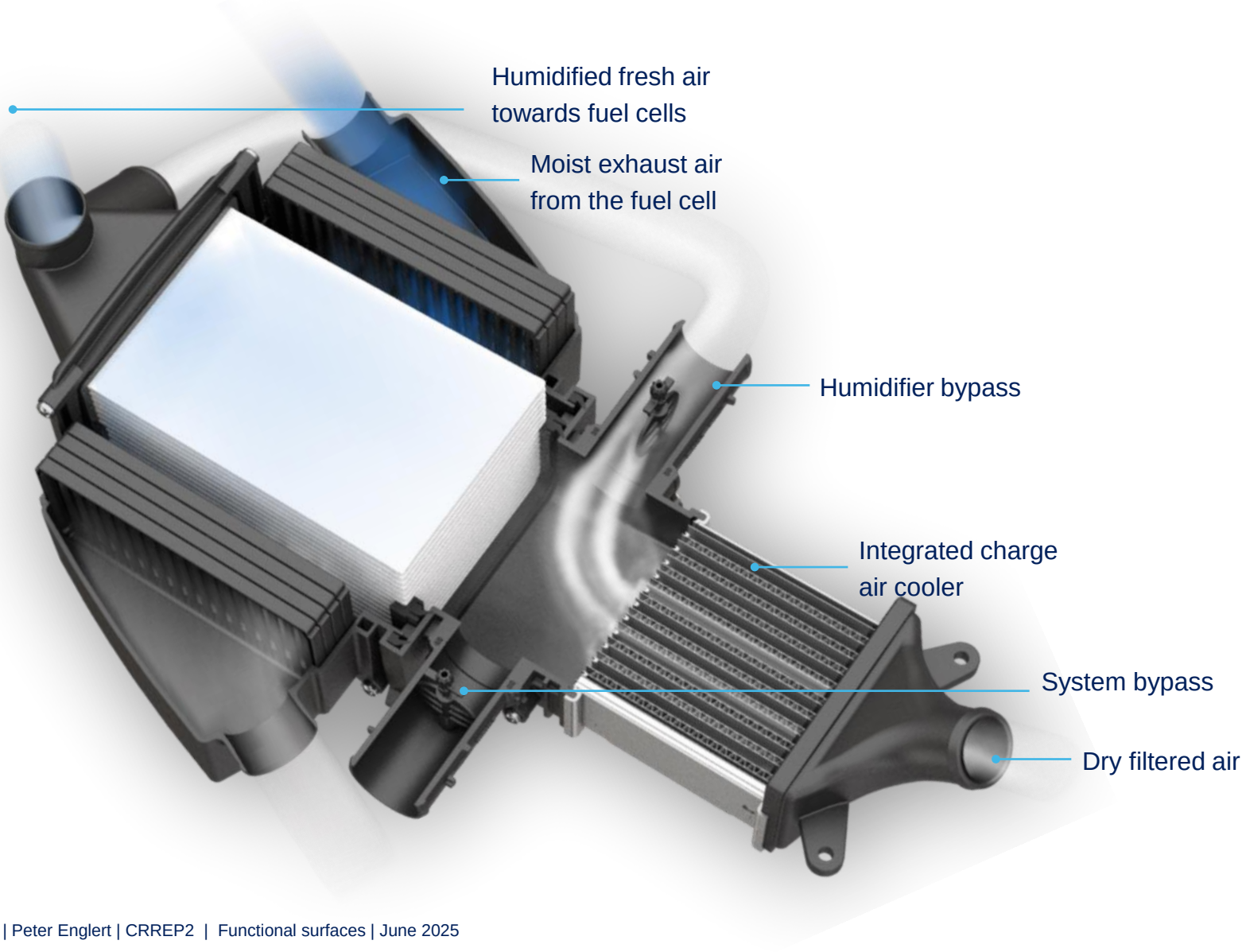
World Premiere: Fuel Cell Cooling Module with Evaporation Cooling for More Performance



Performance Cooling Module
enabling high power heavy-duty fuel cell applications.

Evaporative Cooling
Optional function to increase cooling performance by up to 50 kW.

