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H_2 Powertrains for the road traffic of the future

A3PS
Paths to Climate-Neutral Mobility
Sustainable Propulsion Concepts and Energy Carriers for Carbon-Neutral Future - EUROPE AS FRONTRUNNER

- Motivation for Hydrogen (H_2) engines
- Applications in commercial vehicles and off-road
- Key Research- and Development challenges

DAIMLER MAHLE NAGEL HONEN SUPERFINISHEN PUREM by Eberspächer KIT Karlsruher Institut für Technologie

Founding idea „Allianz Wasserstoffmotor“

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Initial workshop 3rd July 2020 @ KIT

KIT Karlsruher Institut für Technologie

22 companies support the concept of the „Allianz Wasserstoffmotor“

Key conclusions:

a) Hydrogen direct injection combustion is feasible

b) Technical challenges can be solved using established development processes

c) It is sensible to introduce this technology for future commercial vehicles

4 companies and KIT have founded the “Allianz Wasserstoffmotor” and act executive committee

Hydrogen as the energy of tomorrow

A Brief look back in history

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„Water is the coal of the future. Energy of tomorrow will be water which is separated into Hydrogen and Oxygen using electricity. Those two elements will secure energy supply of the future.“

1874 Jules Verne „The Mysterious Island“

What has happened since the 2000s?

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- **Original driver**
  - In the case of the passenger car (BMW) → CARB ZEV
- **Today's driver**
  - CO_2-neutral fleet
- **H_2 infrastructure development in relevant markets: JP, KR, CN, EU**
- **Attractive H_2 prices through scale-up of generation and distribution**
- **Significant further development of the modern combustion engine**
  - Increase in power density through turbocharging
  - Tank technology, synergy with fuel cell
  - H_2 direct injection seems technically feasible
  - Exhaust gas aftertreatment from diesel engine can be largely adopted/simplified

