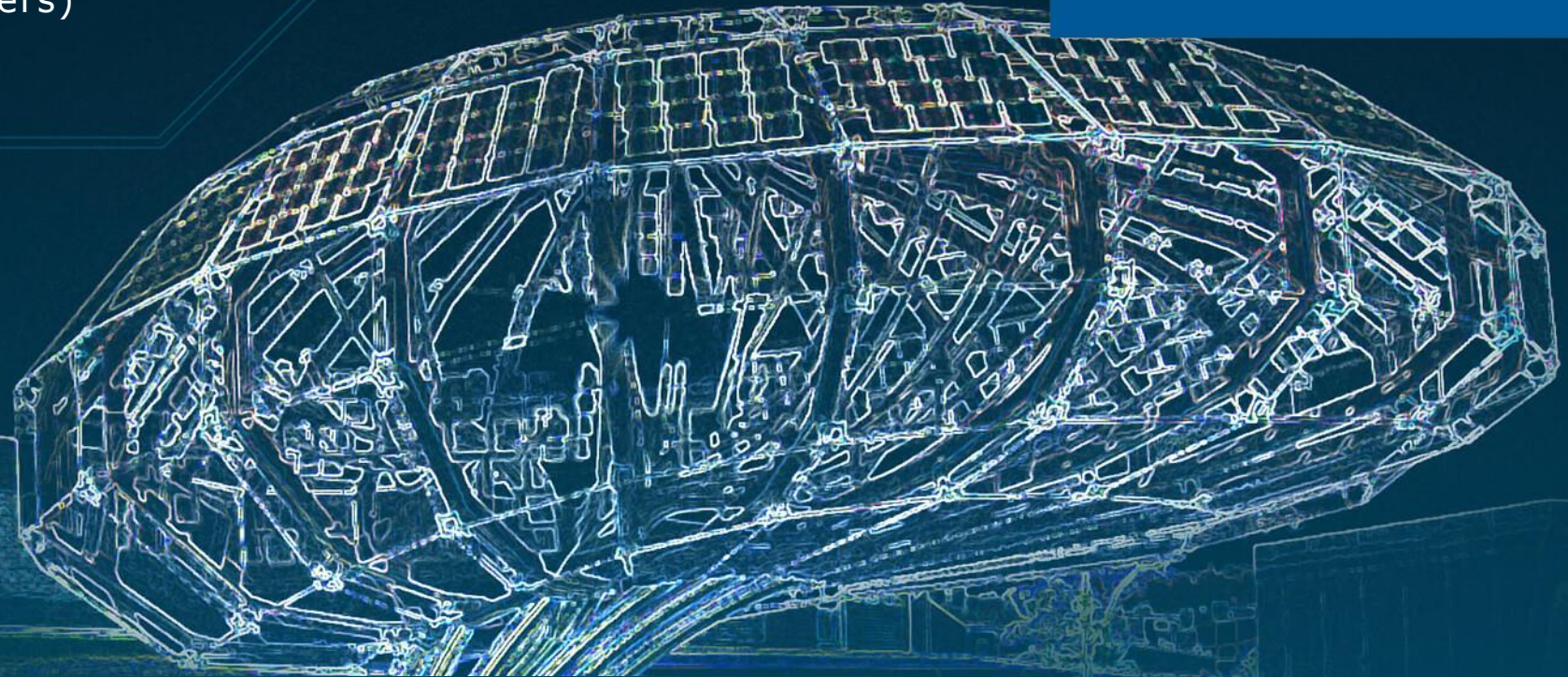


AVL List GmbH (Headquarters)



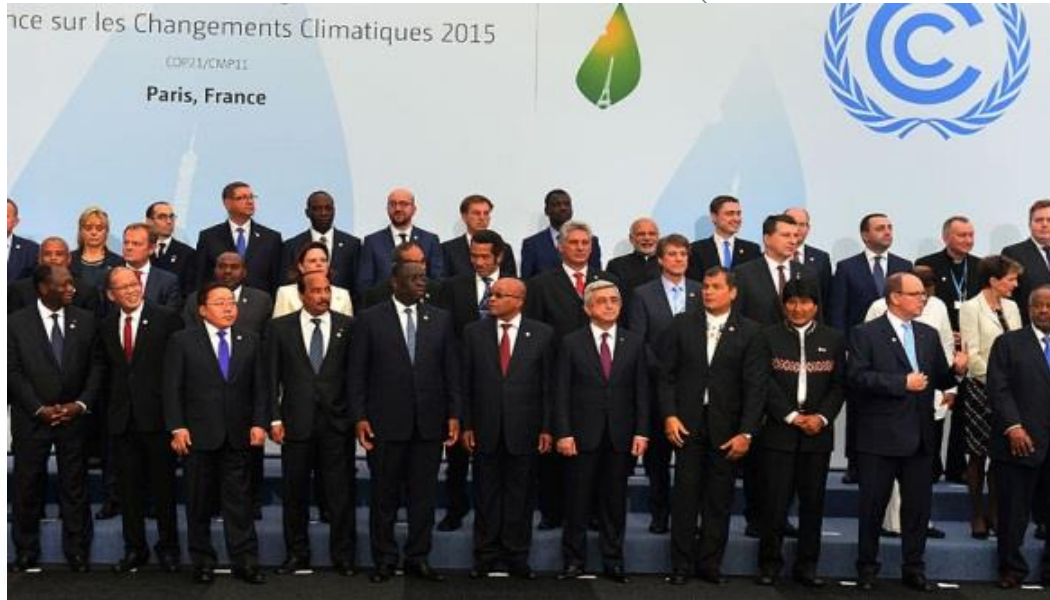
AVL Fuel Cell

Dr. F. Moradi

Senior Product Manager Fuel Cell

Challenges

Climate change



Reducing emissions from transport

>80% reduction of GHG emissions by 2050 from 1990 baseline.

