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H_2 ICE Hybrid Powertrain for LCV Application

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H_2 ICE Democar

Finanziert von der Europäischen Union
NextGenerationEU

Gefördert durch:
Bundesministerium für Wirtschaft und Klimaschutz
aufgrund eines Beschlusses des Deutschen Bundestages

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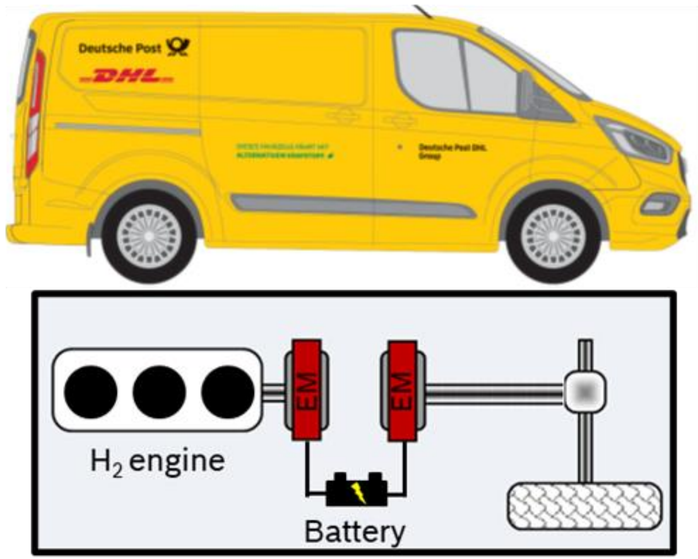
Agenda

- Project Scope of the “H_2 ICE Democar” Project
- Hydrogen Engine
- Hydrogen Exhaust Gas Treatment
- Transient Results
- Summary

„H_2 ICE Democar“



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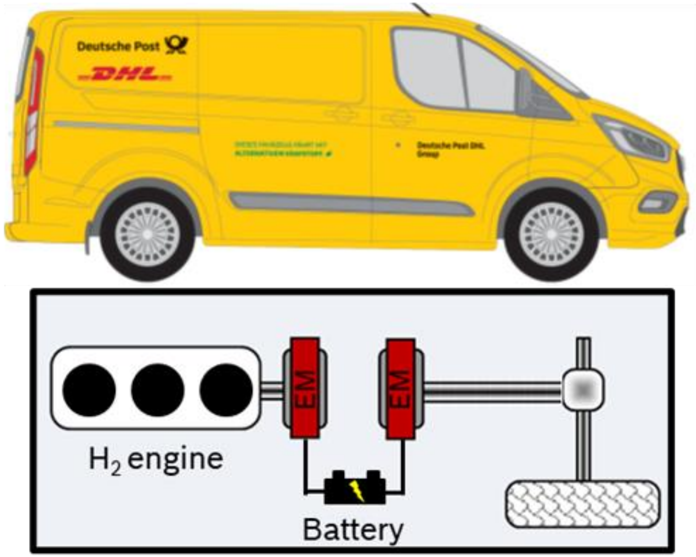

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H_2 ICE Hybrid Powertrain for LCV Application

Project Scope of the "H_2 ICE Democar" Project

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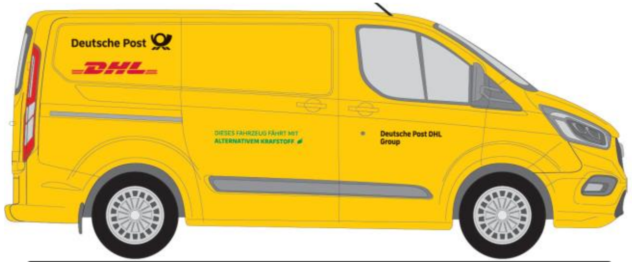

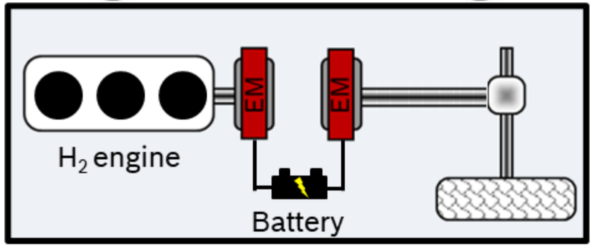

Potential transfer into series development

Future LDVs with H_2 engine

Project target: TRL 7 „System prototype demonstration in operational environment"

Demonstration of H_2 engine application in a serial hybrid democar based on Ford Transit Custom PHEV.

