AVL H_2 INTERNAL COMBUSTION ENGINE

The AVL Hydrogen Race Engine

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AVL HYDROGEN INTERNAL COMBUSTION ENGINE

Current Global H_2-ICE activities: OEMs and Suppliers

Toyota Racing Demo

	US	Europe	India	China	Japan
PC H_2-ICE	No activities	Growing interest (esp. HP/Race)	No activities	Advanced projects	Advanced projects
Bus & Truck H_2-ICE	Strong increase in interest in H_2-ICE activities	Global epicenter of H_2-ICE (11-13l engines) Fleet-CO_2 reduction as driver (-30% in 2030)	First H_2-ICE activities on OEM side ARAI starting to investigate H_2-ICE	Growing interest in H_2-ICE technology Still focus on CH_4/Methanol	As hydrogen is a major pillar in future energy policy strong interest in H_2-ICE
NRMM H_2-ICE	No activities	High interest	No activities	No activities	High interest

Increasing Interest in H_2 Engines also for Passenger Cars and Racing Applicatins

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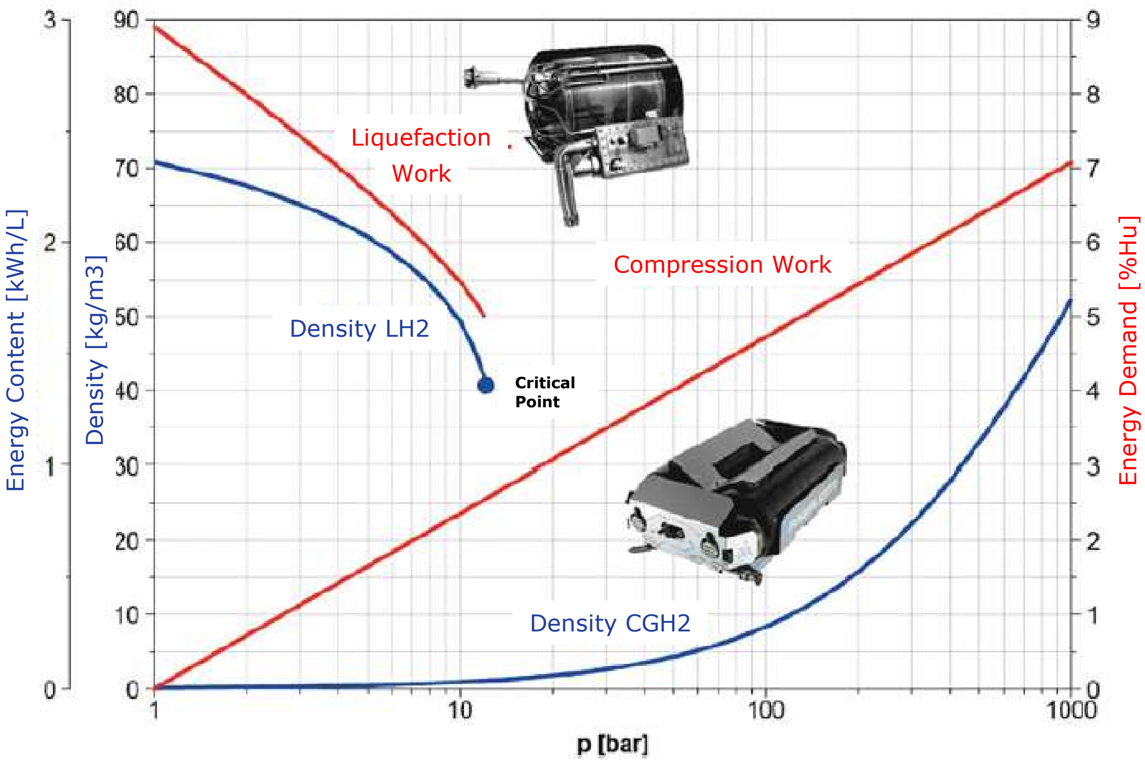
Hydrogen Storage – CGH_2 vs. LH_2 – Density & Compression/Liquefaction Work



- Density of liquid hydrogen (LH_2, 2–4bar) is at least 50% higher compared to compressed gaseous hydrogen (CGH_2, 700bar)
- maximum storage density
  - CGH_2 (700bar): **1.3kWh/dm³** ($T_{Ambient}$)
  - LH_2 (2–4bar): **2.3kWh/dm³**
  - Gasoline (1bar): **8.8kWh/dm³** ($T_{Ambient}$)
- Ideal processes assumed for liquefaction & compression work
- actual technical process efficiencies are even lower leading to considerable energy demand

➢ **LH_2 holds an advantage over CGH_2**

➢ **both are far away from standard gasoline**

Source: Klell, M.; Eichlseder, H.; Trattner, A.: „Wasserstoff in der Fahrzeugtechnik – Erzeugung, Speicherung, Anwendung", ATZ/MTZ technical book, 4th edition, Springer/Vieweg, ISBN 978-3-658-20446-4

Storage: LH_2 holds an advantage over CGH_2 – both are far away from standard Gasoline

AVL HYDROGEN INTERNAL COMBUSTION ENGINE
Hydrogen as a Fuel for Internal Combustion Engines

Pros

- **High grav. Energy Content**
  – 120 MJ/kg gravimetric
  – ~ 3 times higher than gasoline
- **Wide Operation Limits**
  – ~ $1 \leq \lambda \leq 4$
  – excellent lean burn & dilution capability
- **Low Ignition Energy**
  – easy to ignite
- **High Flame Speed**
  – suited for high speed

Contras

- **Low Density**
  – ~ 10 times lower than CNG
- **Low vol. Energy Content**
  – weak energy content in engine
- **Reactive Molecule**
  – prone to combustion anomalies
- **Low Quenching Distance**
  – burns close to surroundings
  – high wall heat loss