Green technologies

BATTERY ELECTRIC VEHICLE

Battery

High Energy Efficiency

Slow Charging Infrastructure

Energy /Power Density

City, Urban Range

Long Charging Time

FUEL CELL VEHICLE

PEM Fuel Cell (Fuel: Hydrogen)

High Energy Efficiency

Hydrogen Infrastructure

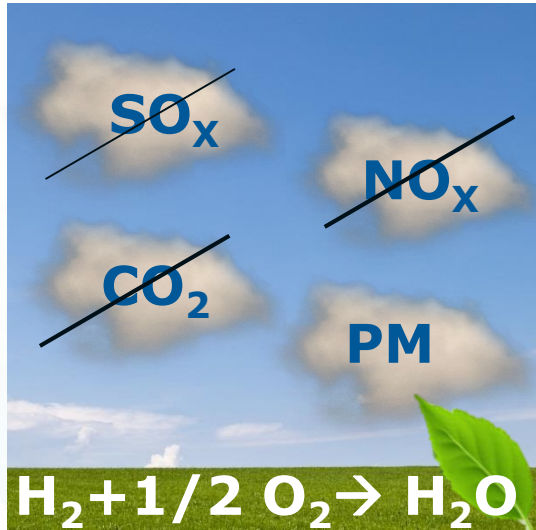
Energy /Power Density

Long Distance Driving Range

Short Refueling Time

Motivation for Fuel Cell

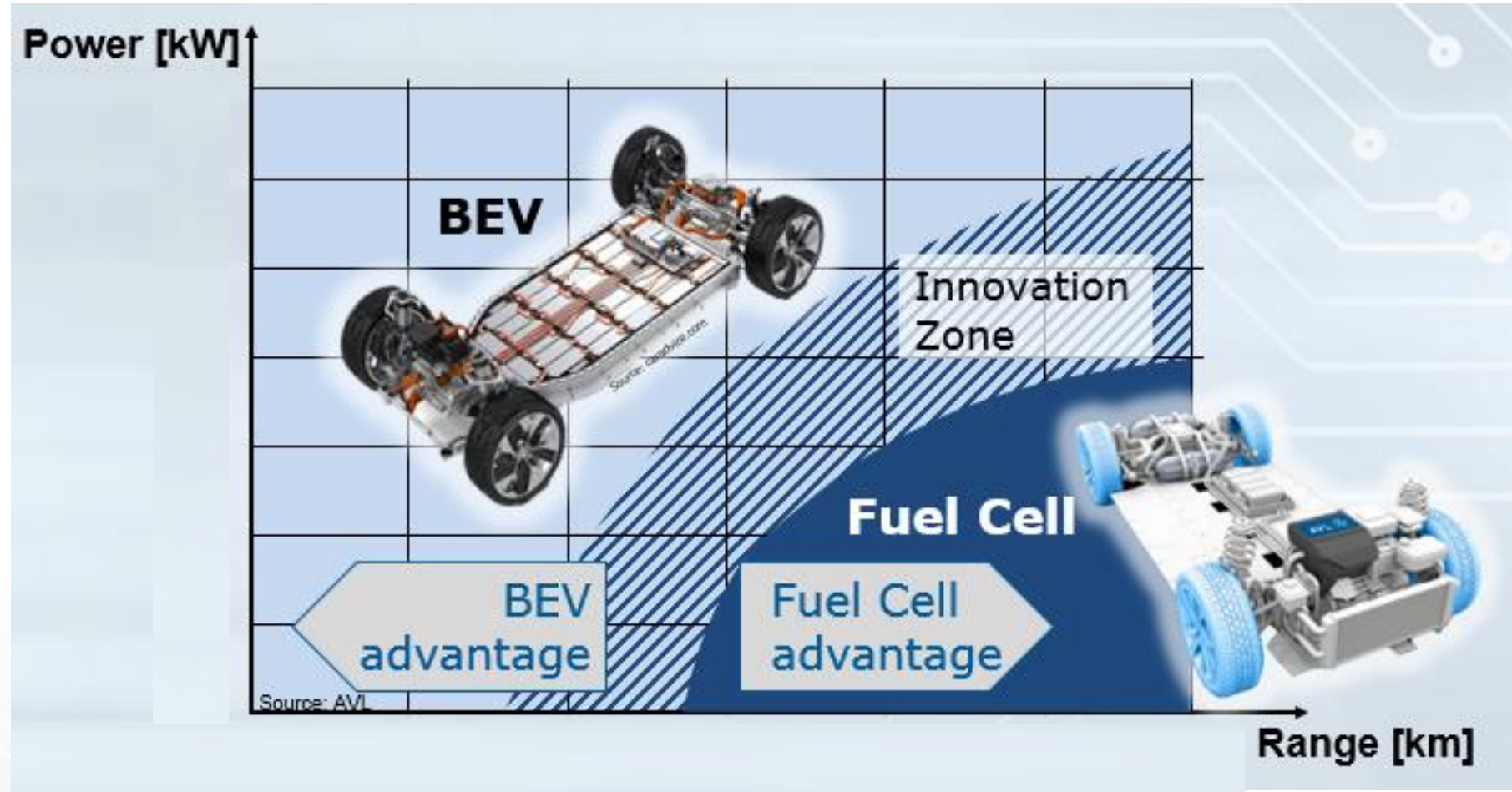
Motivation for Fuel Cell



Zero emissions vehicles

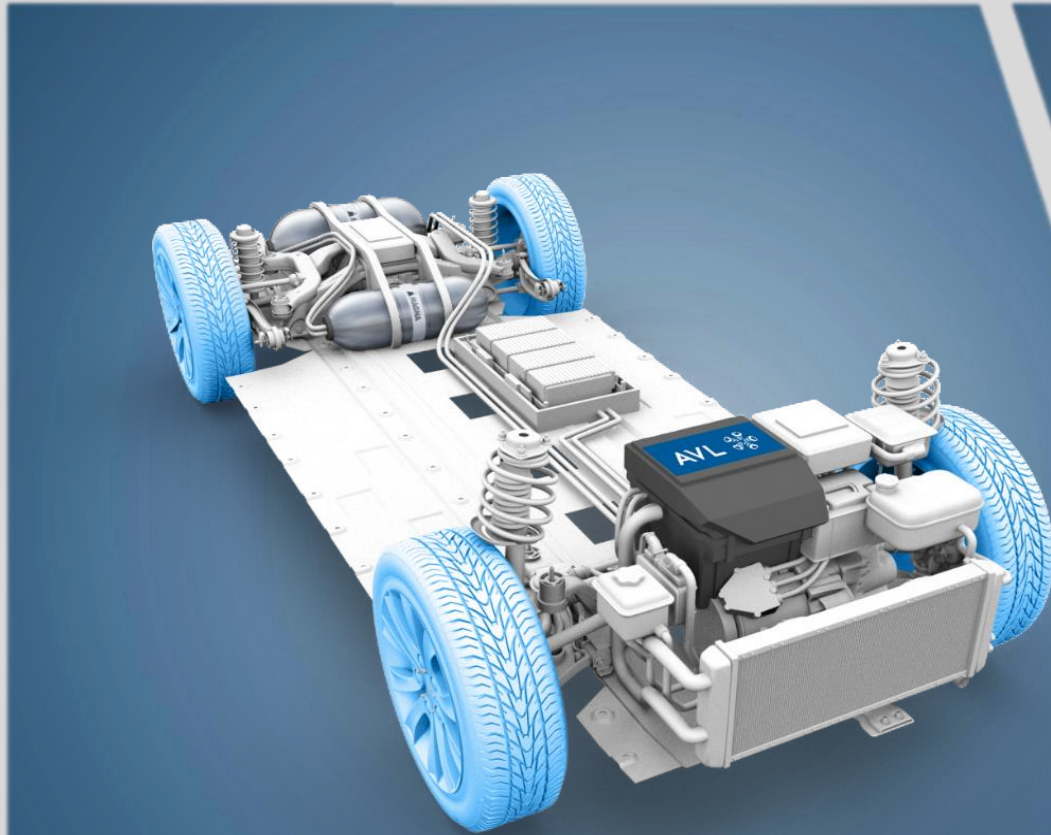


~3 minutes to refuel