The H_2 engine as a complement in the future powertrain

All paths needed on the way to CO_2 neutrality

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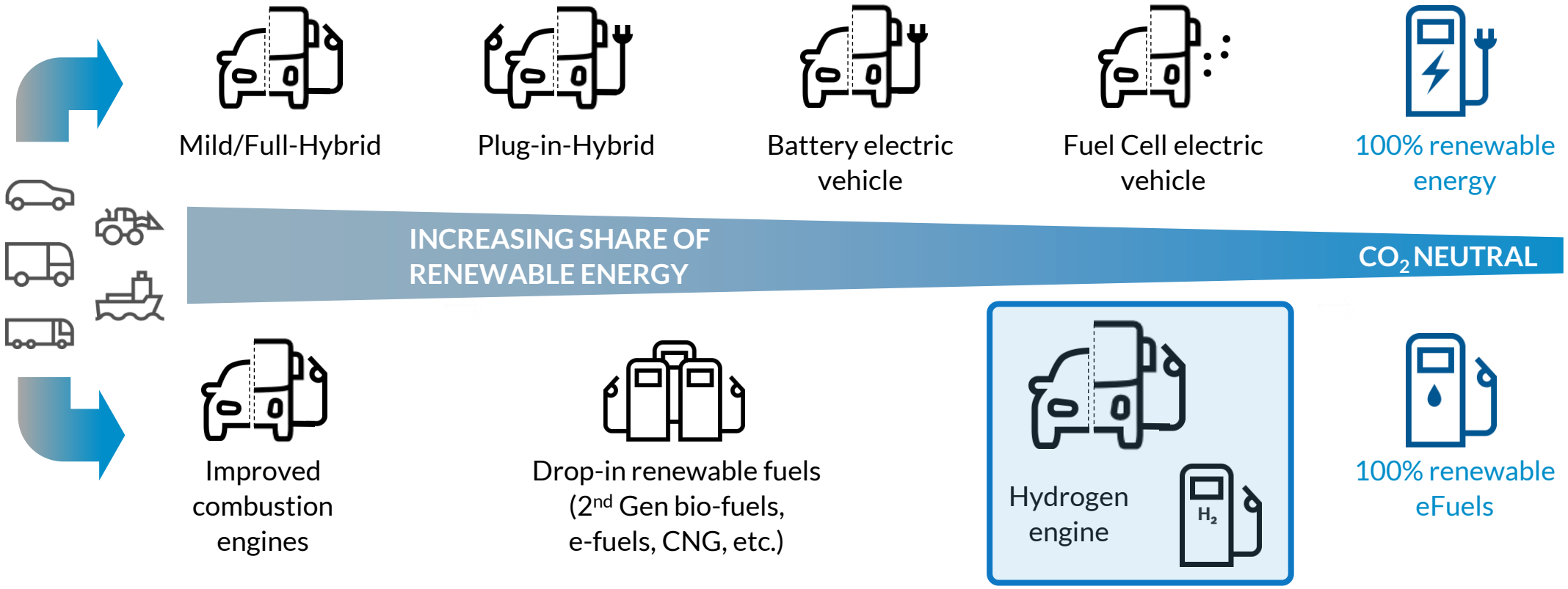
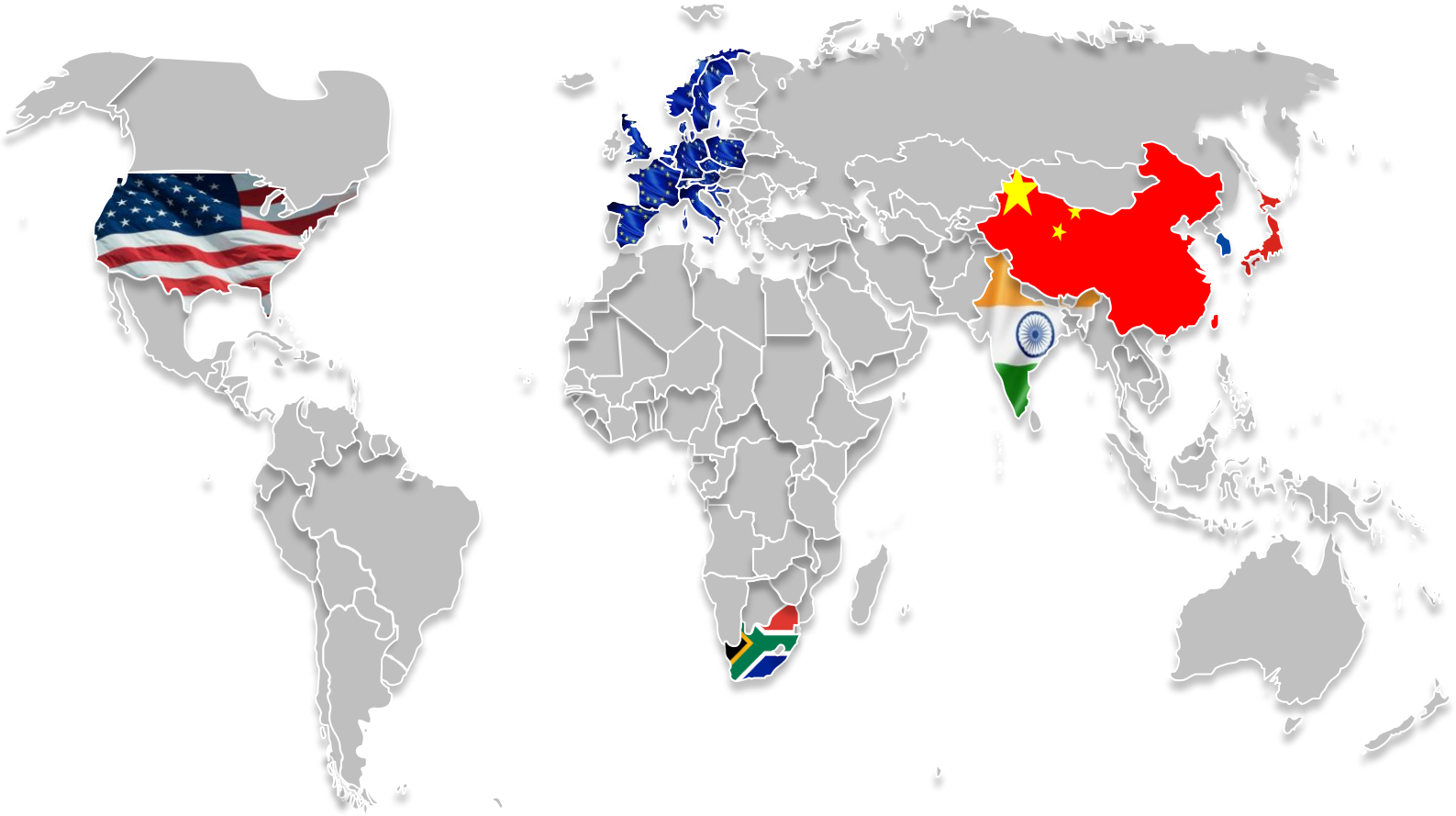


Following a technology-open approach, both Fuel Cell and H_2 engine should be included as possible solutions for hydrogen driven mobility.

2021, International Vienna Motor Symposium, Bosch: H_2 ICE Powertrains for future on-road Mobility

The H_2 engine as a complement in the future powertrain

A purely European idea?



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High worldwide interest in all relevant markets

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Paths for CO_2 neutral heavy-duty applications

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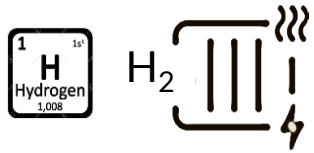
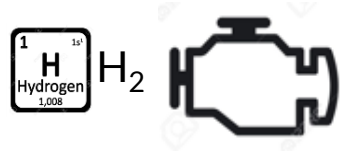
Example: HD long haul truck, 500km/day min. 15t payload

BATTERY ELECTRIC

H_2 FUEL CELL



H_2 ENGINE



Requirement: Renewable („green“) energy is mandatory basis for a CO_2 neutral mobility in both battery electric and hydrogen powertrains!