H_2 Offers Unrivalled Combustion Features but is tricky to Handle / Control

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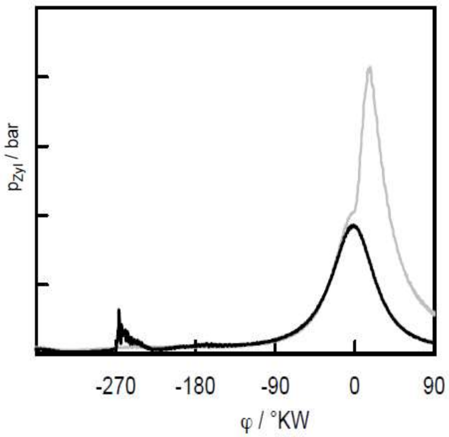
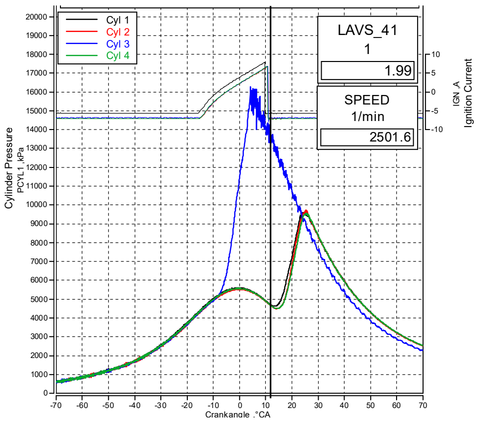
Operation Challenges @ Hydrogen Engine Operation & Development

Backfire



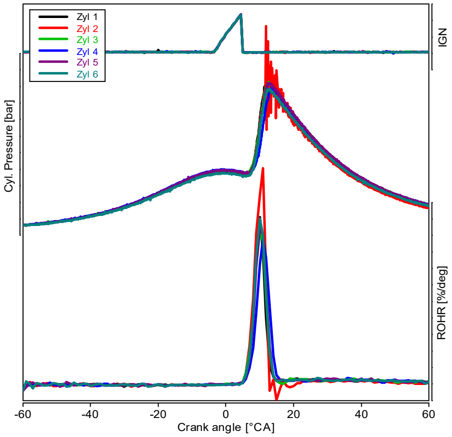
Backfire into suction path
- inflammation during suction phase on hot sources
- occurring for PFI concepts

Pre-Ignition



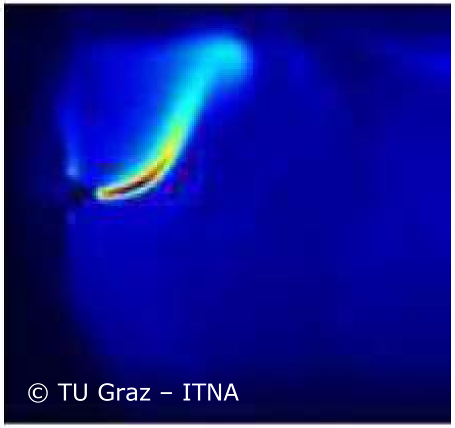
Pre-Ignition
- H_2 molecule highly reactive
- weak ignition sources may trigger irregular combustion

Knocking



Knock
- H_2 molecule highly reactive
- especially prone to knocking in stoichiometric conditions

DI Injector Leakage



Hydrogen DI Injector Leakage
- small H_2 molecule
- no lubrication capability
- issue for DI inj. tightness/lifetime

Source: "CO2 reduction in commercial vehicles - the AVL hydrogen engine"

Mitigation of Combustion Anomalies is tricky with Hydrogen

AVL HYDROGEN INTERNAL COMBUSTION ENGINE

H_2–ICE Basic Operation Concepts for Passenger Car

Highest Power!

IV. λ=1 + combustion moderator
Moderate boost pressure

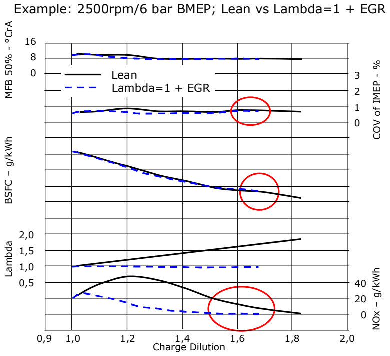
- Water inj. and/or EGR to handle IRC!
- NO_x aftertreatment with TWC

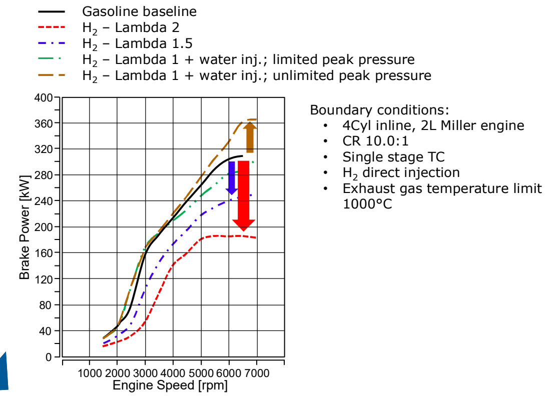
I. Pure Lean Operation

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

H_2-ICE
Operation Concepts

Example: 2500rpm/6 bar BMEP; Lean vs Lambda=1 + EGR





II. Lean + EGR

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

III. λ=1

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

H_2 can be operated lean, but also at Lambda=1 plus Combustion Moderator

AVL HYDROGEN RACE ENGINE DEMONSTRATOR
Project Motivation & Partners

AVL RACETECH

HUMDA
HUNGARIAN MOTORSPORT DEVELOPMENT AGENCY

Project Motivation & Partners

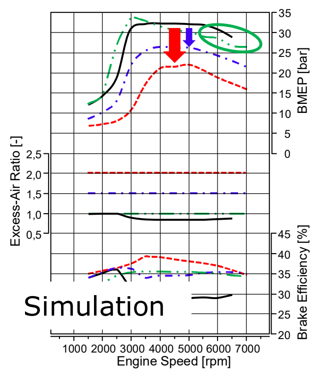
- AVL RACETECH governed project
- Purpose: Demonstrate power potential with H_2 Fuel
- Why: Strong interest in carbon-neutral / carbon-free ICE based motorsport

