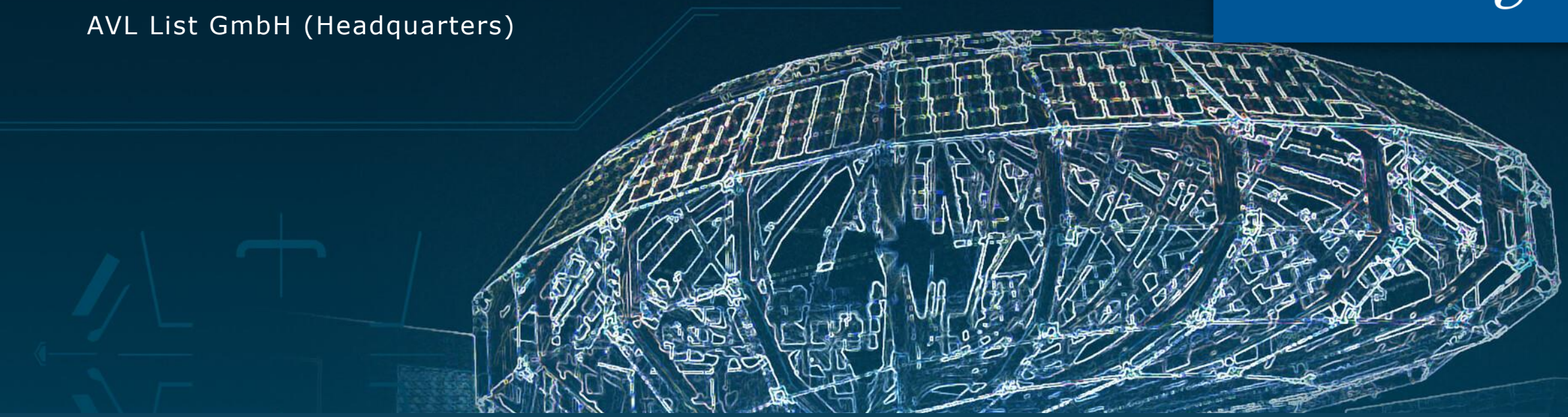
AVL List GmbH (Headquarters)