There are multiple paths to a CO_2 neutral future.
The H_2 engine is a valuable technical option.

The H_2 engine as a complement in the future powertrain

Diverse applications → complementary solutions

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Today
ICE as "all-rounder"

Use case

Regulations

Local political decisions

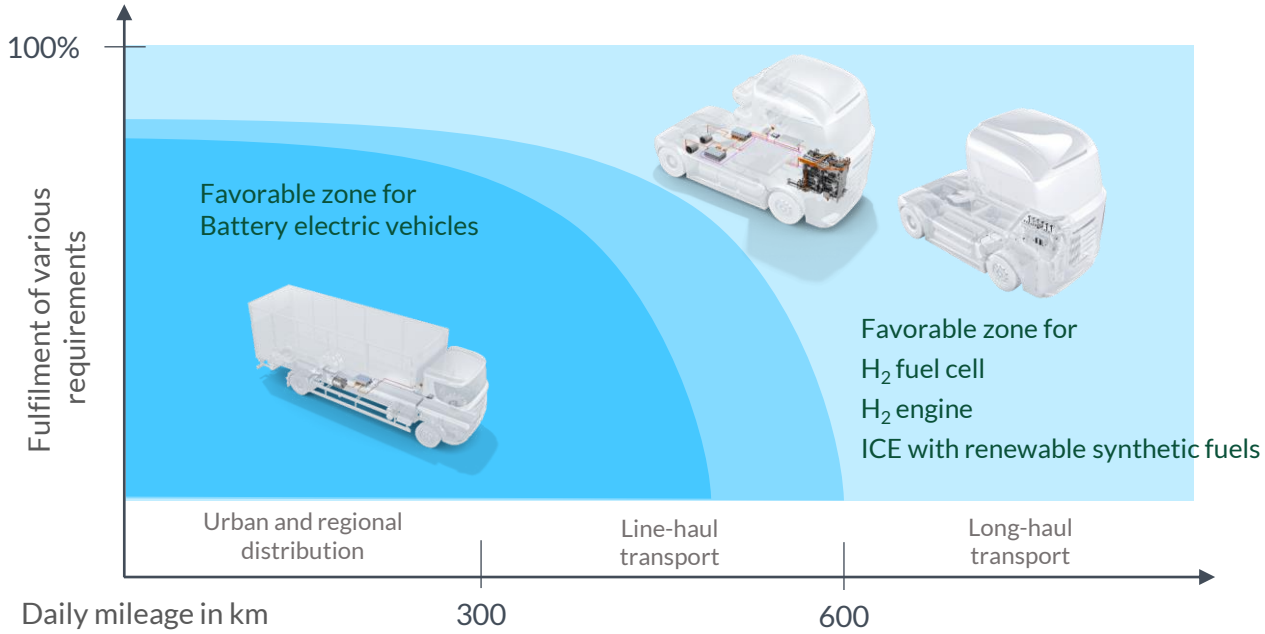
Strategic decisions
by vehicle manufacturers
and logistics operators

New business models,
e.g. pay-per-mile

Infrastructure

...

CO_2 neutral mobility



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Diverse applications → complementary solutions