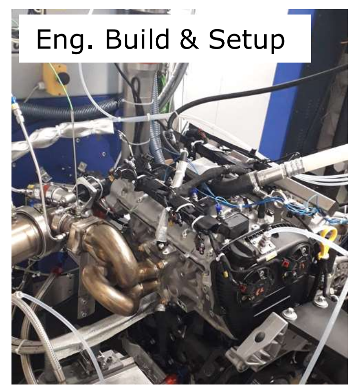
  Motorsport will not use BEVs everywhere
- Partner: HUMDA

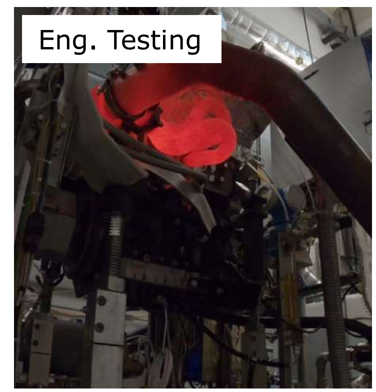
AVL HYDROGEN RACE ENGINE DEMONSTRATOR
Engine Description & Power Targets

AVL H_2 Race Engine Demonstrator

- 2.0L in-line turbocharged 4-Cyl. Engine
- Hydrogen Single Fuel Operation
- Hydrogen Direct Injection (H_2-DI)
- Targeted Power Density: 150kW/l
- $\lambda \approx 1$ Operation + PFI Water Injection for Combustion Moderation
- Air & Exhaust Flow Optimization







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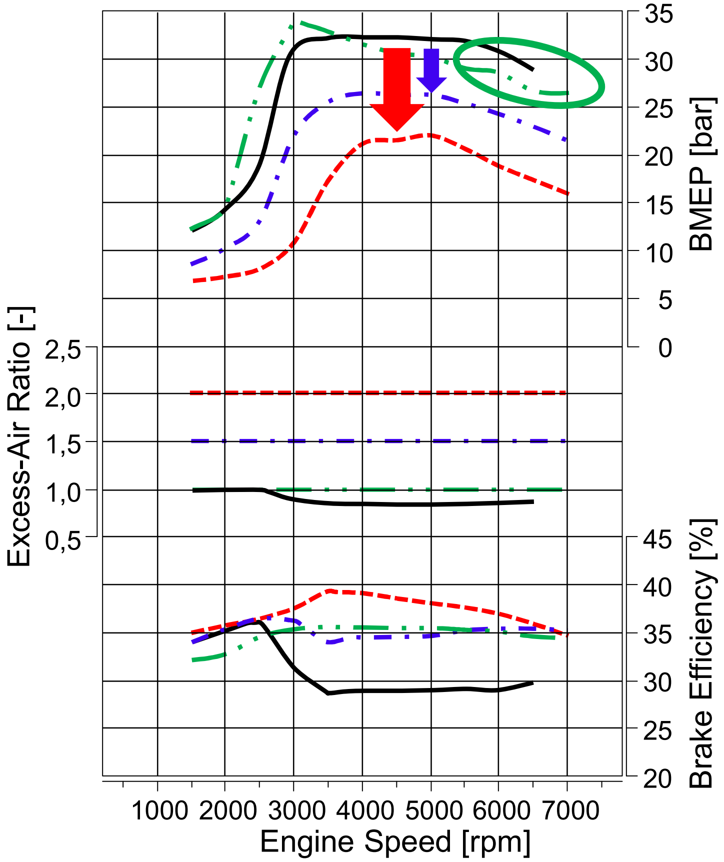
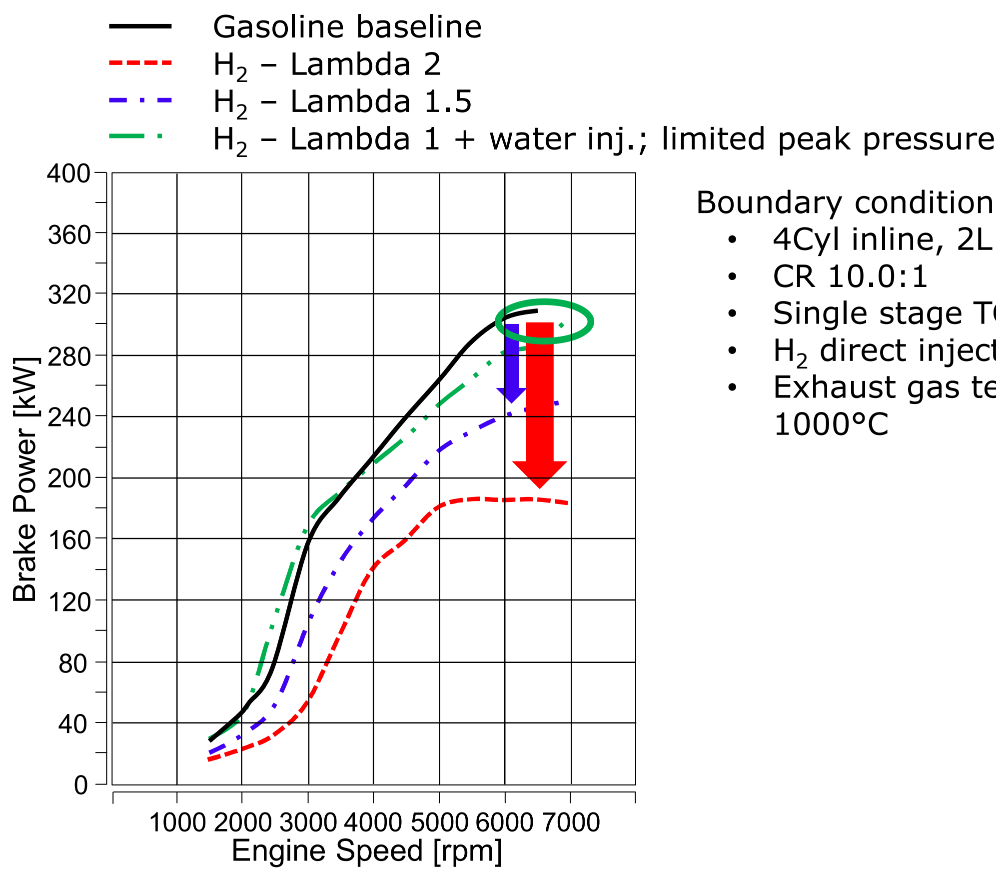
1D Performance Simulations





