Reliability Solutions for Hydrogen Internal Combustion Engines

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Reliability Solutions for Hydrogen Internal Combustion Engines
Hydrogen ICE as solution for CO_2 neutral* transportation

Hydrogen fuel is considered as **CO_2 neutral** & has the potential for **"zero-emission-vehicle**"**

Hydrogen ICE for Heavy Duty vehicles come with **similar costs as diesel/natural gas** engines

Capability to ensure **high system efficiencies** for Heavy Duty operation cycles (full load operation)

Short **time to market**

High **tolerance** to **low purity hydrogen** and therefore gas **engine like reliability**

Potential to **prolong the lifecycle of conventional powertrain** vehicles & **protect investments in existing infrastructure**

* Tank-to-Wheel
** Qualification as $Z(CO_2)EV$: CO_2 below 1g/kWh
CO_2 Sources: Lube Oil, AdBlue

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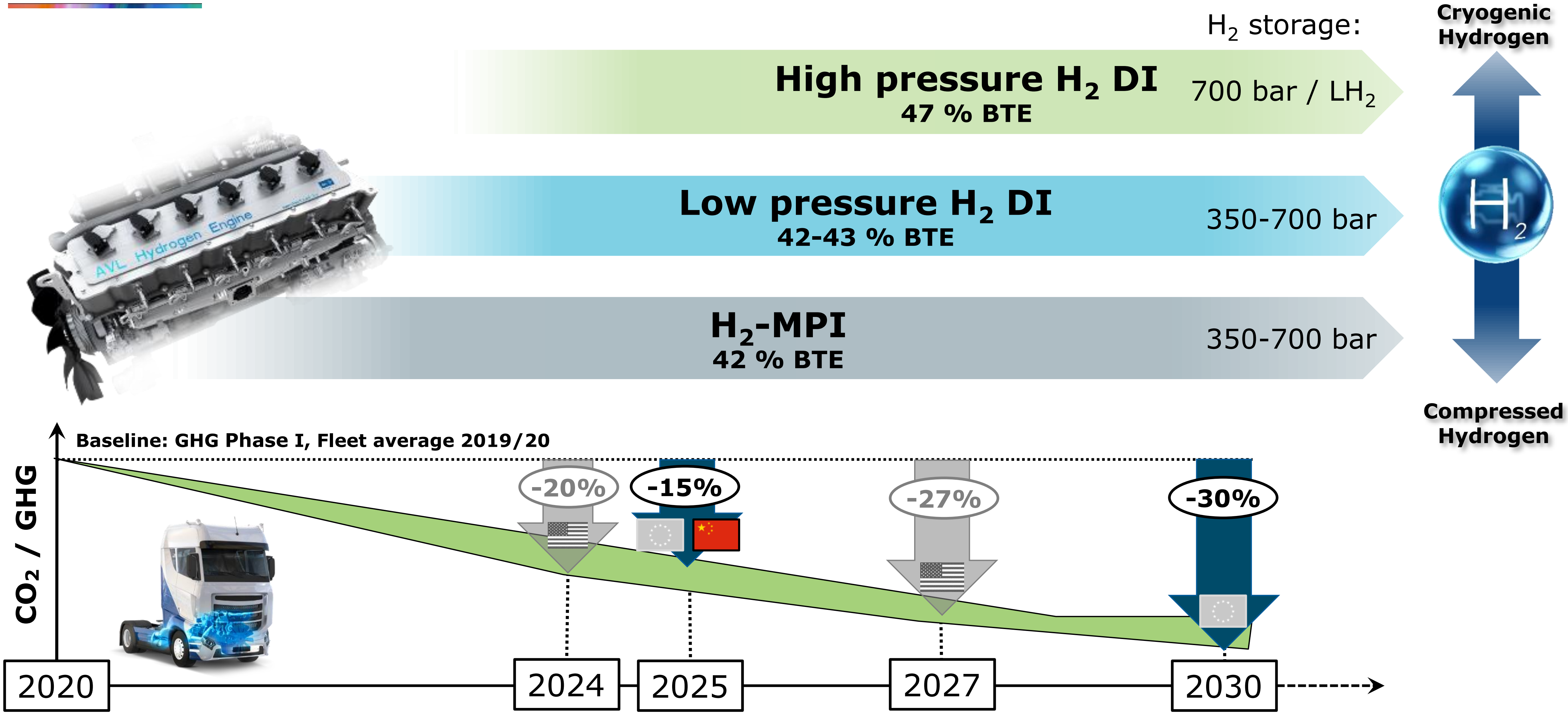
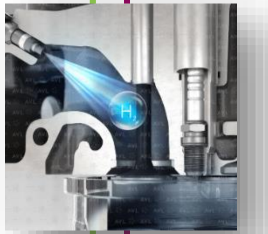
HD H_2-ICE Roadmap until 2030+



