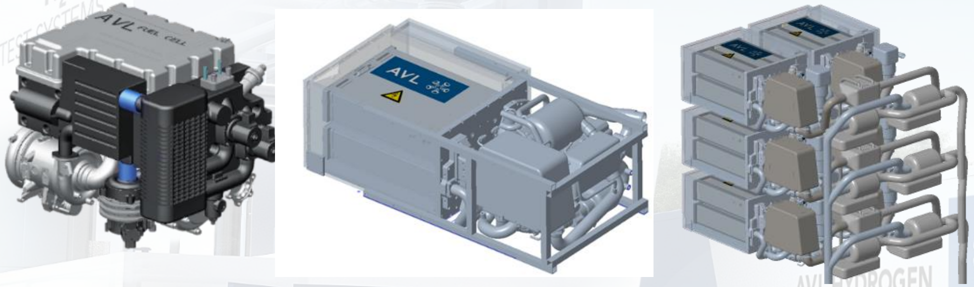
High Efficiency Hydrogen ICE

Carbon Free Powertrain for Passenger Car Hybrids and Commercial Vehicles

Hubert FRIEDL, Christian MARTIN

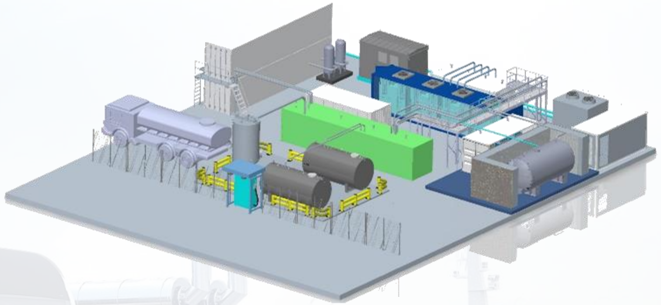
Hydrogen & Fuel Cell @AVL

Hydrogen Mobility



Fuel Cell Systems & Stacks for PC, CV, Rail and Marine

Synthetic Fuels & Chemicals



e-Fuel Production based on SOEC

SOEC based Power-to-X

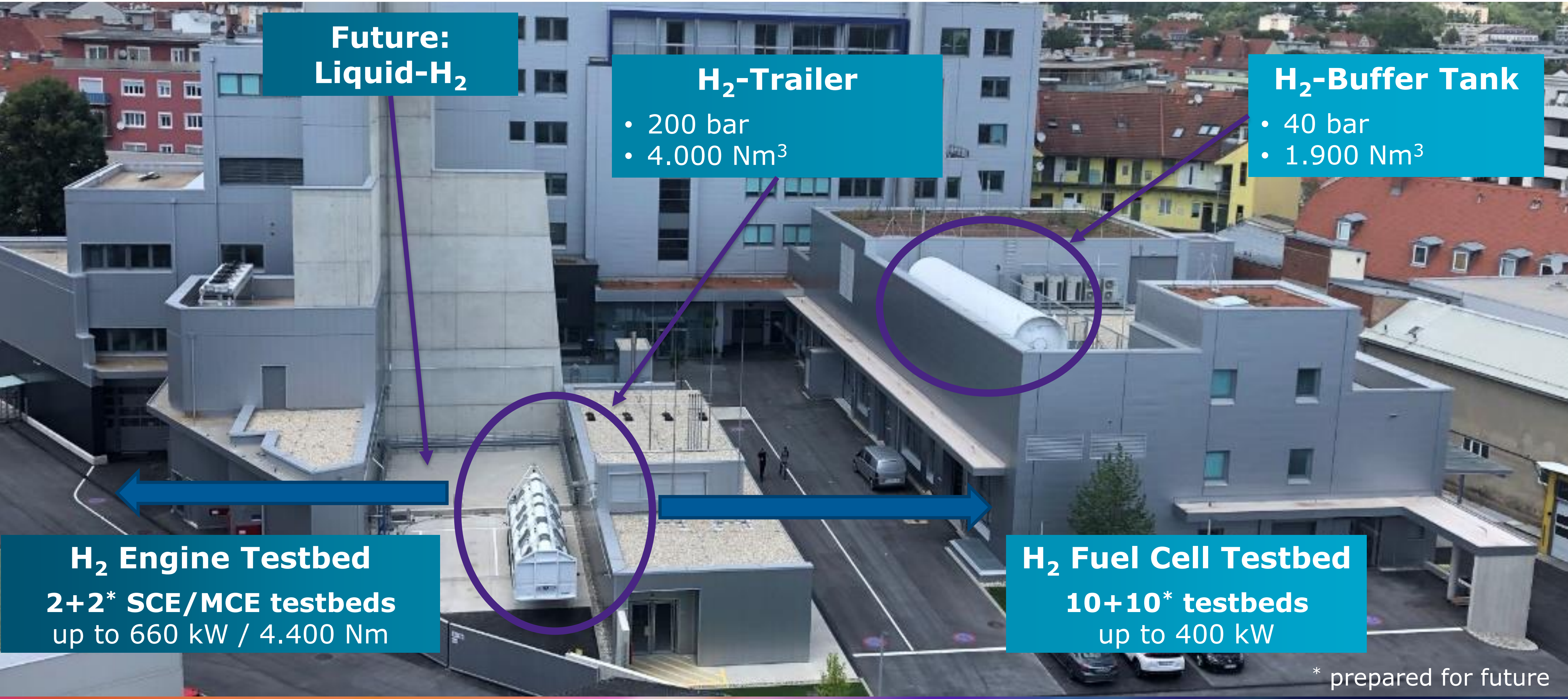
Fuel flexible SOFC X-to-Power

Renewable Energy Storage

Hydrogen for Industry Greening the grid

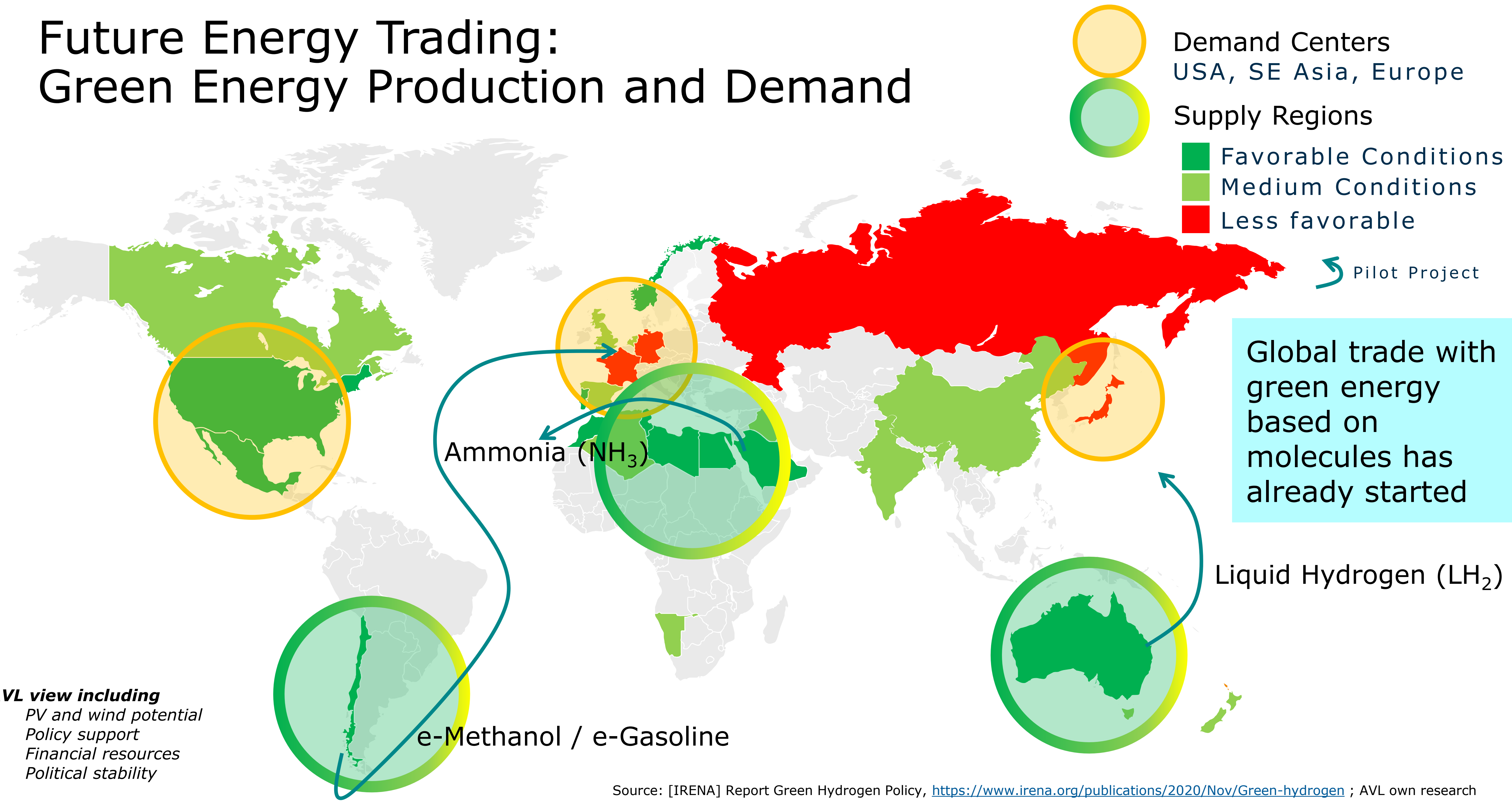
Hydrogen Internal Combustion Engine

AVL Hydrogen Testing – Graz - Central H_2 Infrastructure



* prepared for future

Future Energy Trading: Green Energy Production and Demand



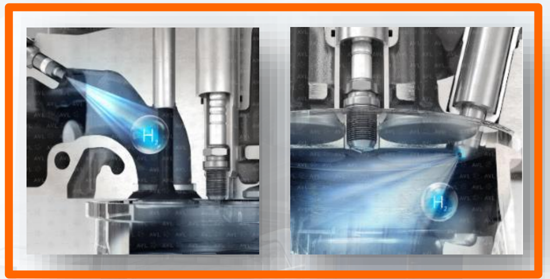
Global trade with green energy based on molecules has already started

