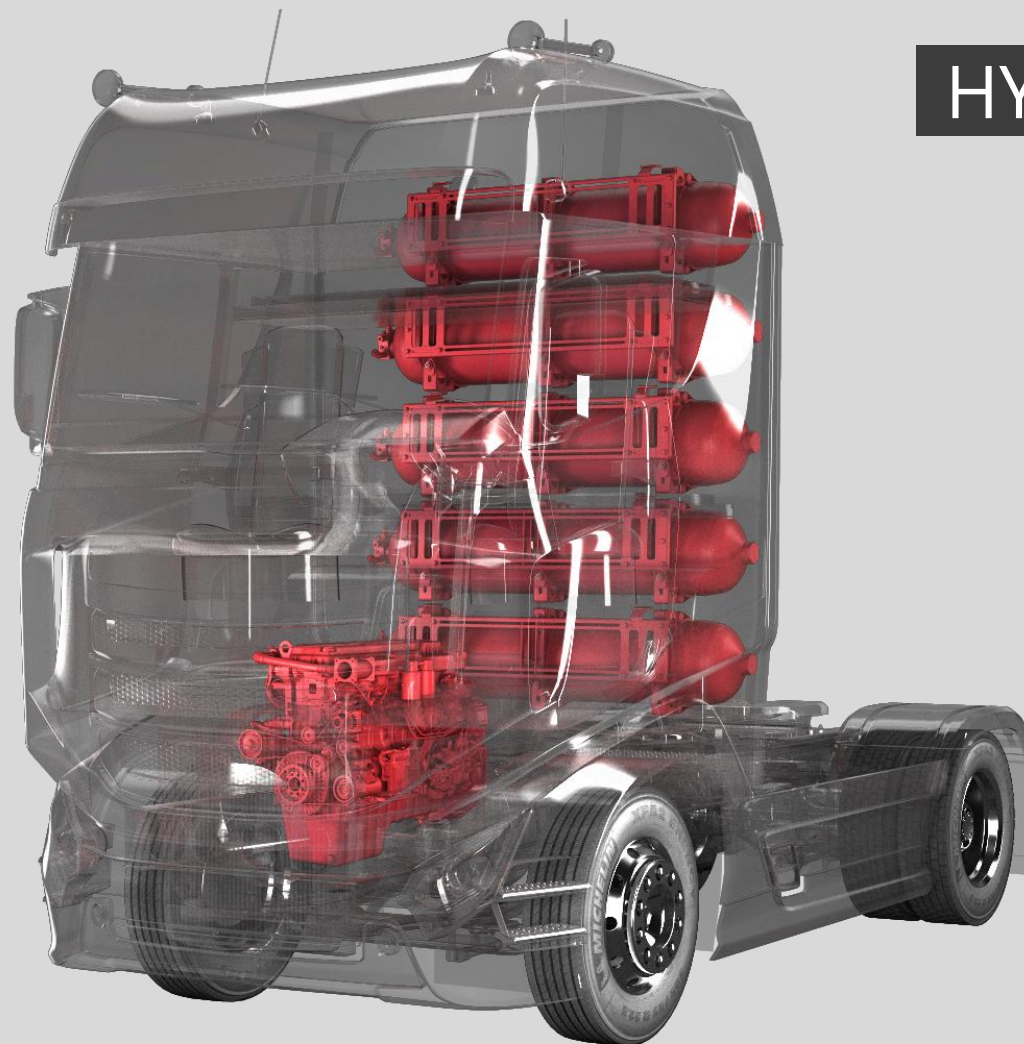