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 / Torque can be Achieved by Combining - Lambda=1 plus Water Injection

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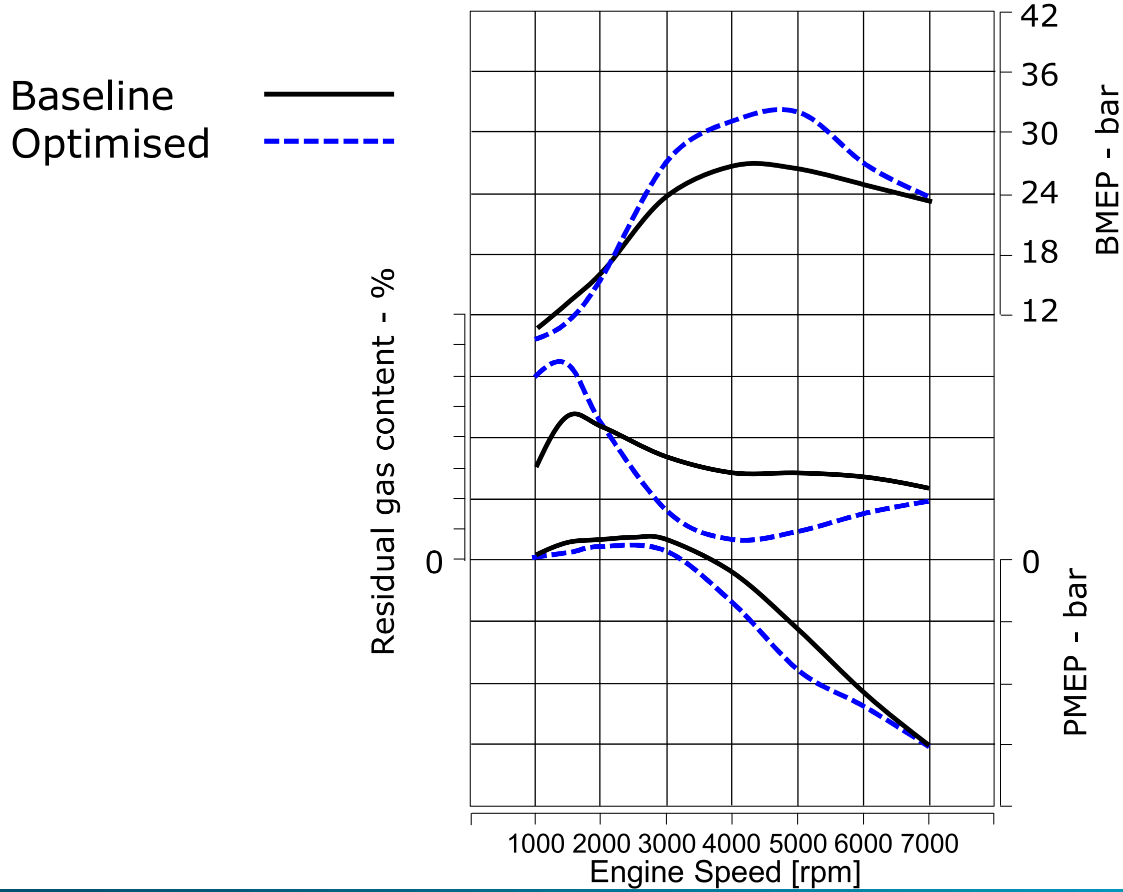
1D Performance Simulations



The specific gas dynamic layout allows low pumping work and very low (hot) residual gas content in the combustion chamber. This reduces knock, preignition and the need for high boost pressure.