AVL view including

- *PV and wind potential*
- *Policy support*
- *Financial resources*
- *Political stability*

Source: [IRENA] Report Green Hydrogen Policy, https://www.irena.org/publications/2020/Nov/Green-hydrogen ; AVL own research

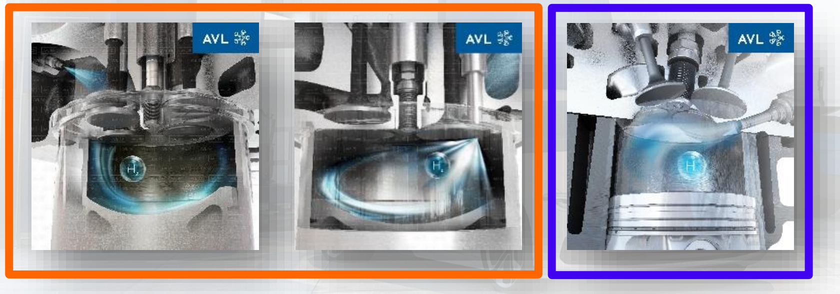
Main Hydrogen Combustion Concepts for Passenger Cars and Commercial Applications



Commercial, LCV – flat head

MPI or Low Pressure DI

Mixture formation **swirl** based



Commercial – flat head

PC – pentroof

Commercial – pentroof

MPI or Low Pressure DI

Mixture formation **tumble** based

H_2 Low Pressure

Homogeneous Combustion / Spark Ignited

AVL

AVL Hydrogen Engine Targets

- BMEP level: 24 bar
- Power: 350 kW
- BTE: >42 %
- Post EU VI emission
- Transient performance for commercial vehicles
- Maximum similarities to base engine