Reliability Solutions for Hydrogen Internal Combustion Engines
Hydrogen Combustion Concepts for Commercial Applications

Homogeneous Combustion / Spark Ignited

7~20 bar Injection Pressure




Multi Point Injection (MPI)

Mixture formation swirl or tumble based

20~30 bar Injection Pressure


Low Pressure DI

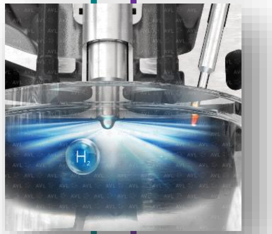
Mixture formation swirl or tumble based

Diffusion Combustion / Compressed Ignited

250~300 bar Injection Pressure

High Pressure DI

Diesel pilot



High Pressure DI

Carbon free ignition

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The AVL Hydrogen Engine – Fact Sheet

AVL Hydrogen Engine Facts

12.8l NG base engine LP-DI (MPI)
Diesel to gas conversion done by AVL

BMEP level 24 bar

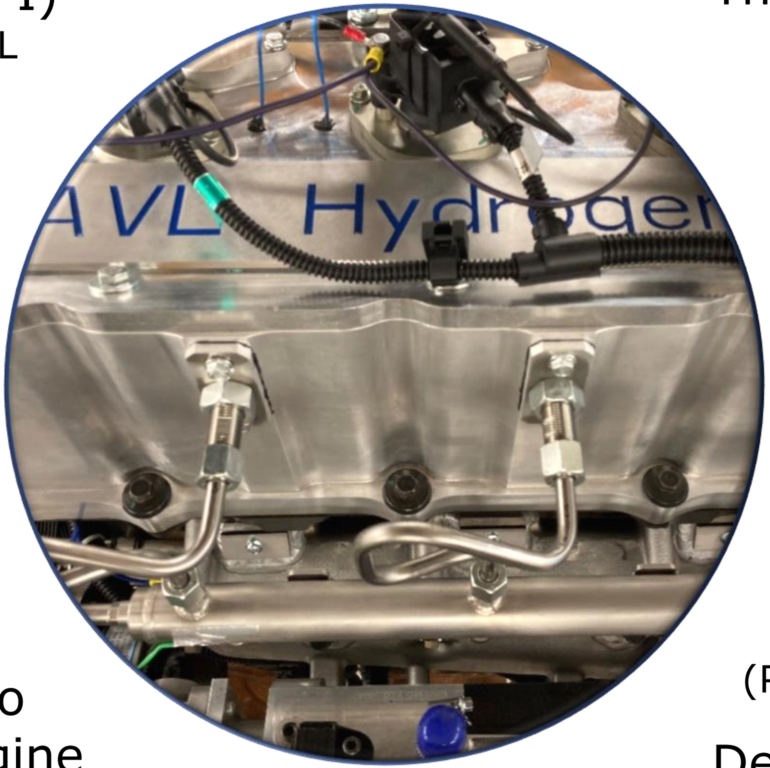
Power level 350 kW

BTE 42 % demonstrated

Post Euro VI emissions

Transient performance for conventional PT-vehicle

Maximum similarities to base engine



AVL Tasks & Responsibilities

Thermodynamic layout

Design conversion to H_2

Combustion & air path layout

Sensor & Actuator definition

AVL RPEMS controller

Testbed development & calibration

Supplier management
(Procurement of all H_2 components)

