Alternative dual- and mono-fuel concepts for decarbonization of future commercial engines

Future technologies toward decarbonization of commercial engines

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Agenda

Motivation and drivers for future technology

Future fuels for on-highway applications

- System development from concept to series
- NOx conformity in real-driving cycles

Decarbonization of off-highway applications

- E-fuels and the development trend
- Examples of Methanol-based and H_2-dual-fuel engines

Summary and Outlook

Motivation for Alternative Powertrain Structures
Commercial Vehicle Applications

- CO_2 is our main challenge … and our main technology driver!

EU „Vision Zero“ Climate neutral Europe by 2050

2020 — 2030 — 2040 — 2050 — Year

EU CO_2 regulation HD trucks

EU: ***Fleet reduction*** *targets:* *(reference MY2019)*

- **-15%**
- **-30%**
- 2% min. fleet share of LEV/ZEV (trucks only, Buses & coaches excluded)
- minimum share of clean vehicles in public procurement and service contracts

Emission legislation HD trucks

EU: Euro VI E — Euro VII (assumed)

USA: EPA/CARB Ultra Low NOx (Phase In 2024-2031)

EU 2050 goal: 60% cut in transport emissions

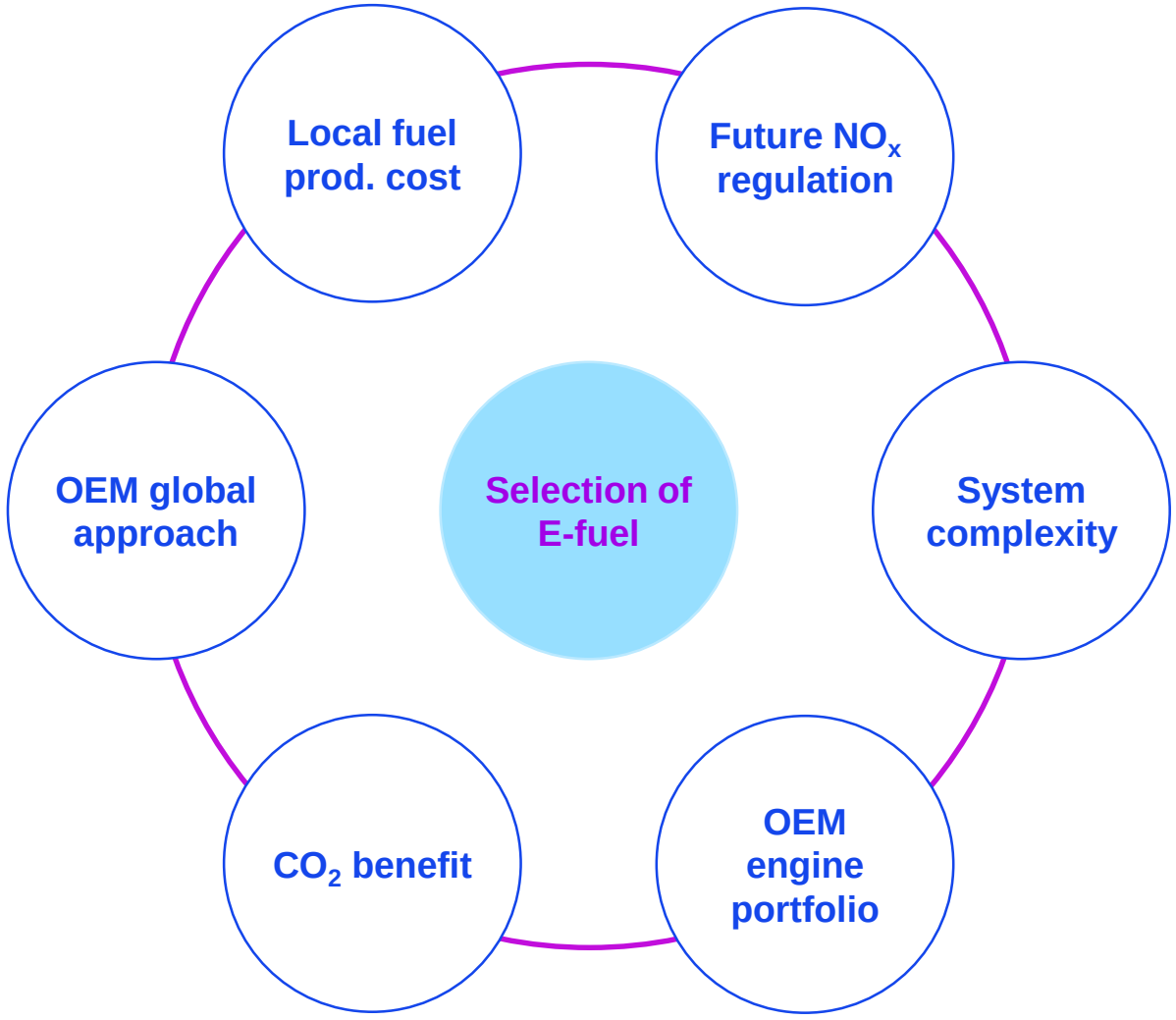
→ **Most important vehicle classes for EU CO_2 reduction are 4, 5, 9, 10**