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

Motivation



PEM Fuel Cell Vehicle

Fuel Type

Range

Diesel

450 km/min

Battery electric 400V

10 km/min

Battery electric 800V

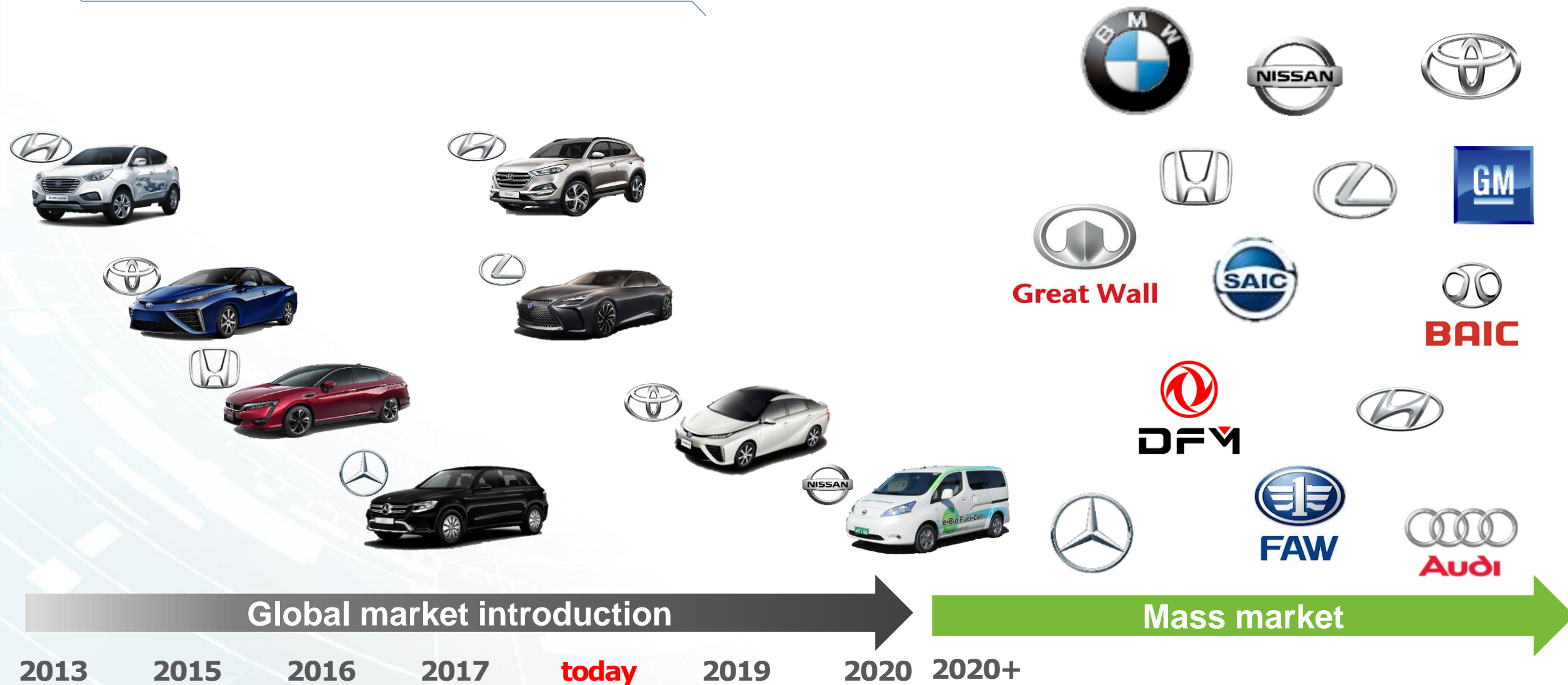
45 km/min

Hydrogen

250 km/min

Fuel Cell Market

Fuel Cell Market



Fuel cell for commercial vehicles & buses



DAIMLER



TOYOTA



HINO



DAIMLER TRUCKS



TOYOTA



KENWORTH

PACCAR

Global market introduction

Mass market

2016

2017

today

2020+

Fuel cell for forklifts & trains



amazon.com
Walmart

- ✓ Zero emission for indoor operation
- ✓ 3min refill