Deriving Reference DVP for H_2-ICE

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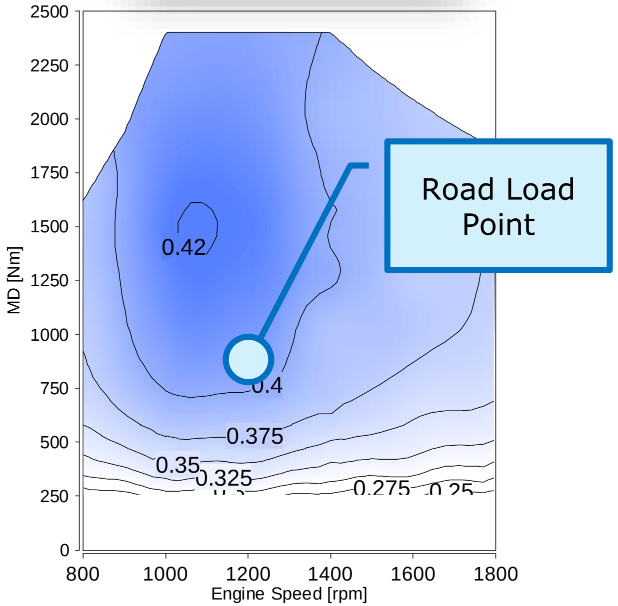
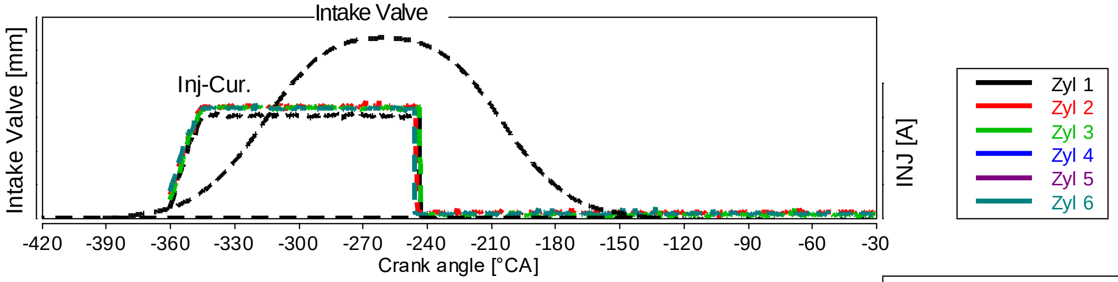
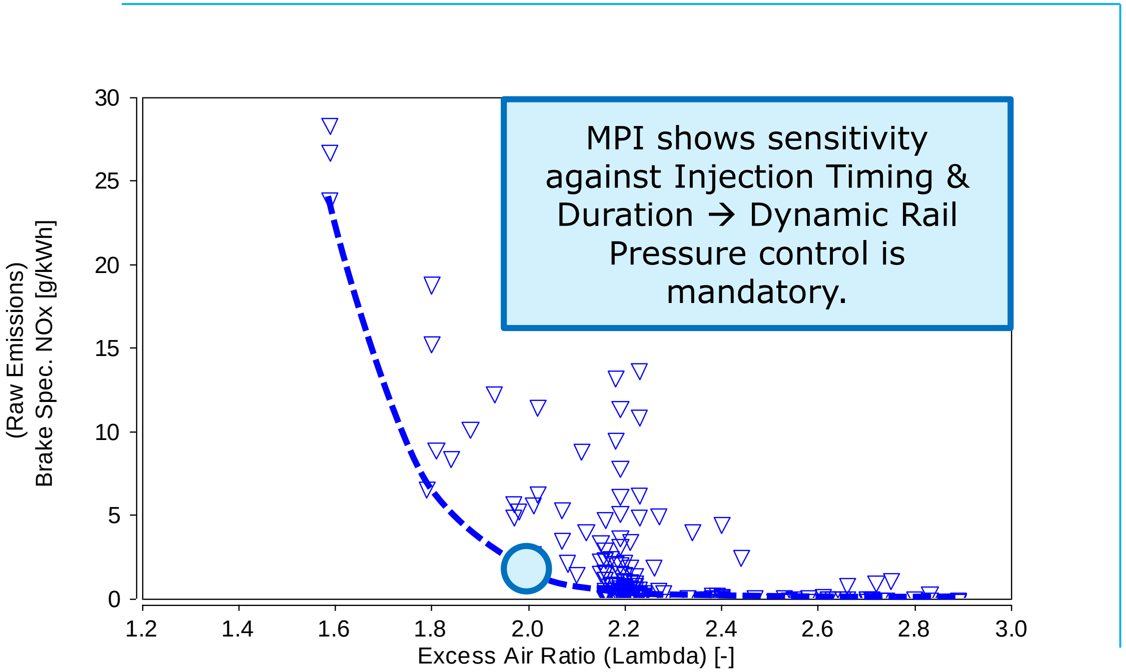
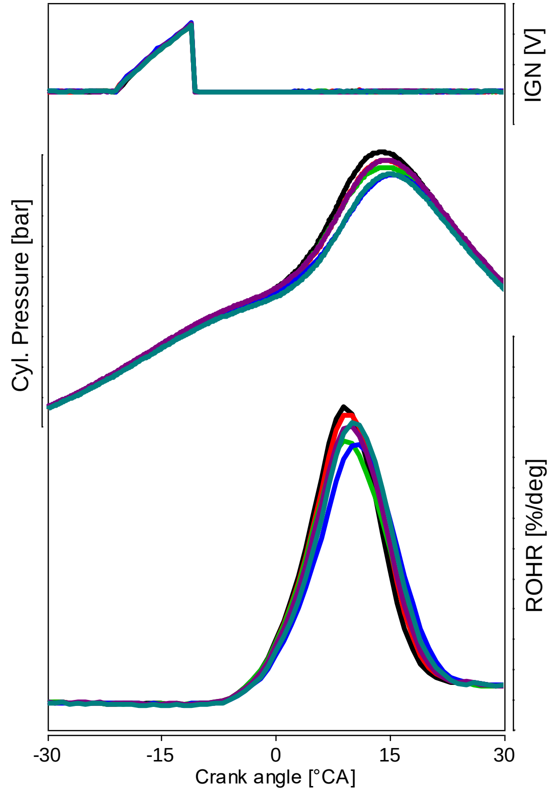
NO_x/Excess Air Ratio Optimization - MPI