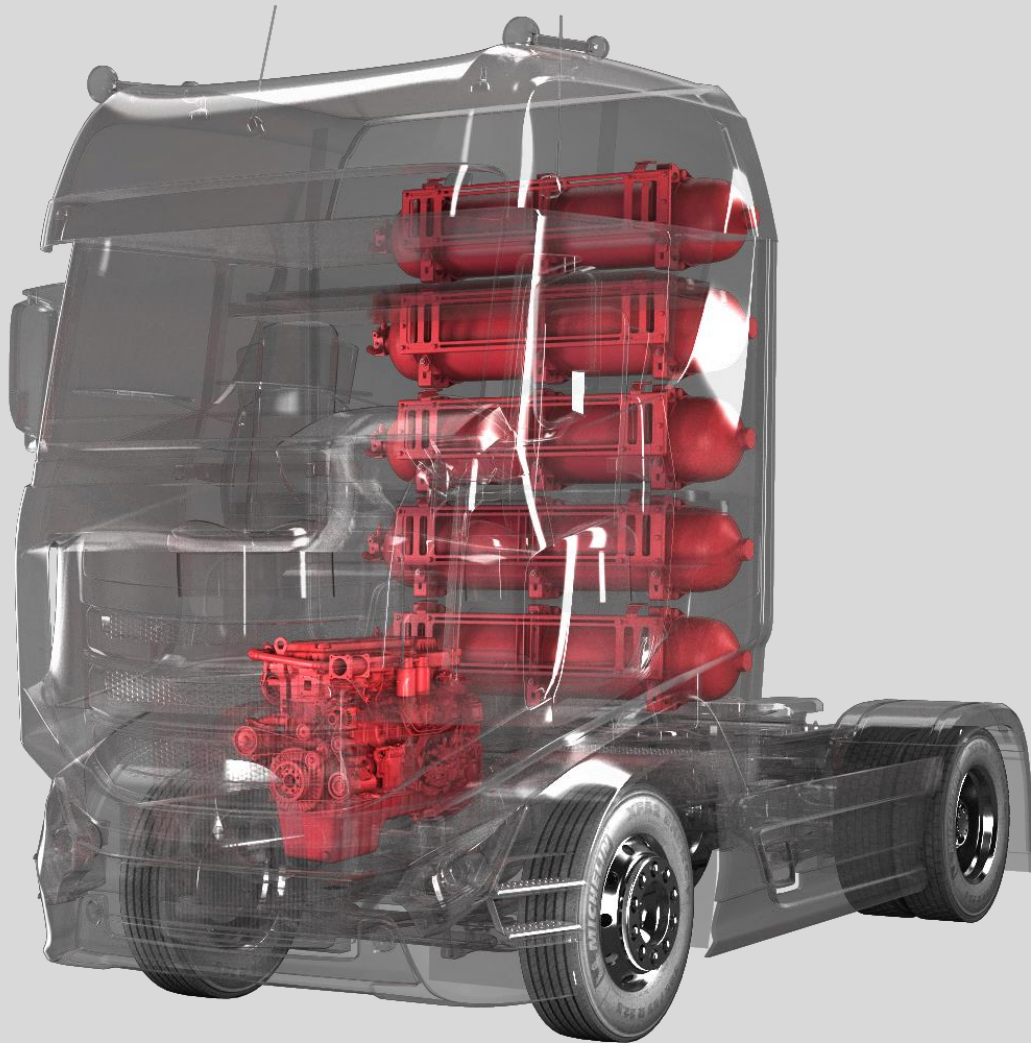


