

PEM Fuel Cell Powertrain

Which application makes sense – a study

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AVL ENTERPRISE DEVELOPMENT

RESEARCH 10%
of turnover in-house R&D

INNOVATION 1500
granted patents

STAFF
9.500 employees

65% engineers and
scientists

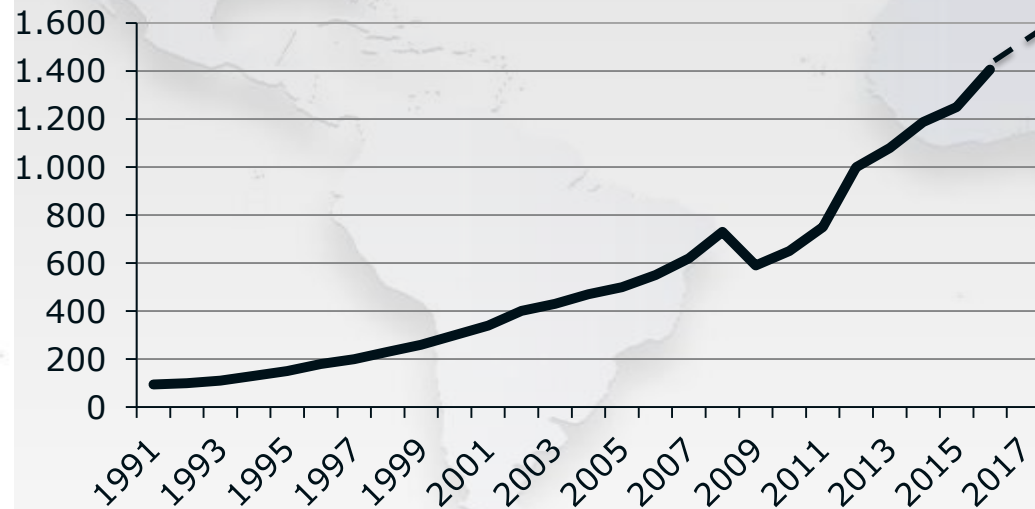
GLOBAL FOOTPRINT

- 30** engineering locations
- **>220** testbeds
- Global customer support network

EXPERIENCE
70 years !

5 powertrain
elements

GROWTH



SALES

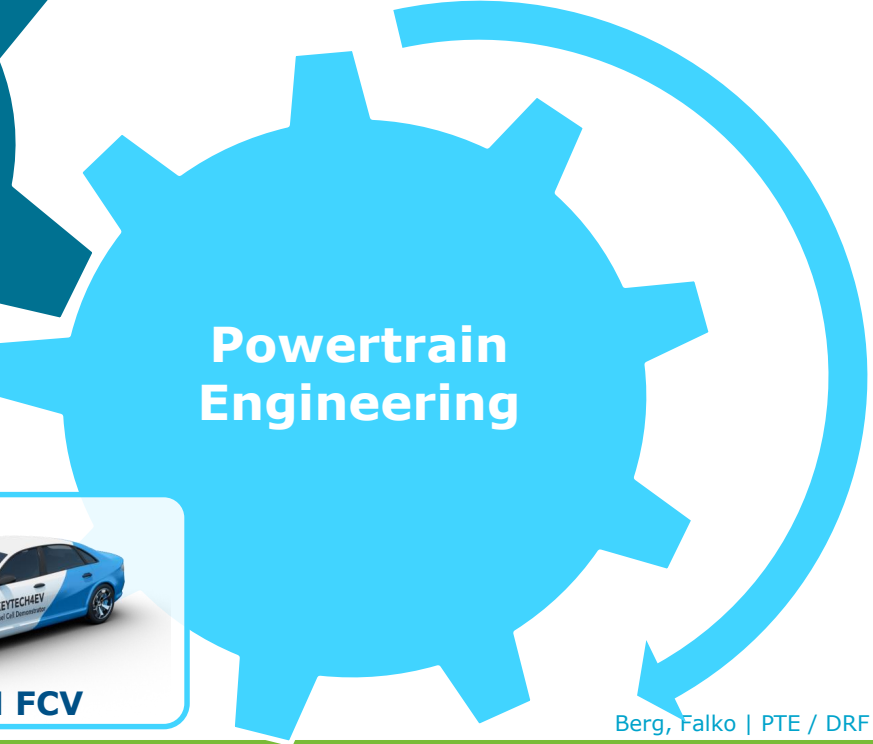
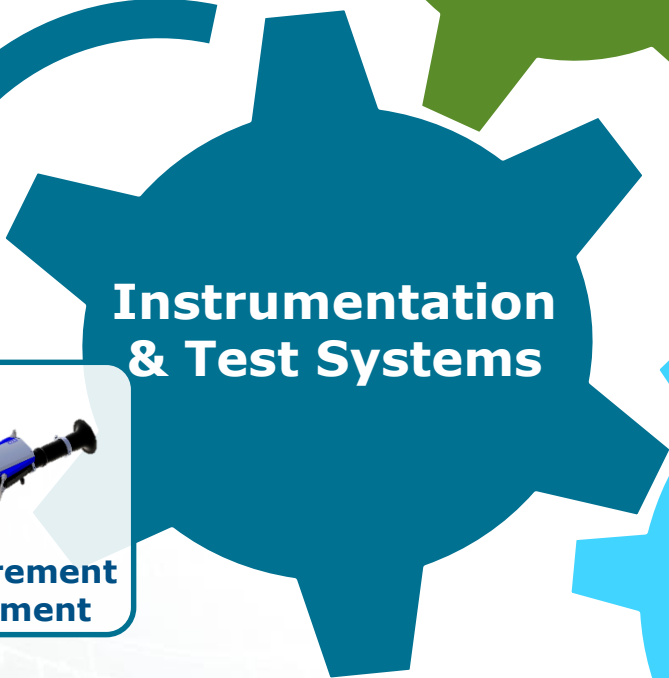
1995:
0.15 billion €