Multi Point Injection (MPI)









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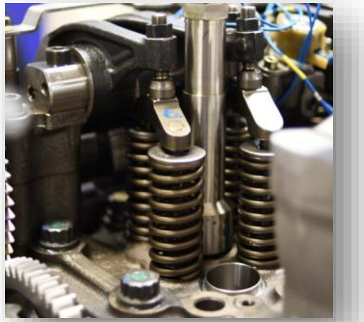
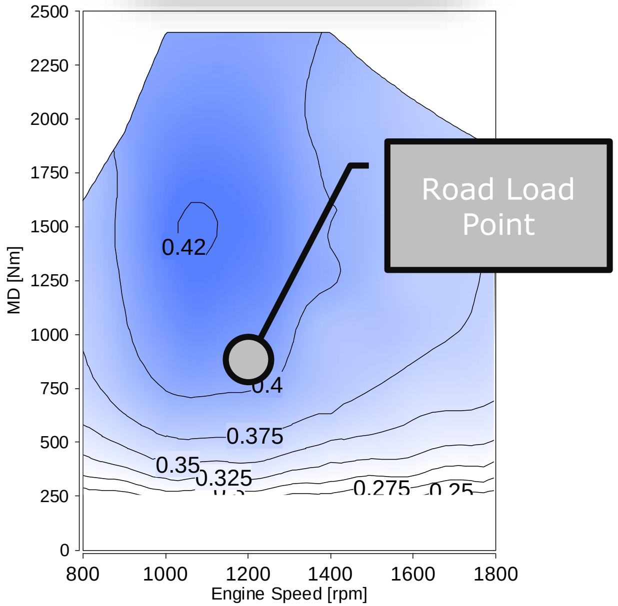
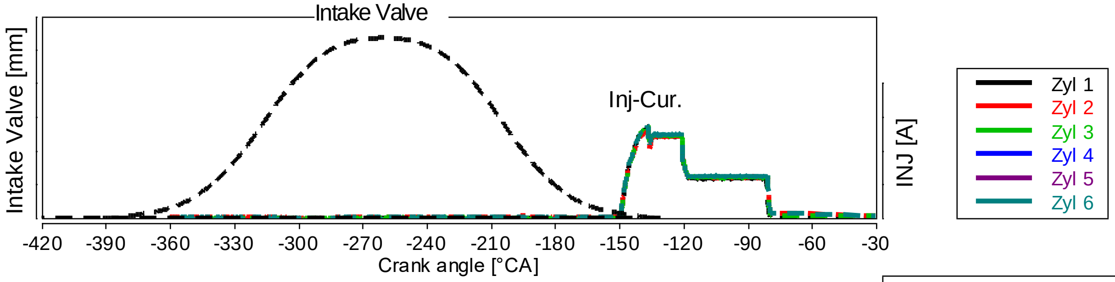
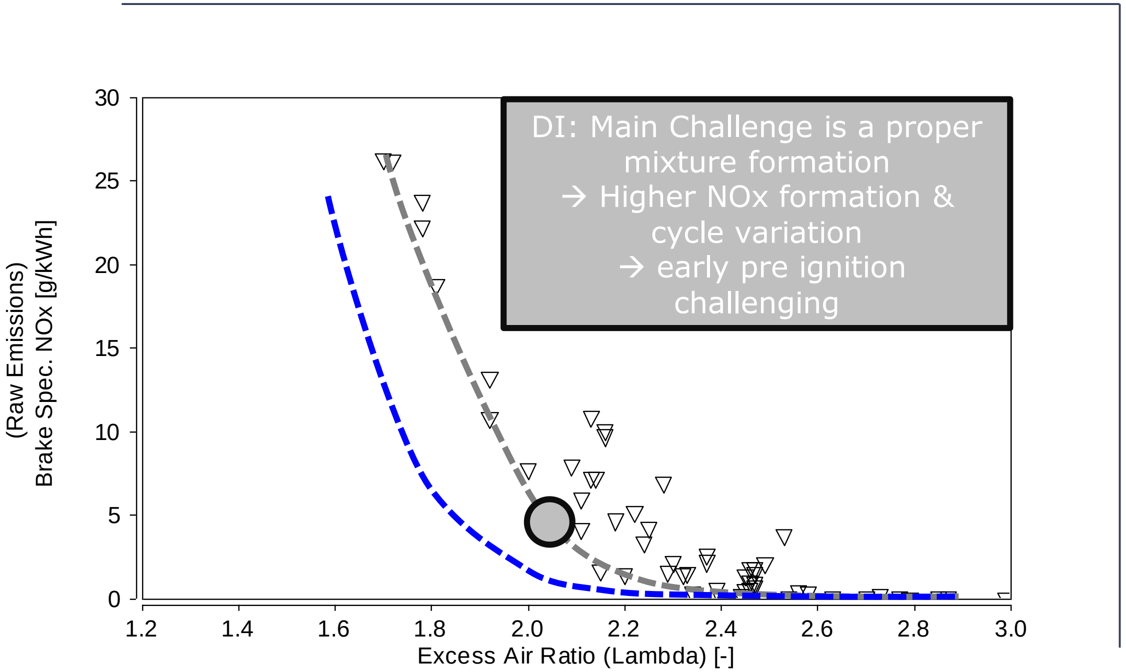
NO_x/Excess Air Ratio Optimization - DI