Cathode Air Flow Module – Highly Integrated Design



Highly integrated design
incl. charge air cooler, humidifier and water separation.

Up to 50% higher water transfer rate
(compared to best competitor) enable increased operation temperature and lower fuel cell membrane degradation.

Maximum performance
with 50% lower pressure losses results in +1% peak power and efficiency increase.

MAHLE

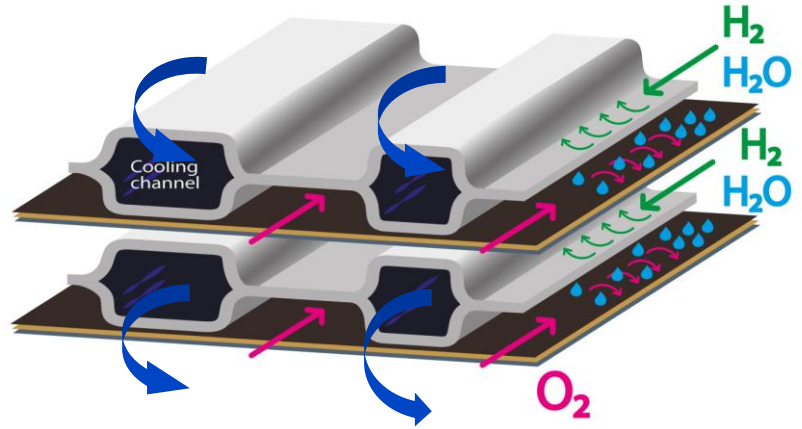
Challenges of the Fuel Cell cooling circuit

- **Requirements**
- The coolant has direct contact to the electric Bi-Polar plate

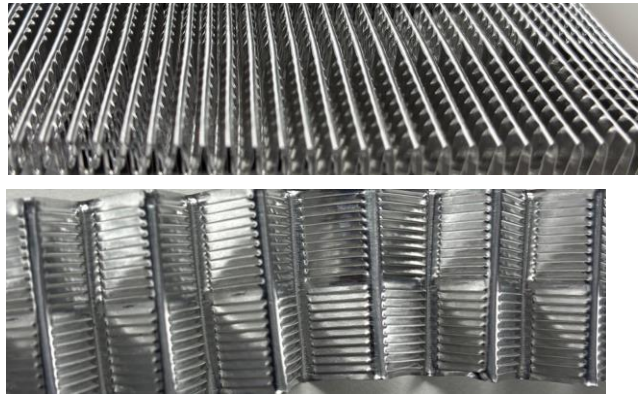
  ➔coolant conductivity must be stabile below 5µS /cm

  – No interaction with the inner surfaces of Aluminum Heat Exchanger and Bipolar plates ➔ no Ion leaching
  – Water / Glycol mixture is mandatory due to heat capacity
  – High efficient (brazed) Aluminum Heat Exchanger needed due to low ΔT

- **Challenge for the Cooling circuit**
  – Aluminum and other metal surfaces can oxidize the glycol to highly conductive organic acids (activation temp. > 80°C)
  – Residues from manufacturing (brazing) process must be washed out
  – Ion leaching of the inner metallic surface must be barred



Bipolar plate with coolant flow



High efficient heat transfer fins

An inner passivation & coating for Aluminum Heat Exchanger is needed to ensure the coolant efficiency & quality

MAHLE

MAHLE solution for Functional Heat Exchanger Inner Surface Coating

- **In principle Aluminum ceramics like Aluminum oxide showing a good thermal flow and highly inert behavior**