A Specific Gas Dynamic Layout Allows Lowest Residual Gas Content

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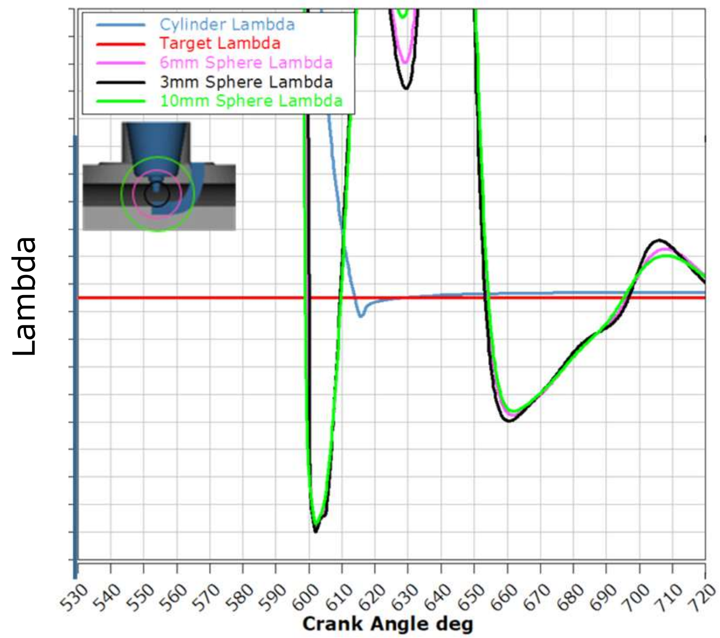
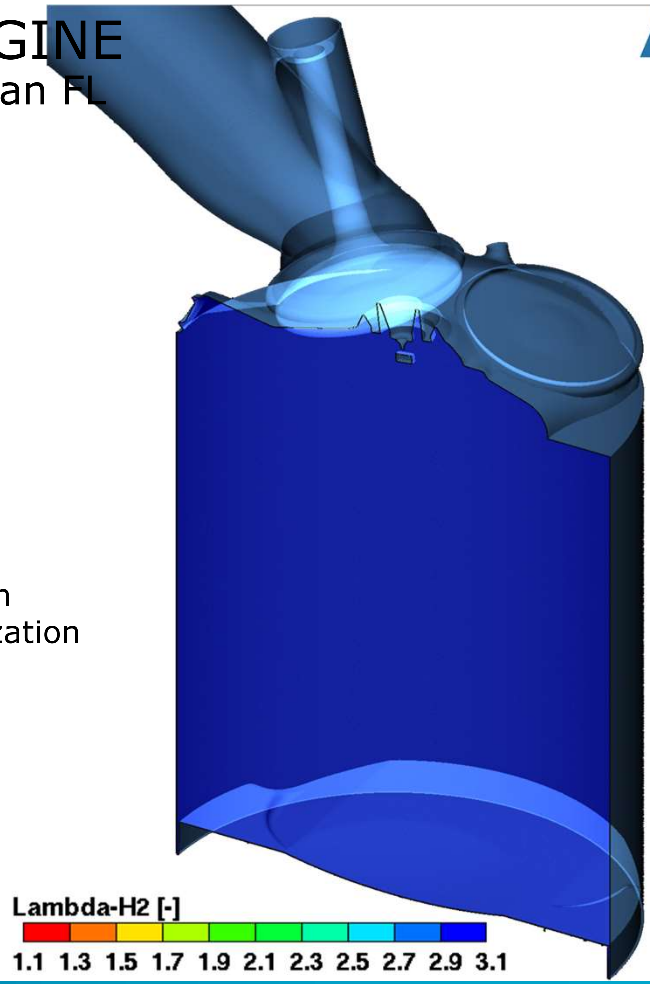
CFD Simulation – Example: Mixture Formation Process @ Lean FL

530 deg CA



Despite late injection sufficient homogenization can be achieved



Late Injection Allows Increase in Power and Still Homogeneous Mixture

AVL HYDROGEN INTERNAL COMBUSTION ENGINE

Parts Considerations – Engine Upgrades for Hydrogen Demonstrator

Parts Considerations – Engine Adaption for AVL H_2-ICE Race Engine Demonstrator – Overview*

Component	Action
Intake Manifold	Adaption (aluminum part recommended)
H_2-DI Injectors, H_2 Rail & Inj. Oiling Sys.	Addition (need to be H_2 specific)
H_2 Pressure Regulator	Addition (2-stage tank & engine)
Water Injection (WI) System	Addition (for combustion moderation)
Spark Plugs	Adaption (need to be very cold; ensure good heat transfer)
Ignition Coils	Adaption (no residual charge - preignition)
Turbocharger	Adaption (acc. boost pressure requirement)
Exhaust Camshaft & Cam Train	Adaption (for proper gas exchange and speed potential)
Exhaust Manifold & Downpipes	Addition/Adaption (for high power output & low back pr.)
Valve Seat Rings, Valves, Valve Guides	Adaption (wear)
Crankcase Ventilation & Oil Separation	Adaption (low H_2 concentration, water)
Pistons, Piston Rings, Conrods	Adaption (wear)
Cylinder Head	Adaptions (PFP, SP & inj. cooling)
Engine block	Adaptions (PFP, cooling)
Crankshaft	Adaptions (PFP, cooling)

bold … demonstrator level (reliability discounted)

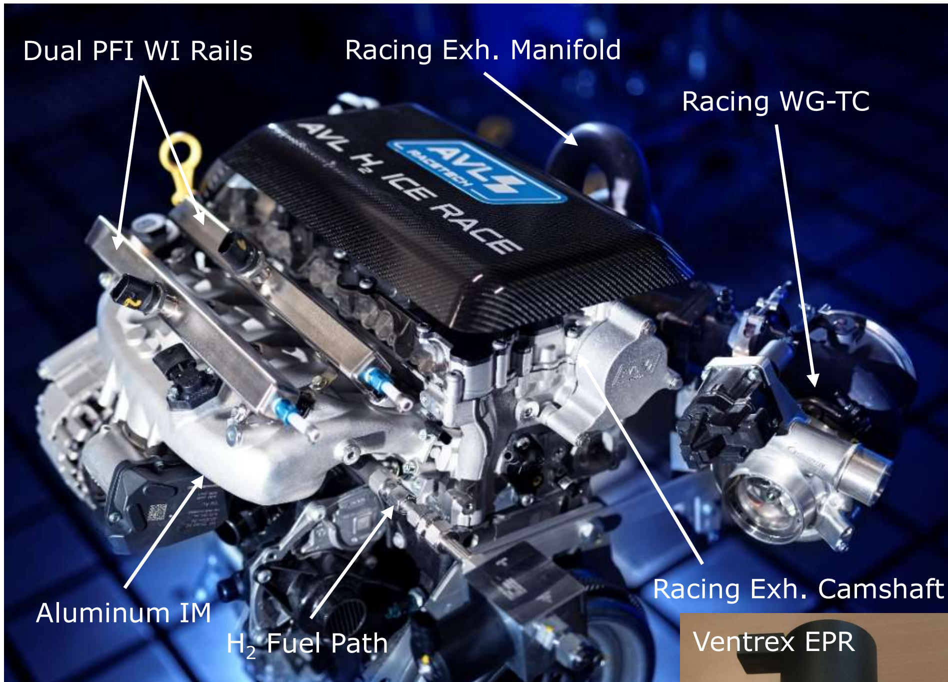
- scope of change required depends on the base engine,H_2-ICE requirements and operation concept (here: $\lambda=1+WI$)
- especially the weak lubrication capability of hydrogen (even worse than CNG) will require mechanical development for friction partner reliability especially with focus on series production and/or racing application durability → mech. improvement & durability testing required