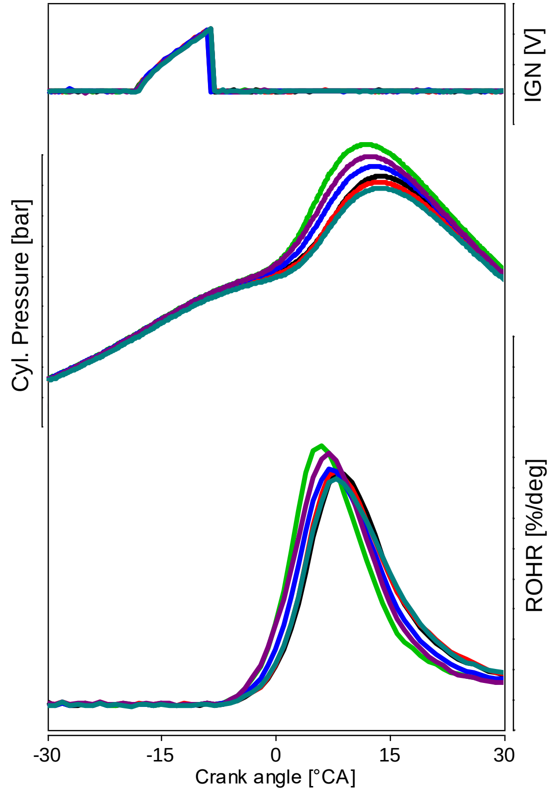
Direct Injection (DI)











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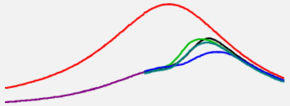
Hydrogen ICE challenges and AVL solutions

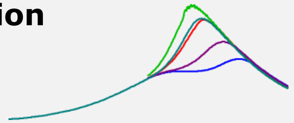
Challenges Combustion

Commercial ICE

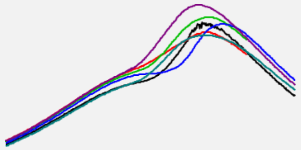
Early Pre-Ignition / Backfire



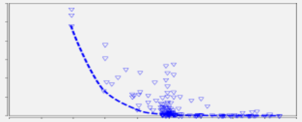
Late Pre-Ignition



Cycle Variation@high load (DI)



Best NO_x/Lambda trade off

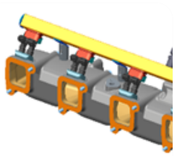


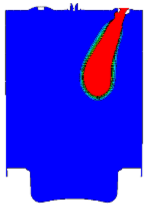
AVL ADDED VALUE
Hydrogen ICE development

AVL

Optimal pairing of blow cap & charge motion

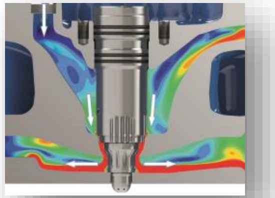
- Optimized mixture formation
- Avoid residual gas





Cooling of fire deck & spark plug

- Pressed sleeve solution for best cooling and TMF
- AVL advanced top down cooling



P&E / Mechanical Development

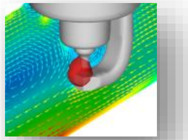
- Avoid oil carry over
- Combustion chamber: no edges and corners
- Optimal piston cooling