High Efficiency Hydrogen ICE
The AVL Hydrogen Engine: Optimization steps

Main Limitation

Backfire
Preignition
Knocking
Homogenization

Cooling of fire deck and spark plug

- AVL advanced Top-Down Cooling (TDC*)
- Improved spark plug heat dissipation

Gas exchange improvement

- High efficiency turbocharger
- Optimized valve lift curves

Optimized spark plugs and ignition coils

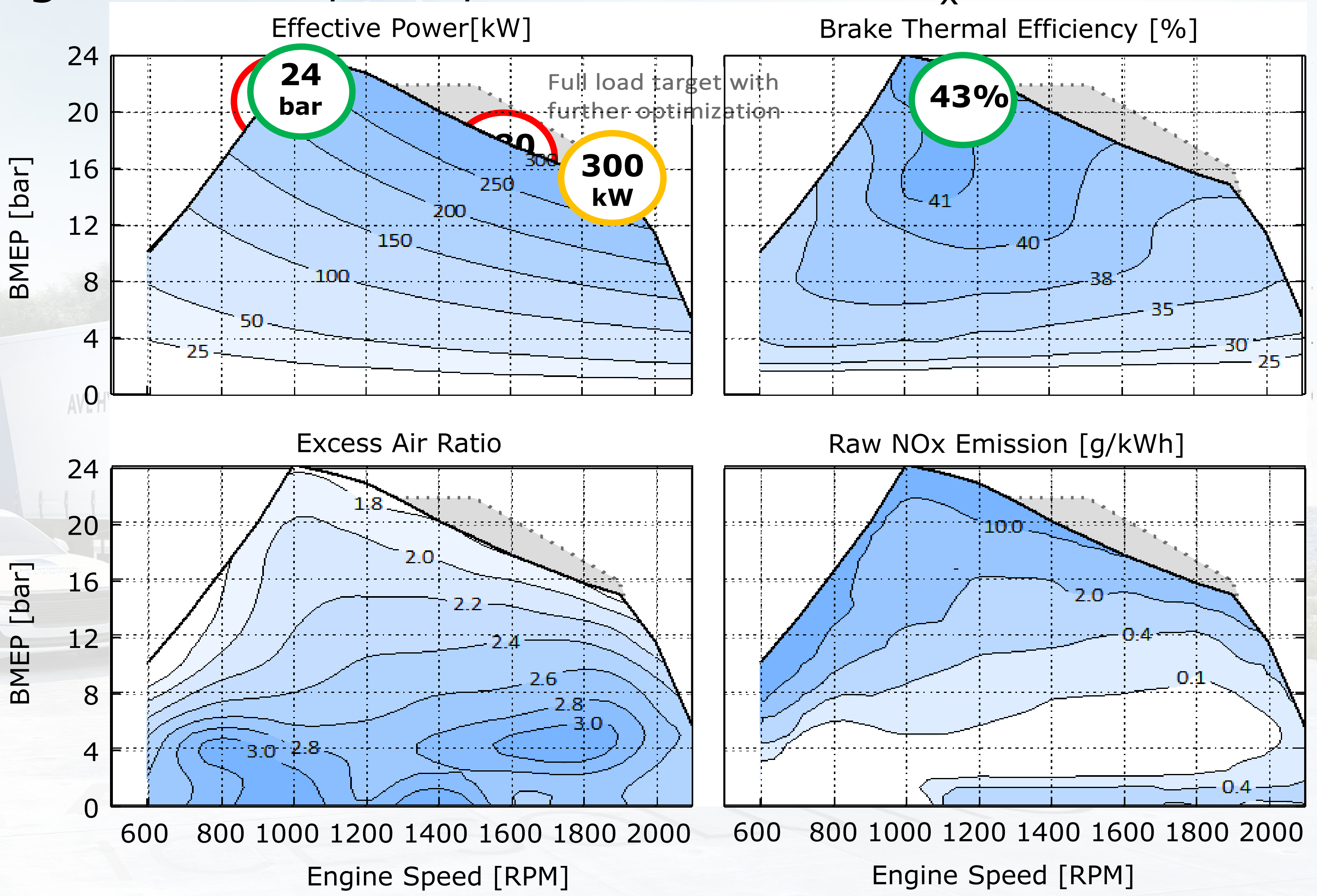
Optimized operation strategy

- Upgraded AVL H_2-RPEMS software
- CFD optimized operation

* AVL patent application

High Efficiency Hydrogen ICE

The AVL Hydrogen Engine: Power, BTE, EAR and Raw NO_x



Main Limitation

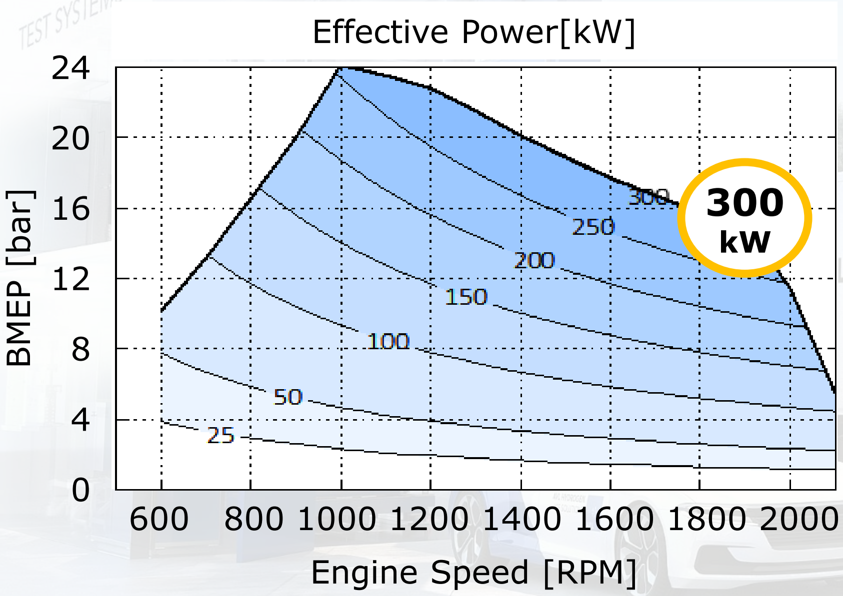
Backfire

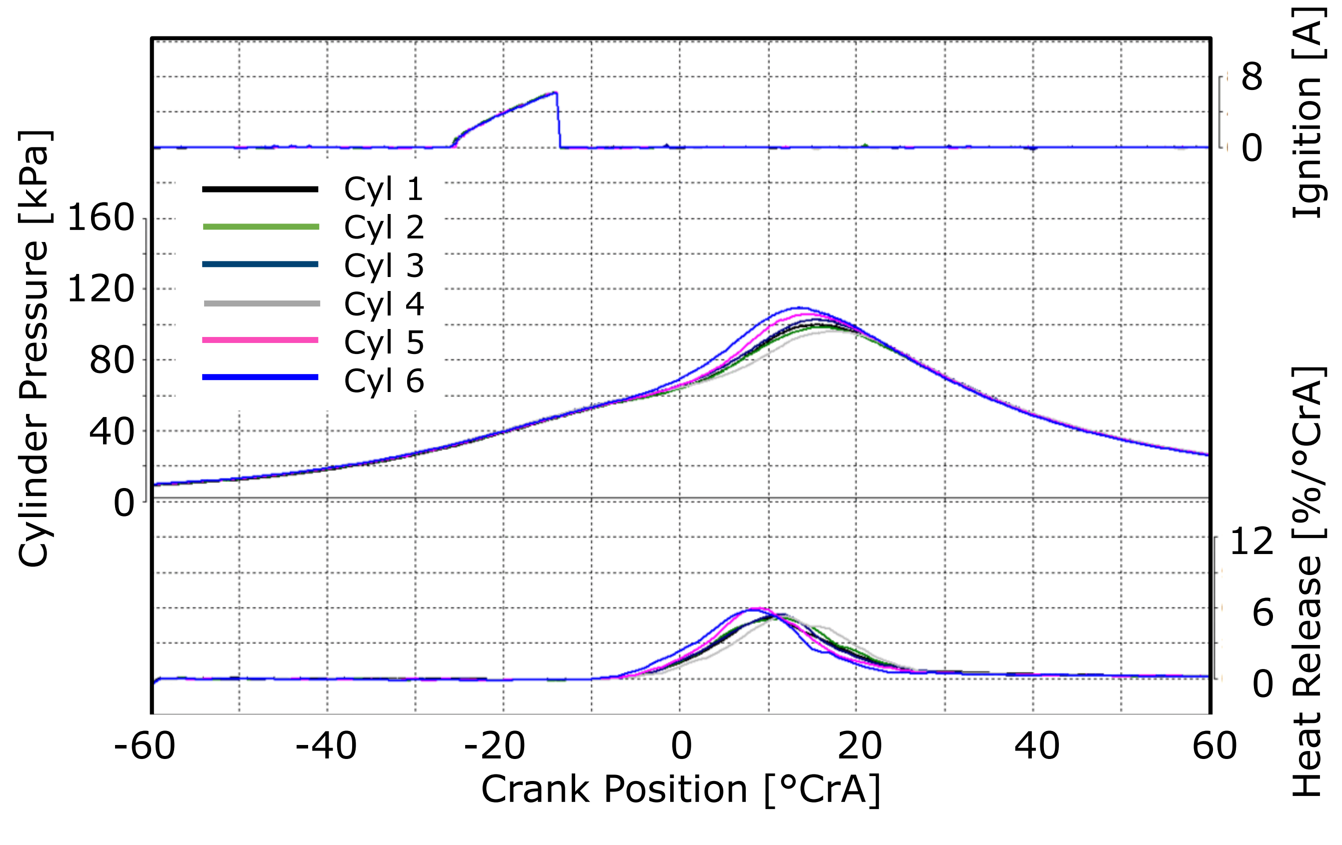
Preignition

Knocking

Homogenization

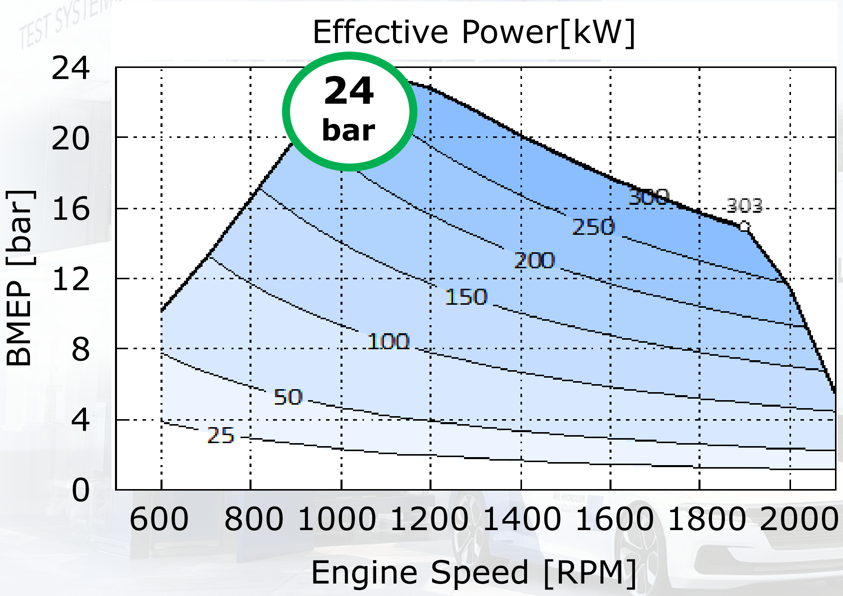
High Efficiency Hydrogen ICE
The AVL Hydrogen Engine – current peak power

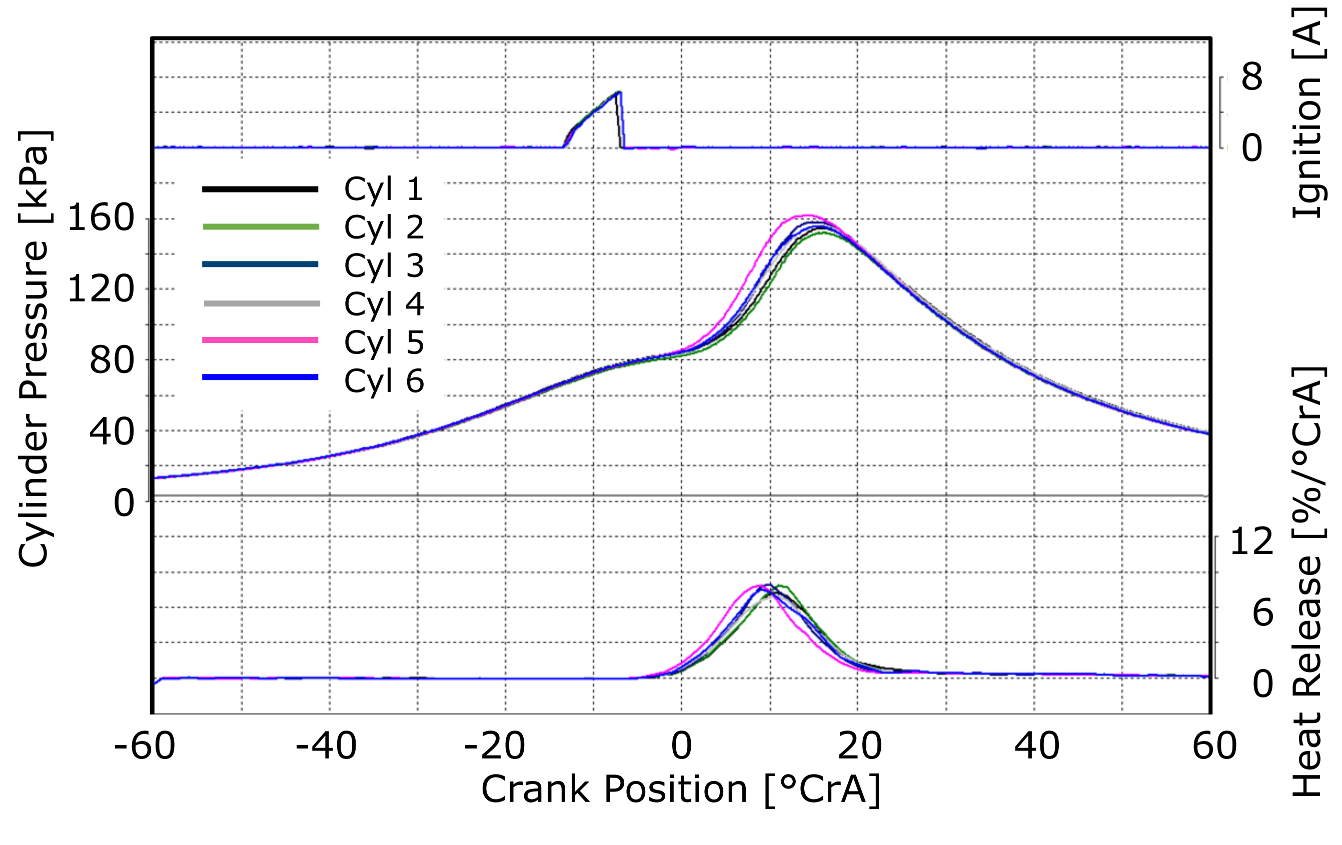




Stable engine operation with 300 kW @ 1900 rpm

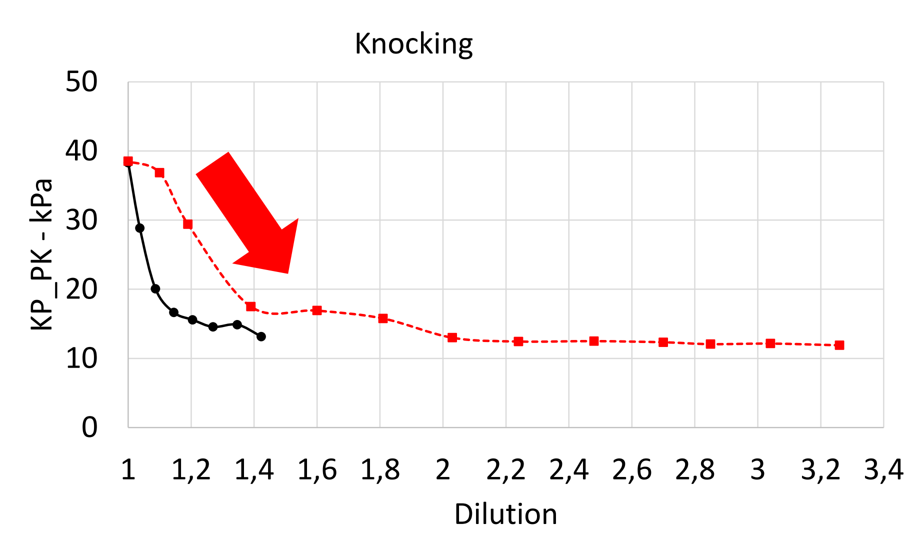
High Efficiency Hydrogen ICE
The AVL Hydrogen Engine: max. BMEP