Advanced Fuel Cell Systems for Transport Applications

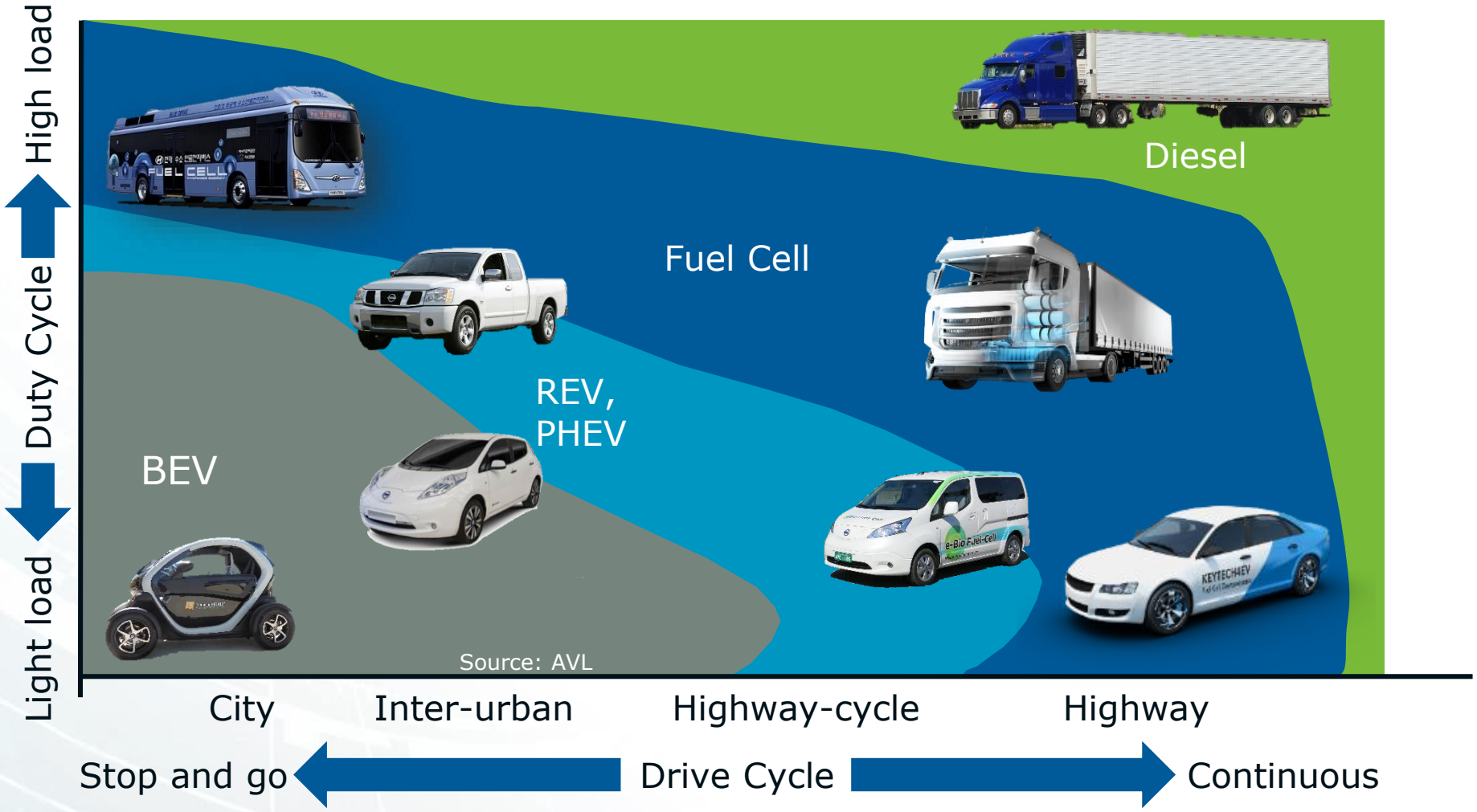
A3PS Conference, Vienna

15th of Nov. 2019

Juergen Rechberger

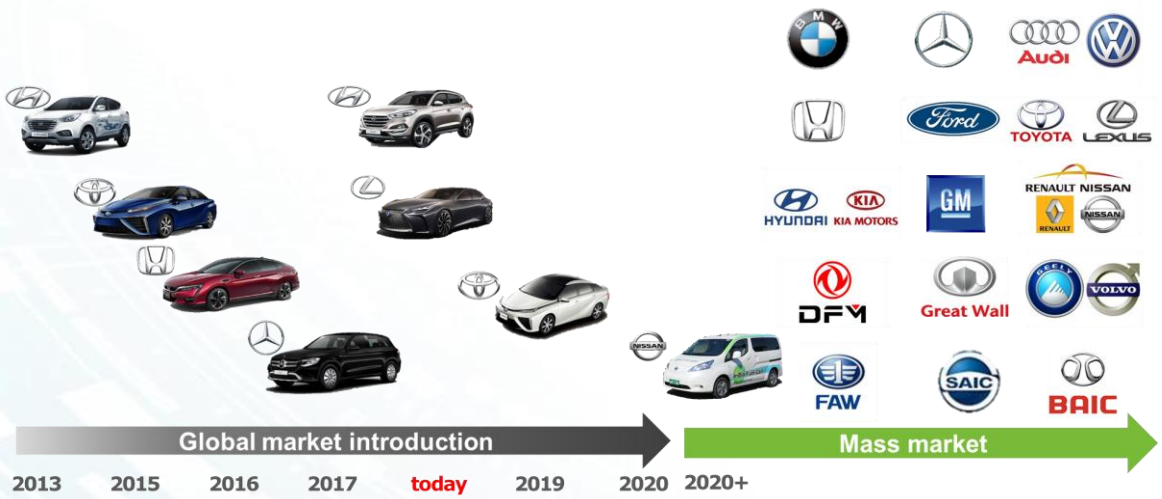
Global Head of Fuel Cell Development

Affordable e-Mobility - Application Map

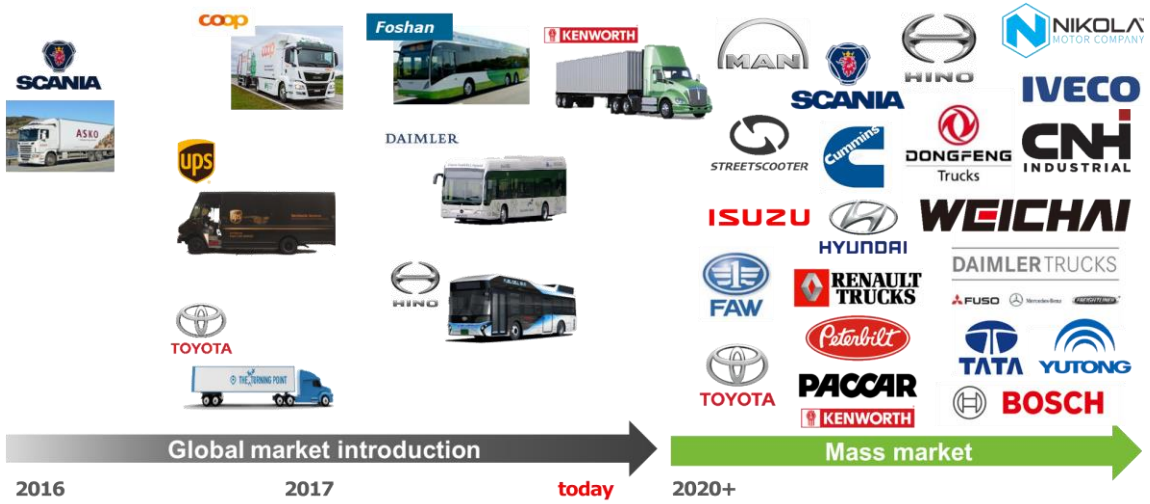


Fuel Cell in Automotive

Passenger Car



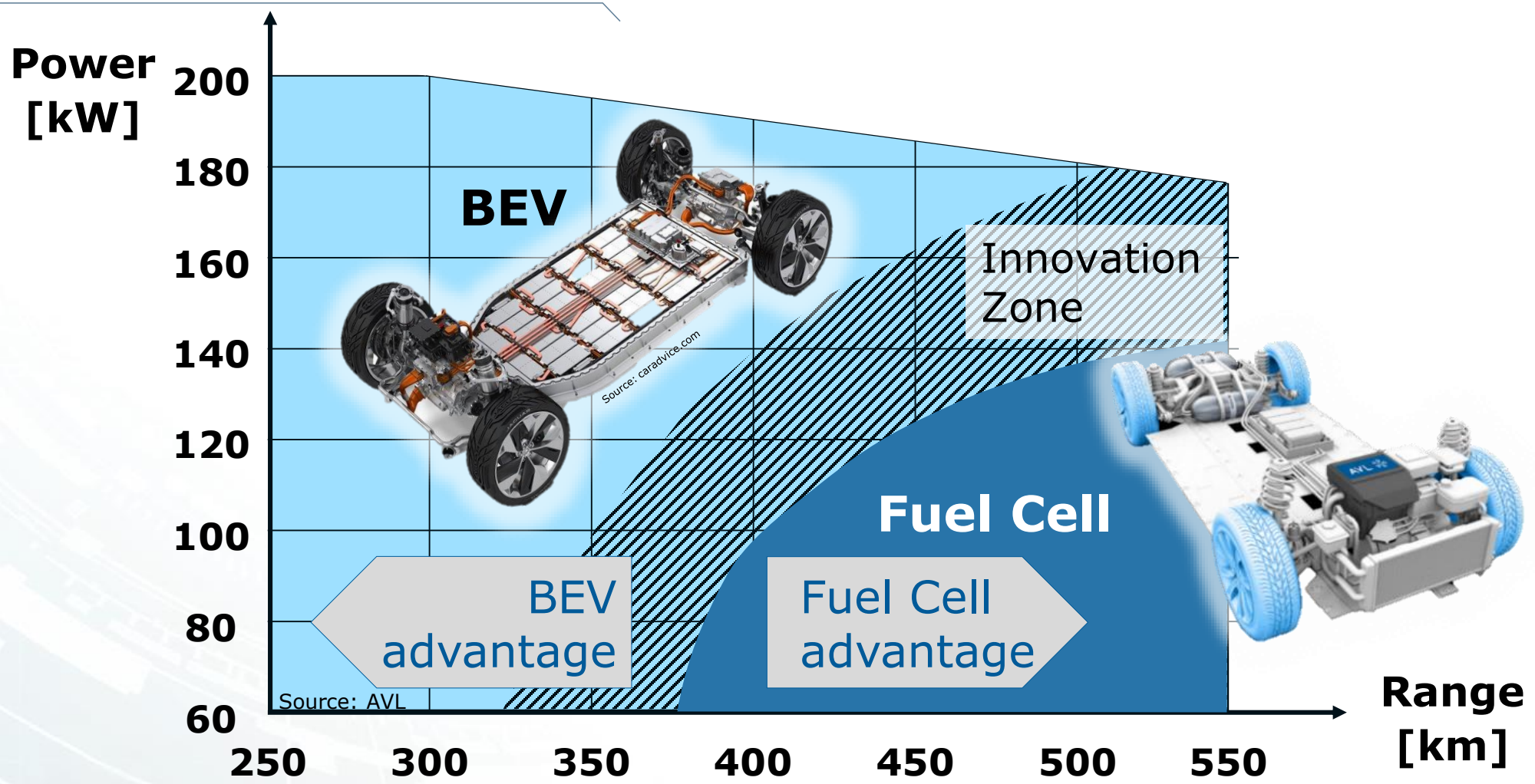
Commercial Vehicle



Strong momentum for Fuel Cell/H_2 driven by commercial vehicles and China

Passenger Cars - Fuel Cell

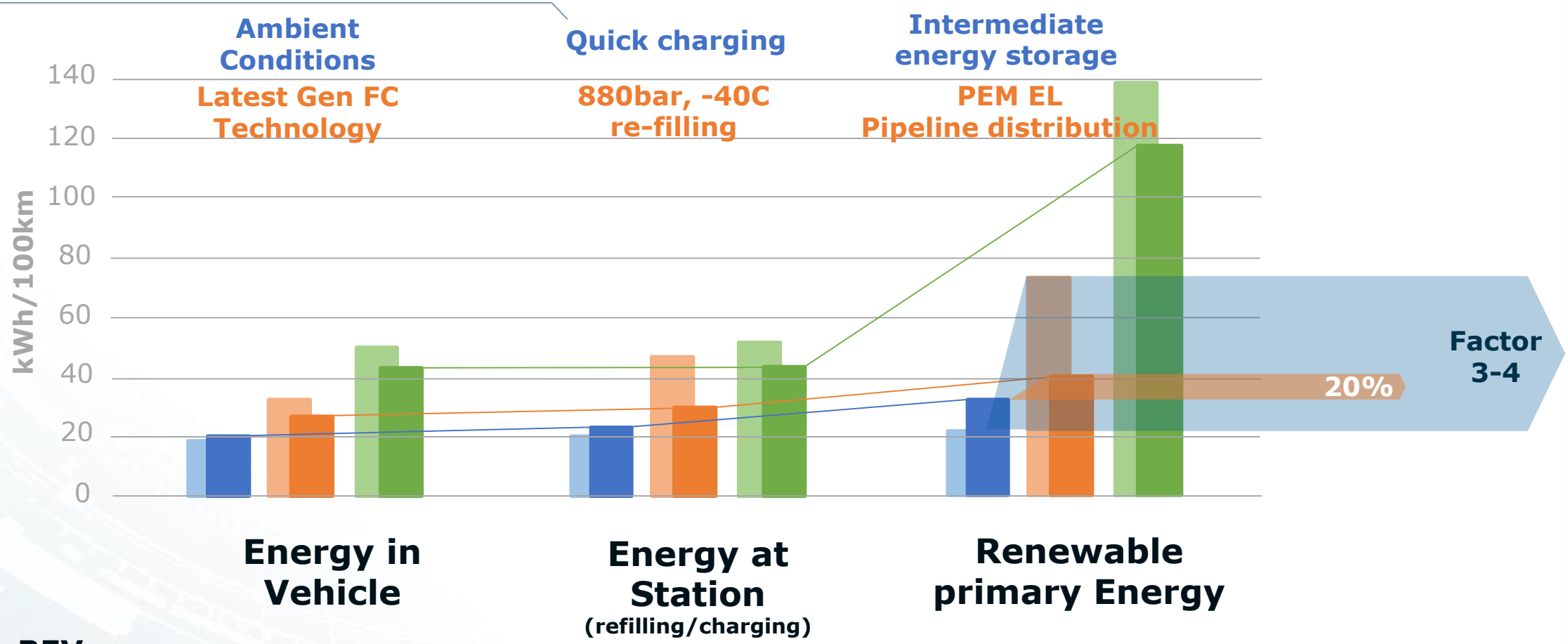
Powertrain Cost Comparison



For larger & long range vehicles, FCVs will be lower cost than BEVs

Renewable Energy Consumption Comparison

BEV, FCEV & ICE with synth. Gasoline



- **BEV**
- **FCEV (H_2)**
- **ICE Hybrid (Synth. Gasoline)**

Passenger car, 15kWh/100km mechanical energy
BEV: LiIon, 12kW & 100kW Charge
FCEV: PEM/H2, 880bar/-40°C, PEM EL
ICE: Full Hybrid, PEM EL/Fischer Tropsch

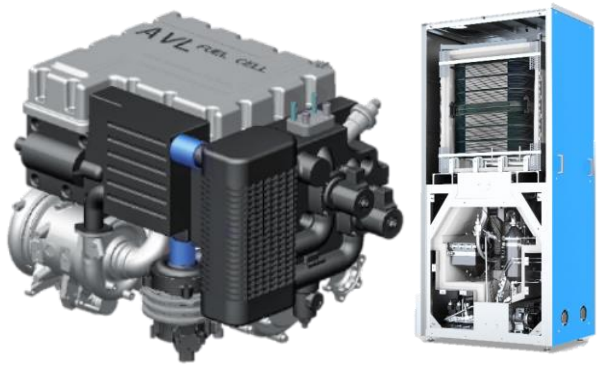
AVL Activities in Fuel Cell

PEM Stack Engineering

AVL Fuel Cell Canada

Fuel Cell System Development

PEM + SOFC



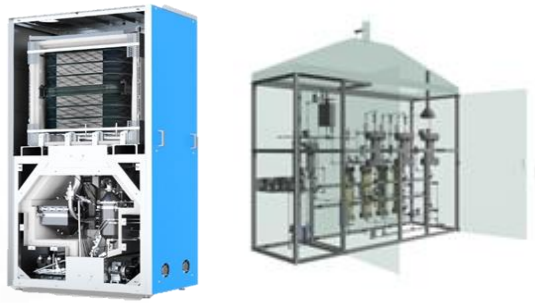
Integration & Application Development