2017:
1.55 billion €

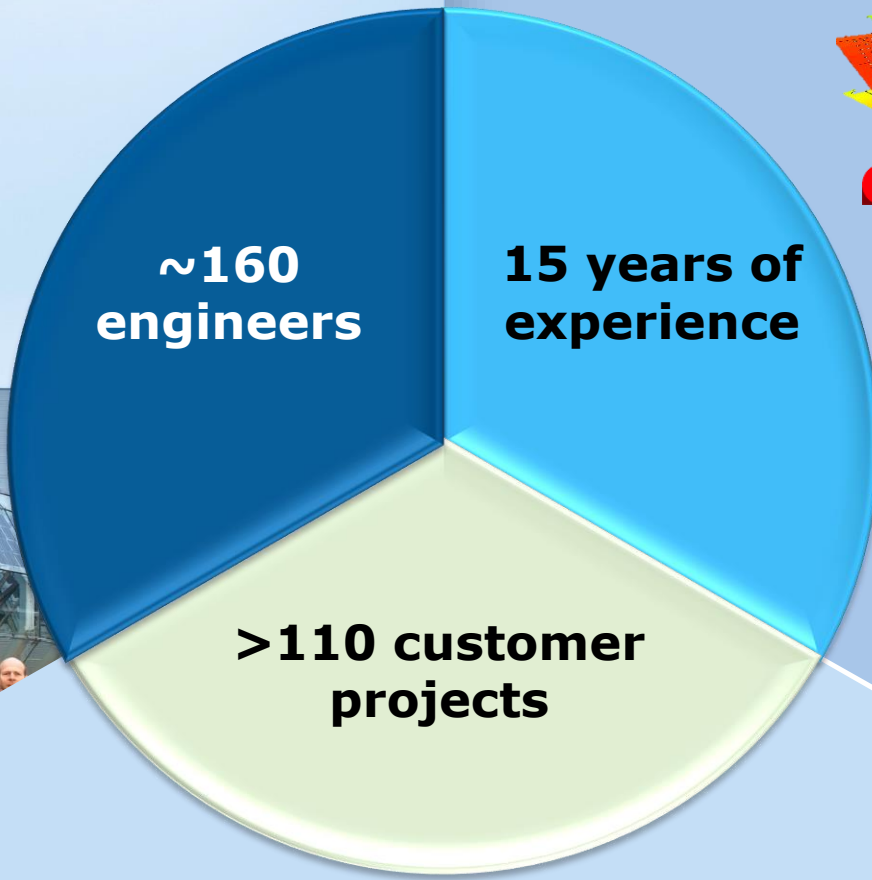
Plan 2018:
1.71 billion €

**ONE
PARTNER**

AVL Fuel Cell



AVL Fuel Cell

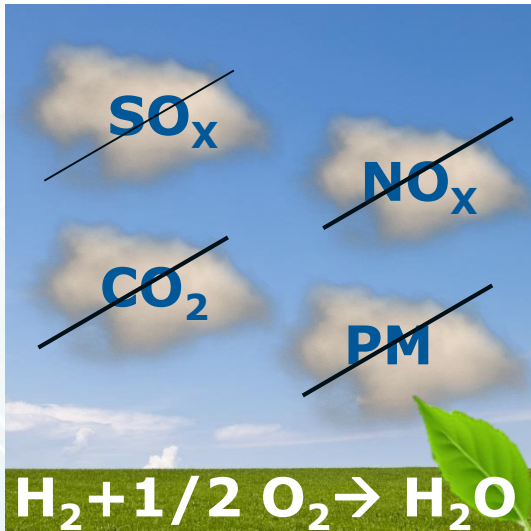


12 PC automotive OEMs **5 CV OEMs**
8 non-automotive OEMs **6 tier 1/2** **3 SOP programs**

Fuel Cell Application

Motivation for Fuel Cell

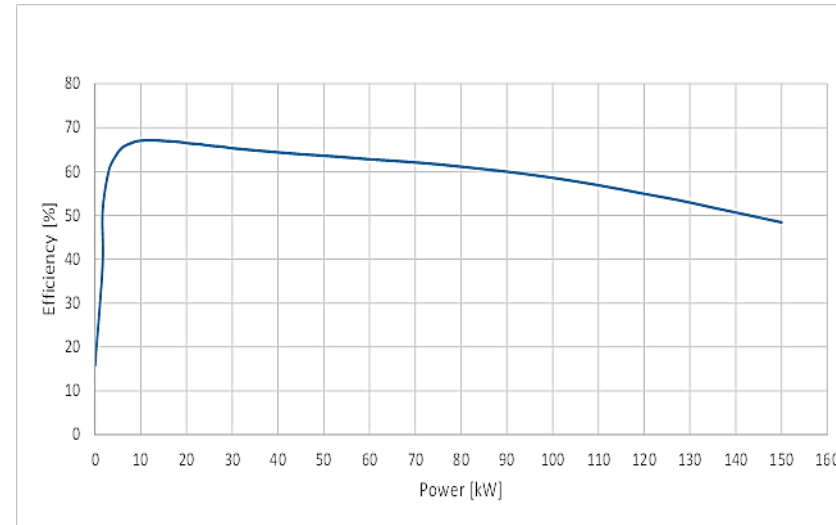
Advantages of Fuel Cell Technology



Zero emissions