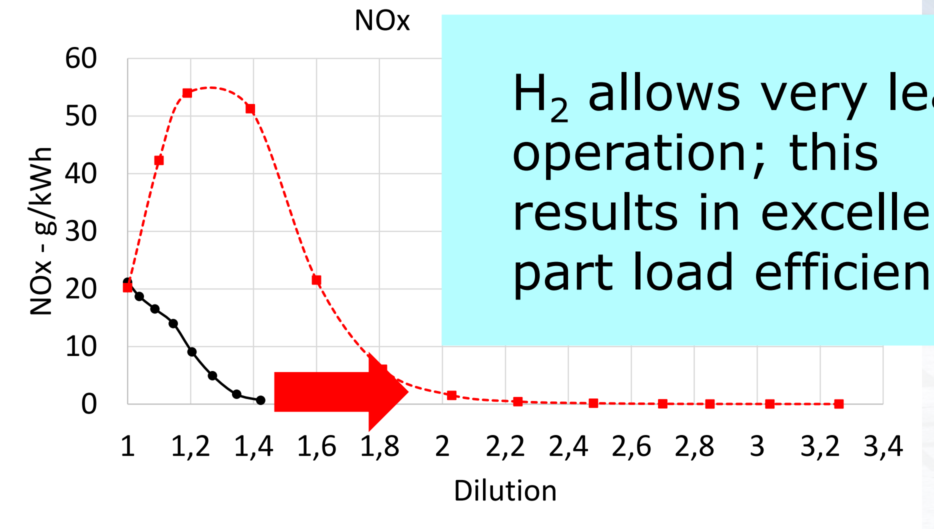


Stable engine operation with 24 bar BMEP @ 1000 rpm

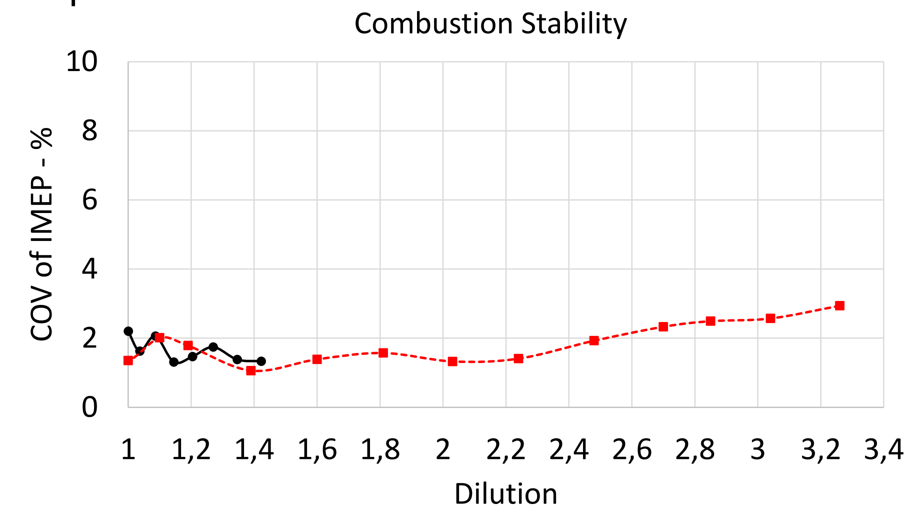
Hydrogen ICE NO_x, Efficiency, Knock Tendency and Combustion Stability; Lean vs Stoichiometric & EGR; Part Load



Lean
Lambda=1 plus EGR



H_2 allows very lean operation; this results in excellent part load efficiency



H_2-ICE @ Passenger Car
H_2 ICE Basic Operation Concepts

H_2-ICE
Operation Concepts

IV. Lean in PL & λ=1/combustion moderator at HL/FL

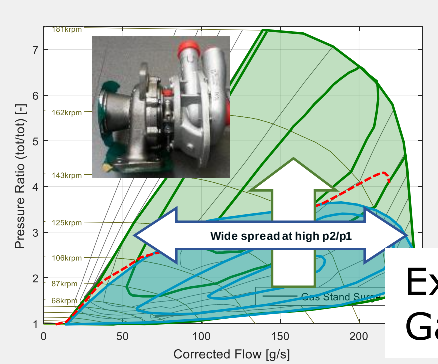
- Moderate boost pressure
- Water inj. and/or EGR to handle IRC!
- NO_x aftertreatment @ HL/FL w. TWC

I. Pure Lean Operation

- λ≈2.5 for lowest NO_x
- Very high boost pressure
- NO_x aftertreatment with or w/o SCR

III. Lean in PL & λ=1 at HL/FL

- Lowest boost pressure
- λ=1 most prone to **IRC!**
- NO_x aftertreatment @ HL/FL w. TWC



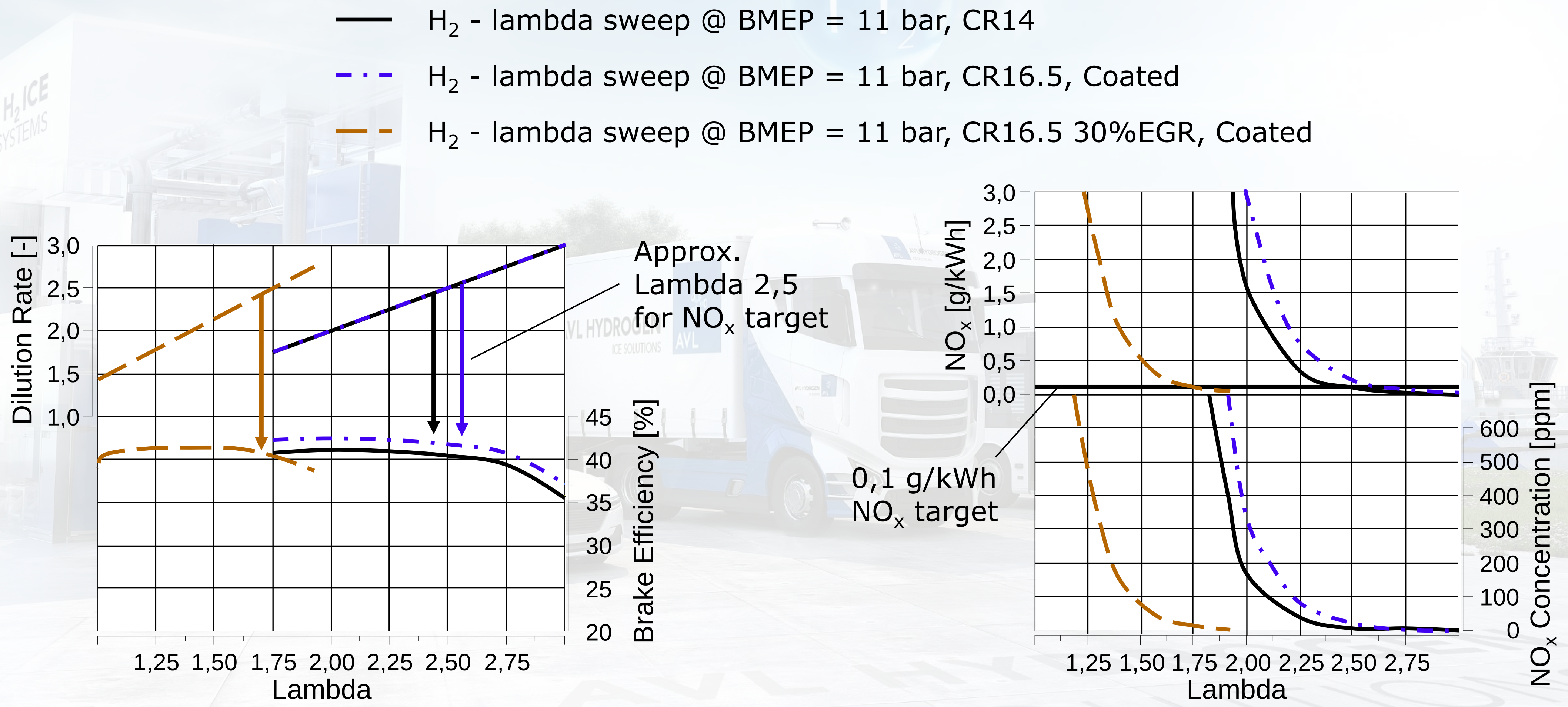
Example:
Garrett SC-TC

II. Lean + EGR

- Slightly lower boost pressure
- EGR reduces NO_x
- NO_x aftertreatment with or w/o SCR