- ✓ 24/7 operation, no battery charging or swapping
- ✓ Lower TCO than battery forklifts

15.000 FC forklifts sold



- ✓ First fuel cell train in Germany in 2017
- ✓ Speed:140 km/h
- ✓ Range: 1000 km

ALSTOM CEO: We do think that by 2030 at least 10% of the whole fleet will shift from diesel to hydrogen.

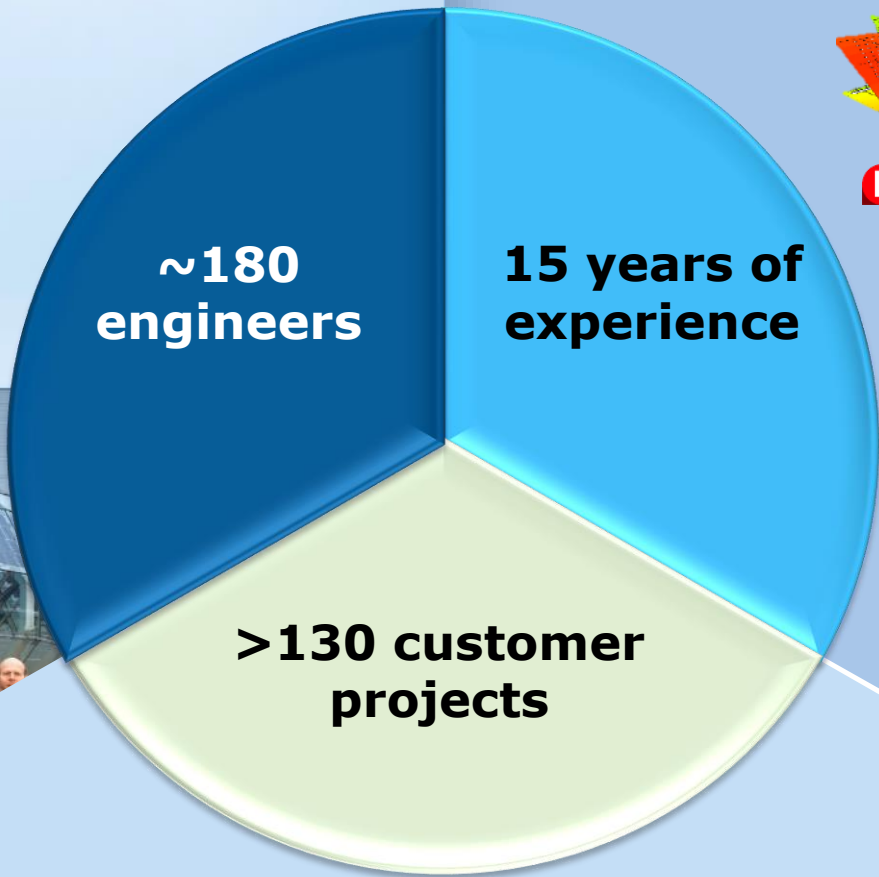
Visions of Hydrogen Council in 2030



- 1 in 12 cars in Germany, Japan, and South Korea and California powered by H₂
- Globally 10 to 15 million fuel cell cars
- Globally 500,000 fuel cell trucks
- Deployment of fuel cell trains and passenger ships