→ **Significant CO_2 reduction for long-haul applications required**

→ **At the moment no CO_2 regulation for off-highway. It can be assumed that off-highway will follow on-highway**

Selection of E-fuel

Considering Regulation and OEM Boundary Conditions



Multiple e-fuels under development

- Main motivation is the CO_2 regulation. For which regulation (well-to-wheel, tank to wheel, etc.) which e-fuel strategy is better?
- There are multiple OEMs working on different e-fuel in EU, USA, etc.
- Selection of the most promising e-fuel depends on multiple factors
- Individual definition of e-fuel required

→ IAV can support on all above points from consulting to system development

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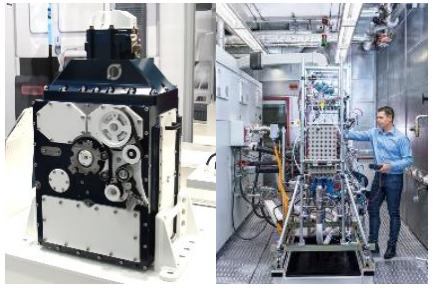
IAV Model-based System Development Methodology

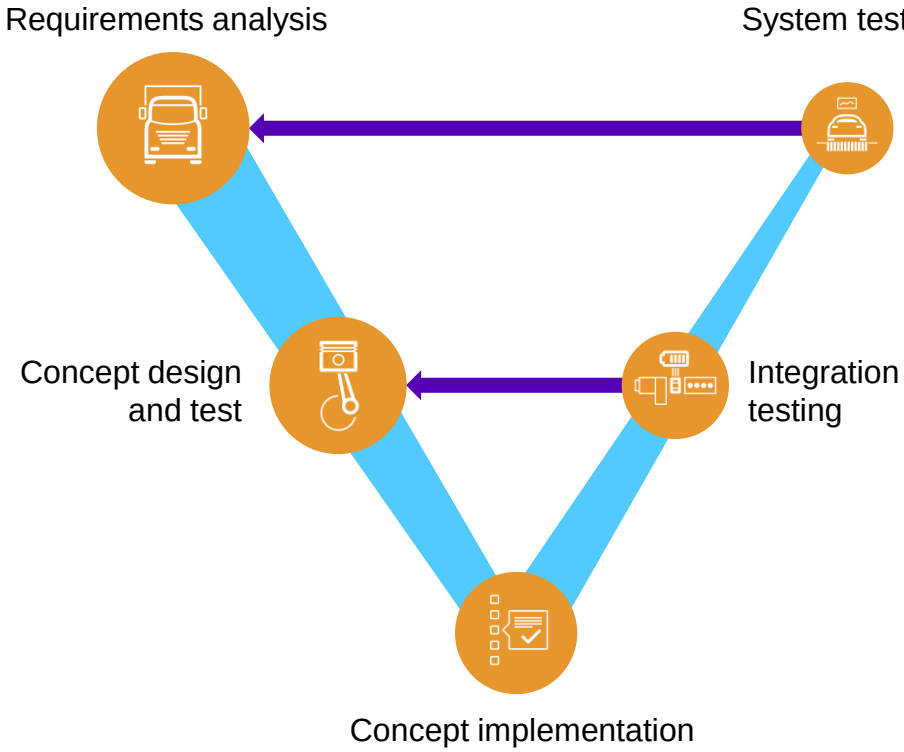
From Concept to Series Preparation

Overall system simulation

IAV testing environments



References and development process

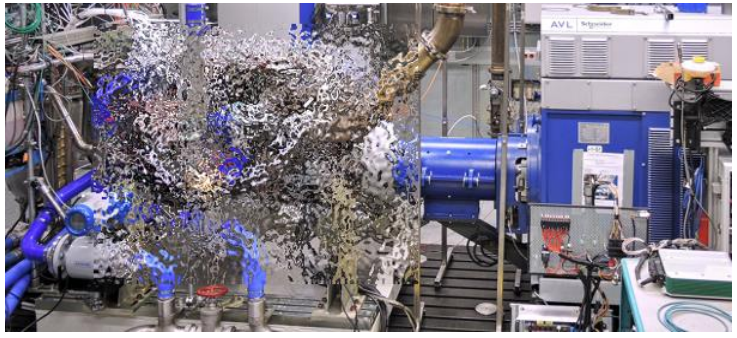


SW development

H_2 fork lift / GANE fuel test

→ Long-term experiences with the state-of-the-art technologies for the complete system development

IAV references: H_2 combustion engine development



H_2 engine concept development for On-Highway EURO VII

- Technology evaluation: water injection, pent roof, H_2 PFI & DI
- Single-cylinder testing
- Delivery IAV Hydrogen combustion model
- Concept study from air-path, combustion and design up to EAT

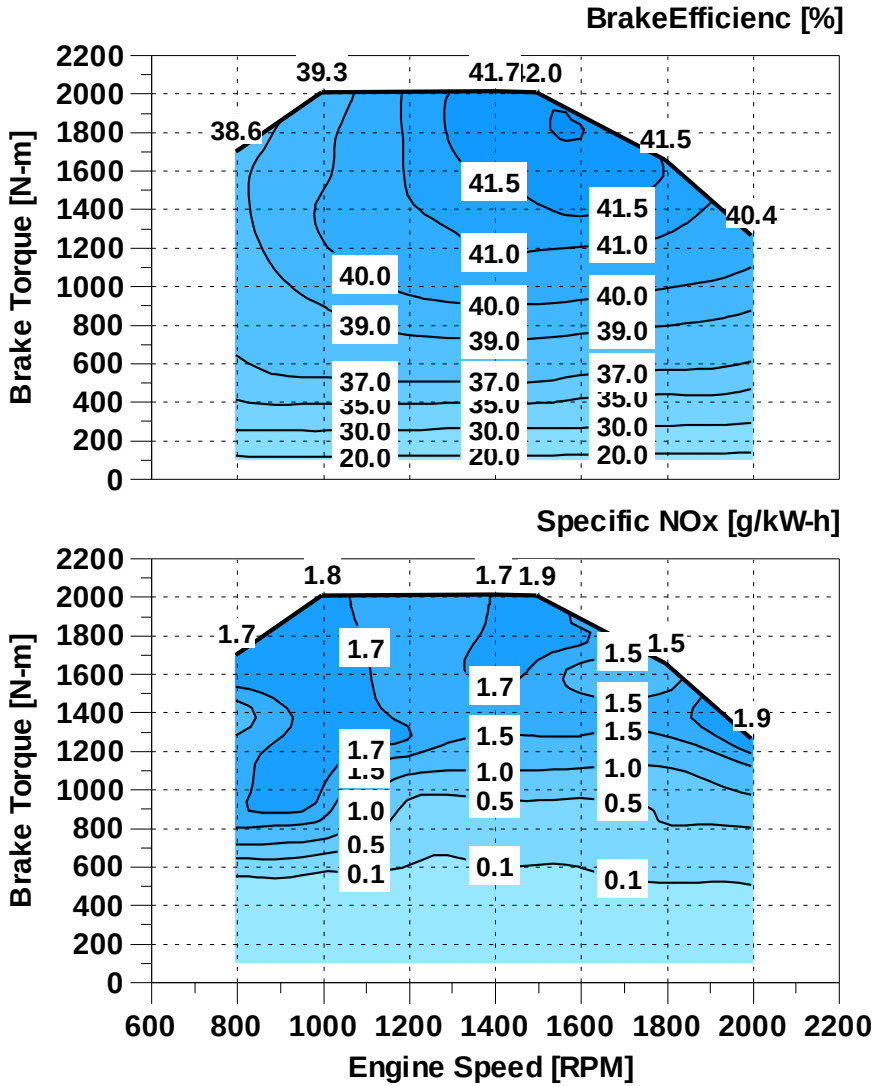
Calibration 13 L HD H_2 engine for Off-Highway