OCTOBER 5TH – 7TH, 2020  
THE AACHEN COLLOQUIUM  
SUSTAINABLE MOBILITY

**HYDROGEN**

**ICE**





- 2-Stage turbocharging offers possibility of lean air fuel ratio even at higher load points
- Engineering targets
  - Brake mean effective pressure ~ 20 bar
  - Effective engine efficiency > 42%
- Variation of
  - compression ratios
  - turbulence level
  - spark plug layout
  - to evaluate effect on engine efficiency and peak firing pressure for different air fuel ratios

# Hydrogen offers wide range of possible combustion system layouts in combination with different aftertreatment systems



HYDROGEN COMBUSTION ENGINES CAN BE EITHER WAY BASED ON DIESEL AND GASOLINE ENGINES

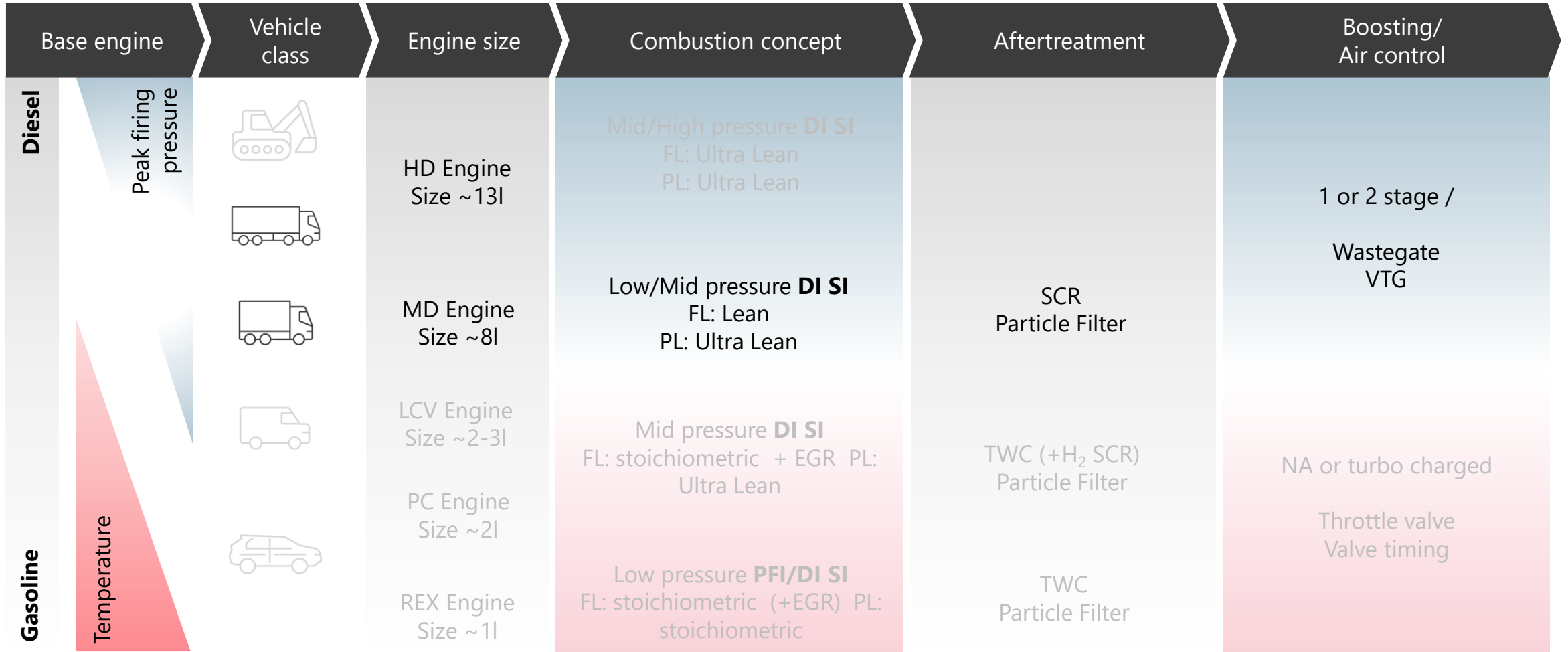
Base engine	Vehicle class	Engine size	Combustion concept	Aftertreatment	Boosting/ Air control
Diesel	  Peak firing pressure	HD Engine Size ~13l	Mid/High pressure <b>DI SI</b> FL: Ultra Lean PL: Ultra Lean	None	1 or 2 stage / Wastegate VTG
		MD Engine Size ~8l	Low/Mid pressure <b>DI SI</b> FL: Lean PL: Ultra Lean	SCR Particle Filter	
	  Temperature	LCV Engine Size ~2-3l	Mid pressure <b>DI SI</b> FL: stoichiometric + EGR PL: Ultra Lean	TWC (+H <sub>2</sub> SCR) Particle Filter	NA or turbo charged
		PC Engine Size ~2l	Low pressure <b>PFI/DI SI</b> FL: stoichiometric (+EGR) PL: stoichiometric	TWC Particle Filter	Throttle valve Valve timing
Gasoline		REX Engine Size ~1l			

Low pressure < 30 bar, Mid pressure 40 – 60 bar, High pressure > 200 bar

# For MD and HD vehicle class low/mid pressure in combination with lean full load and ultra lean part load operation seems most favorable