AVL Fuel Cell

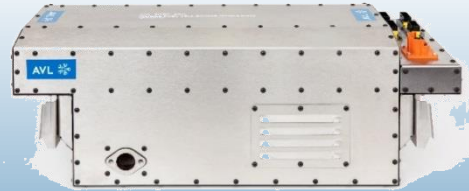
AVL Fuel Cell



12 PC automotive OEMs **6 CV OEMs**
10 non-automotive OEMs **6 tier 1/2** **3 SOP programs**

Fuel Cell Systems

Two technology options for automotive industry



Solid Oxide Fuel Cell (SOFC)



Polymer Electrolyte Membrane Fuel Cell (PEMFC)



Range Extender



Efficiency: up to 55%

Both technologies can be used for passenger cars & commercial vehicles



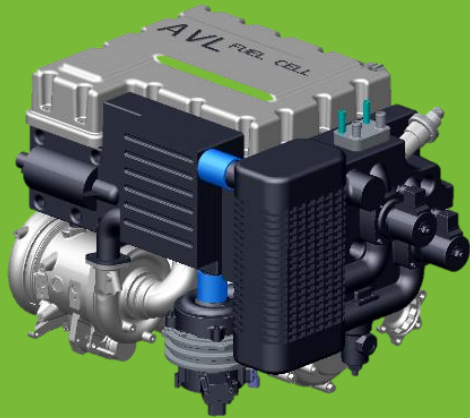
Main Propulsion & Range Extender

Efficiency: up to 55%



Fuel Cell Product Lines

PEM
(Emission free)



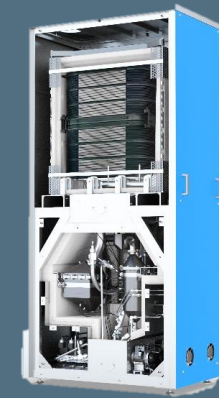
PEM Fuel Cell Engine
20-150 kW



SOFC
(Almost emission free, only CO₂ emission)



SOFC APU/Range Extender
3-30 kW

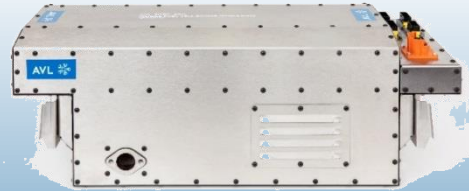


SOFC Stationary Power Generator
kW-MW



Fuel Cell Systems

Two technology options for automotive industry



Solid Oxide Fuel Cell (SOFC)



Polymer Electrolyte Membrane Fuel Cell (PEMFC)