Fuel Cell Test Systems

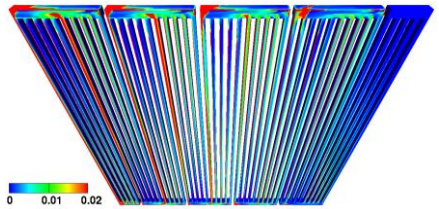
AVL

GREENLIGHT INNOVATION

Energy Storage & H_2/Synfuel Production



Fuel Cell Simulation Tools



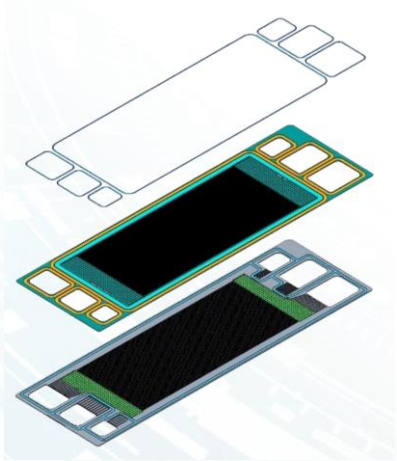
FM

CM

400 engineers in fuel cell powertrain, testing and simulation

AVL Value Chain

CELL | **STACK** | **SYSTEM** | **APPLICATION**

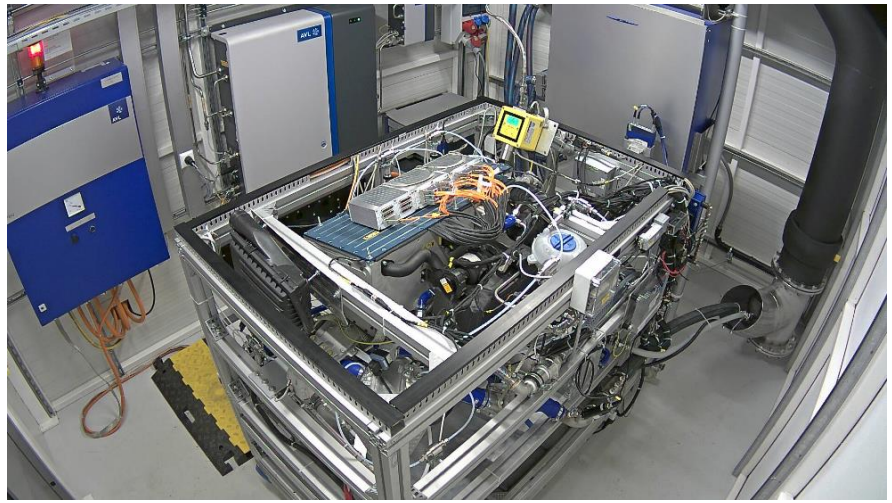


PEM Technology

SOFC Technology

AVL Fuel Cell Test Center

- **170kW climate chamber PEM system test rig available @HyCentA**
- **New Fuel Cell test center will open in Q1/20:**
  - **Space up to 25 test rig**
  - **System- subsystem & component test rigs**
  - **HD system test rig up to 400kW**
  - **1st full scale PEM test rig in operation**



AVL Fuel Cell Canada

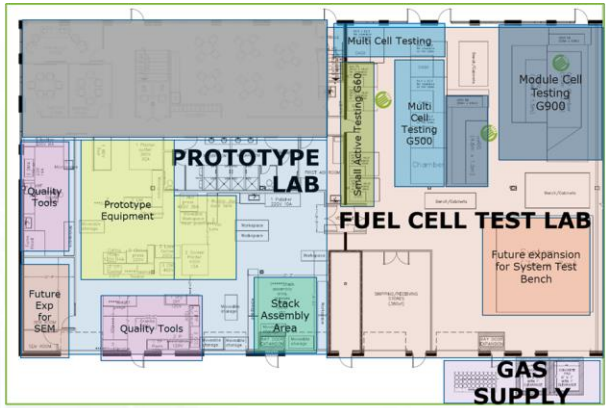
Mission:

Development of world class PEM Stacks for PC & CV applications

Facts:

- ✓ AVL Fuel Cell Canada registered
- ✓ Office rented: 8602 Commerce Court, Burnaby
- ✓ Start of operation: **July 2018**
- ✓ Number of engineers: 33 (30 from former Daimler/Ford stack development JV - AFCC, 1 from Ballard)

Available from Q4/2019



Prototype Lab: 4000ft²
- Build and assemble stacks
- Temperature and humidity controlled