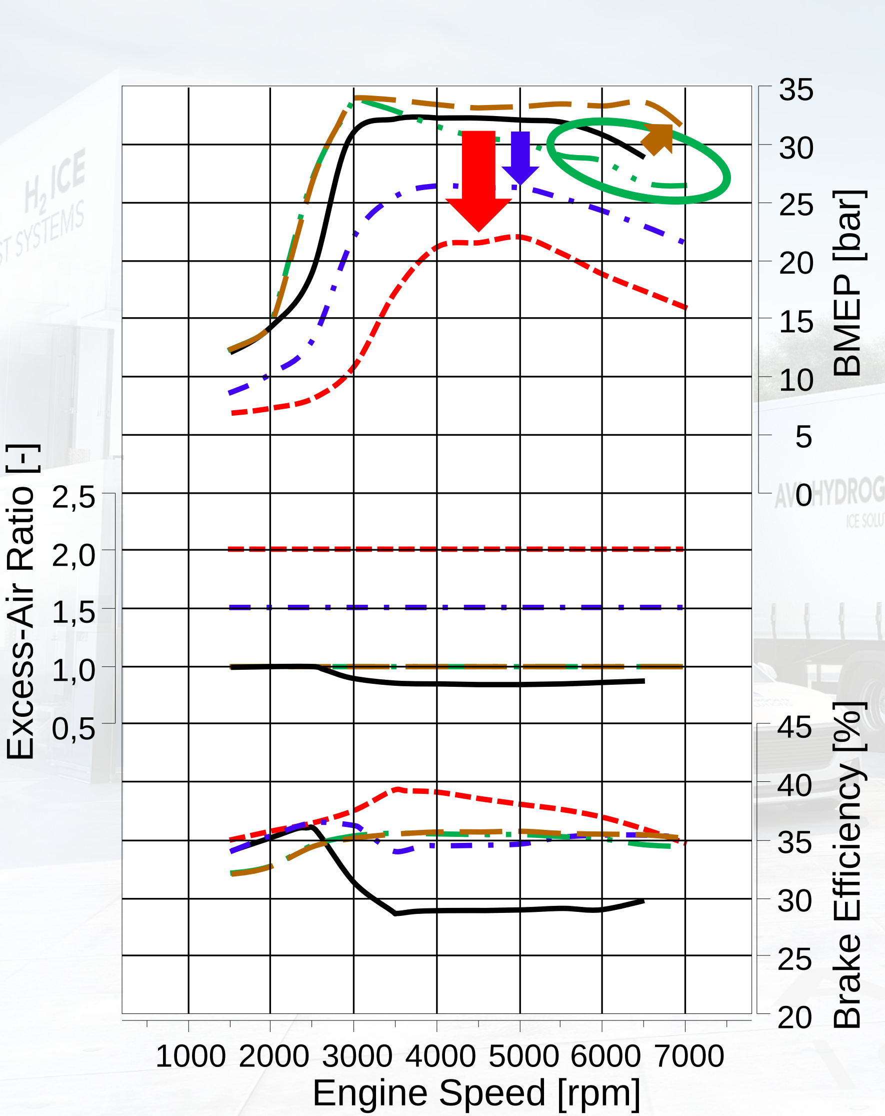
H_2 requires high boost pressures and needs a combustion moderator

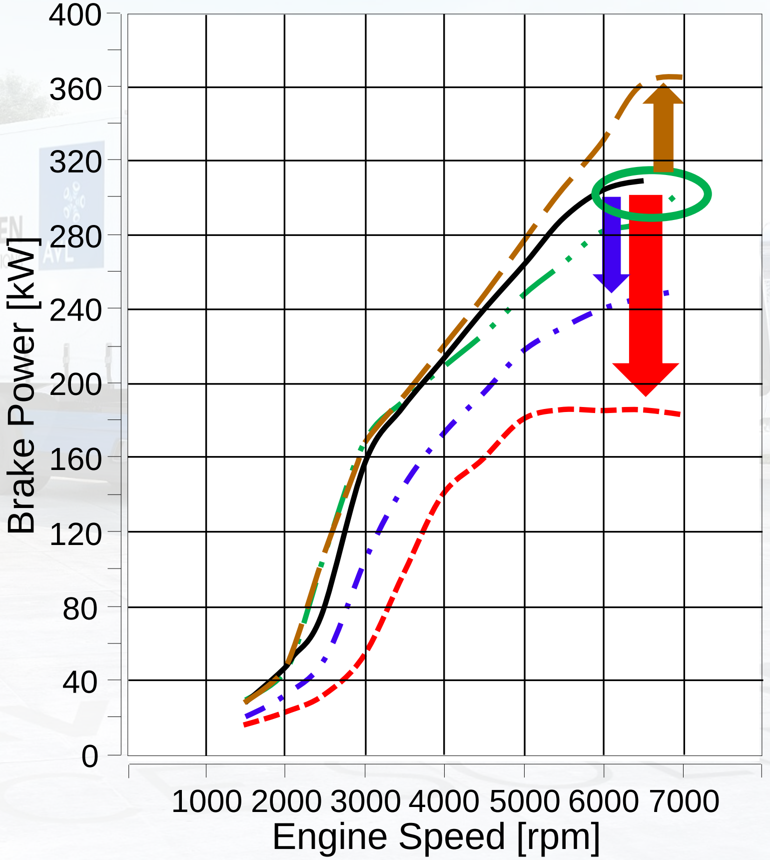
H_2 Dedicated Hybrid Engine; BSFCmin - λ vs EGR; Efficiency; Simulation



High compression ratio, lean operation and thermo swing coatings allow excellent efficiency

Highest Performance H_2 Engine – Full Load; Single Stage TC; Simulation



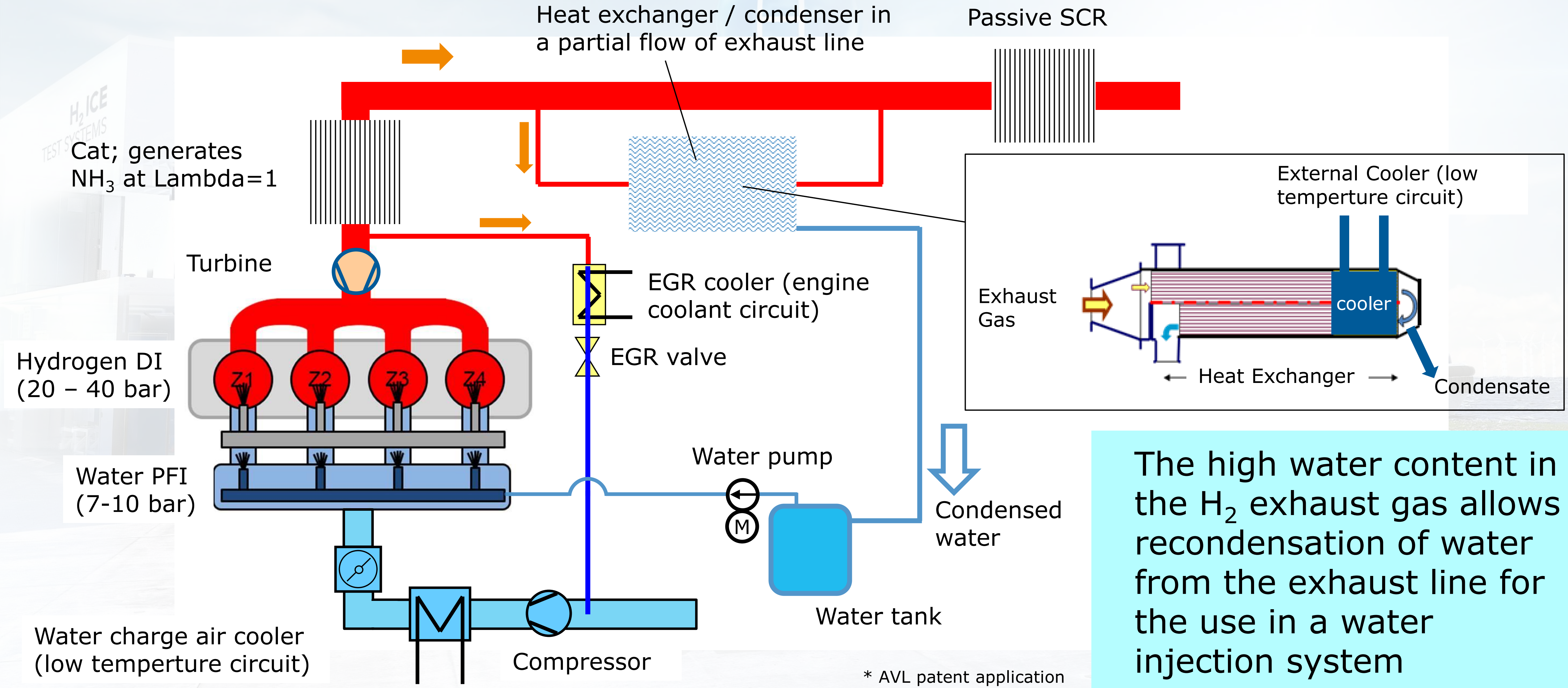


Boundary conditions:

- 4Cyl inline, 2L Miller engine
- CR 10.0:1
- Single stage TC
- H_2 direct injection
- Exhaust gas temperature limit 1000°C

Highest power and torque can be achieved by combining Lambda=1 operation and water injection