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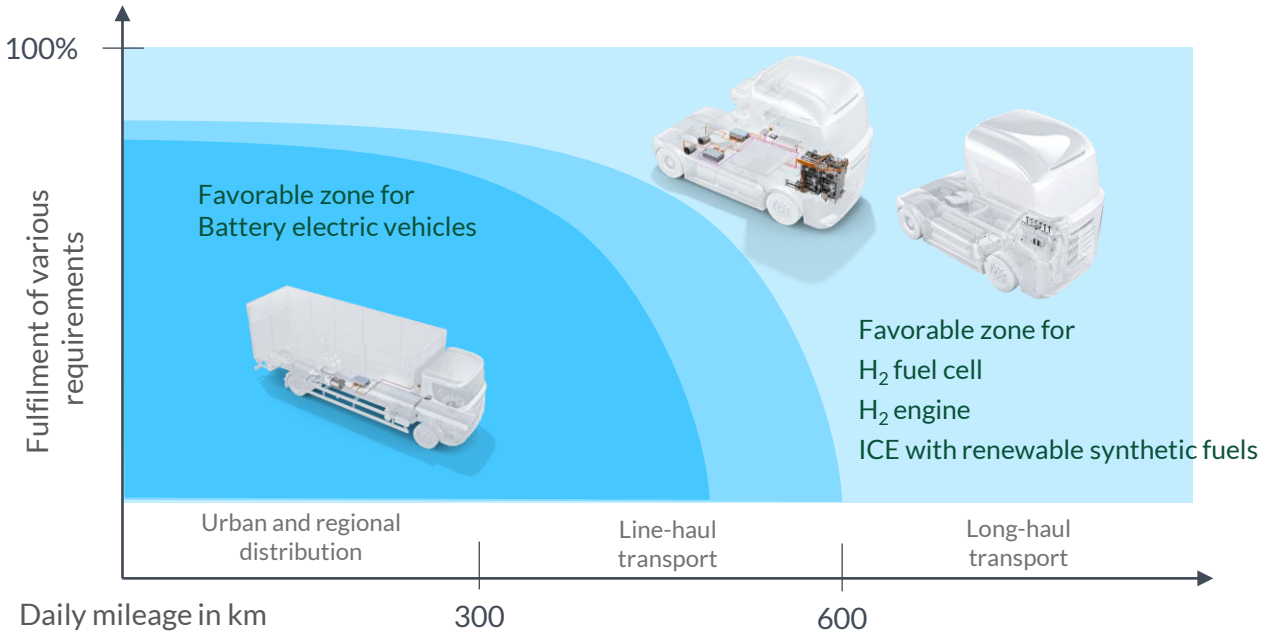
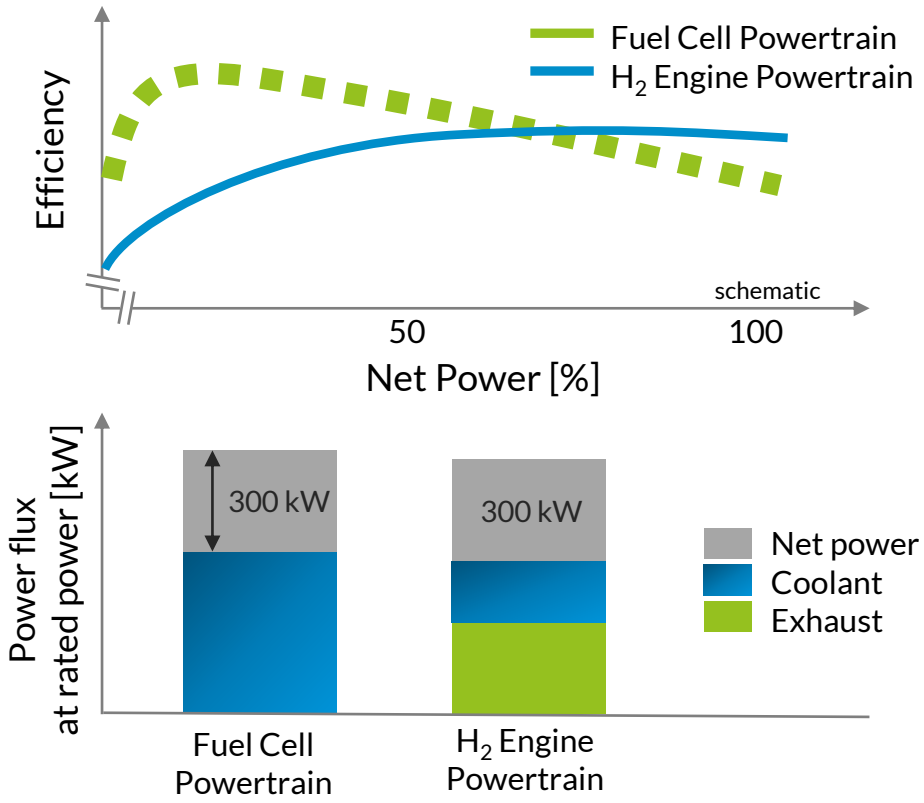
CO_2 neutral mobility



Focus on Fuel Cell and H_2 Engine



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The H_2 engine as a complement in the future powertrain

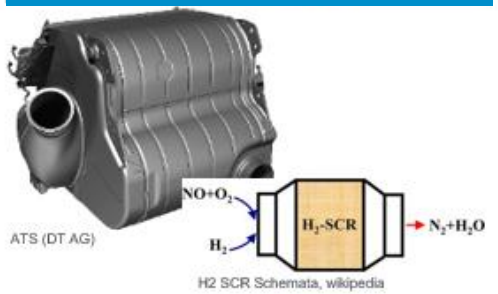
Challenges of the hydrogen engine

Technical

ENERGY CONVERSION IN ENGINE

Bosch Direkteinspritzung System / Zündkerze

EMISSIONS



ATS (DT AG)

H2 SCR Schemata, wikipedia

TANK SYSTEMS

Prototype LNG tank system, hdgas.eu

MATERIALS

Kongresshalle Berlin Einsturz, Wikipedia, Fotograf: Herbert Orth
Wasserstoffversprödung, Wikipedia, Uwe Aranas or alternatively © CEphoto

Social

For the realisation of the H_2 engine as a key future technology option there are 4 main technical challenges, as well as social aspects and public perception to be addressed.