LDV: Light Duty Vehicle, PHEV: Plug-in Hybrid Electric Vehicle, TRL: Technology Readiness Level

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Challenge: “Convert existing Vehicle to H_2 Operation”

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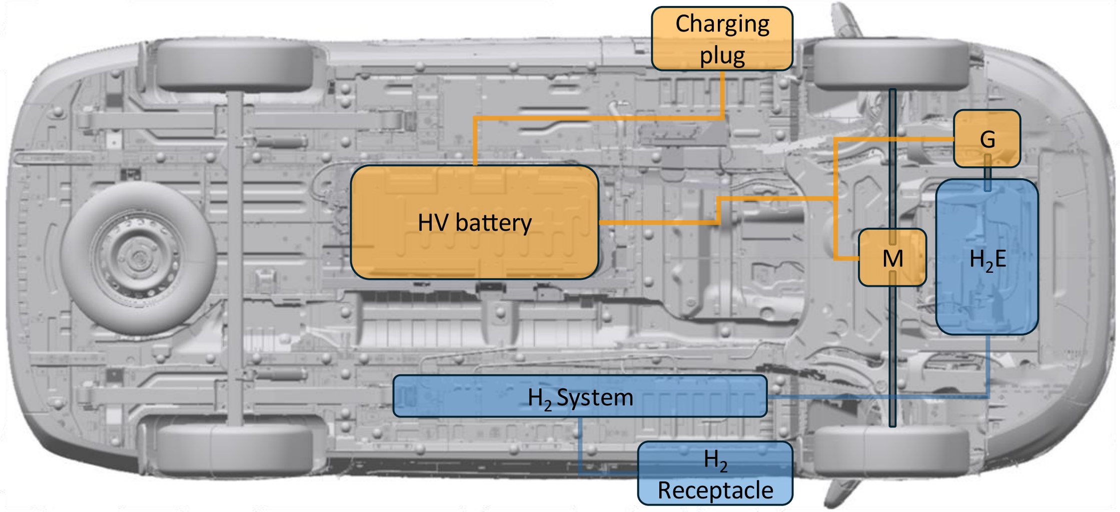

Vehicle specification	
Vehicle mass:	2705 kg
Battery capacity:	13.6 kWh
EM types:	60 kW generator, 92 kW e-motor
ICE type:	1.0 l EcoBoost H_2
H_2 system:	4.6 kg H_2 at 700 bar

Key modifications
H_2 engine
H_2 exhaust gas treatment
H_2 system
H_2 vehicle controls

Serial hybrid powertrain enables a vehicle operation strategy for maximized efficiency and minimized emissions.

H_2E: hydrogen engine, G: generator, M: electrical traction machine, HV: high voltage, ICE: internal combustion engine

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- **Hydrogen Engine**
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H_2 ICE Hybrid Powertrain for LCV Application
H_2 Engine: Engine Modifications for H_2 Operation

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Cylinder head and base engine:
- Reinforced crank train with revised bearings
- New enhanced piston
- Modified intake and exhaust valves + valve seats
- Optimized tribological system: cylinder honing + piston rings

Crank case ventilation:
- Active system
- Enhanced oil separation

1.0 l EcoBoost H_2	
Engine type	I3
Bore / mm	71.9
Stroke / mm	82.0
CR	10.0
Rated power / kW	60

Boosting system:
- All new single stage VGT

H_2 fuel injection system:
- Low pressure direct injection
- Rail with H_2 pressure and temperature sensor
- Pressure regulator

H_2 ignition system:
- "Cold" prototype H_2 spark plug
- Modified ignition coil

$\lambda \geq 2$ operation over entire engine map to maximize thermal efficiency and to minimize engine-out emissions.

VGT: Variable Geometry Turbine, CR: Compression Ratio, λ: relative air-fuel ratio

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H_2 ICE Hybrid Powertrain for LCV Application

H_2 Engine: Stationary Test Results – Overview

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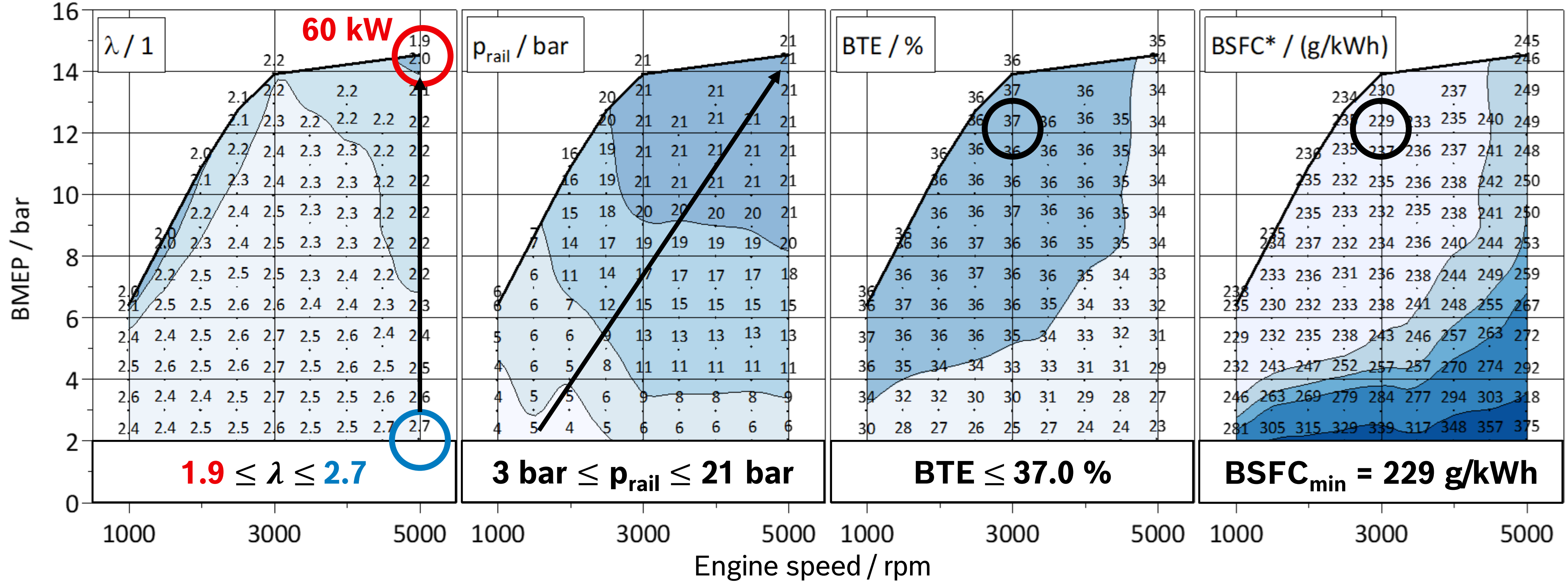