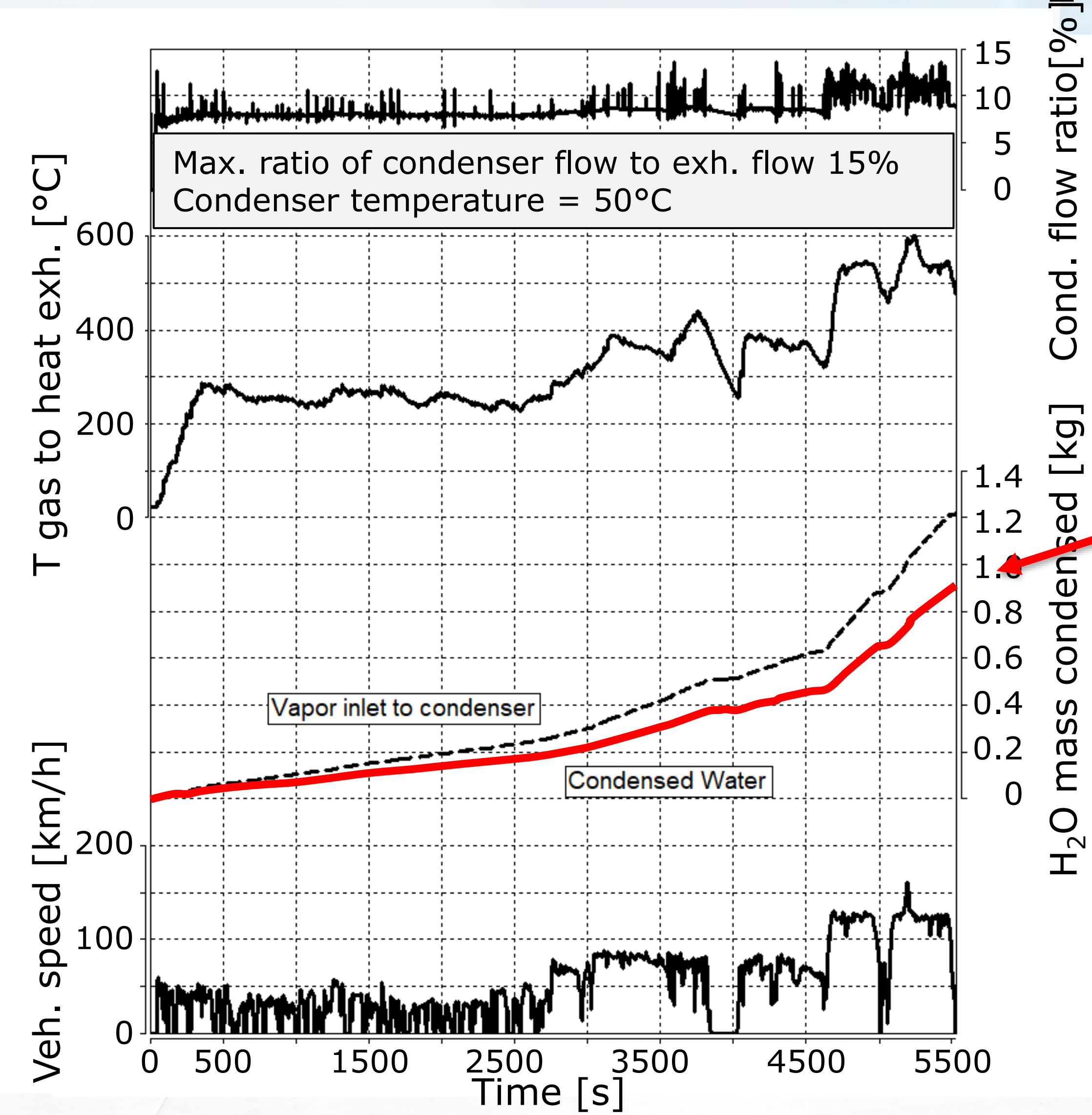
H_2 Low Pressure DI with Water Injection*

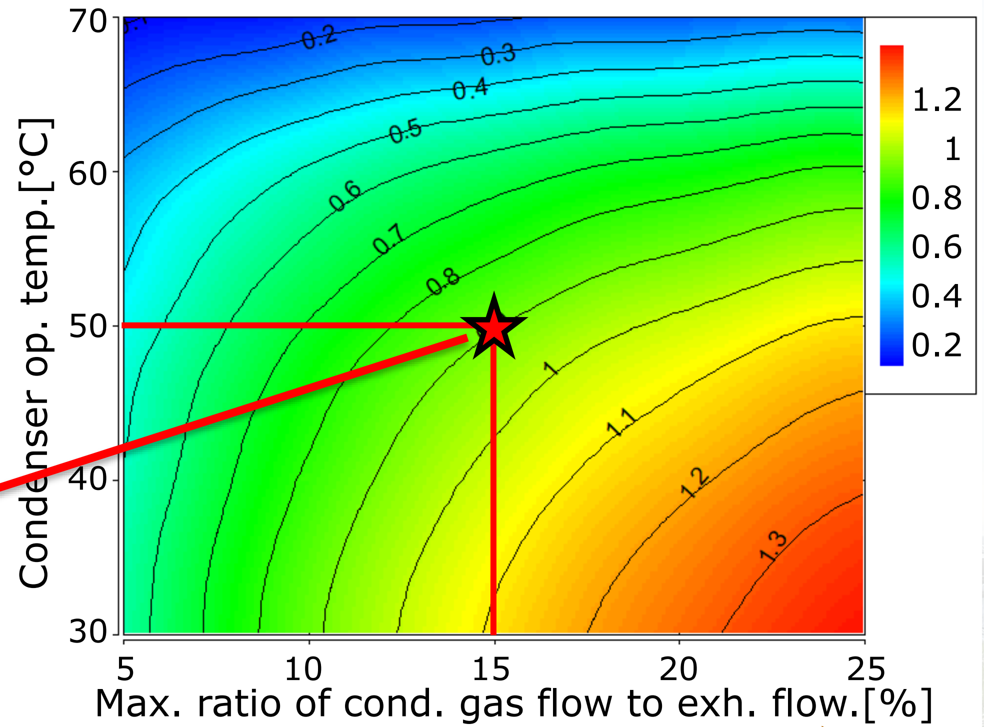


The high water content in the H_2 exhaust gas allows recondensation of water from the exhaust line for the use in a water injection system

* AVL patent application

Example: Water Condensed from Exhaust Gas During RDE Cycle with Lambda=1, H_2 Combustion





Increasing size of heat-exchanger and condenser layout

Required amount of water is between 0,4 and 0,9kg

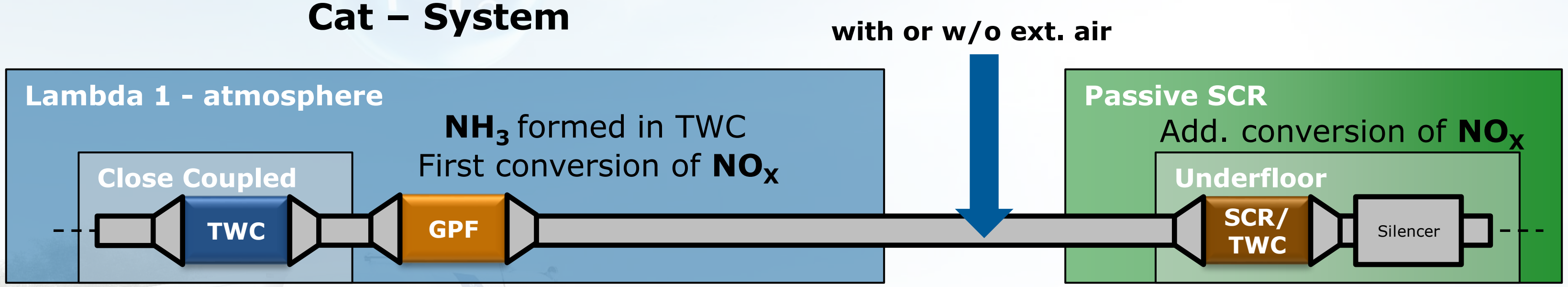
The water amount required to drive RDE and the water amount that can be condensed from the exhaust can be matched

EAS Layout for Passenger Car Engines

λ=1 Operation: Special Feature

- **Passive** SCR operation
- No active Urea dosing required

Cat – System

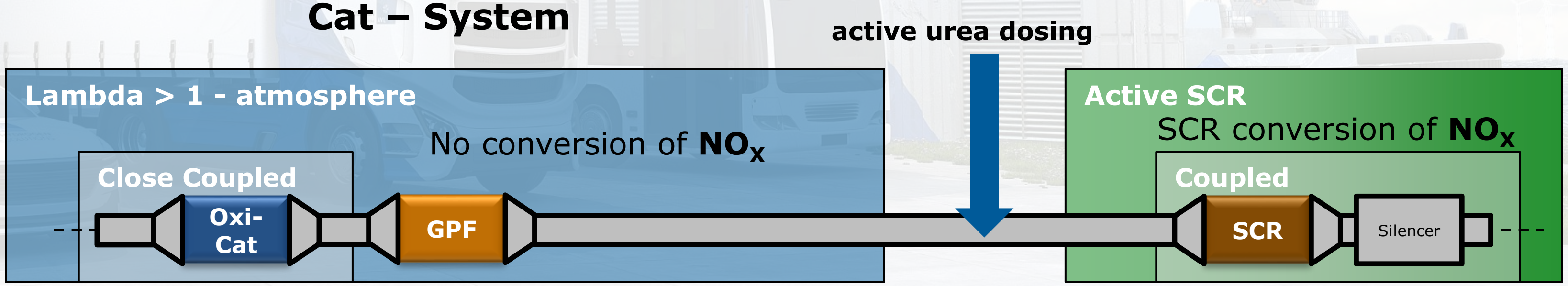


Mechanism: ammonia (NH_3) that is formed in the TWC in λ=1 atmosphere is used as a reduction agent for further NOx emission reduction; tested with gasoline on AVL's ZIE demo car!