} not considered in engine demonstrator project
- ➢ might be needed in next steps for durability and PFP increase

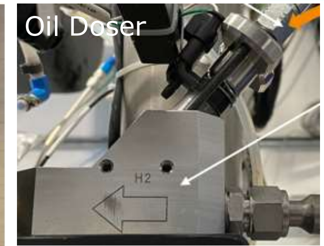
Hardware Adaption was chosen for H_2-ICE Demonstrator

AVL HYDROGEN RACE ENGINE DEMONSTRATOR

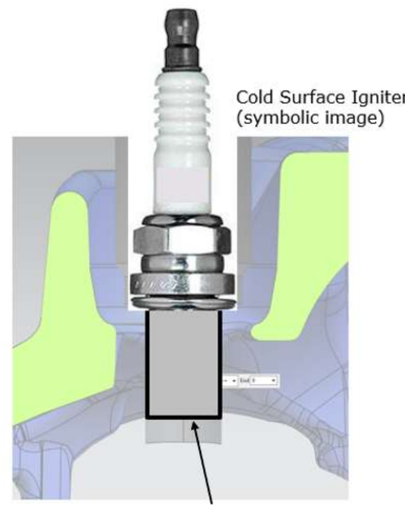
Engine Preparation & Setup



Weissgerber Engineering © H_2-ready Ignition Coils



Phinia © H_2-DI Inj.Sys. + Oiling



Cold Racing Spark Plug

M&H © H_2-DI Fuel Rail

Ventrex © EPR

Considerable Effort was put into:

- Component Selection
- Valve Lift Curve Adaption & Lash Adjustm.
- Aero System Layout
- etc. …

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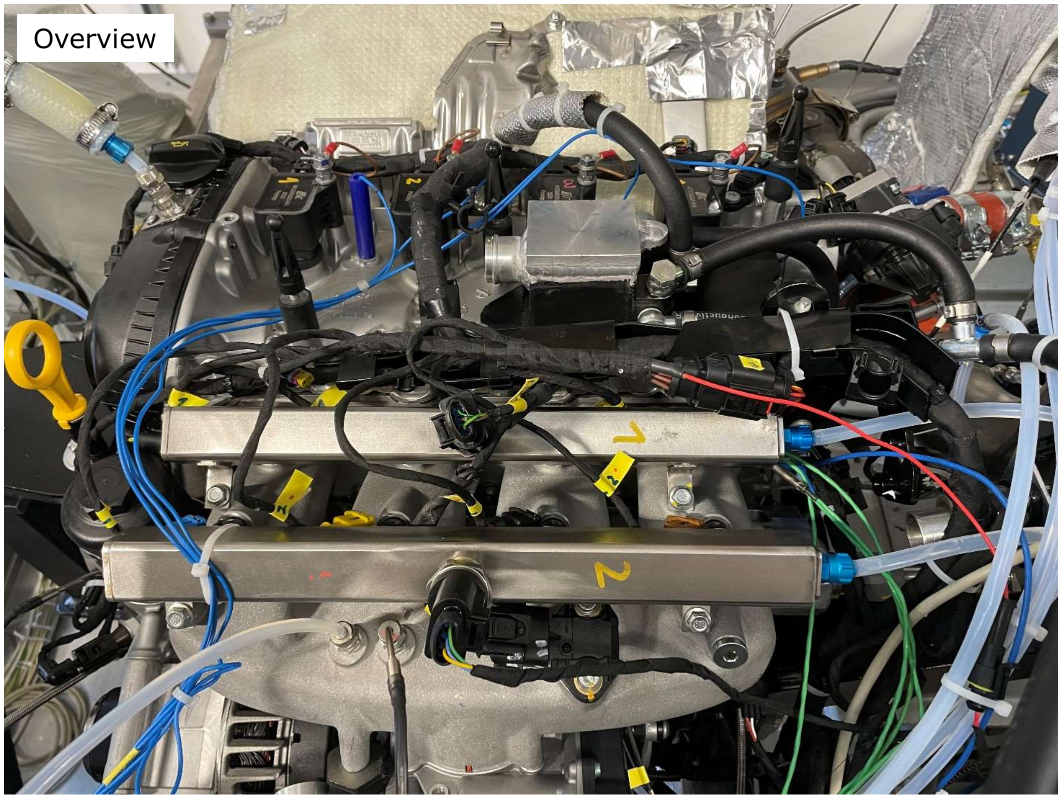
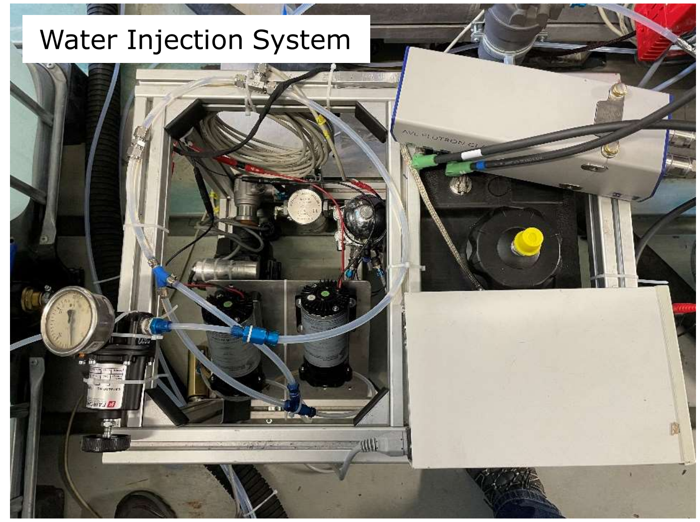
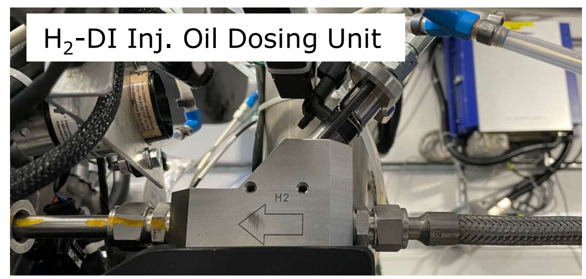
Engine Setup on AVL H_2-ICE Test Bed