- Turbo-charged 13L Hydrogen Mono-Fuel
- H_2 Port Fuel Injection (PFI)
- Engine calibration
- Emission evaluation on NRTC

H_2 tractor development from concept to demonstration

- Holistic system development
- From concept design to machine demonstration
- Concept design, tank and safety, software, calibration up to demo.

Zero emission vehicle using H_2 ICE propulsion system



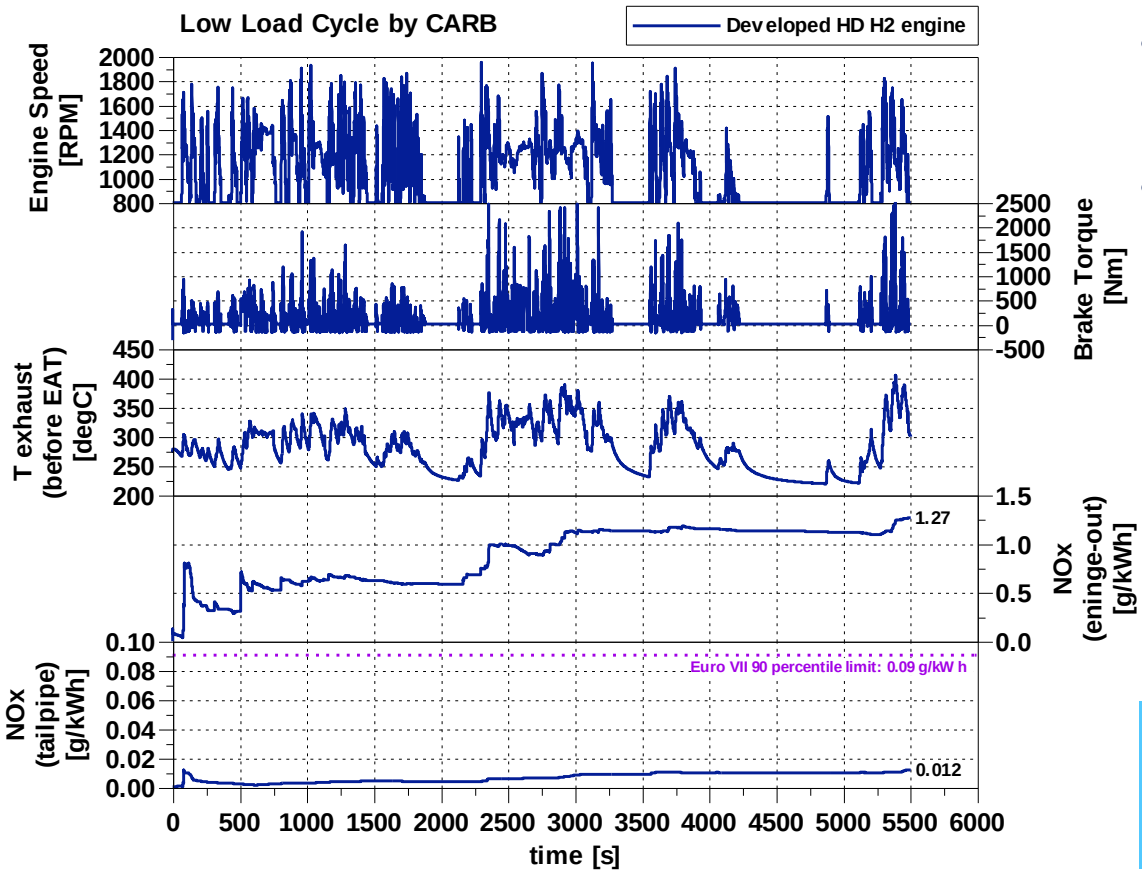
Potentials for zero-emission vehicles using H_2 as fuel