λ>1 Operation: Conv. SCR

- **Active** SCR operation
- active Urea dosing required
- Needs NOx engine out approx. 1 g/kWh

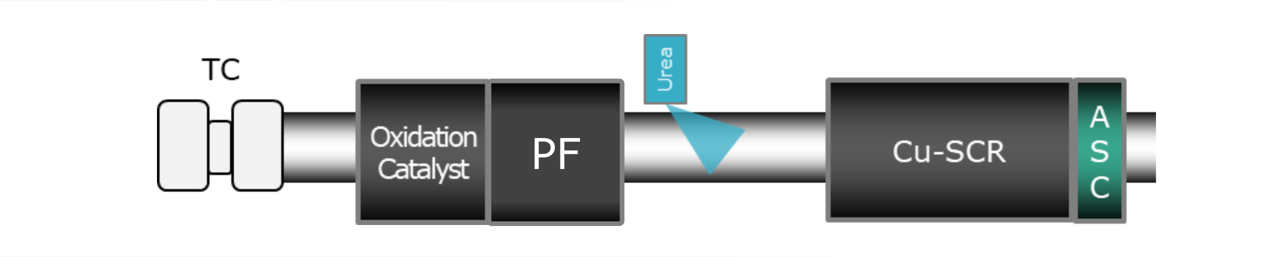
Cat – System

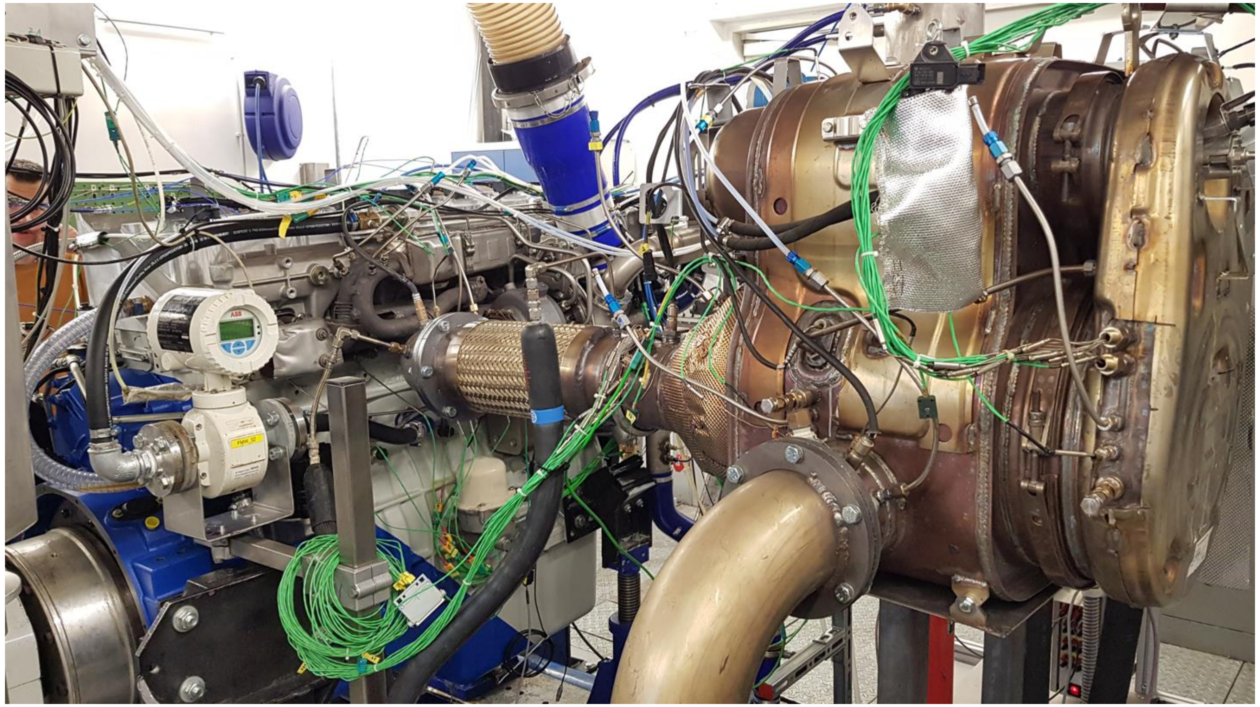


Mechanism: ammonia (NH_3) that is formed in λ>1 atmosphere by external dosing of urea is used as a reduction agent for NO_x emission reduction (conventional SCR)

Aftertreatment systems known from Diesel and gasoline applications can be used for H_2 engines

High Efficiency Hydrogen ICE
AVL Hydrogen Engine: EAS Layout for Euro VI





EAS specifications

Diesel derived EAS

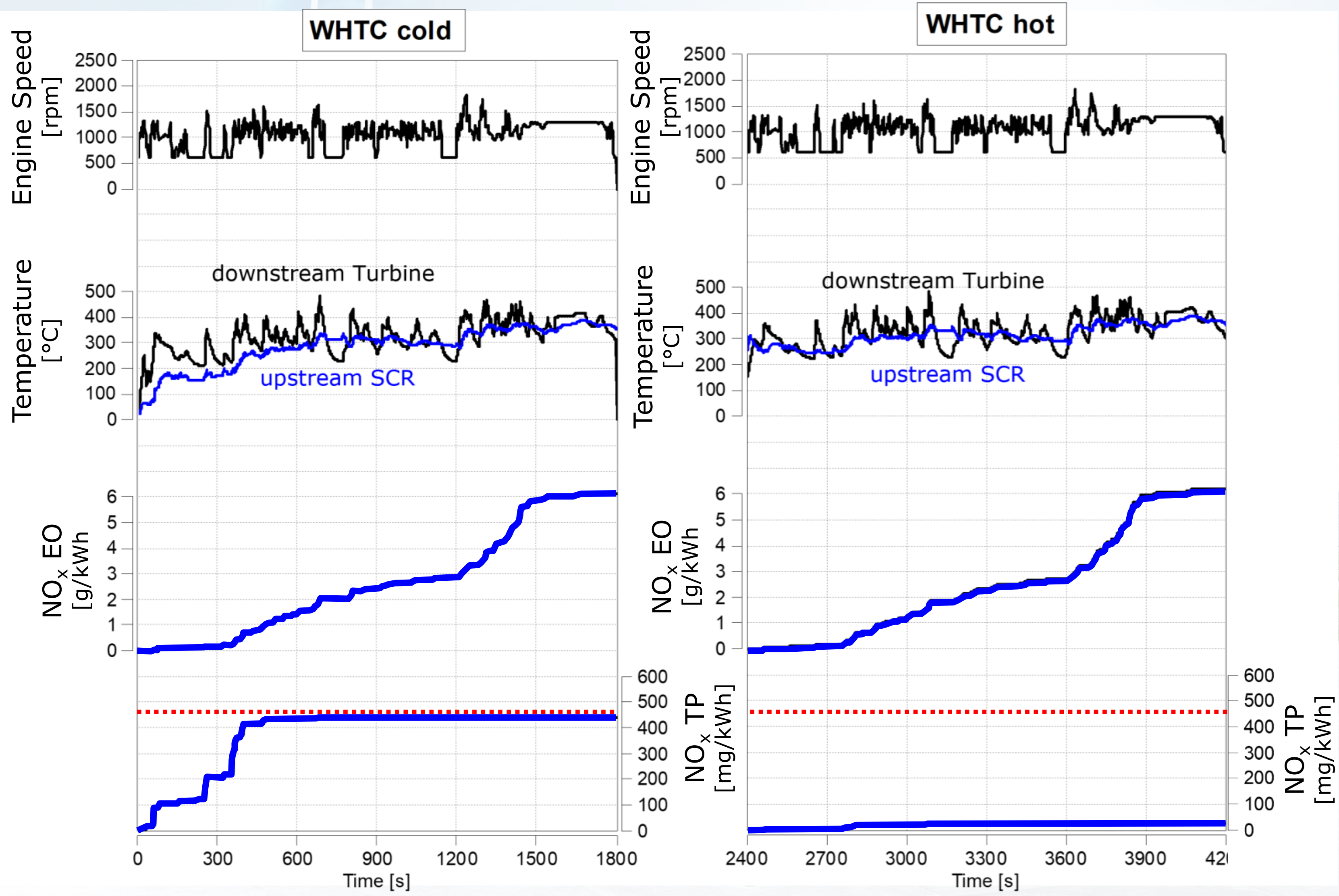
High Efficiency Hydrogen ICE
AVL Hydrogen Engine: EAS Layout for Euro VI; Simulation