Test Lab ~4800ft²
- Test stacks
- All to TS to be supplied by Greenlight

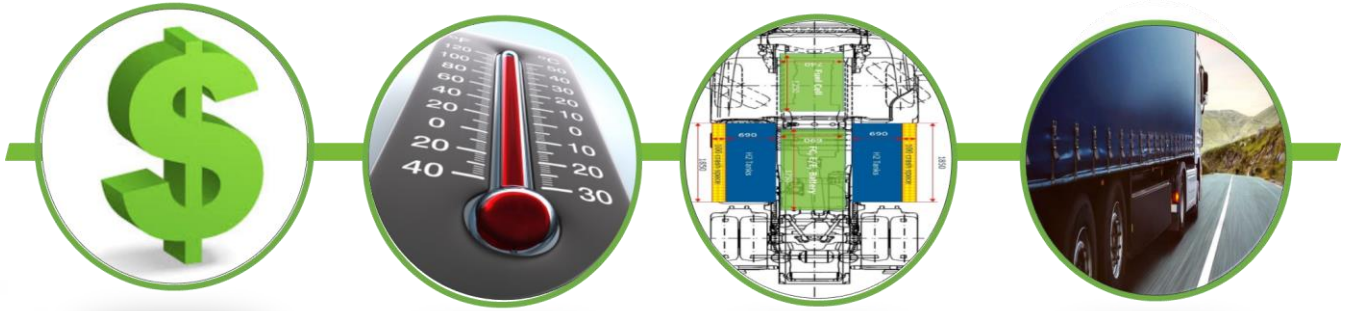
Fuel Cell System Development

Technology Challenges

Passenger Car

Cost Cost Cost Infrastructure

Commercial Vehicles



Cost Cooling Packaging Durability

AVL Fuel Cell Concept Car

KeyTech4EV

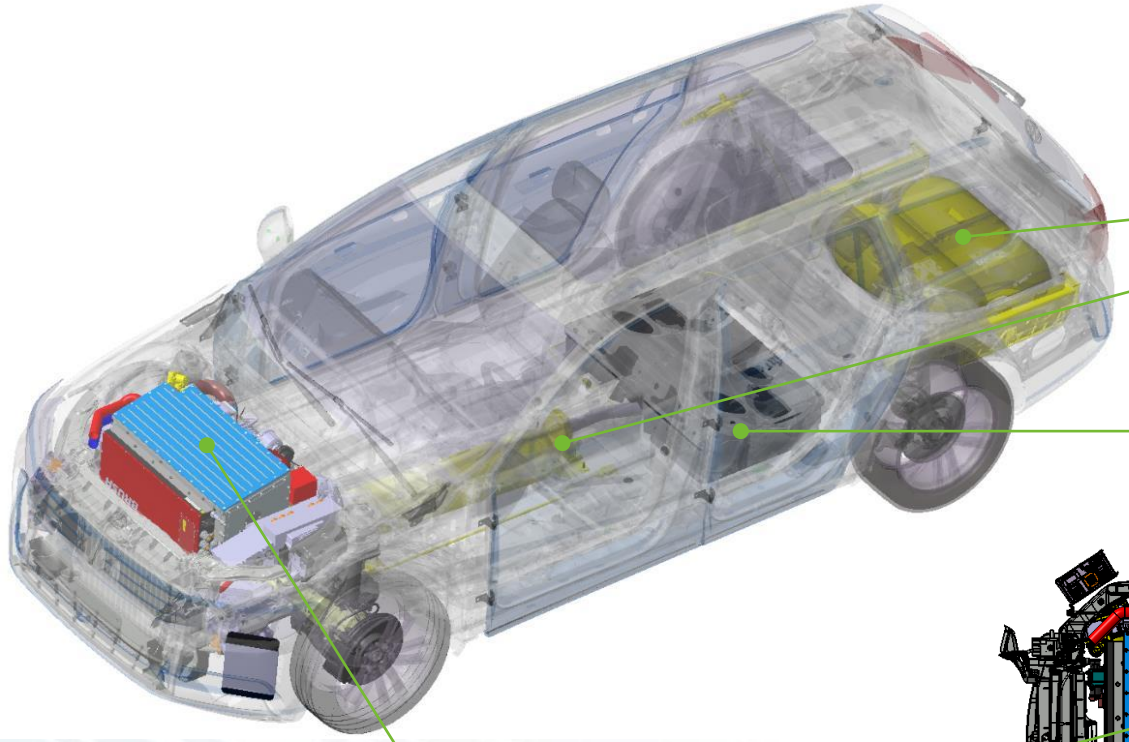
AVL

Vehicle platform	**VW Passat GTE**
Vehicle curb weight	1746 kg
Vehicle gross weight	2182 kg
Battery size	**9.9 kWh**
Battery power	85 kW
Fuel cell power	**~70 kW**
e-drive power	**100 kW**
Hydrogen tank capacity	3.8/5.3 kg
Number of tanks	3/4
Hydrogen refilling time	approx.3 min
Hydrogen consumption	0.8 kg /100 km
Driving range	>600 km