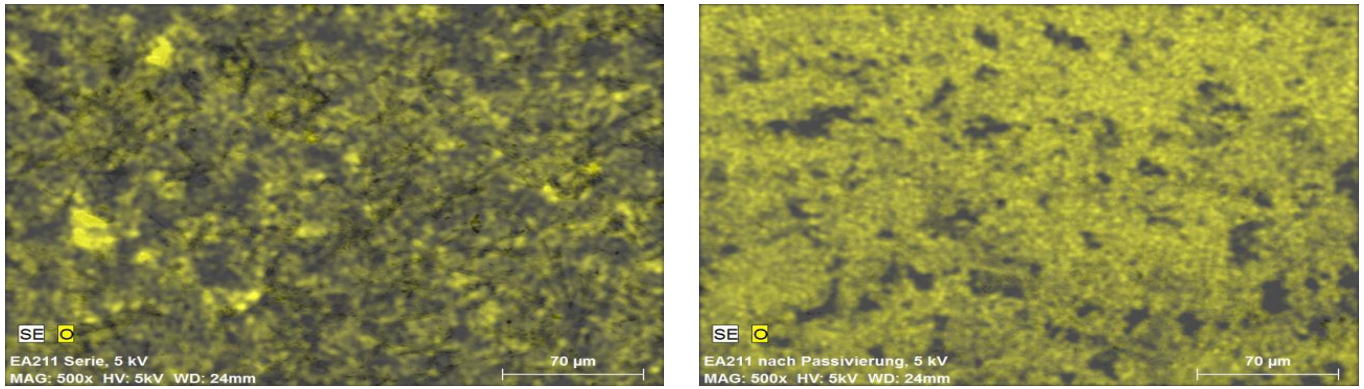
MAHLE developed a special conversion coating to create a nano scale ceramic-like layer direct from the inner metallic Aluminum surface

How it works

- First step: in special flow through process the inner Aluminum surface will be cleaned & activated with etching chemicals

  ➔ Complexing chemical compounds will be integrated in the surface
- Second step: an aqueous thermal process forms a new Aluminum-oxy- hydroxide layer
- Third step: a special heating process forms the inert layer

- ➔ the increase of the oxygen content in the surface indicate the formed nanoscale Aluminum-oxid layer



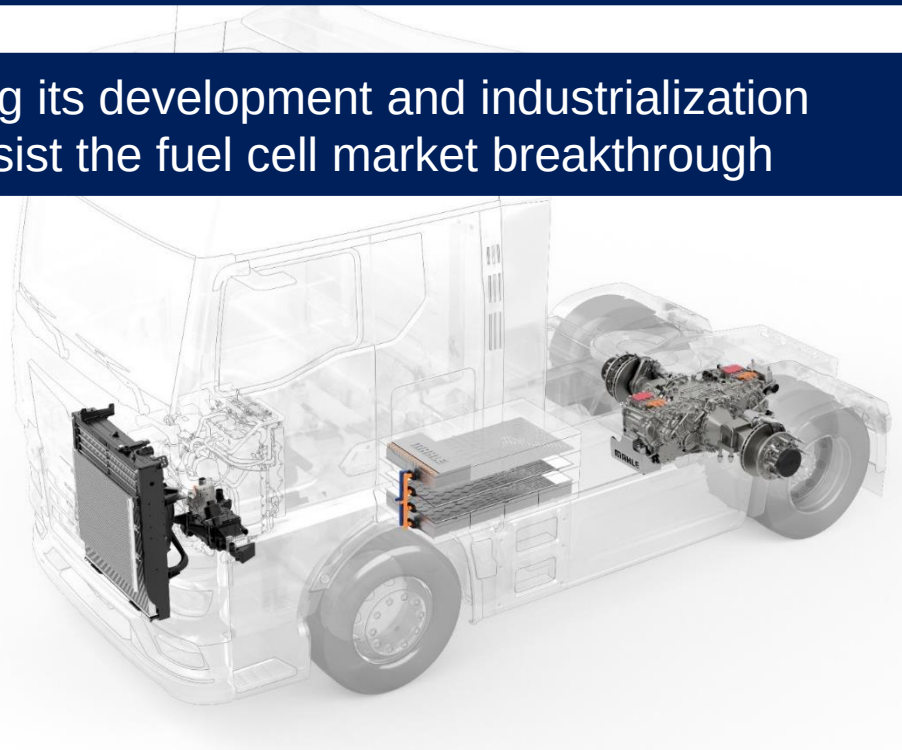
EDX Oxygen mapping before and after surface treatment