Fast refueling (~3 mins)



High system efficiency (~68%)



Silent

BEV vs. FCEV

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

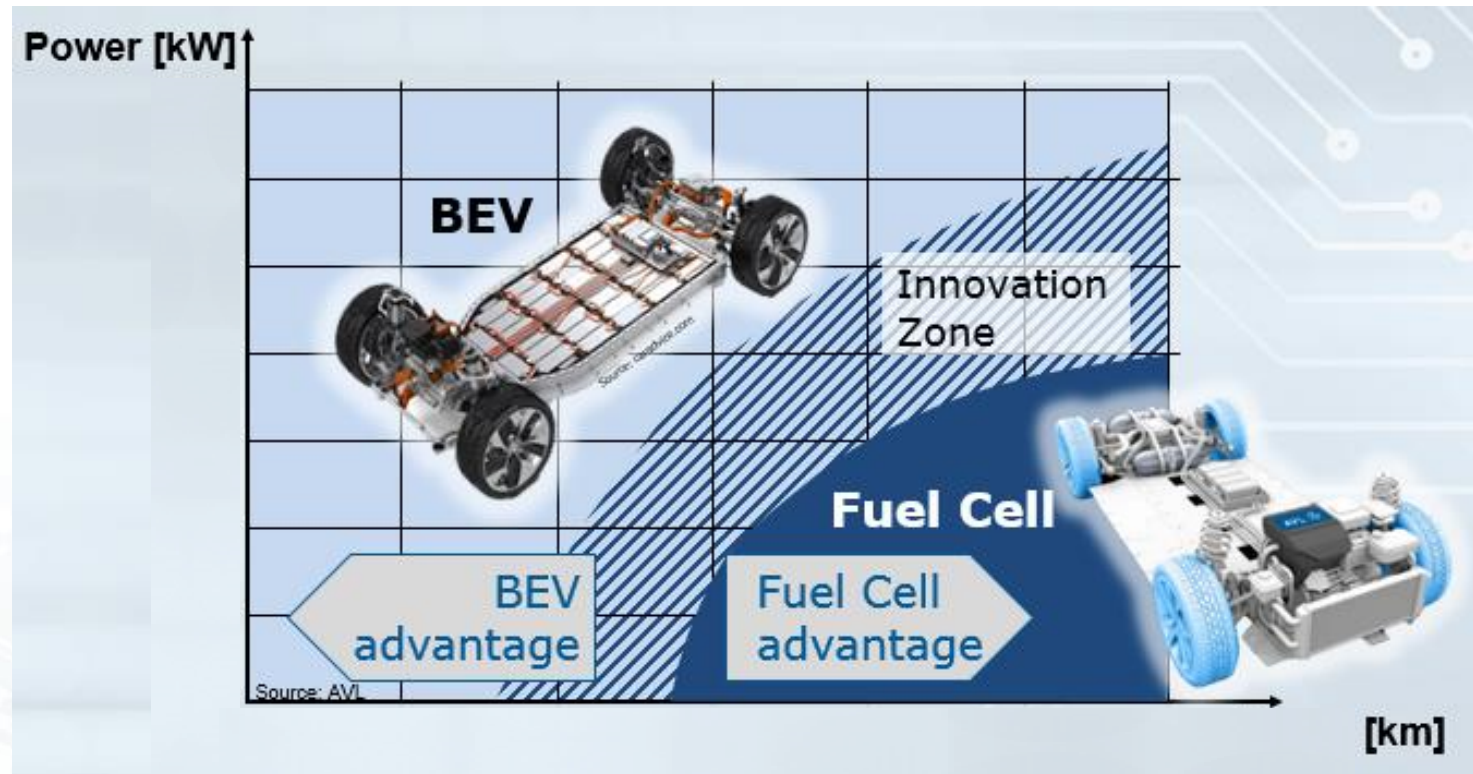
Hydrogen Infrastructure

Energy / Power Density

Long Distance Driving Range

Short Refueling Time

BEV vs. FCEV



For larger & long range vehicles, FC Powertrain will be lower in cost than a comparable Battery Electric Vehicle (BEV) Powertrain