- HD vehicles certified as “zero-emission” required to emit less than 1 g CO_2/kWh
  [Source: EU regulation 2019/1242,
  link: http://data.eu-ropa.eu/eli/reg/2019/1242/oj]
  - Account for CO_2 from DEF (AdBlue), being carbamid (CH_4N_2O) + water mixture

    → 2.0 g/kWh engine-out NOx
- Holistic development from concept and calibration is required to reach the low engine-out NO_x

- Holistic development and evaluation of engine and after-treatment with optimized calibration required

NO_x conformity of H_2 ICE propulsion system



NO_x conformity for future ultra-low NO_x Hyd. engines

- Significant reduction in NO_x limits for future standards (CARB MY27, EPA planned standard, EURO VII)
- H_2 NO_x conformity demonstrated on CARB Low Load Cycle (LLC)
  - Engine-out NO_x emissions < 2.0 g/kWh
    → zero-emission aspect
  - Very low tailpipe NO_x emissions (~ 0.012 g/kWh)
  - SCR-only EAT used
    (No additional EAT heating required – no EHC)

- The future ultra-low NO_x regulation can be reached with advanced system development

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Future Fuels for Off-Highway Applications

Carbon free operation required in the future, for environmental protection also for off-highway app.

Zero CO_2 requirements

Low load applications, e.g. mini excavator

Image source [1]

Image source [2]

High load applications, e.g. large wheel loader

Image source [3]

Image source [4]

Genset / Mining

Image source [5]

Maritime applications

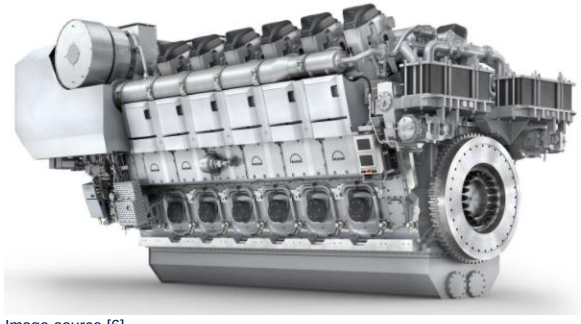
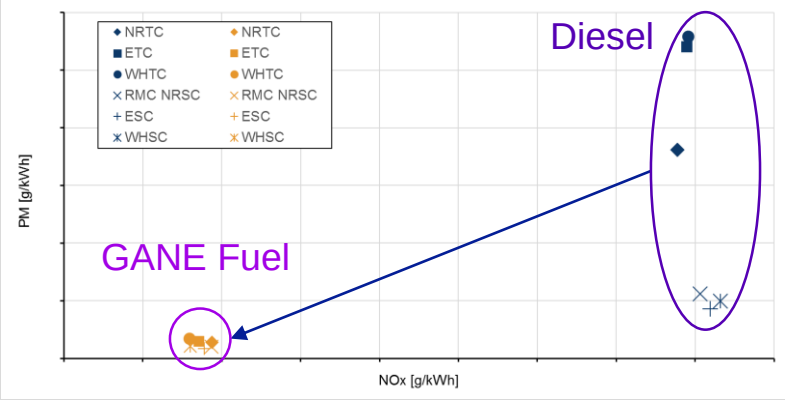


Image source [6]