HYDROGEN COMBUSTION ENGINES CAN BE EITHER WAY BASED ON DIESEL AND GASOLINE ENGINES



Low pressure < 30 bar, Mid pressure 40 – 60 bar, High pressure > 200 bar

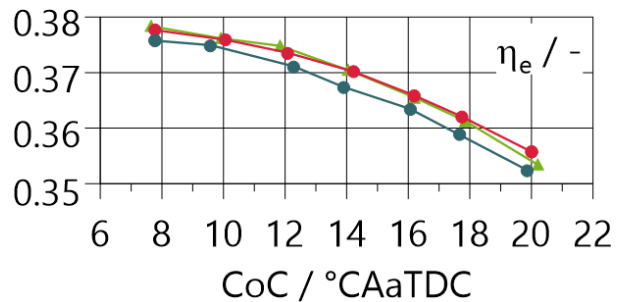
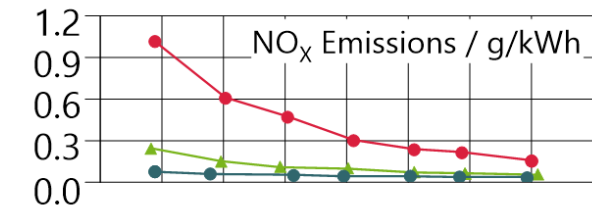
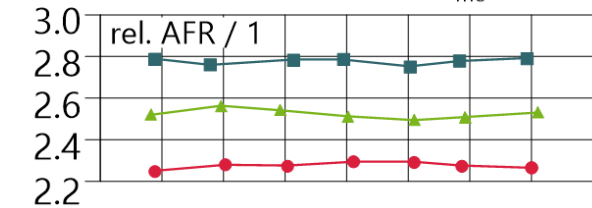
# The multi-cylinder hydrogen commercial engine can be used in multiple operation modes – efficiency optimized as well as emission optimized



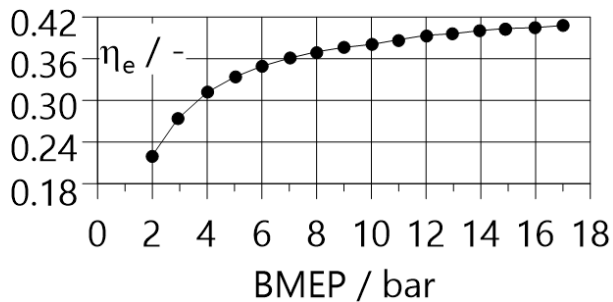
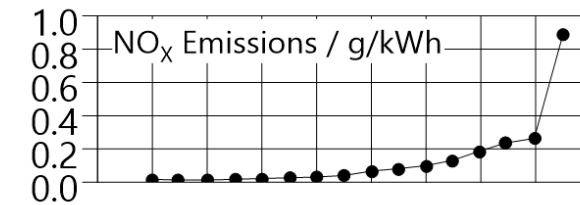
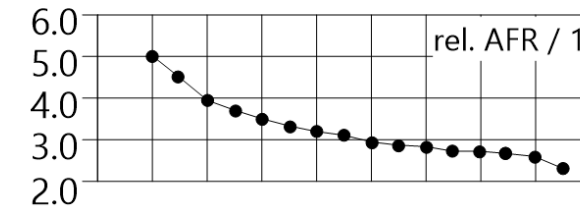
HYDROGEN HD APPLICATION REACHING EFFECTIVE EFFICIENCIES OF 42 %

—●—  $\lambda = 2.3$  —▲—  $\lambda = 2.5$  —■—  $\lambda = 2.8$

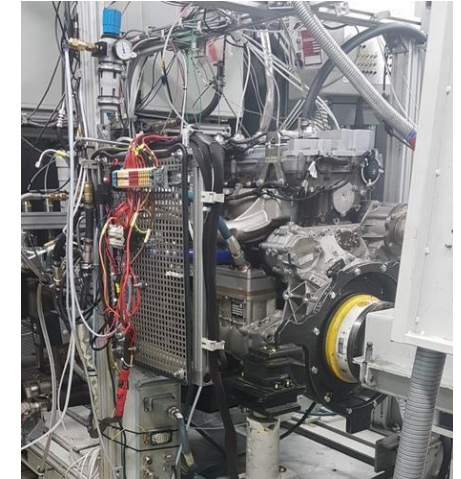
$p_{me} = 8\text{bar}$



MD-Engine 7.7l R6, Fuel: H<sub>2</sub>, PFI  
n = 1400 1/min, 2-Stage TC



- Engineering targets
  - BMEP ~ 20 bar
  - $\eta_e > 42\%$
- 2-Stage turbocharging
  - lean air fuel ratio even at higher load points
- Steady state trade off
  - EGR vs. lean operation
  - Volumetric efficiency vs. turbulence level (burn duration)
  - NO<sub>x</sub> emission level vs. exhaust gas temperature (best air fuel ratio)