Challenges Key Components

Injection System

Durability / Reliability
Flow rate optimization

Ignition System



Dedicated Ignition Coil

- residual loads
- uncontrolled spark events

Dedicated Spark Plug

- Cold, small gap, little electrode protrusion

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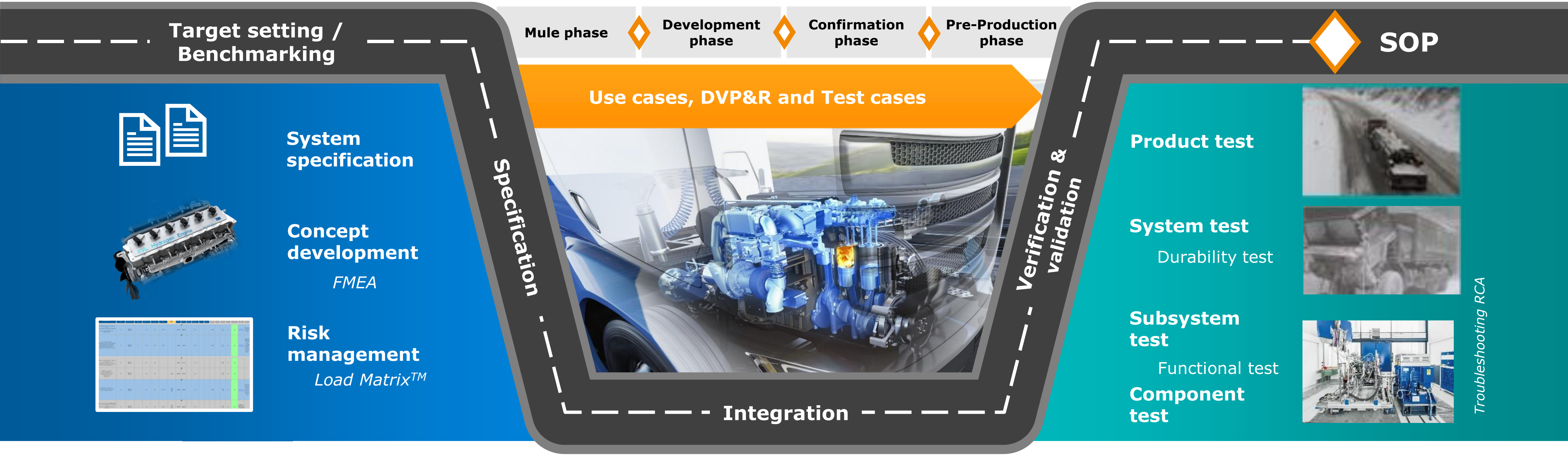
Verification & Validation based on AVL Load Matrix™



AVL Load Matrix™ Approach is accompanying the Complete Product Development Process

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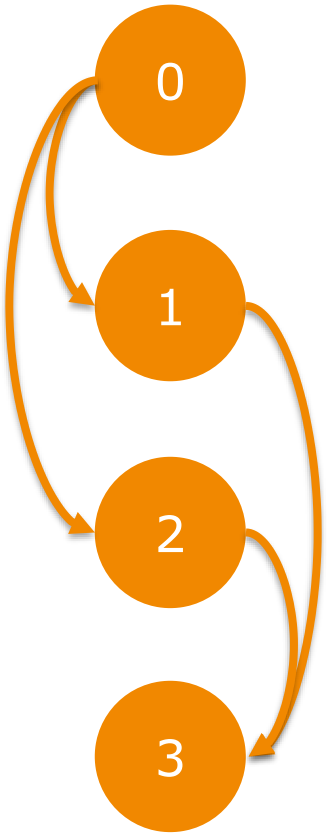
Considered Reference DVP Variants for H_2-ICE



Baseline DVP: AVL HD Engine DVP

- Baseline for evaluation is the current AVL HD-Gas/Diesel DVP with focus on Mechanical Development & Validation