Range Extender



Efficiency: up to 55%

Both technologies can be used for passenger cars & commercial vehicles

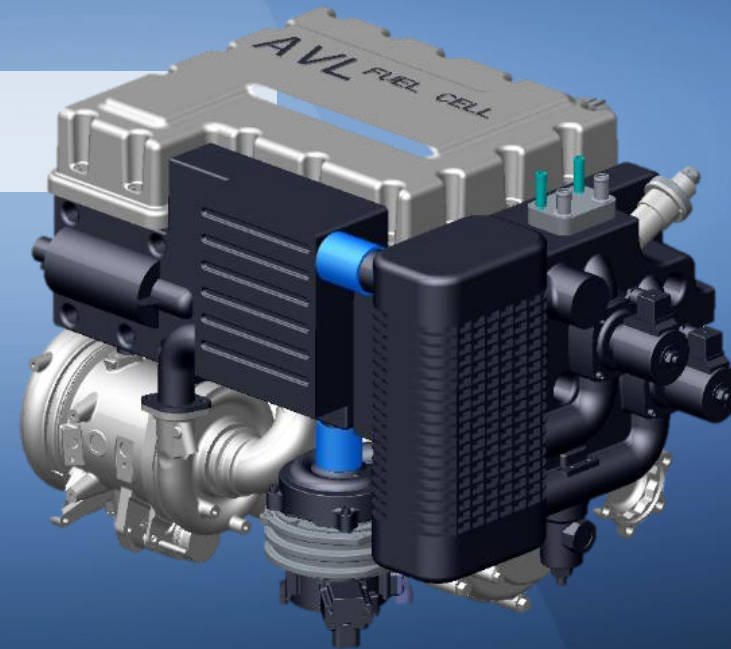


Main Propulsion & Range Extender

Efficiency: up to 55%



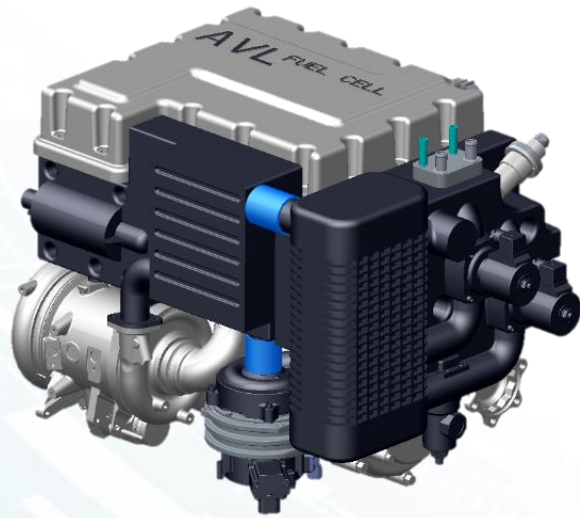
AVL PEM Fuel Cell



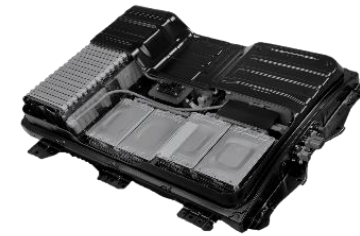
AVL PEM Fuel Cell Engine



Fuel Cell Engine
70 kW



Battery
10 kWh

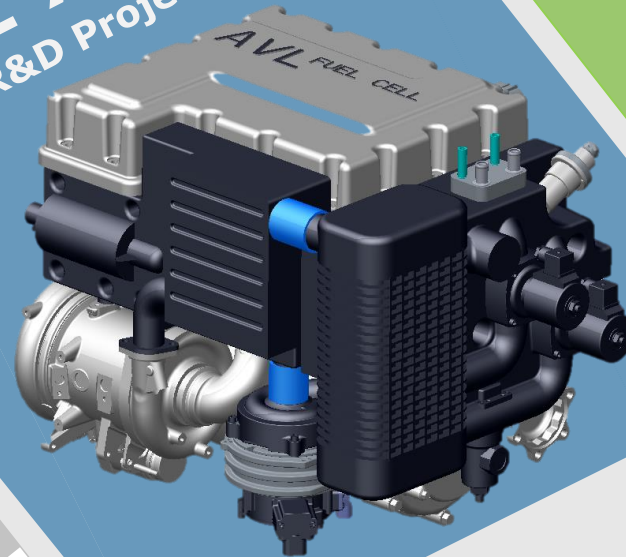


Customized High Performance PEM Fuel Cell Module/ Powertrain



**Downscale
(e.g. 30 kW)**

**AVL 70 kW
(R&D Project)**



**Upscale
(e.g. 120 kW)**



Customized solution with reasonable development effort

AVL PEM System USPs

A detailed 3D rendering of the AVL PEM fuel cell system, showing the fuel cell stack, compressor, and various control components. The fuel cell stack is labeled 'AVL FUEL CELL'. The system is shown in a blue-tinted environment with a glowing blue circle around it.

High efficiency (High performance stack & compressor, AVL IP for fuel cell system & vehicle control)

Passive hydrogen recirculation (No hydrogen pump needed → lower power consumption & higher efficiency)

High power density

Diagnostics based system control (AVL THDA) → Extension of fuel cell system's lifetime