AVL Fuel Cell Concept Car

KeyTech4EV

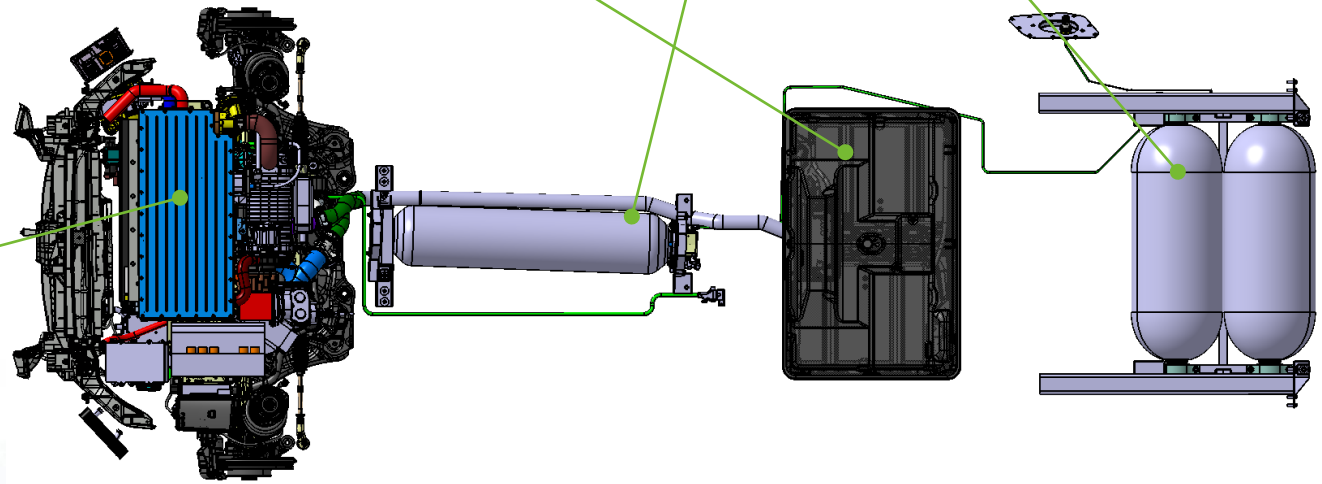
AVL



MAGNA

3 Cylinder H_2 Storage

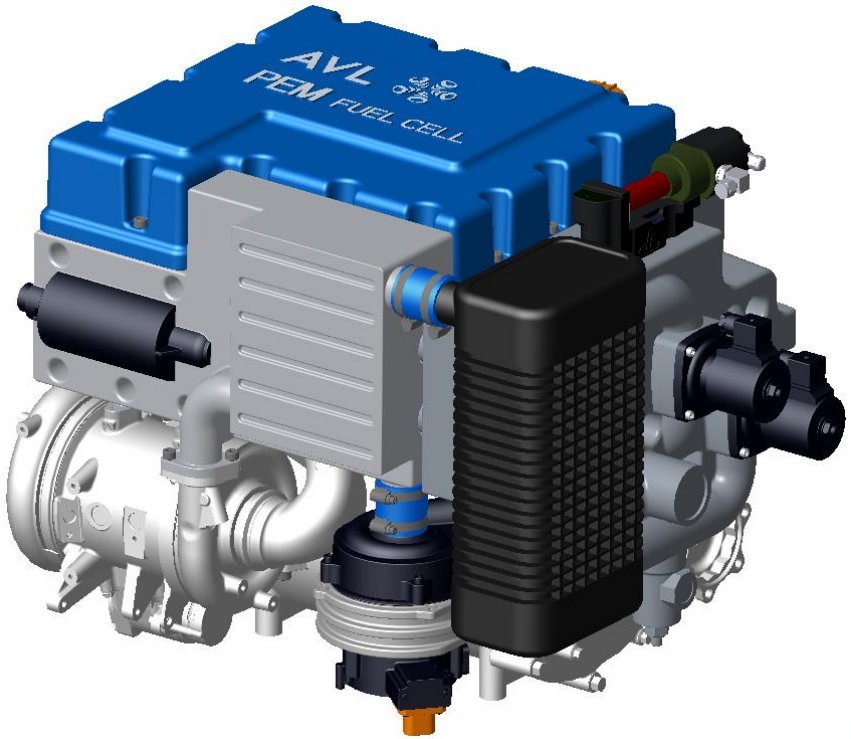
9.9kWh Battery



70kW Fuel Cell System

100kW e-Drive

AVL PEM Fuel Cell Engine



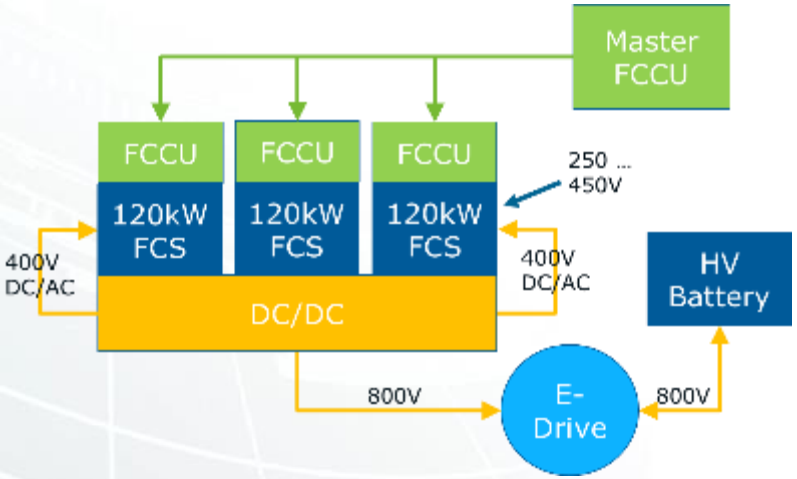
FC Gross Power	70kW
FC Net Power	55-60kW
Efficiency	46-60%
Dynamics T90	<1s
E-Motor	100kW
Lifetime	6.000 hrs

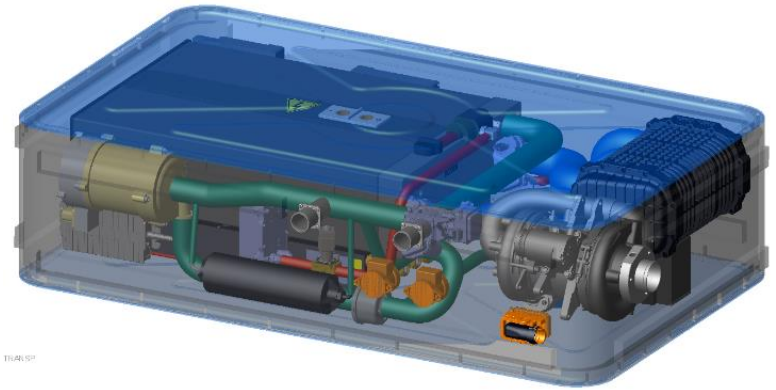
Modular Fuel Cell Systems for Truck & Bus
Parallel Operation of PEM FC Systems

HYTRUCK Objectives:

- Modular Truck fuel cell system
- Power density/durability tradeoff
- Hydrogen Storage Solution
- Key components (stack, DC/DC,…)

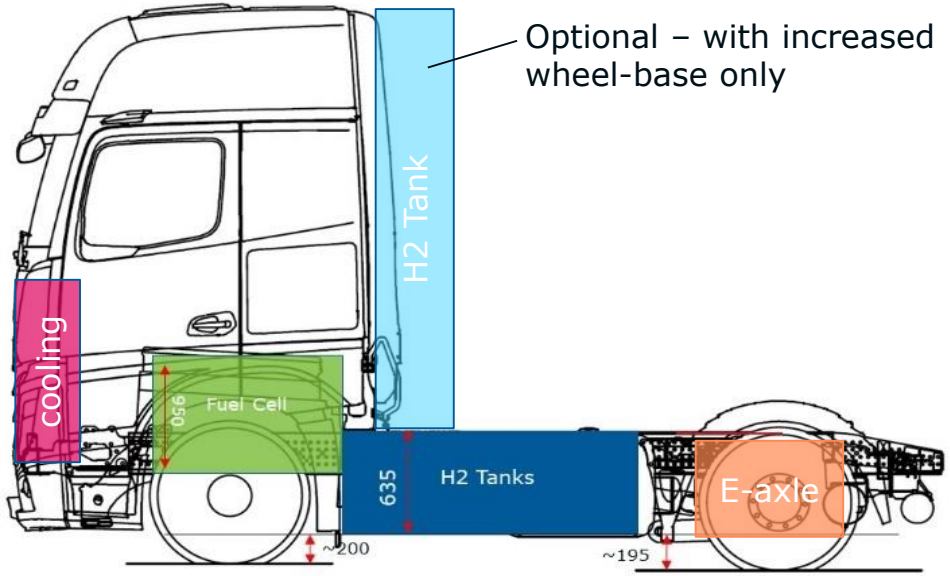
HYTRUCK Architecture:

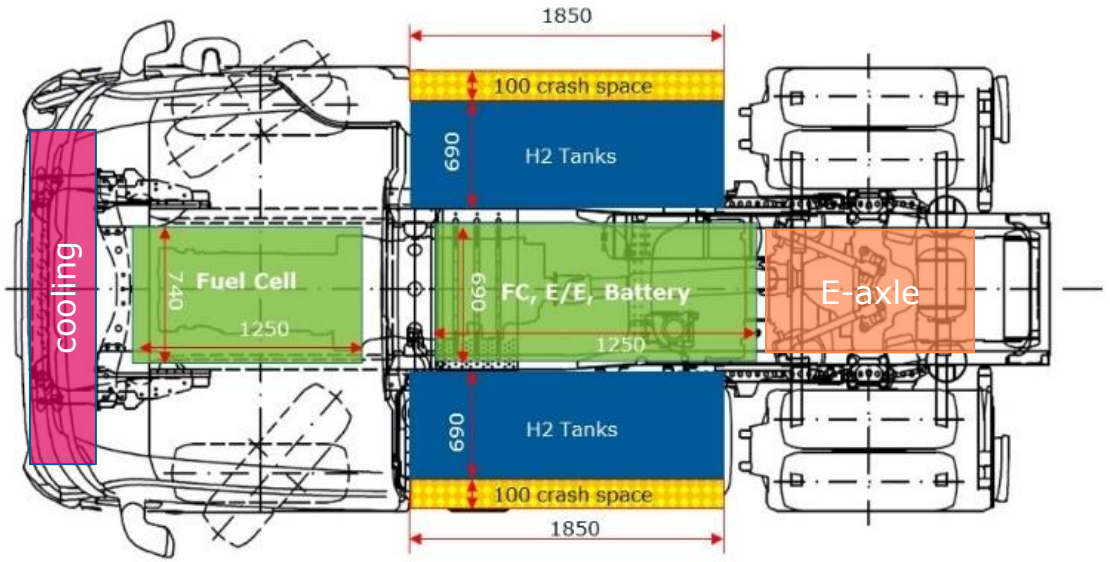




100kW Truck FCS Module (Concept Design)