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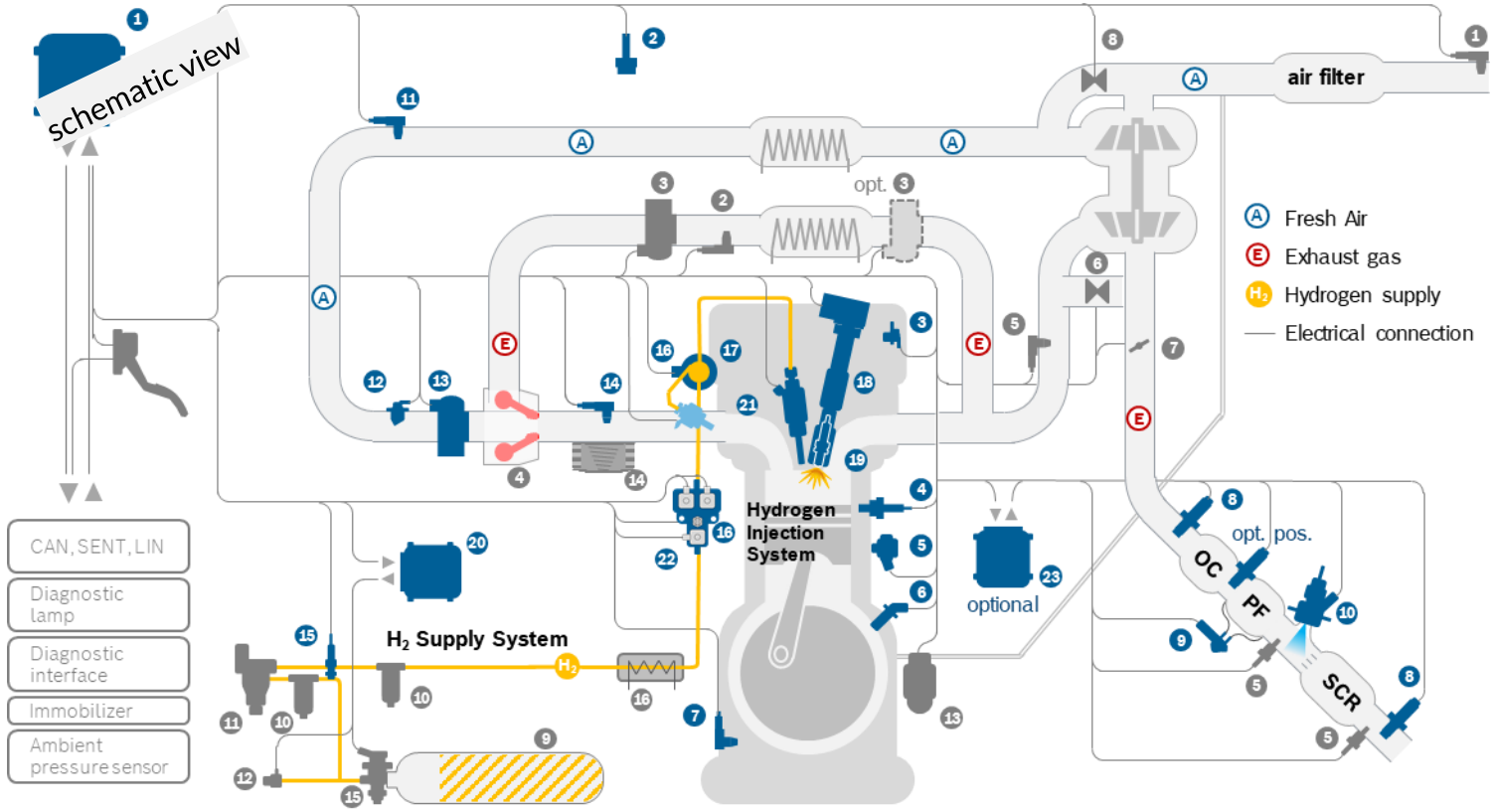
The H_2 engine as a complement in the future powertrain

System layout, hurdle or opportunity?



Component set up

1. Engine control unit
2. H_2 safety sensor
3. Phase sensor
4. Engine temperature sensor
5. Knock sensor
6. Speed sensor
7. Oil p/T sensor
8. NOx Sensor (under evaluation)
9. Differential pressure sensor
10. AdBlue dosing module
11. Boost p/T sensor
12. Pressure-based air flow meter
13. Throttle valve
14. Manifold p/T sensor
15. H_2 high-pressure sensor
16. H_2 medium-pressure sensor
17. Hydrogen Injection - Rail
18. Ignition coils
19. Spark plugs
20. H_2 Storage control unit
21. Hydrogen Injection – PFI/ Direct Injector
22. Hydrogen Injection - Pressure Regulator
23. Dosing control unit