Operating temperature: -40 to 60°C

1. AVL PEM Fuel Cell Reference Projects



SOP, 30 kW Range Extender



✓ Phase 1 finished

Confidential

SOP, 100+ kW



Confidential

Project Examples

AVL PEM Fuel Cell Plug In Concept Car

- ✓ 55 kW PEM fuel cell
- ✓ 10 kWh battery



PEM Fuel Cell Passenger Car

- ✓ Advanced diagnostics
- ✓ Anode subsystem design
- ✓ System controls & SW

CONFIDENTIAL



FCEV PC SOP 2022

AVL is strategic development partner for FCEV SOP in 2022

CONFIDENTIAL



Advanced PEM Stack Diagnostics

- ✓ Lab-test project
- ✓ Vehicle integration
- ✓ New failure modes

12 OEMs



HD Truck PEM Fuel Cell System

- ✓ Concept study
- ✓ Feasibility study
- ✓ FC System Design

CONFIDENTIAL



30KW REX SOP

30kW PEM REX for CV, SOP development Phase 1 finished

CONFIDENTIAL



AVL Solid Oxide Fuel Cell



AVL Solid Oxide Fuel Cell



Up to 60% efficiency



Practically emission free



No PM emissions



Very low noise



Conventional/Bio fuels



Range Extender/APU

NISSAN
MOTOR CORPORATION



>600km Range

5kW SOFC REX

30l E100 Tank