Reference DVP 1: H_2 Engine converted from Gas Engine

- Convert an existing gas engine with high similarities into a H_2 engine

Reference DVP 2: H_2 Engine converted from Diesel Engine

- Convert an existing diesel engine with high similarities into a H_2 engine

Reference DVP 3: Engine developed dedicated to H_2

- Development of new engine family exclusively for H_2

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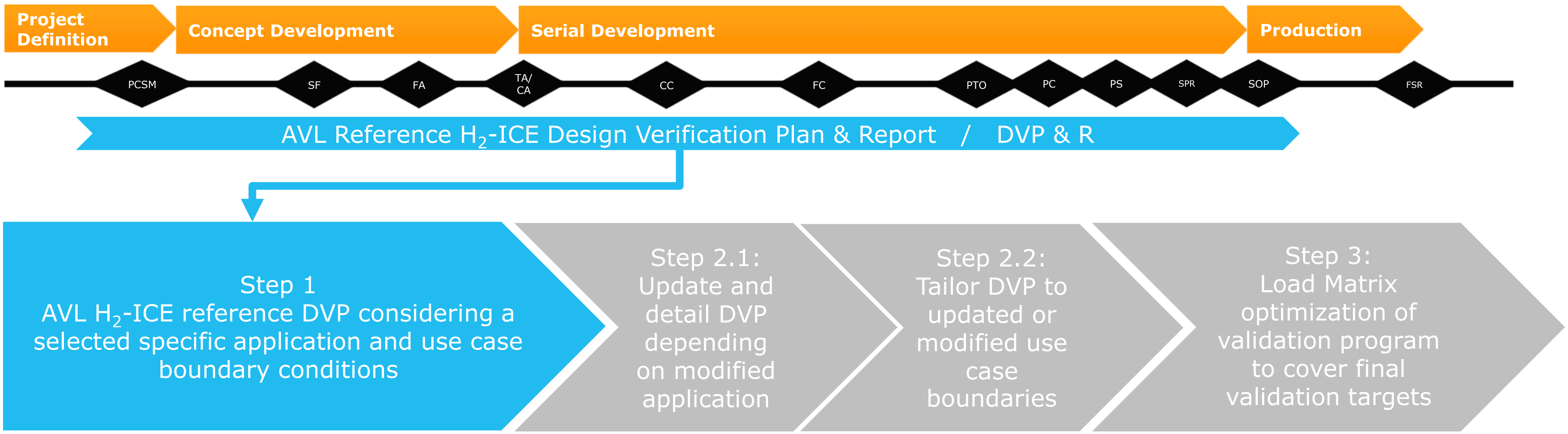
Tailoring of AVL Reference DVP



Tailoring of AVL reference DVP for series dev. of modified application and/or use case

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Load Matrix™ – 4 Module to Success

What needs to be tested?
How can it fail?

– **test the right things**

System Analysis

Customer Usage and Targets

Damage Calculation

Test Program

How are the systems used?

How reliable and durable do they need to be?

– **test the right amount**

How do we model failure?

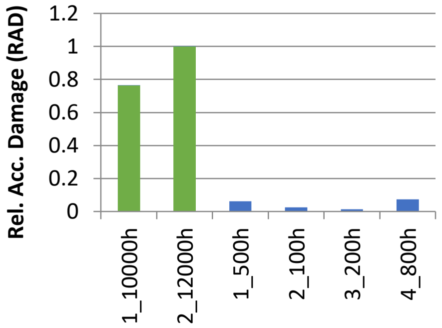
How is it being tested?

– **consider physics of failure**

What is the test program?

– **test appropriately and the right time**

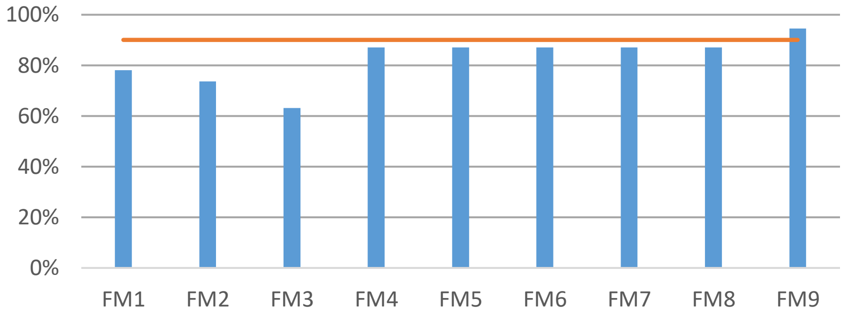
Testing Optimization



Reliability Evaluation

How **good** is the test program?

Demonstrable Reliability



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AVL System Analysis Approach for H_2-ICE Reference DVP

System Analysis

"What needs to be tested and how can it fail?"