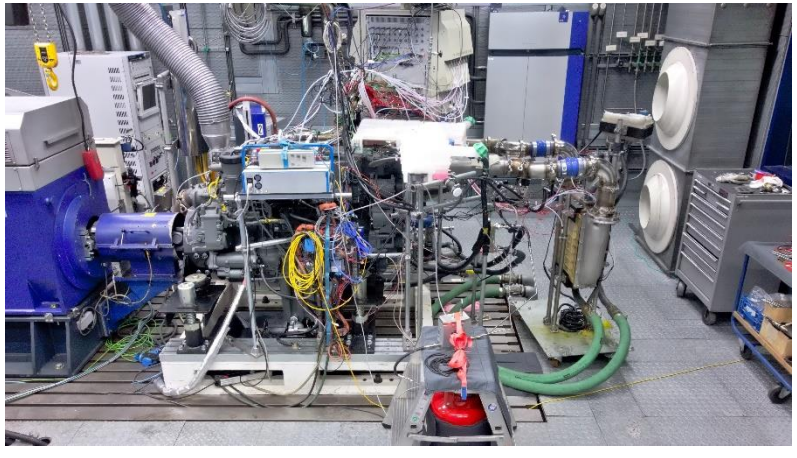
- Low energy demand → Alternative powertrain structures like BEV in general possible with range limitations
- High energy demand → Alternative fuels required for CO_2 reduction

IAV reference: GANE Fuel

A Methanol-based fuel for compression ignition engines



- For further results see SAE 2021-01-1198



Key advantages

- ~ 80% NO_x reduction with similar BTE as Diesel
  - combustion similar to Diesel, higher BTE possible
- > 80% PM reduction → no soot measured, no PM-NO_x-trade-off
- > 99.5% PN red. → PN Stage V / Euro VI compliant without DPF
- up to 10% CO_2 reduction in emission cycles achieved

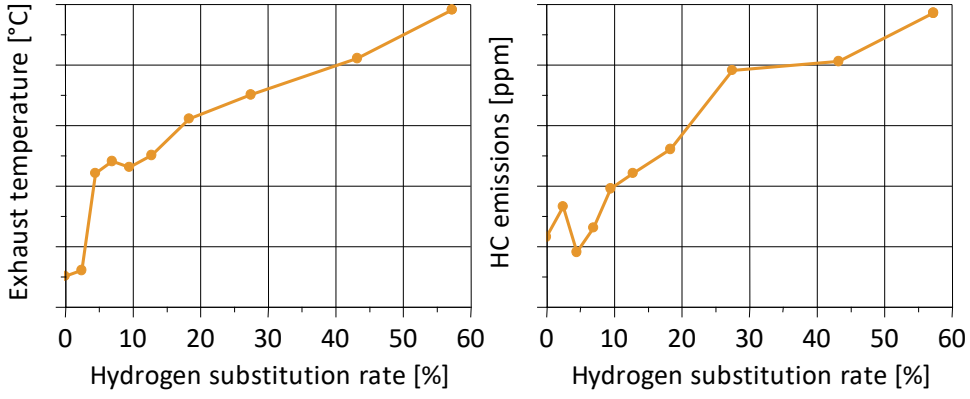
Key challenges

- Fuel flow approx. 2.4x larger → Adaptation of tank and supply sys.
- Mechanical wear of the injection system
- No DME approved components currently available
- No ready legislation for mixed fuels and CO_2 reduction