2. SOFC Range Extender/APU Project Examples

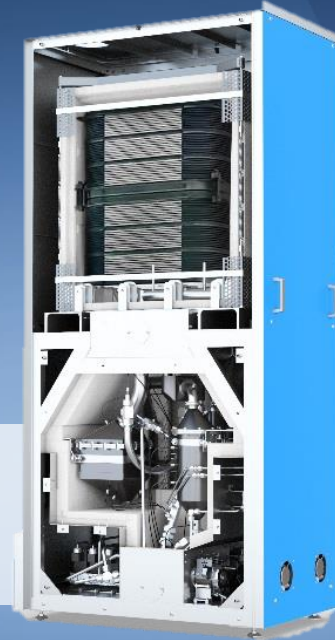


+10 kW Range Extender

3 kW APU



SOFC CHP



AVL SOFC Stationary Power Generator



FUEL

Biogas



Biomass



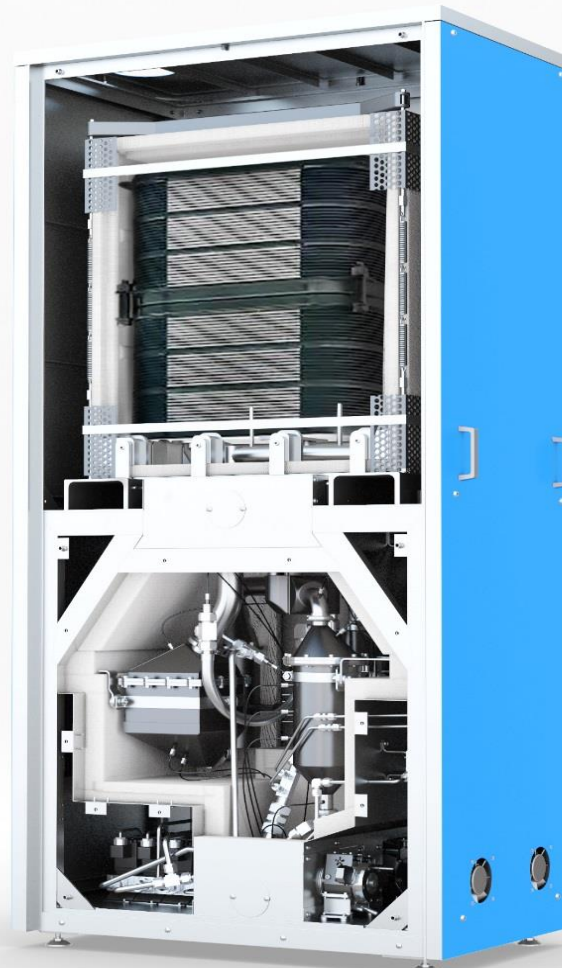
Natural Gas



Renewable Diesel



SOFC CHP



PRODUCTS

Electricity



Cooling Power



Heat

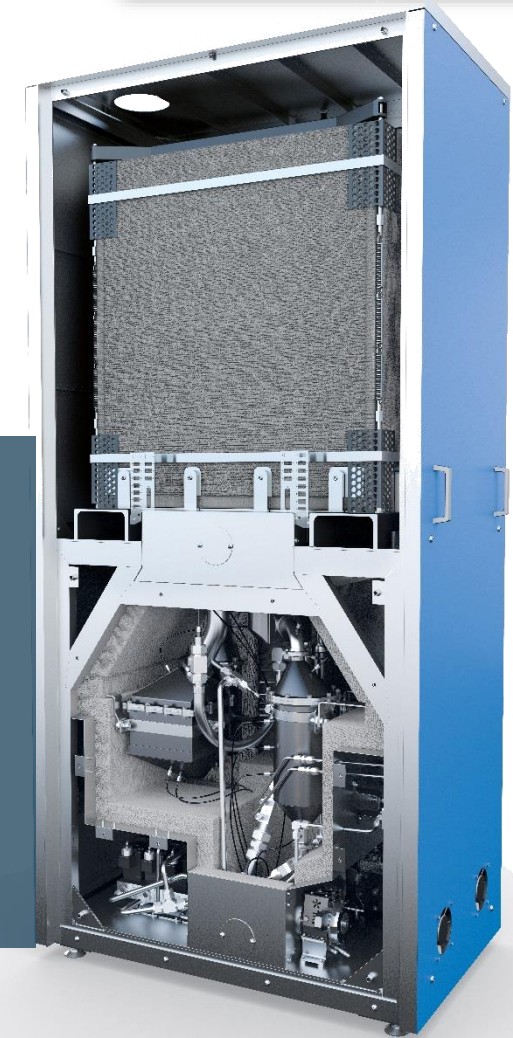


AVL SOFC Stationary Power Generator

Power range: kW- MW

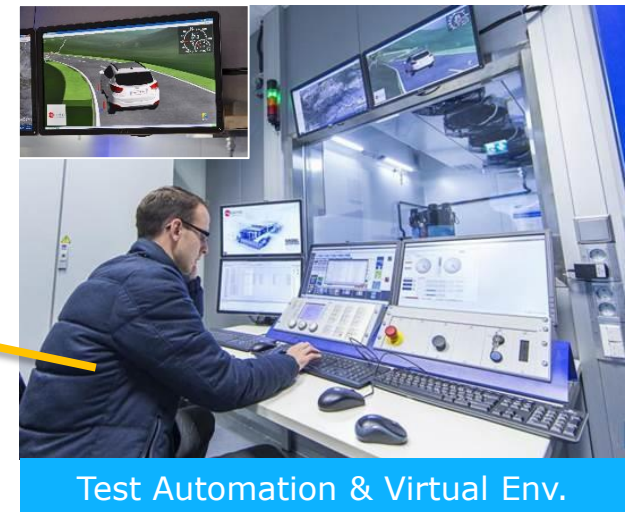
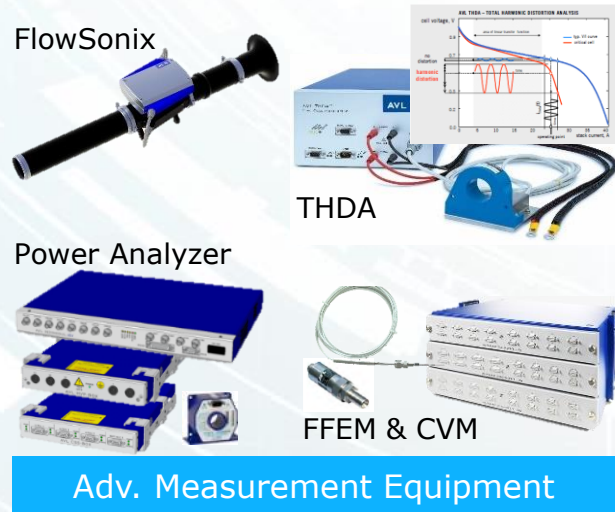
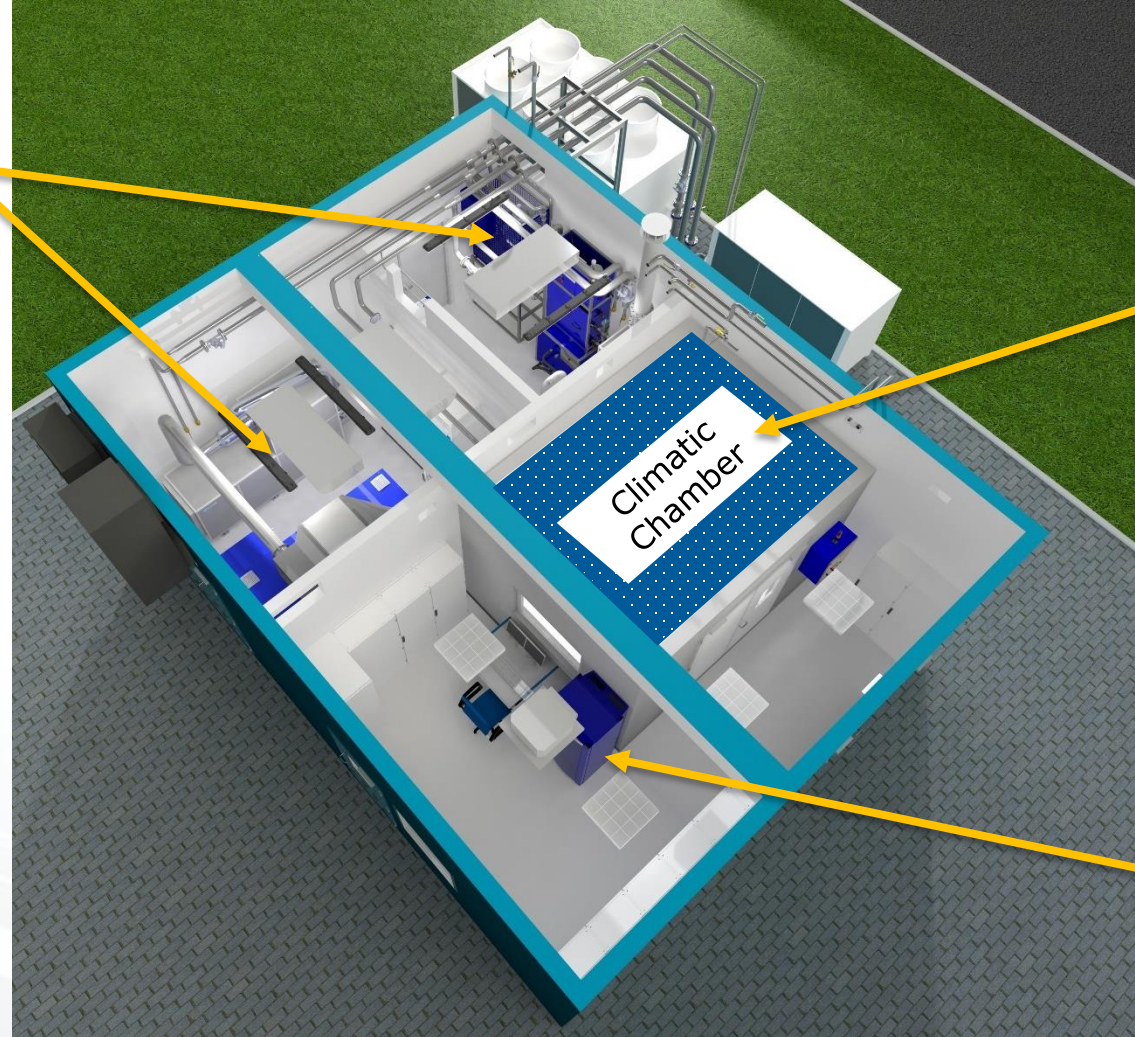
Electrical efficiency: 60%

Total efficiency: 95%



TRL7 for 10kW System → Ready for in-field customer demonstrations

Full scale fuel cell system testbed



Test Systems



*>23
Years*



*>70
Years*



Fuel Cell Test System

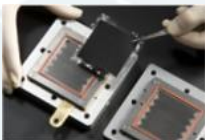
Customer Benefit

Powertrain & Vehicle Test System

Automation System

Emerald

PUMA Open for Fuel Cell



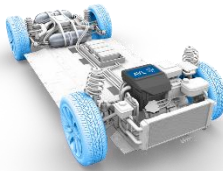
Cell Test Bed



Stack Test Bed



System Test Bed



Powertrain Dyno



Chassis Dyno

Thank You



www.avl.com