1. Ambient humidity / T sensor
2. EGR p/T sensor
3. EGR valve
4. EGR mixer
5. Exhaust temperature sensor
6. Waste gate
7. Brake flap
8. Electronic dump valve
9. H_2 gas tank
10. H_2 filter
11. Pressure regulation block
12. H_2 filling receptacle
13. Crank case ventilation with Pressure sensor
14. Explosion relief valve (opt.)
15. H_2 tank valve with integrated temperature sensor
16. Opt.: H_2 Temp. conditioner

2021, International Vienna Motor Symposium, Bosch: H_2 ICE Powertrains for future on-road Mobility

Complex system layout – BUT: For manufacturing processes of engine and components there is already an established development environment in Europe with associated value creation in production

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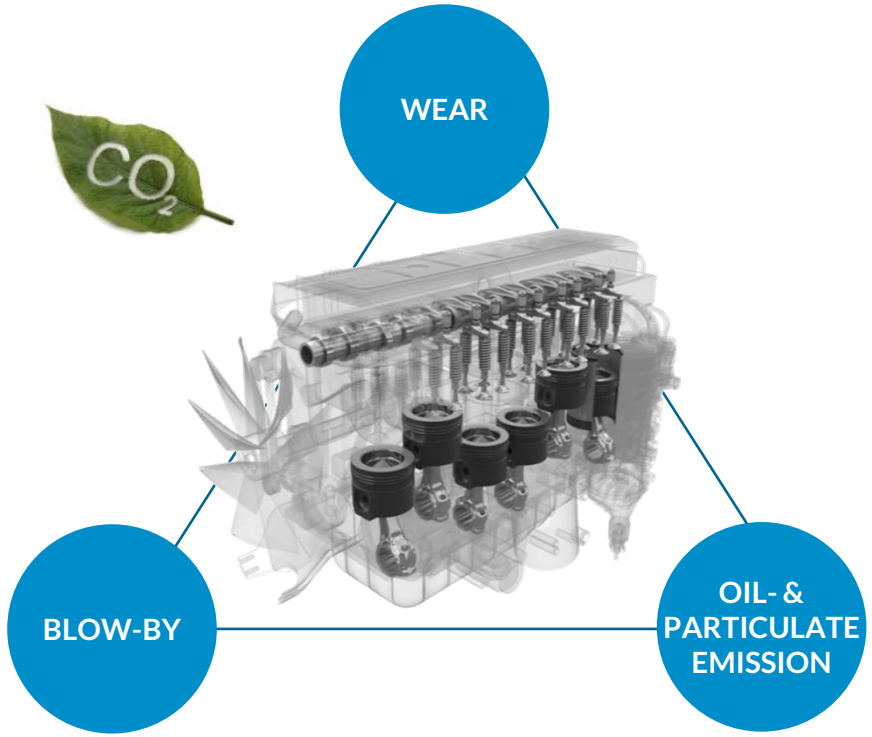
Challenges for engine components

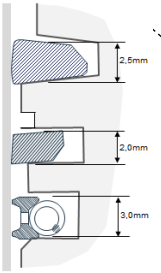


INTAKE VALVE

- Material and coating combinations for „dry“ operating conditions → wear resistance

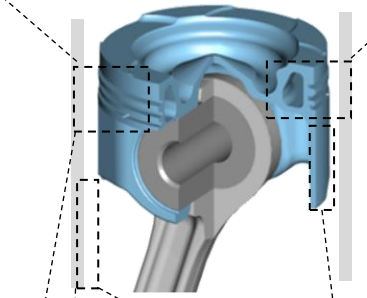
EXHAUST VALVE

- Materials for high temperature applications
- Wear resistance with high contact forces at seat inserts



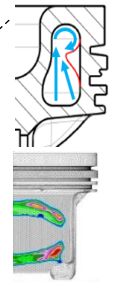
PISTON RINGS

- Low friction coatings with low viscosity oils
- Blow-by of H_2
- Oil- & particulate emissions



CYLINDER LINER

- Surface and honing structure



PISTON

- H_2 embrittlement resistive materials
- Knock sensitivity
- Wear by oil dilution / water in oil
- Optimised ring grooves

Hollistic component optimisation and increased robustness required
Emission reduction and wear protection measures need to be balanced

The H_2 engine as a complement in the future powertrain

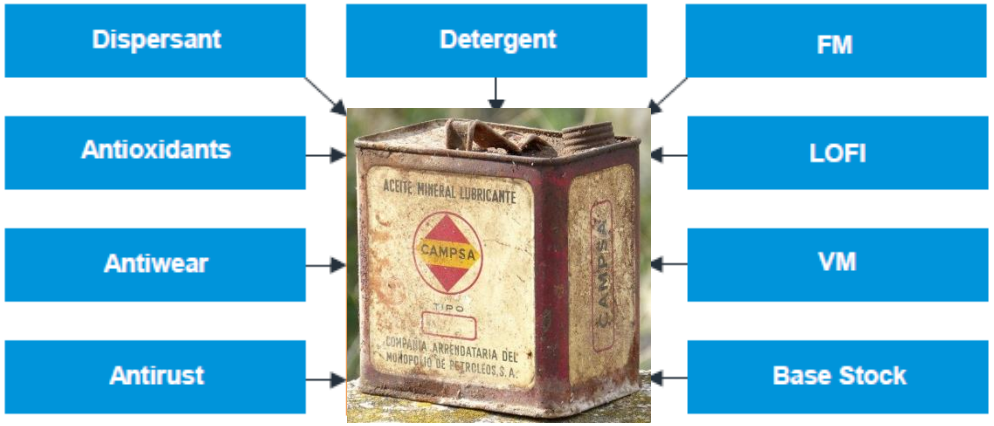
Challenges for engine periphery and lubricants