Packaging of Fuel Cell Trucks





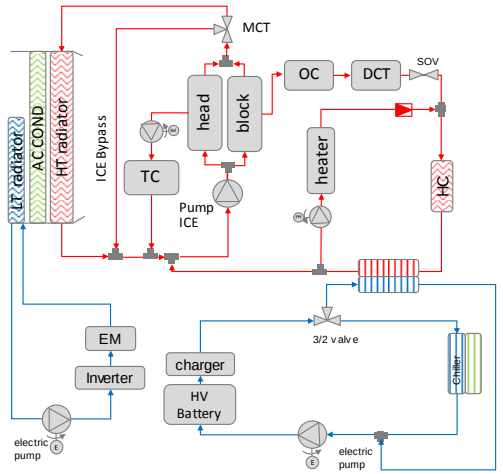
Example: Short wheel-base tractor
(high volume application)

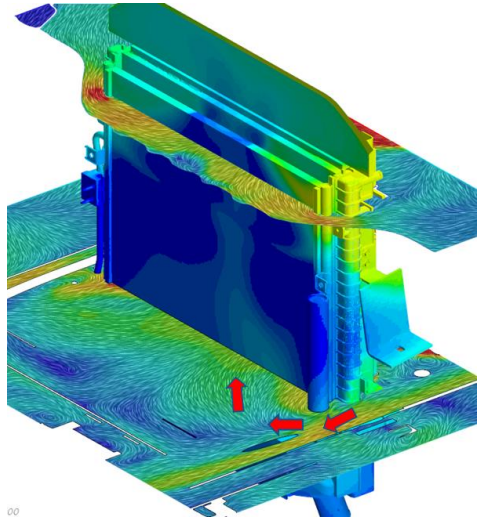
- 300kW Fuel Cell System will fit into engine space
- H_2 Tank system very challenging to integrate for long range (>50kg H_2)

Solutions for FC Truck Cooling

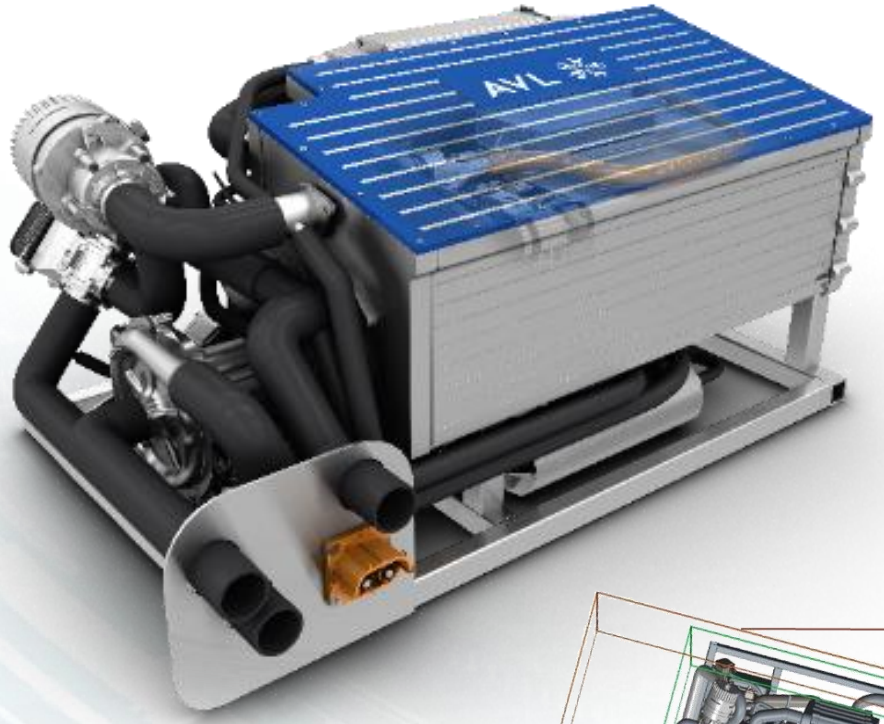
Solutions

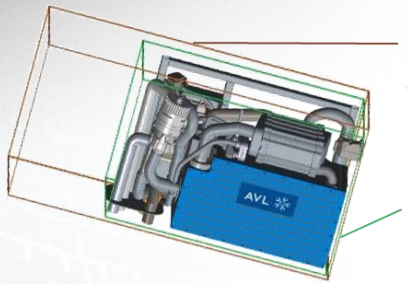
- Increase front area by 60%
- Clean up front radiator by moving AC system to the roof
- Limit fuel cell power via battery hybridization
- Add side cooler and fans
- **Increase the stack temperature**





35kW PEM REX AVL Design for SOP





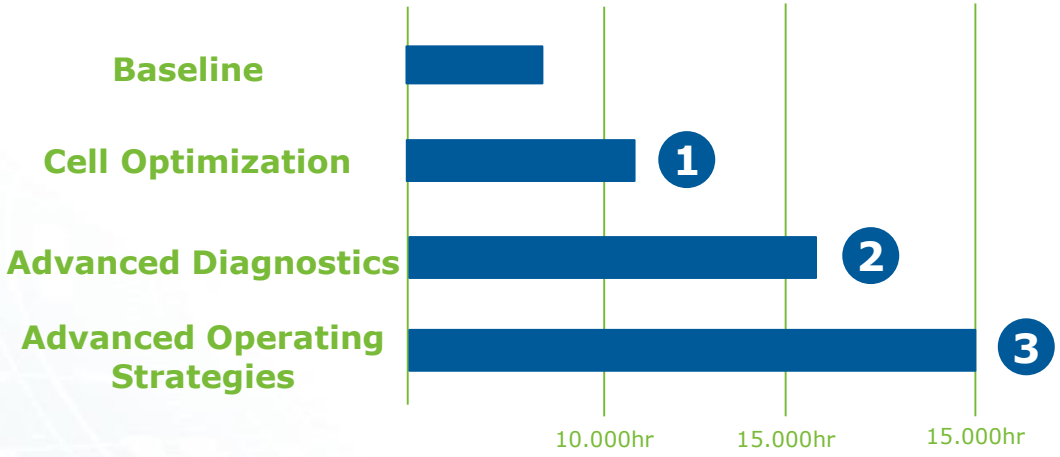
Best solution on the market

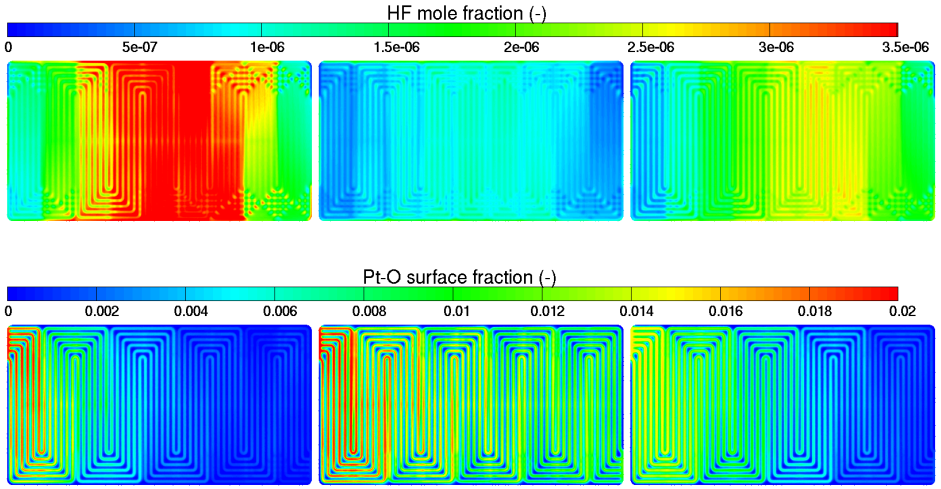
AVL Design

GENERIC SPECIFICATION	PEM / H2 2019
Max. net. Power	35 kW
Min. Power	10% of max Power
el. Efficiency @max Load (system/stack level)	42/56%
el. Efficiency Peak (system/stack level)	58/72%
T90 Time	>1s
Start-up Time (20°C, to 90% Load)	<3s
Cold Start Temp.	-20°C
Freeze Start Time (to 90% Load)	< 45s@-20°C
Dimensions	50L
Weight	65kg