Modularity of Fuel Cell Systems

Modularity of PEM Fuel Cell Systems

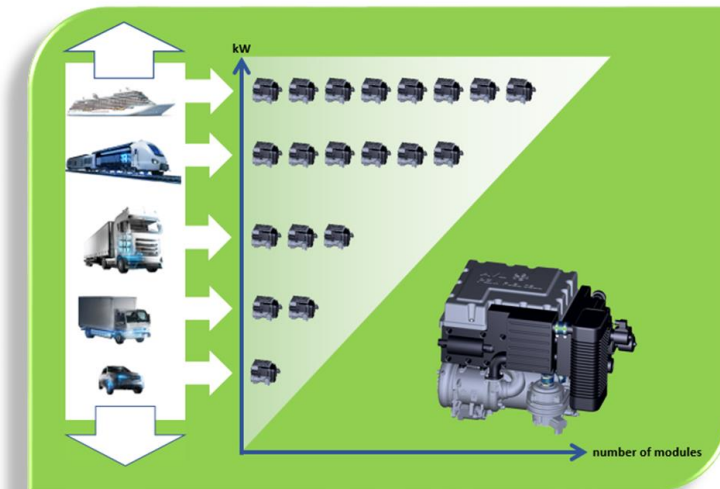
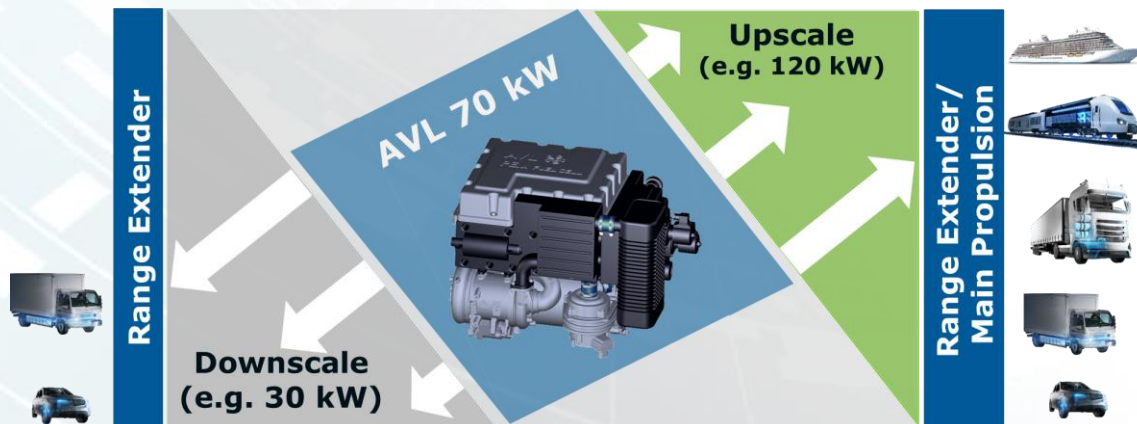
Modularity of FC systems exists on system and powertrain level

System level

- FC systems are clustered in power ranges (e.g. 30 kW, 50 kW, 100 kW)
- Balance of Plant components are developed to meet requirements of these power ranges