→ Promising e-fuel with Diesel-like combustion system

IAV references: Heavy hauler Diesel-Hydrogen dual-fuel development

Source: https://www.liebherr.com

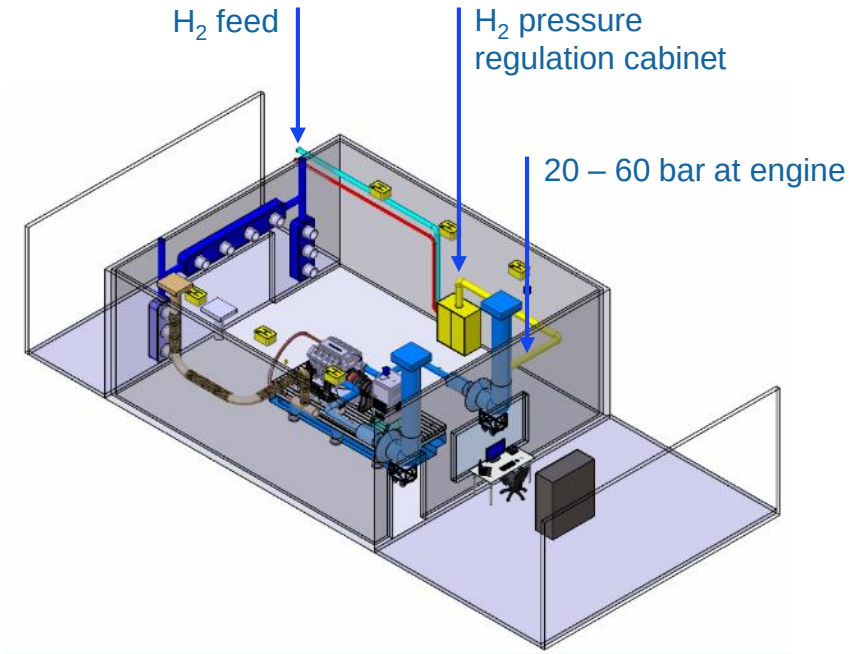


- Hydrogen-Diesel dual-fuel combustion system development for a heavy hauler in north America
- Minimum change of engine with maximum substitution rate of Hydrogen
- The whole development of Hydrogen tank and supply system as well as integration of a injection Kit
- Model-based concept development
- 2 L single-cylinder test data for dual fuel operation with Diesel-hydrogen for model validation
- Up to 60% hydrogen substitution rate can be reached at 1600 rpm & 11 bar IMEP (comp. ratio approx. 15)

→ Using of the IAV single-cylinder engine to build up the combustion characteristics.

→ The 1-D engine simulation is used to build up the full engine behavior.

IAV's Medium and Heavy-duty ICE Cells



- IAV is enhanced engine test benches for hydrogen
- Suitable from LD to HD Commercial Vehicle engines
- Testing from component up to full engine calibration and series preparation

- 20 asynchronous dynos for CV out of 50 in total @ IAV

MD Test Benches

B07:	330 kW / 1,400 Nm	
B08:	220 kW / 934 Nm	
B09:	460 kW / 981 Nm	
C01:	330 kW / 700 Nm	CNG
G09:	500 kW / 1,000 Nm	CNG
G10:	235 kW / 1,000 Nm	CNG
G15:	550 kW / 1,100 Nm	CNG
G16:	500 kW / 1,000 Nm	CNG
U02:	330 kW / 1,400 Nm	
U03:	330 kW / 1,400 Nm	
U04:	330 kW / 1,400 Nm	
J01:	265 kW / 506 Nm (business partner)	
Br03:	330 kW / 1,400 Nm (business partner)	

HD Test Benches

B14:	660 kW / 3,500 Nm	
B15:	780 kW / 5,000 Nm	
C02:	650 kW / 3,500 Nm	CNG
G07:	550 kW / 2,500 Nm	CNG
G14:	660 kW / 3,500 Nm	H2
U01:	660 kW / 3,500 Nm	CNG

Heavy HD Test Bench H2

G13: 1,470 kW / 7,000 Nm

Operations:
C: Chemnitz, G: Gifhorn, B: Berlin,
U: Detroit, J: Tokyo, Br: Sao Paulo

CNG – Natural Gas capable,
H2 – Hydrogen capable

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- 30 % CO_2 reduction cannot be achieved with a „Diesel-only“ strategy
- There is a need for zero CO_2 alternative propulsions
- Hydrogen mobility (FC and ICE), e-fuels, electrifications
- HD Hydrogen system development from concept to series
- Large potentials for decarbonization in off-highway sector
- IAV demonstrated a methanol-based HD CI engine
- Retrofit, especially for large-bore engines

→ **Promising results and continuous development of commercial engines**

Contact

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