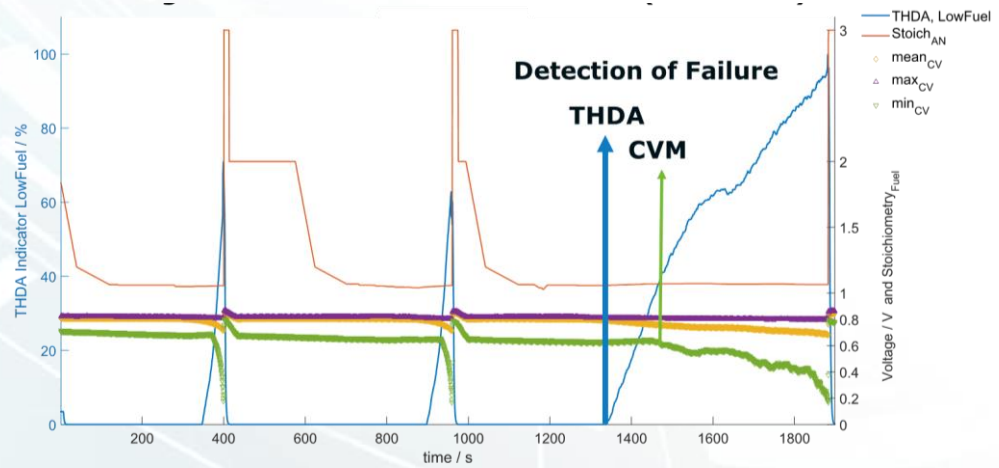
35kW PEM REX System - SOP in China 2020

Fuel Cell Durability Development

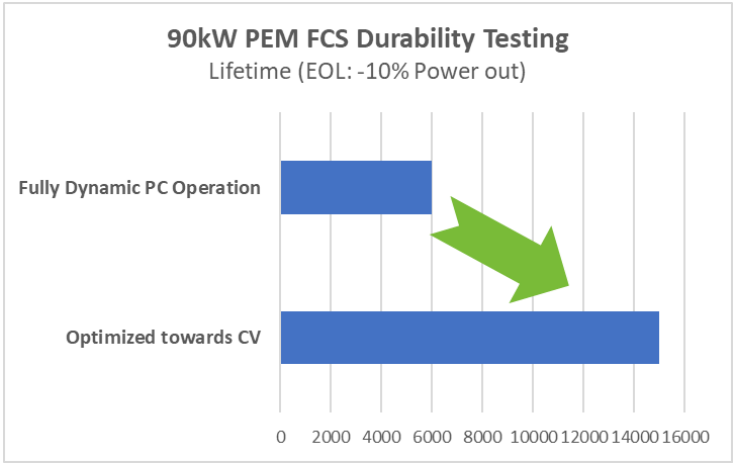




1 CFD Cell Optimization with Damage Models

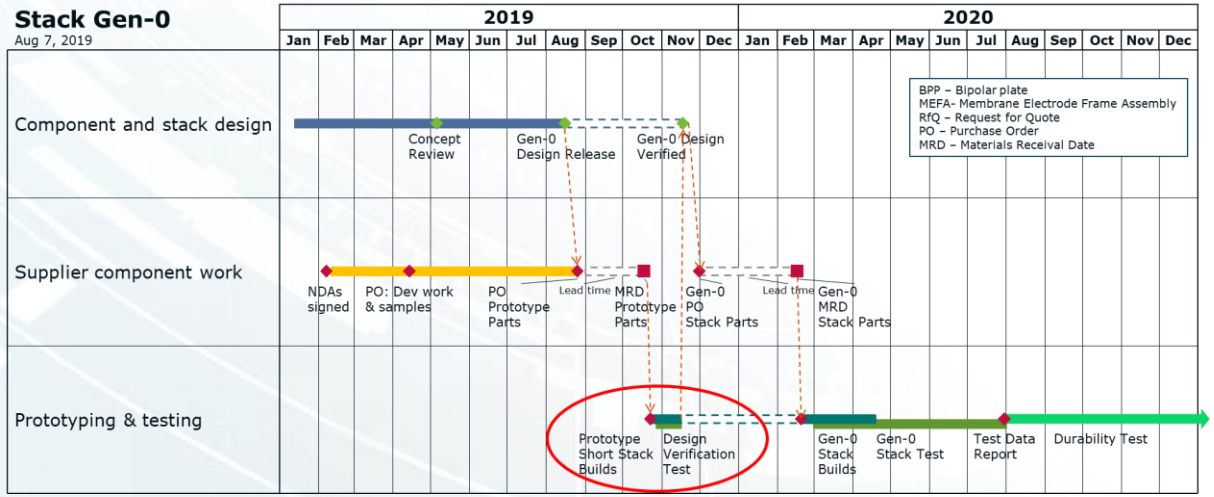


2 Detection and avoidance of Damaging Operating Conditions with THDA



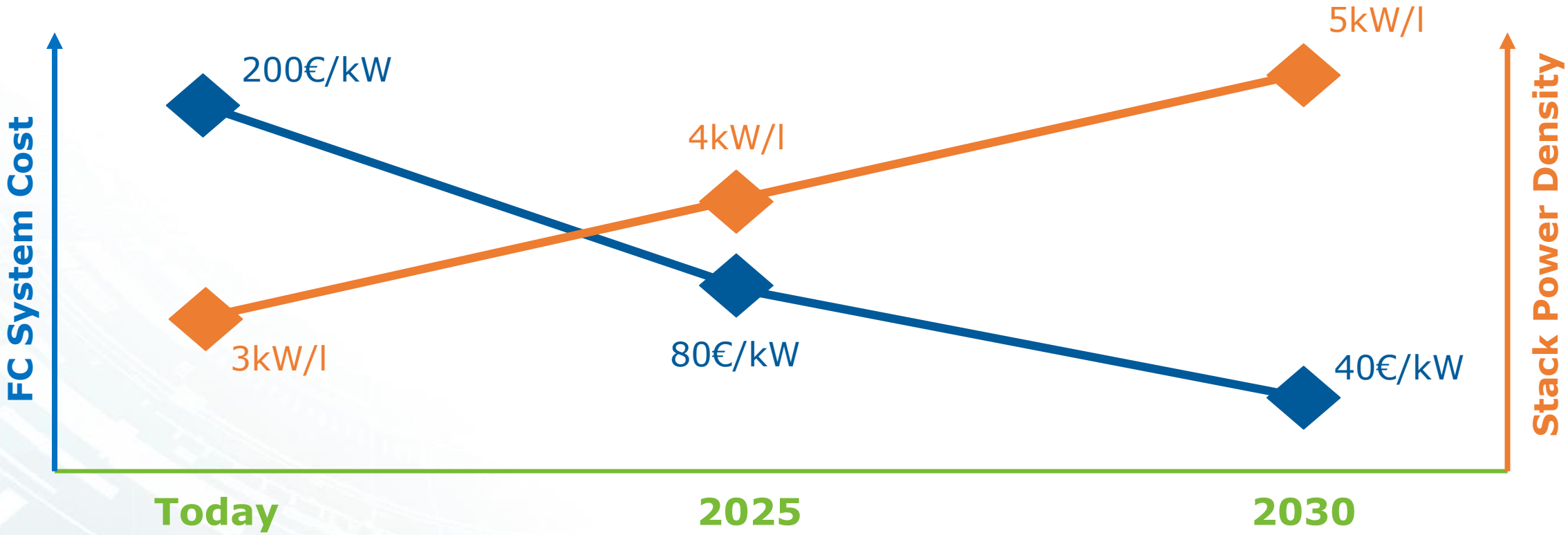
3 Optimization of Operating Strategy with 1D Damage Models