Powertrain level

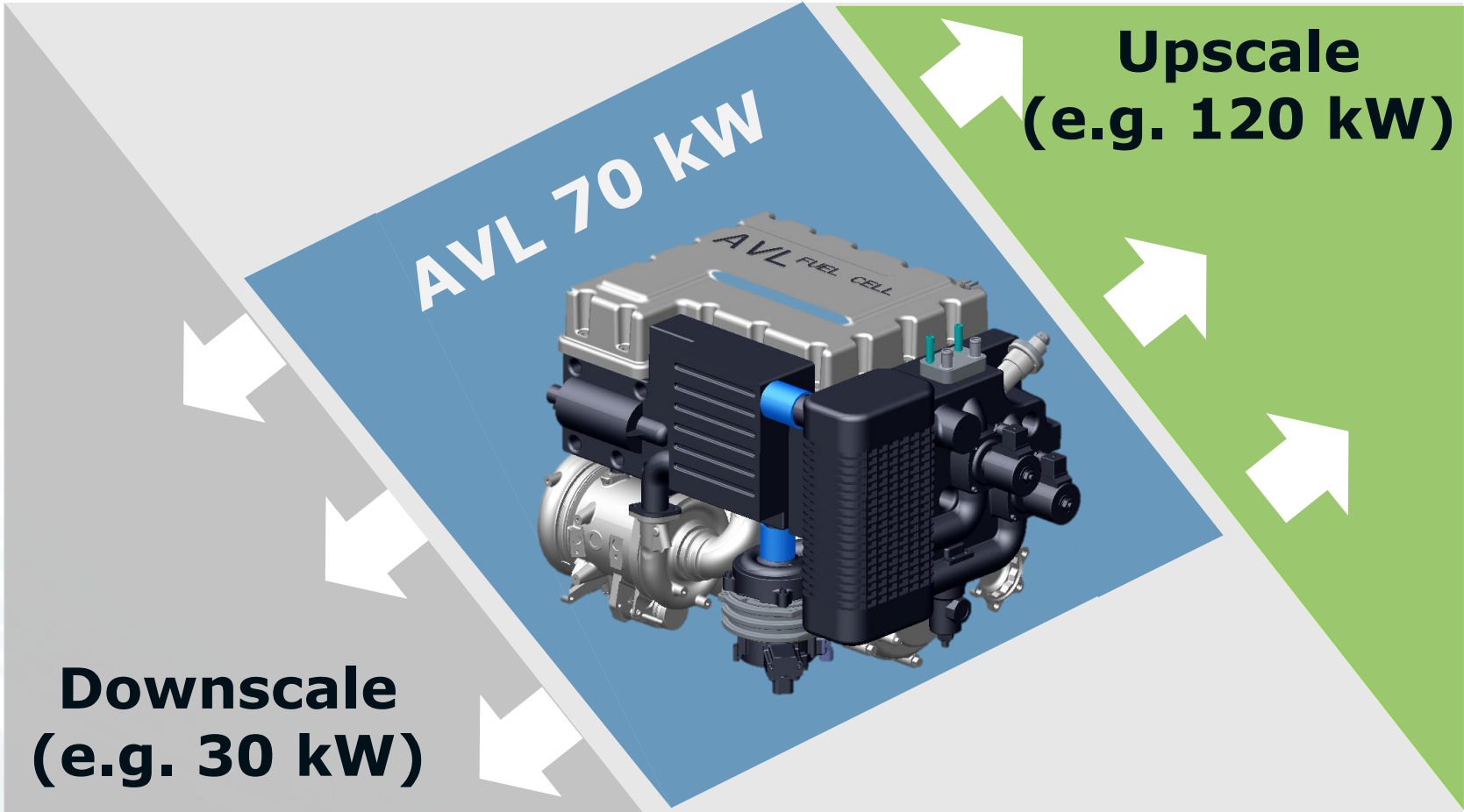
- Especially for high power applications
- Carry-over of FC system components from passenger cars for commercial vehicles
- Increased production volumes lower the overall manufacturing costs



Customized High Performance PEM Fuel Cell System/ Engine



- Vehicle Size**
- Train
 - MD Truck
 - LD Truck
 - City Bus
 - Passenger car



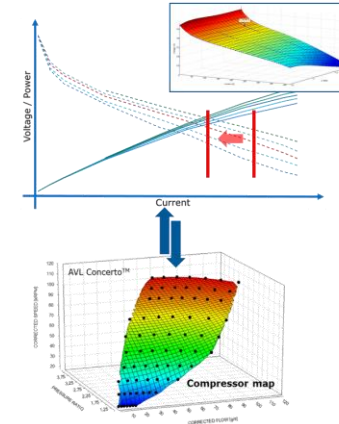
- Train
 - HD Truck
 - MD Truck
 - LD Truck
 - Bus
 - Passenger car
- Vehicle Size**

Customized solution with reasonable development effort

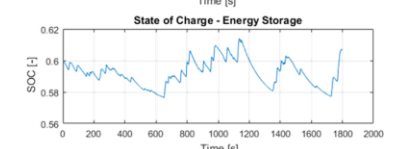
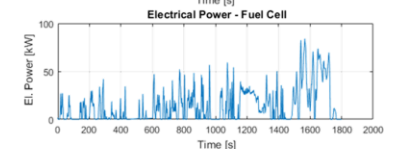
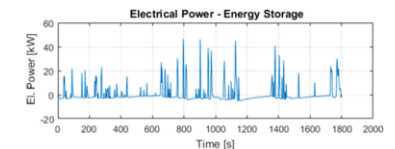
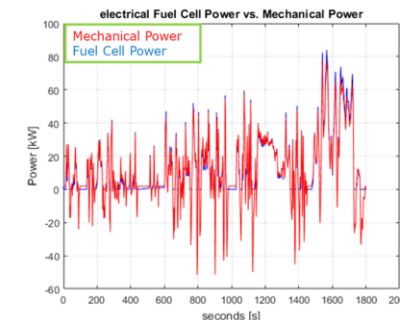
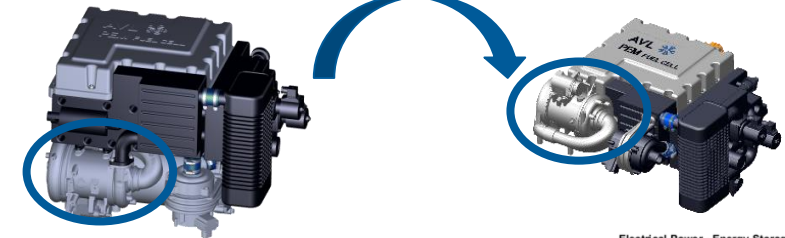
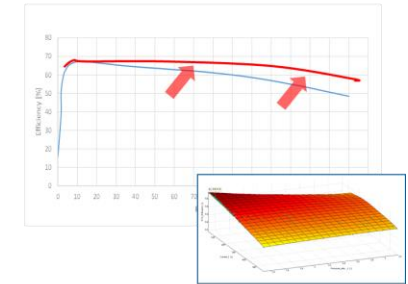
Modularity of PEM Fuel Cell Systems – System Level