Project Team

System Information

Technical Know-how

FMEA / FTA

Failure Mode Data Base

Design

System

Data collection

FP sheet…Failure Parameter sheet

FP sheet

- System Overview ✓
- System Prioritization ✓
  - **Evaluation of risks:**
  - 1: Low risk
  - 2: Medium risk
  - 3: High risk
- Failure Mode Definition ✓
  - Component / Location
  - Failure Physics
  - Operating Conditions
  - Aggravating Conditions

Failure Modes relevant for Verification → Design Verification Plan (DVP) related tasks

Failure Modes relevant for Validation ✓ → Project specific selection of failure modes → Definition and assignment of damage models

updating FP-sheet due to project mitigation

Failure mode LCF of Cylinder head selected ✓

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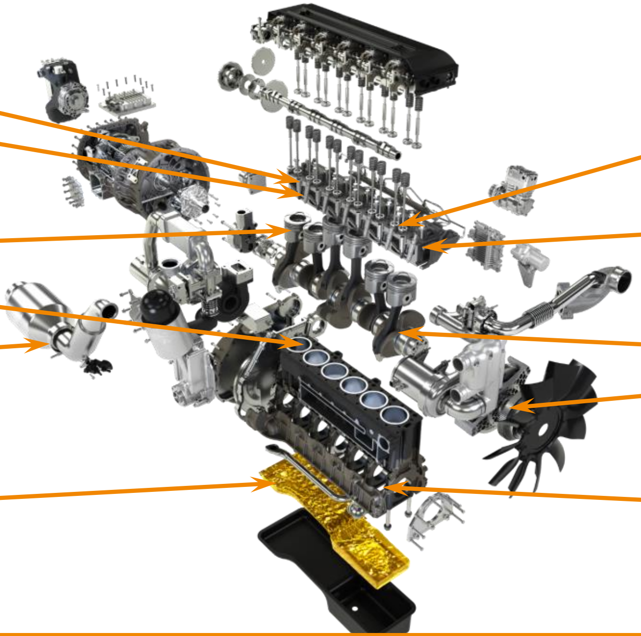
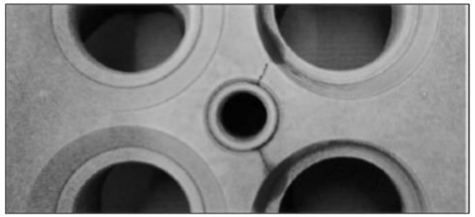
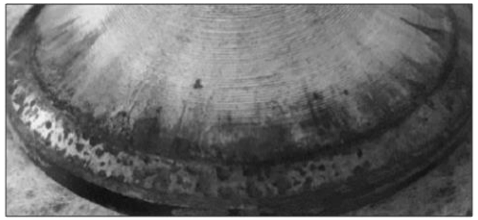
Impacts of H_2 on Mechanical Development & Validation





Main H_2-failure parameters

- Combustion irregularities
- Management of water content
- Oil input into combustion
- Hydrogen slip into crankcase
- Hydrogen embrittlement



Load Matrix™ based AVL Hydrogen Engine reference DVP to address impacts of H_2

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Relevance of Failure Modes compared to Diesel Engine

Failure Mode	Diesel Engine	CH_4 Engine ($\lambda = 1$)	H_2 Engine ($\lambda > 1.7$)	Main Relevant Engine Subsystems for Development
Irregular Combustion Events	O	>	>>	Combustion Chamber, Piston Group, Ventilation System, Spark Plug, DI-Injector
Oil Input into Combustion	O	>	>>	Piston Group, Ventilation System
Hydrogen Content in Crankcase	n.a.	n.a.	>>	Ventilation System
Durability of Injectors	O	=	>>	Injectors, Cylinder Head, Cooling System
Hydrogen Fuel Supply Components	n.a.	n.a.	>>	Fuel Supply System
Water Content of Exhaust Gas	O	>	>	EAS, Ventilation System
Valve Seat Wear	O	>>	>	Valve, Valve Seats, Cylinder Head
Thermo Mechanical Fatigue – Cylinder Head Cracks	O	>	=	Combustion Chamber, Cylinder Head
Piston Temperature – Oil Coking	O	>	<	Piston Group, Piston Cooling, Cooling System
Durability of Spark Plugs	n.a.	O	<	Spark Plugs

O Reference for development relevance   Relevance for Development: < Lower   > Higher   >> much higher   n.a.: not applicable

Focus on Relevant Engine Subsystems during Hydrogen Engine Development

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Summary & Conclusion

- **Hydrogen** is one major pillar of future **CO_2 neutral goods transport**
- **Main challenge** for mobile usage of hydrogen is **storage & fueling infrastructure**
- The **Hydrogen ICE** promises **short time to market** based on already **existing engines & vehicle infrastructure**
- **AVL Hydrogen Engine** is the **technology demonstrator** for:
  - MPI & LP-DI Technology
  - Customer acceptance by ensuring power and transient performance
  - Compliance with future emission legislation
- **Major development challenges for reliability**:
  - Definition and prioritization of relevant failure modes and parameters for hydrogen combustion
  - Definition of Reference DVP for Hydrogen ICE
  - Tailoring and optimization of Reference DVP to specific applications and use cases

AVL - THE partner for H_2-ICE development from early concept until SOP!

THANK YOU

Send questions/comments to:

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