INJECTION SYSTEM

- H_2 embrittlement resistive materials
- Wear resistance under „dry“ operating conditions

CRANK CASE VENTILATION (CCV)

- H_2 in CCV system
- High efficiency oil separation



LUBRICANTS

- Oil dilution by combustion water contamination
- Additive formulations for H_2 operation → e.g. no soot contamination
- Water based lubricants

Hydrogen as fuel poses new requirements to both materials and engine periphery (e.g. media management)
New approaches with lubricants and their additives are to be developed

The H_2 engine as a complement in the future powertrain
„Classic“ emission as a challenge?

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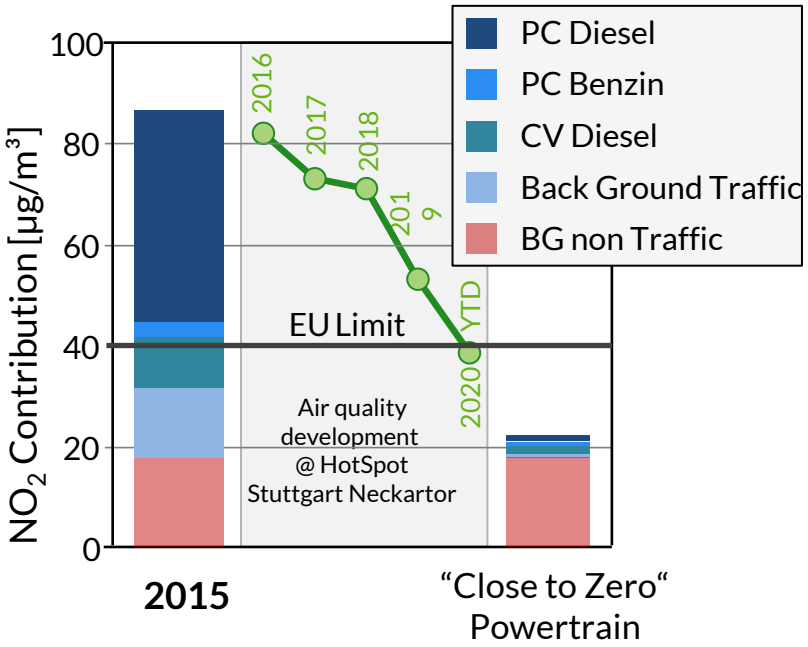
Initial condition – Diesel PT

Air Quality simulation @ Stuttgart Neckartor



Comparison: Exhaust gas emission H_2 vs. Diesel

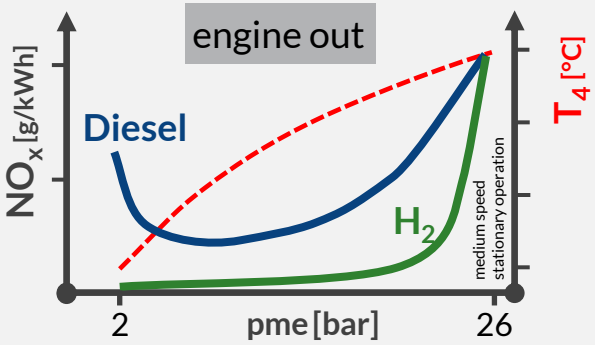
Schematic view

PM PN HC CO

H_2: Extreme low values due do C-free fuel + Oxidation catalyst + particle filter working

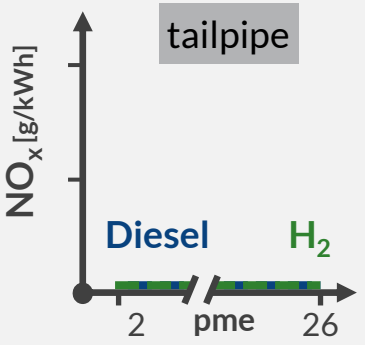
NO_x

H_2: For low/medium load lower NO_x engine out emissions + SCR working



SCR-catalysts

lower NO_x concentrations @ low/medium load supportive



“Classic emissions” are no longer a challenge for the diesel engine
The hydrogen engine supports exhaust gas aftertreatment via the combustion properties of H_2