- Optimization of BoP components are optimized to meet requirements of dedicated power range
 - e.g. compressor development
 - Mass flows
 - Pressure ratio
 - Efficiency
- Carry-over of components between different power ranges is possible depending on stack operational characteristics
- Clustered components still allow FC system efficiencies close to ideal efficiency
 - CAE methods for component selection

Optimization of efficiency & power density



System design and component matching



Modularity of PEM Fuel Cell Systems – Powertrain Level

Singular Fuel Cell system

300 kW



Modular Fuel Cell system

100 kW



Power output

Use cases

Power density

Weight

Package space

Reliability

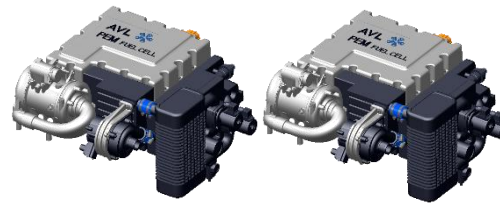
Lifetime / Durability

- No flexibility in power output
- Fewer use cases / commercial vehicle sizes
- **Higher power density**
- **Lower weight**
- Lower package space demand
- High reliability
- Not fail-safe
- Low flexibility in operating strategies to achieve prolonged lifetime of the FC powertrain

- **Flexible power output** due to modularity
- Transferable to **different commercial vehicle** sizes and use cases
- Lower power density, depending on number of modules
- Higher, due to increased number of BoP components
- Higher package space might be required;
- **Higher flexibility in packaging**
- Higher reliability
- **Fail-safe**
- **High freedom in operating strategies**
- Prolonged lifetime
- Homogenous distribution of load
- Shut-down of single modules
- Distribution of total operating hours

Modularity of PEM Fuel Cell Systems– Powertrain Level

Modular 100 kW Fuel Cell System for Commercial Vehicles



The modular fuel cell system addresses due to its versatility many commercial use cases from LD to MD and HD application

Modularity of PEM Fuel Cell Systems – Powertrain Level

Modular FC systems can address lifetime/durability targets of FCEV

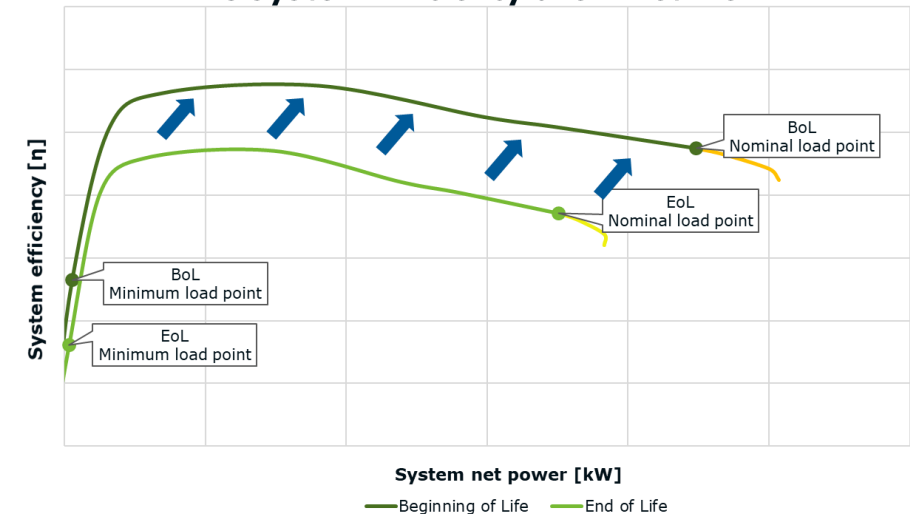
Fuel cell lifetime/durability

- Cell degradation in the range of 5-25 $\mu\text{V/h}$ (12-7.5 $\mu\text{V/h}$ DOE & EU targets)
- In real world operation 2-4 times higher!
- Passenger car (PC) systems lose $\sim 15\%$ of power after 6.000 h
- PC fuel cell stacks in „battery charger operation“ can reach ~ 15.000 h

Potential solutions for increased lifetime/durability

- Modular System Approach
- Range Extender Operation (low dynamics)
- Operation at low current density
- Operation with low dynamics (hybridization strategy)
- Regeneration cycles
- Improved stack design