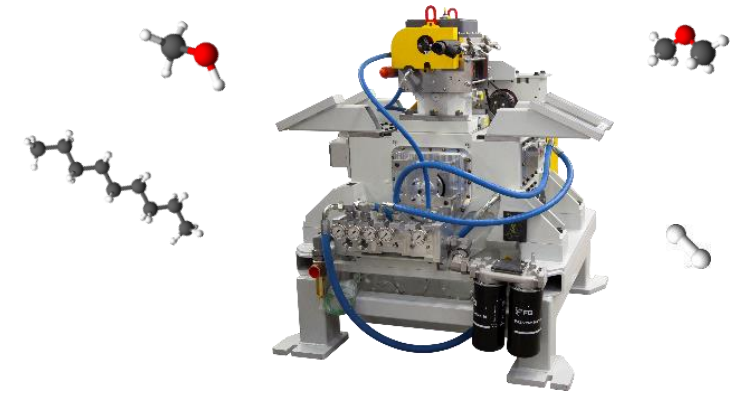


# Leveraging our profound experience in the field of fuels research, we have set up a heavy-duty single cylinder engine suited for alternative fuels



## HYDROGEN INVESTIGATION Q4/2020

- Investigation of injector vs. spark plug position
- Optimization of hydrogen nozzle using 3D CFD
- Dedicated piston design for hydrogen combustion



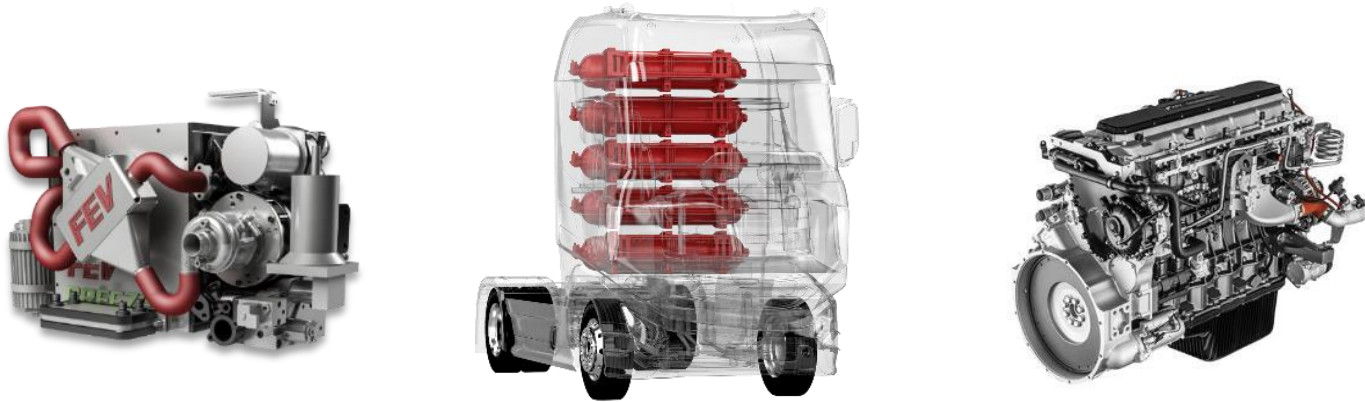
## KEY FACTS

- Power unit based on Daimler OM 471
  - Bore: 132 mm, stroke: 156mm,  $V_H$  2.13 dm<sup>3</sup>
- Beyond state of the art combustion systems
  - Flexible cylinder head design **w/ alternative position for injector or spark plug**
  - CI / SI + **PFI/Direct Injection of alternative liquid or gaseous fuels**
  - **Boost pressure up to 8 bar** at full load
  - Peak firing pressure up to 300 bar
  - FIE: Fluids up to 3000 bar , digital rate shaping, dual fuel operation
- Infrastructure for gaseous and liquid fuels of all kind
  - **H<sub>2</sub>**, DME, methanol, alkanes, OME, CNG

# FEV's test benches at the testing facility "European Technical Center" in Aachen are hydrogen ready – 7 test benches available today



CENTER FOR MOBILE PROPULSION – HYDROGEN READY ICE AND FUEL CELL TEST BENCHES



- Hydrogen specs:
  - 60 bar H<sub>2</sub> pressure upstream ICE/FC
  - 35 kg/h max. H<sub>2</sub> fuel flow
  - H<sub>2</sub> quality range from 3.0 ... 8.0
- Bench features:
  - Full transient operation (WLTP, WHTC, WHSC, RDE-cycles, etc.)
  - Up to
    - 500 kW FC electrical power
    - 640 kW IC engine power
    - 4500 Nm IC engine torque
  - Flow measurement of H<sub>2</sub> and Air
  - FEV FEVER emission measurement