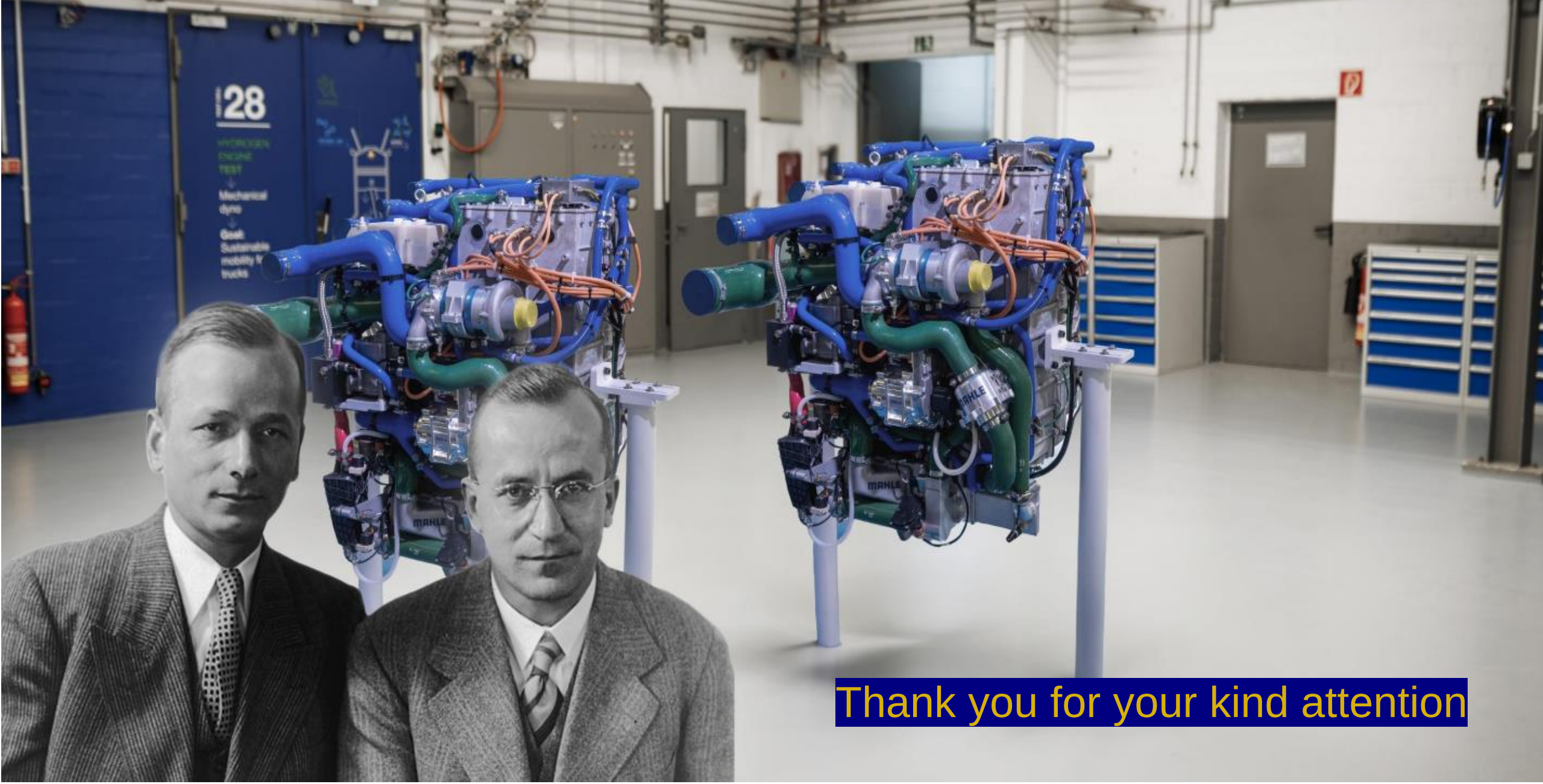
Summary

MAHLE Heat exchanger fulfil the strongest cleanliness requirements for Fuel Cell cooling circuits
More than 3000 heat exchanger are in function in global Fuel Cell mobility applications

MAHLE Fuel Cell components are suitable for series production

MAHLE is using its development and industrialization expertise to assist the fuel cell market breakthrough




Thank you for your kind attention