EAS specifications

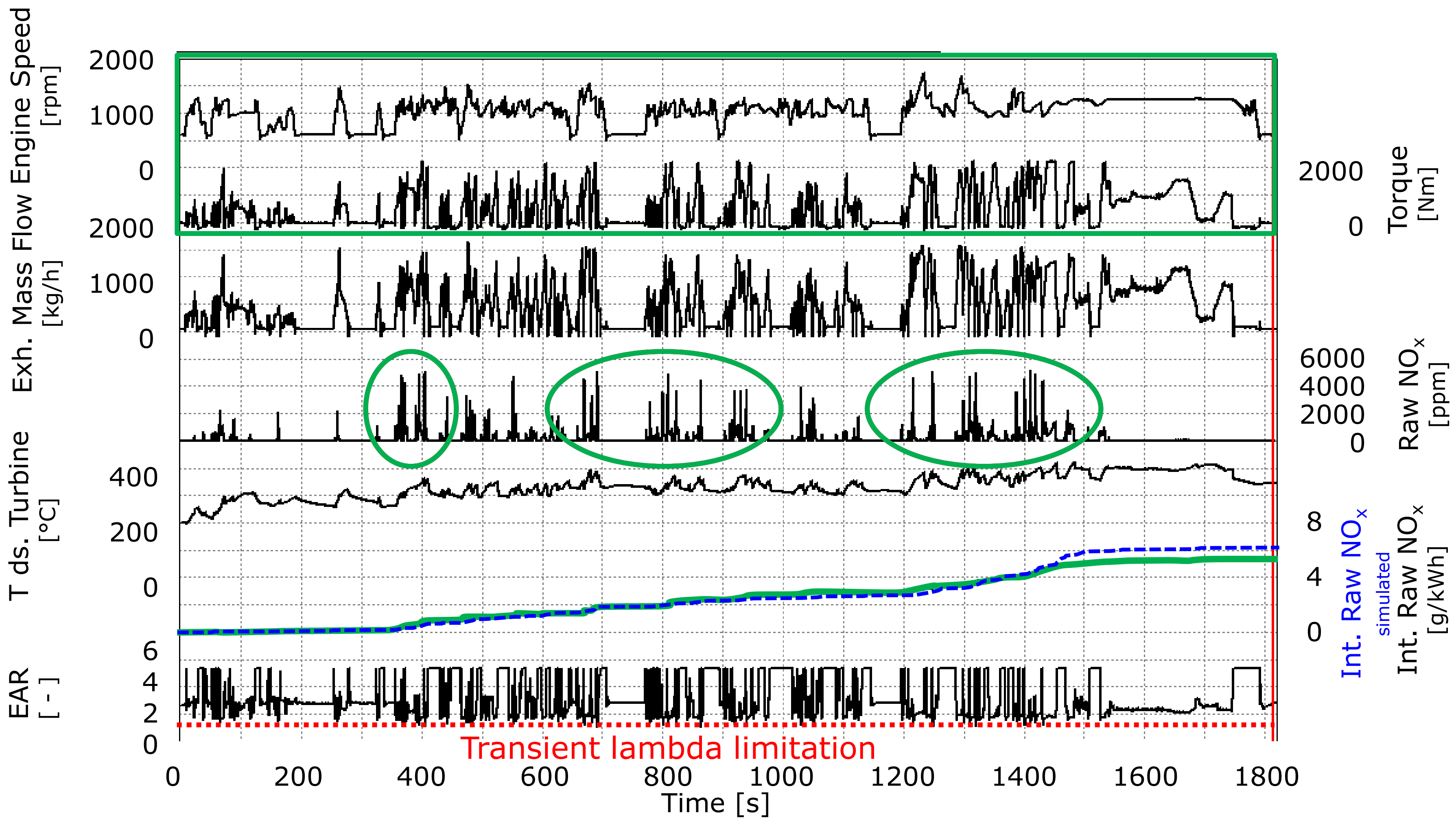
Diesel derived EAS

Syngas based & simulation optimized SCR (for 6 g/kWh EO)

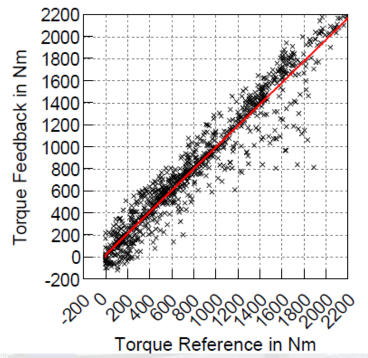
Model based SCR control



High Efficiency Hydrogen ICE
AVL Hydrogen Engine: WHTC Test Results



22 bar BMEP
300 kW

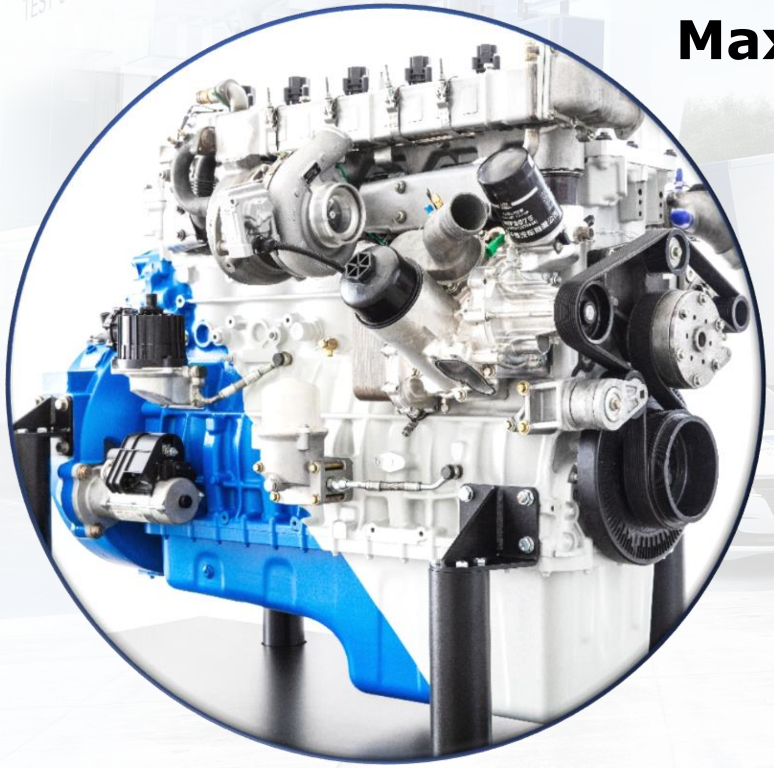


Lambda limit: 1,8 for transient NOx limitation

Confirmation of simulation results & EU VI capability

High Efficiency Hydrogen ICE
AVL Hydrogen Engine: WHTC Test Results

The AVL Hydrogen Engine – Status and Achievements



Maximum similarities to base engine
ensured

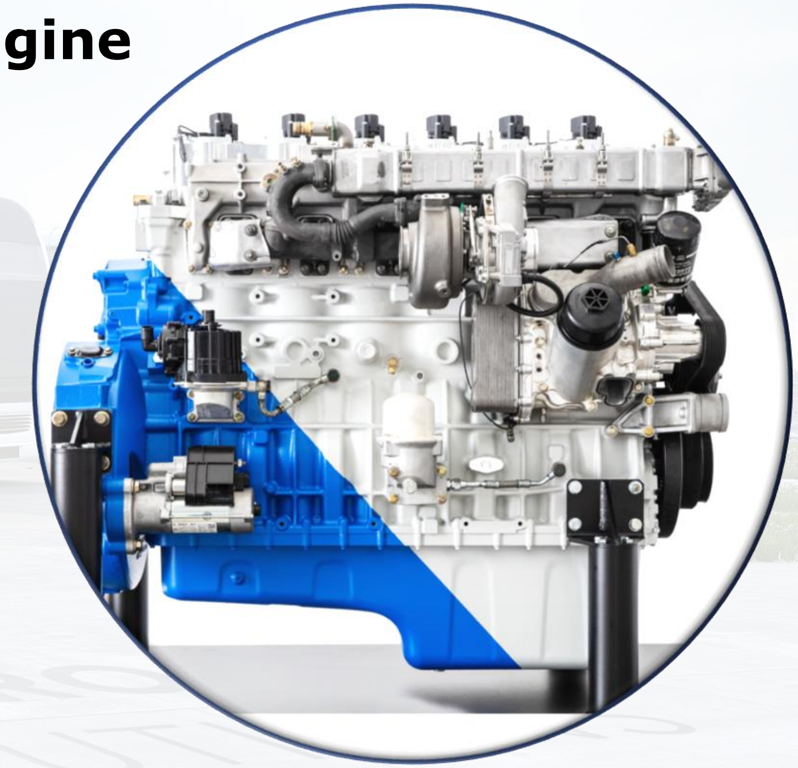
BMEP 24 bar
demonstrated

BTE 43 %
demonstrated

Performance target demo
ongoing

post Euro VI emissions
confirmed

Transient performance for conventional PT-vehicle
confirmed



Summary and Conclusions

- A **sustainable** global energy scenario needs a **chemical energy carrier** – **hydrogen** is the simplest one
- Hydrogen will play a **major role in future transportation** – for **commercial application** and possibly also for passenger cars
- Different **engine baselines** and applications require **specific combustion systems**
- The **AVL Hydrogen Engine** demonstrated **highest torque and power levels, excellent efficiency** – even in transient operation – and **lowest emissions** (post EU VI capability)
- **Dedicated hybrid** PC hydrogen engines can achieve **efficiency levels >42%**
- **High performance** PC hydrogen engines can achieve specific power levels of **up to >150kW/l**
- **Lean operation** provides the best option for part load
- To limit boost pressure demand and enhancing transient performance a **combustion moderator** enables **stoichiometric operation**
- Next to **EGR** also **water injection** - condensed directly from exhaust gas - can serve as **combustion moderator**
- A reasonable aftertreatment system uses an **oxidation or three-way catalyst** plus a passive or active **SCR system**. A particulate filter is used to cope with long term PN originating from oil consumption in worn-out engines.

Acknowledgement

Paul Kapus, Bernhard Raser, Peter Grabner, Anton Arnberger, Renè Heindl, Neil Kunder, Günter Fraidl, Michael Weißbäck

iTnA BOSCH Garrett ADVANCING MOTION VENTREX ACT BLUE

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