# FEV FUTURE TRUCK SERIES

- Hydrogen Powered Future
  - Heavy duty truck powered by hydrogen
  - Infrastructure / TCO Analysis
- Component design and simulation Fuel Cells
  - Challenges and solution approaches for fuel cell systems
  - Modelling and development framework for fuel cell vehicles, systems and BOP components
- Component design and simulation H2 ICE
  - Combustion system layout
  - Turbocharger design
  - Aftertreatment system
  - Control Software
- Virtual calibration methods for alternative fuels
  - Challenges of alternative powertrain development
  - FEV virtual powertrain development process
  - Virtual calibration

**FEV WEBINARS FUTURE TRUCK SERIES**

Session 1	Session 2	Session 3	Session 4	Session 5
<b>Goal: Trends and Legislation</b> • Global market opportunities • Technology readiness levels • Market forecasts • Regulatory trends	<b>Local and National Legislation</b> • ICE and alternative powertrains • CO2 targets • Ultra Low CO2 & zero-emission vehicles • Market forecasts • Regulatory trends	<b>Alternative Energy and Powertrains</b> • Clean technologies • CO2 targets • Ultra Low CO2 & zero-emission vehicles • Market forecasts • Regulatory trends	<b>Hydrogen Powertrain Future</b> • Hydrogen production • Distribution • Storage • Fuel cell systems • High efficiency engines • High efficiency engines • High efficiency engines	<b>Future Electrification</b> • Global market forecasts • Global market forecasts • Global market forecasts • Global market forecasts

**EU regulations mainly push Zero Emission Vehicles (ZEV) electric, fuel cell & H<sub>2</sub> ICE vehicles; NG and renewable fu**  
 IMPACT ASSESSMENT OF THE REGULATION ON ALTERNATIVE POWERTRAINS

	Battery electric truck	Fuel cell / H <sub>2</sub> -ICE truck
Clean Vehicle Directive	↑	↑
Local access restrictions	→	→
Post EU VI legislation	→	→
Renewable Energy Directive II	↔ <sup>(1)</sup>	↔ <sup>(1)</sup>
Eurovignette Directive	↑	↑

↑ Strong push    ↔ Limited push    → No influence    ↘ Slightly negative impact    ↓ Negative impact

**High efficient powertrains for commercial vehicles, a possible engine technology roadmap for CO<sub>2</sub> reduction**

Year	CO <sub>2</sub> emissions (g/kWh)
2015	~180
2020	~160
2025	~140
2030	~120
2035	~100
2040	~80
2045	~60
2050	~40

• Compression Ratio increase  
 • Optimal piston and high flow injector for optimal fuel injection  
 • Digital air charging  
 • Air management efficiency  
 • Low pressure EGR  
 • Parallel flow reduction  
 • Emission reduction and cooling, oxidation & form-losing  
 • Waste Heat Recovery

**FEV WEBINARS FUTURE TRUCK SERIES**

**FEV**



# FEV Future Truck Series 2020 – Now available on demand

## Contact us via chat to get further details



### GHG – Trends and Legislation

- MD/HD on-road legislation including VECTO
- Technology strategy: CO2, costs, customer needs
- Future powertrain concepts for heavy duty applications

### Low NOx – Trends and Legislation

- MD/HD on-road emission regulation
- Opportunities for Ultra Low NOx, a systems approach
- Ultra Low NOx from a controls perspective
- Introduction of On-Board Monitoring (OBM) – perspective for Post EUVI HD On-Road vehicles

### Alternative Energy and Powertrains

- Clean fuels towards a CO2-neutral transport
- Benefits of HD powertrain hybridization
- Customized control functions to reach low CO2, low emissions and low system cost
- Benefits of virtual powertrain calibration for HD On-Road vehicles

### Hydrogen Powered Future

- Heavy duty truck powered by hydrogen
- Component design and simulation: Fuel cells and bop components
- Component design and simulation: Hydrogen internal combustion engine
- Virtual calibration methods for alternative fueled HD powertrain systems

### Focus Electrification

- Electric Drive Solutions for Commercial Vehicles
- E-Motor and Inverter for Commercial Vehicles
- High Performance Batteries for Hybrid Commercial Vehicles