Overview



Water Injection System



H_2-DI Inj. Oil Dosing Unit

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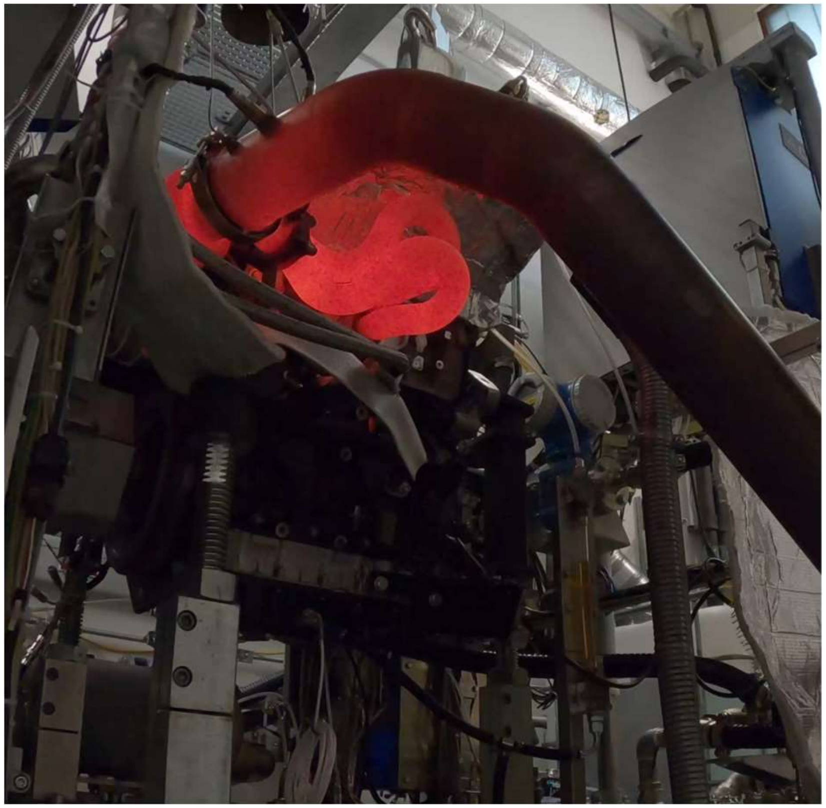
Testing – Engine running on AVL H_2-ICE Test Bed – The Fun Stuff



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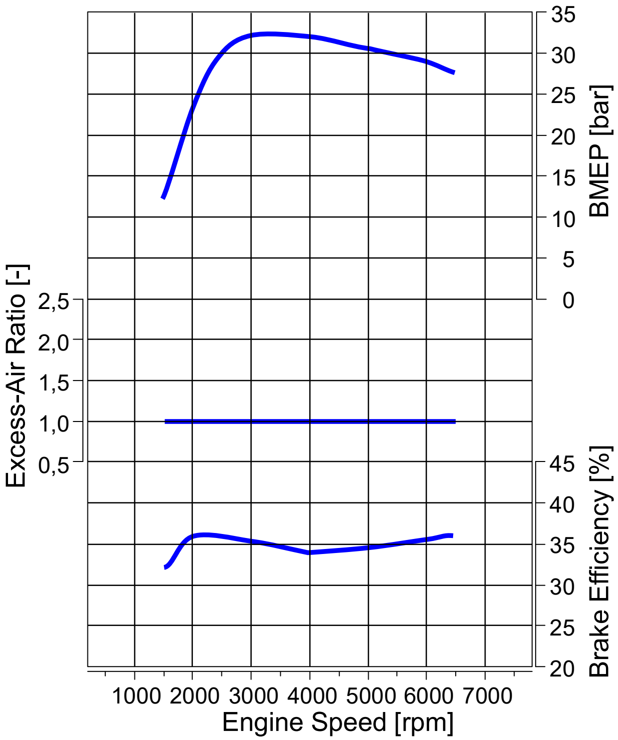
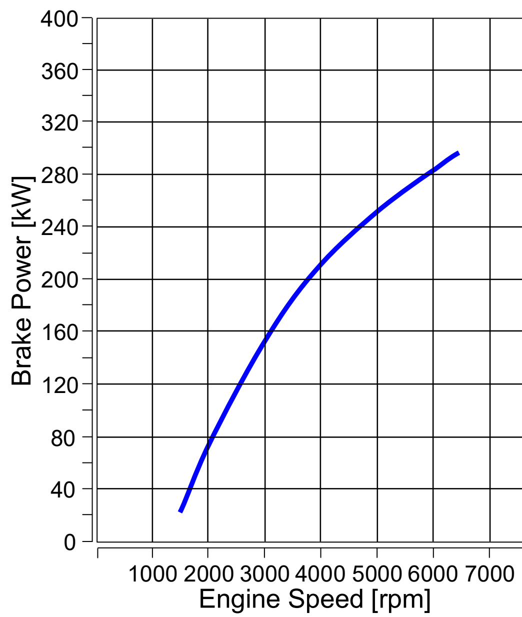
Testing – Engine running on AVL H_2-ICE Test Bed – Target Achievement