FC System Efficiency over Lifetime



Modularity of PEM Fuel Cell Systems – Powertrain Level

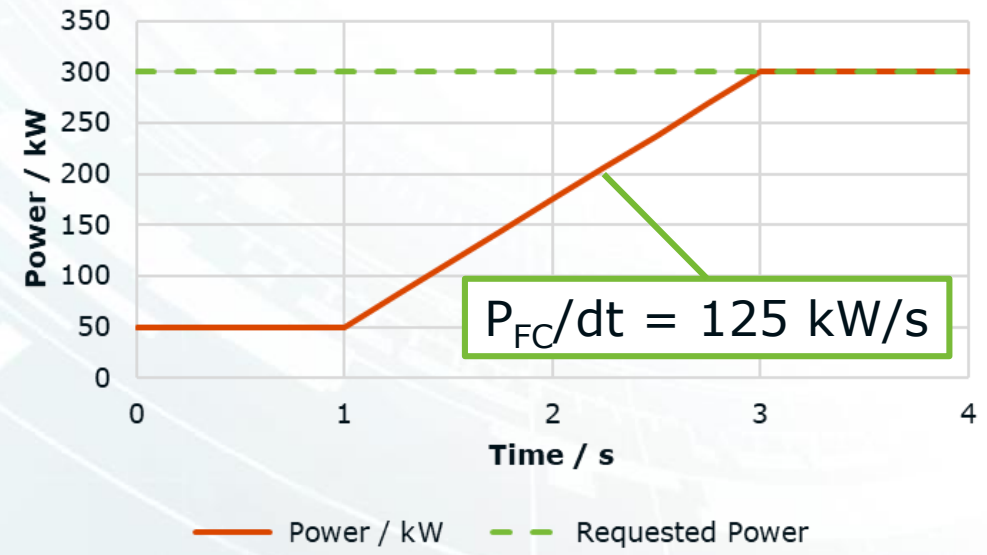


Modular FC systems can address lifetime/durability targets of FCEV

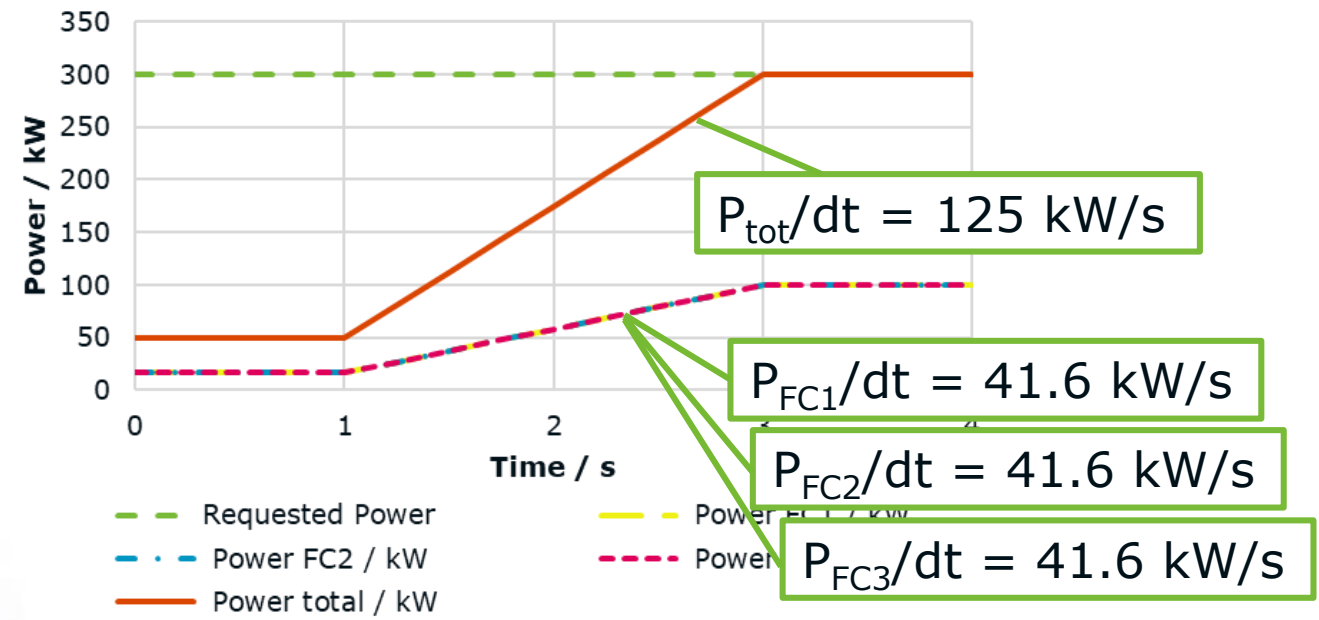
Dynamics in FC systems

- A modular FC system allows to reduce dynamic from each module → positive influence on stack lifetimes