AVL PEM Stack Development



KPI	AVL Stack Targets Gen0-Baseline
Power [kW]	**110** (60-120)
Power Density [kW/L] Compressed cell row w/hardware (no enclosure)	**>3**
Dimensions Cell width x cell length [mm]	130 x 400
Cost indicators:	
Performance	CONFIDENTIAL
Pt loading [mg/cm^2]	CONFIDENTIAL
Lifetime [h] (time to 10% power loss)	**15,000**
Freeze startup capability Freeze-thaw tolerance	-30°C (tbc with system) -40°C

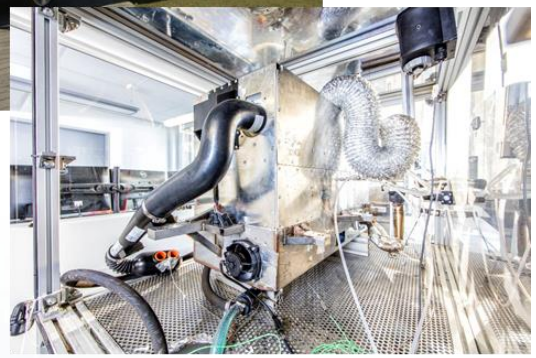
Technology Roadmap (PEM)



Power Density improvement driven by cell performance (CCM) and cell design

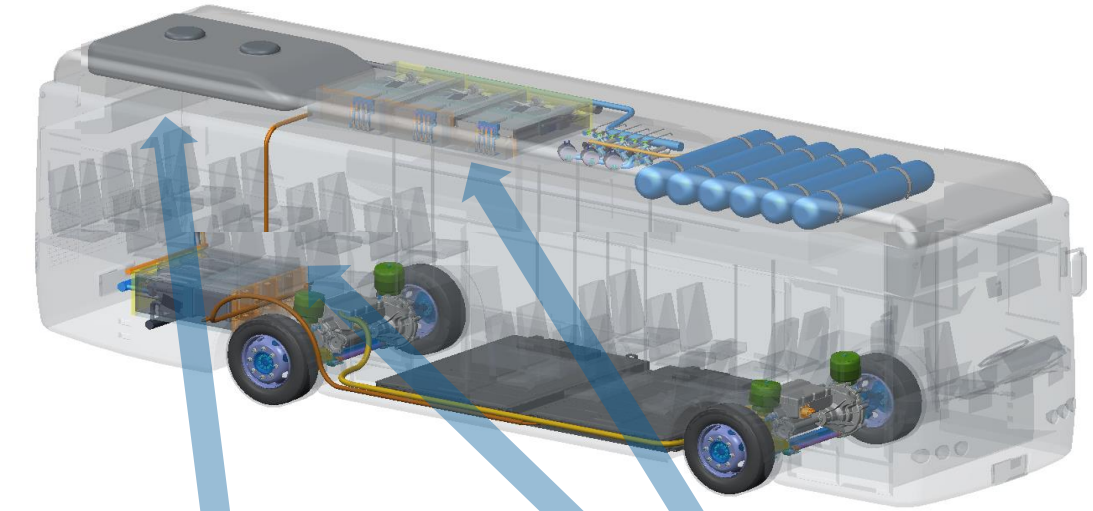
Cost reduction driven by volume

SOFC Range Extender Development



>600km Range

5kW SOFC REX



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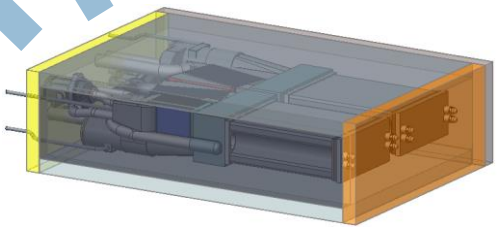


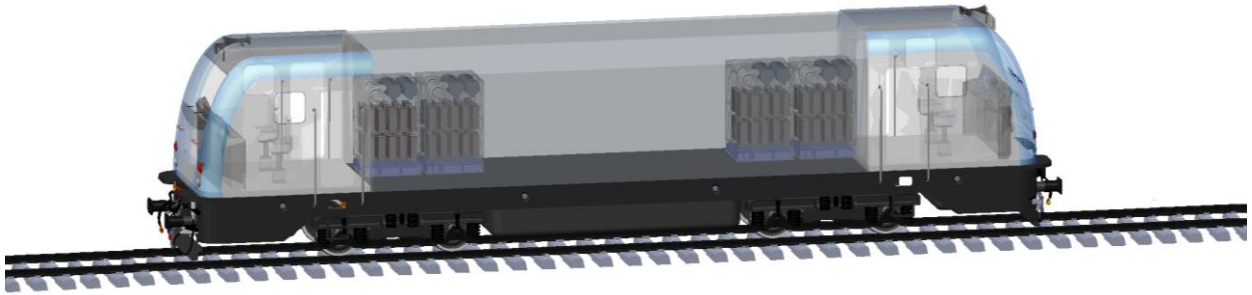
T-HVAC System

30kW SOFC REX

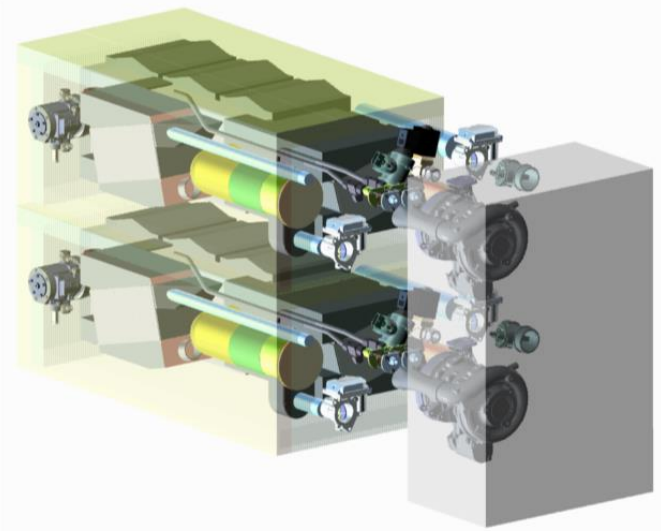
SOFC REX Technology based on biofuels (e.g. eGas) enables extremely WtW efficiencies

Fuel Cell Solutions for Rail & Marine

3MW Marine PEM Power Unit



200kW PEM modular Rail System



25kW SOFC Marine APU (Diesel)

Fuel Cell Adoption/Industrialization has started Rail, Marine & Aviation

Summary

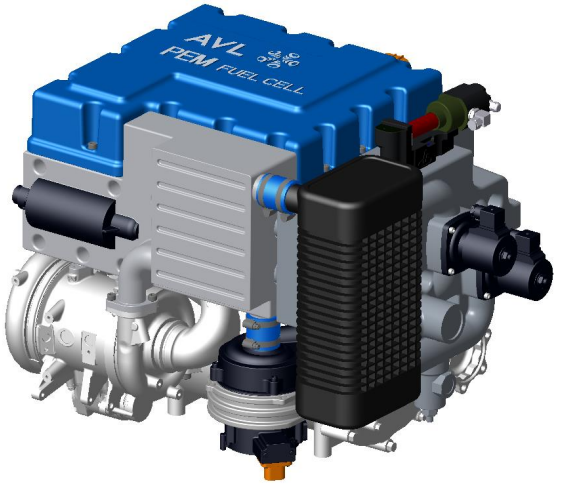
Fuel Cell has economic and ecological advantages in larger & heavier vehicles

Fast refill is a key advantage

H_2 will become an important renewable energy carrier

AVL accelerates investments in H_2/Fuel Cell Technology

Hydrogen Council



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HYTRUCK has received funding from the Austrian Climate and Energy Fund's Energy Model Region programme under grant agreement No 868790.


Thank you!