Measured on AVL H_2-ICE Testbed





Achievements

- Power: 300 kW @ 6500rpm
  150 kW/l Power Density
- Torque: 500 Nm @ 3000 - 4000rpm
- BMEP: 32 bar @ 3000 - 4000rpm

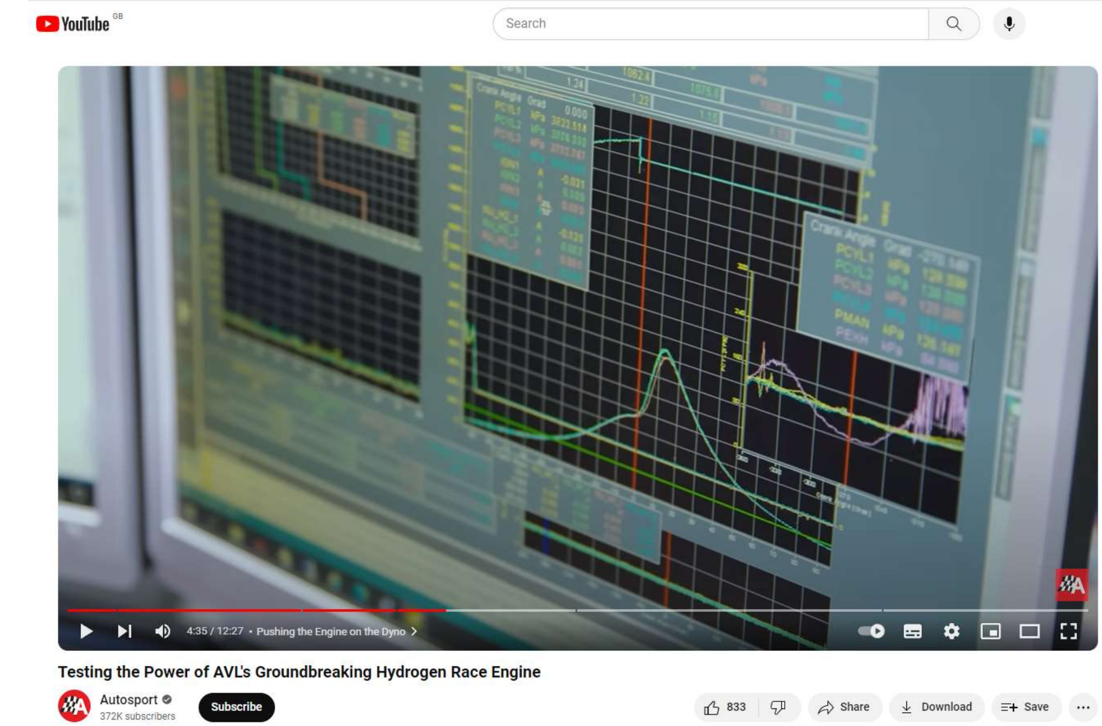
Targets achieved according to initial Press Release

AVL HYDROGEN RACE ENGINE DEMONSTRATOR

Testing – Engine running on AVL H_2-ICE Test Bed – Target Achievement – The Proof

Measured on AVL H_2-ICE Testbed

Search YouTube "AVL Hydrogen Race Engine" to see the team and the engine running



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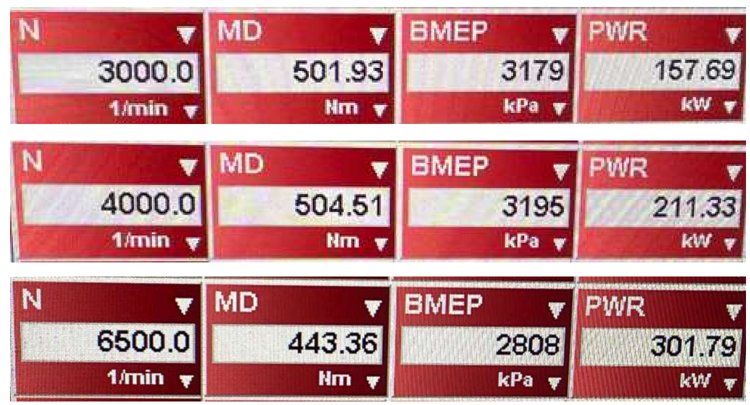

Targets achieved according to initial Press Release

AVL HYDROGEN RACE ENGINE DEMONSTRATOR
Next Steps

- **Engine Dismantle** (started as we speak)
  - Engine has endured testing → check required for improvement potential
- **Potential Engine Upgrade**
  - Engine Reinforcement towards higher PFP capability
  - Reliability requirements to be defined after engine analysis
- **Strategy Adaption to reduce Water Moderation Requirement**
  - potentially moderately lean operation + Water Injection
- **Increase Power Output**
  - There's never enough …
- **Step into Race Car Application**
  - Test Bed is nice – Real Driving is nicer …

AVL is looking for Partners for next Steps – Ideas/Projects highly welcome !

Thank you

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www.avlracetech.com

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