Dynamic power request of 125 kW/s - 1 FC system



Dynamic power request of 125 kW/s - 3 FC systems



Modularity of PEM Fuel Cell Systems – Powertrain Level

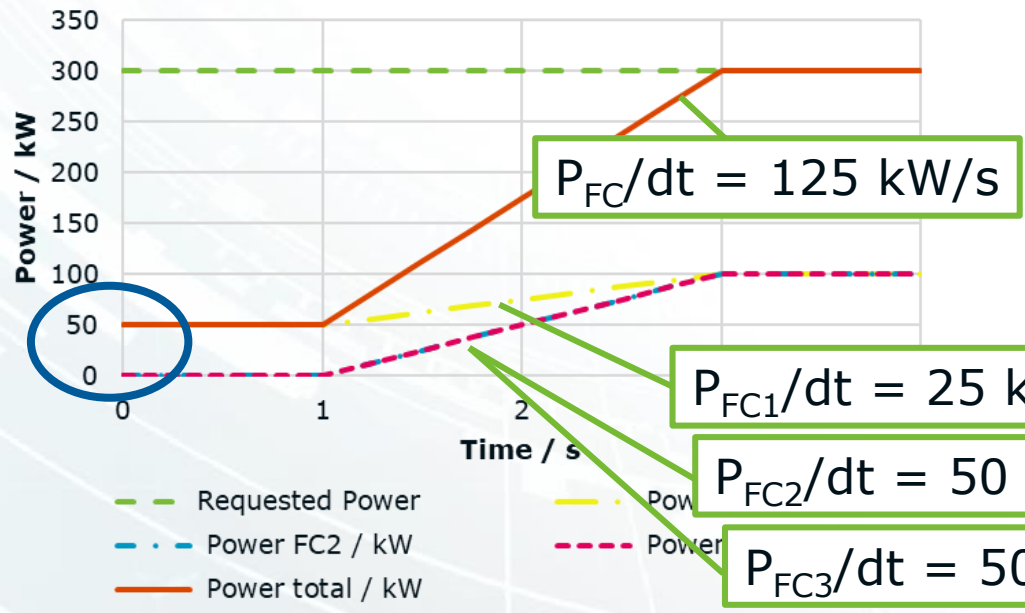


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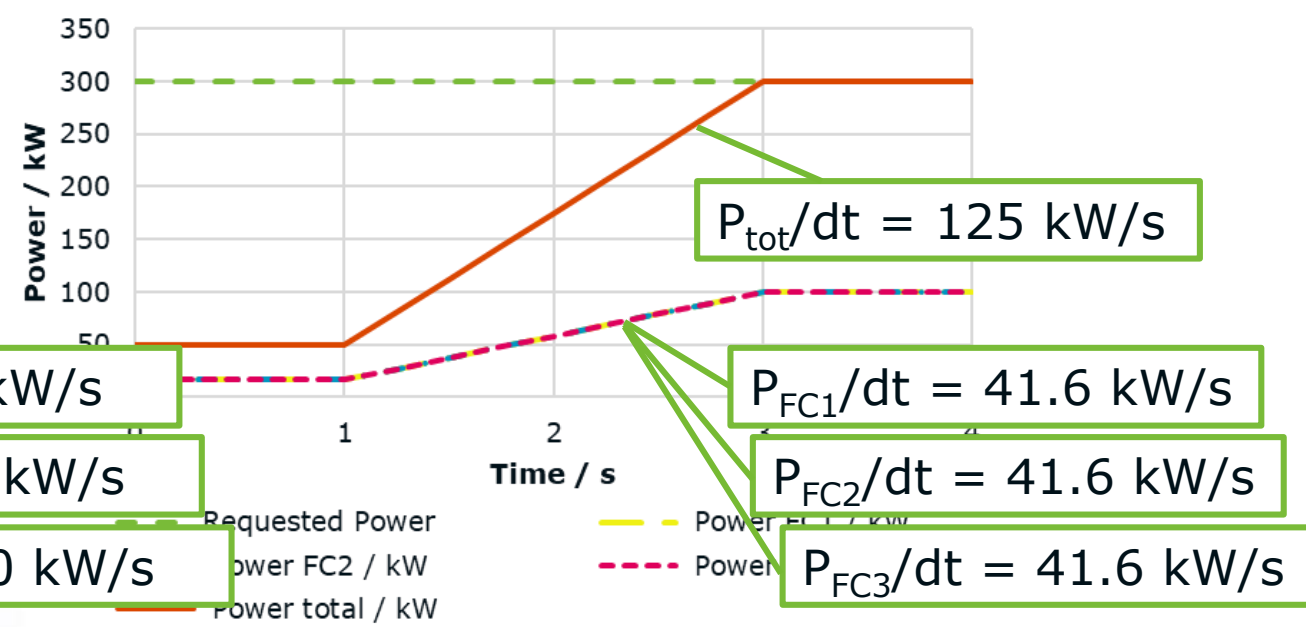
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Dynamic power request of 125 kW/s - 3 FC systems



Dynamic power request of 125 kW/s - 3 FC systems



Summary & Conclusion

▪ **Modularity of Fuel Cell Systems**

- Powertrain level
 - Carry-over of FC system components from passenger cars for commercial vehicles
 - Increased production volumes lower the overall manufacturing costs
 - Modularity allows to target different use cases with same FC system technology
 - Modularity enable long lifetimes/durability needed for commercial vehicle application
- System level
 - FC systems are clustered in different power ranges (e.g. 35 kW, 55 kW, 100 kW)
 - Dedicated development of BoP components to these power ranges reduces overall development effort
 - FC system efficiency close to ideal efficiency can still be achieved

Thank You



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