2021, Digitale CVC-Jahrestagung „Wasserstoff – Innovative Perspektiven für die Nutzfahrzeugindustrie“, Bosch: Wasserstoffbasierte Antriebstechnologien für eine CO_2-freie Mobilität im Nutzfahrzeug

The H_2 engine as a complement in the future powertrain

Exhaust gas aftertreatment challenges + solutions

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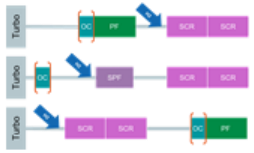
engine boundaries & legislation

Motor:
- $T4_{H2} \approx T4_{Diesel}$
- $NOx_{H2} << NOx_{Diesel}$
- $PN_{H2} << PN_{Diesel}$

EU VII:
- NOx ⬇
- N_2O limit
- PN 10 nm
- OBM

CO_2:
2025 – 15 %
2030 – 30 %

→ **Technologies ready for 2025**

	NH_3-SCR	H_2-SCR	H_2-SCR / NH_3-SCR
	 Stufe 1	 Stufe 2a	 Stufe 2b
Advantage	▪ Well known technology ▪ Existing infrastructure	▪ High low load conversion ▪ Less components	▪ High performance @ full engine map
Challenge	▪ CO_2 neutral ▪ Limited low load conversion	▪ NO_x conversion at higher load ▪ N_2O selectivity ▪ Gas/gas mixing	▪ NO_x conversion at higher load ▪ N_2O selectivity ▪ Gas/gas mixing

[1] 1 g/kWh CO_2 will be achieved at approx. 1.7 g/kWh NO_x engine out

Exhaust gas aftertreatment solutions for H_2 engines „ready to market“ based on established technologies
Further development towards H_2 based de-NOx technologies possible

The H_2 engine as a complement in the future powertrain

Complementary CO_2 neutral powertrains

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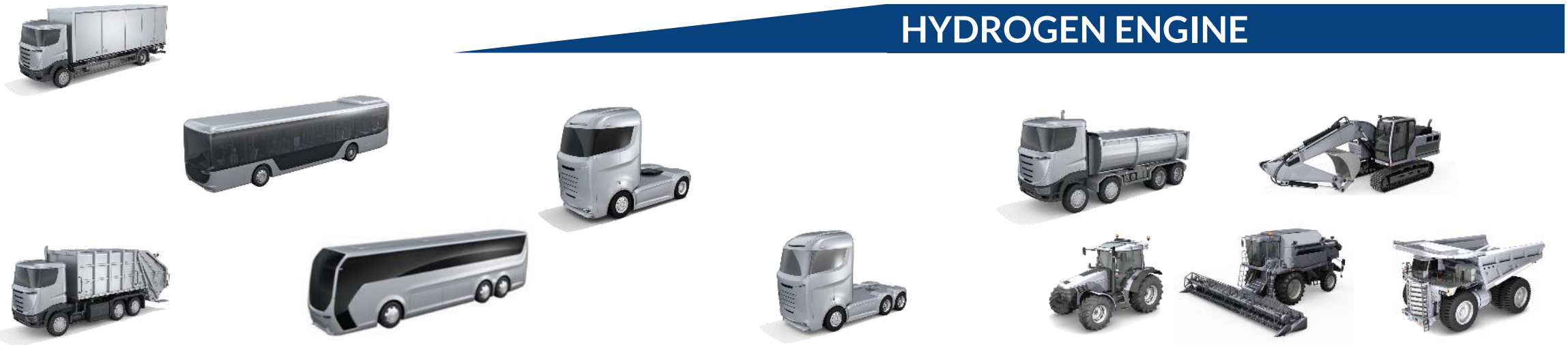
BATTERY ELECTRIC

HYDROGEN FUEL CELL

HYDROGEN ENGINE



Applications of commercial vehicles are highly heterogeneous (e.g. load, power, range, terrain, ….)
→ THERE IS NO „ONE SOLUTION FITS ALL“!
All 3 powertrain technologies will be needed to meet customer requirements across the various applications

2021, Karlsruhe, "Der Wasserstoffmotor", Bosch: H_2-engine in heavy CV application – first optimization of injector and control strategy

The H_2 engine as a complement in the future powertrain

Conclusions

- Hydrogen as an energy carrier for heavy-duty commercial vehicles is mandatory for achieving the global Paris climate agreement targets
- In terms of robustness, speed to market and total cost of ownership, the hydrogen engine represents a very attractive CO_2 neutral technology option, especially for heavy-duty applications of the future
- The H_2 engine can complement battery electric and hydrogen fuel cell powertrains in commercial vehicles. It can open the possibility to meet the customer demands across the various applications.
- The technology of the hydrogen engine is demanding, basic research and pre-development work is ongoing and the “Allianz Wasserstoffmotor” members are convinced that the technology can be put to trial in test vehicles from 2023
- Hydrogen engine technology offers the opportunity to maintain technological leadership in Europe in a potentially key future technology

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Thank you very much for your kind attention!

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