Engine can be operated with $\lambda \geq 2.0$ and $p_{rail} \leq 21$ bar up to 60 kW: best BTE = 37 %, $BSFC_{min}$ = 229 g/kWh.

*Converted to gasoline according to heating values of gasoline and hydrogen, BMEP: brake mean effective pressure, λ: relative air-fuel ratio, p_{rail}: rail pressure, BTE: brake thermal efficiency, $BSFC_{min}$: minimum brake specific fuel consumption

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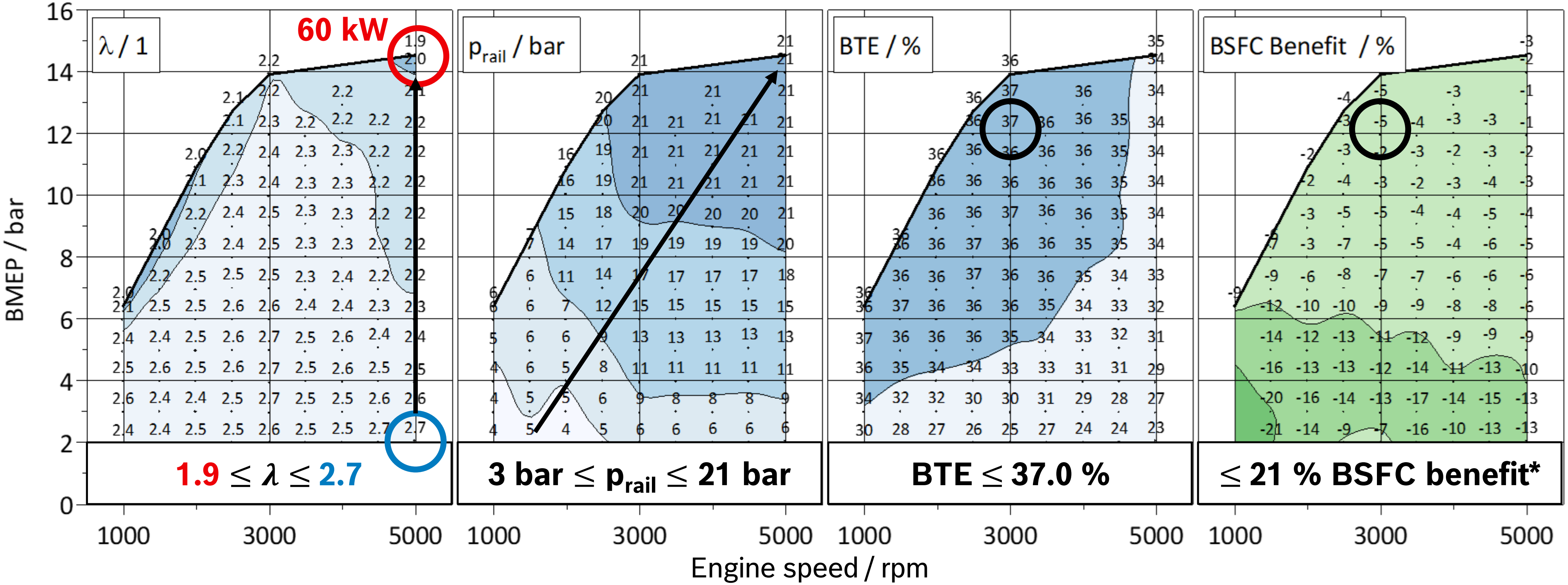

Engine can be operated with λ ≥ 2.0 and p_{rail} ≤ 21 bar up to 60 kW: best BTE = 37 %, $BSFC_{min}$ = 229 g/kWh.

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H_2 ICE Hybrid Powertrain for LCV Application

H_2 Engine: Stationary Test Results – Operation Limits

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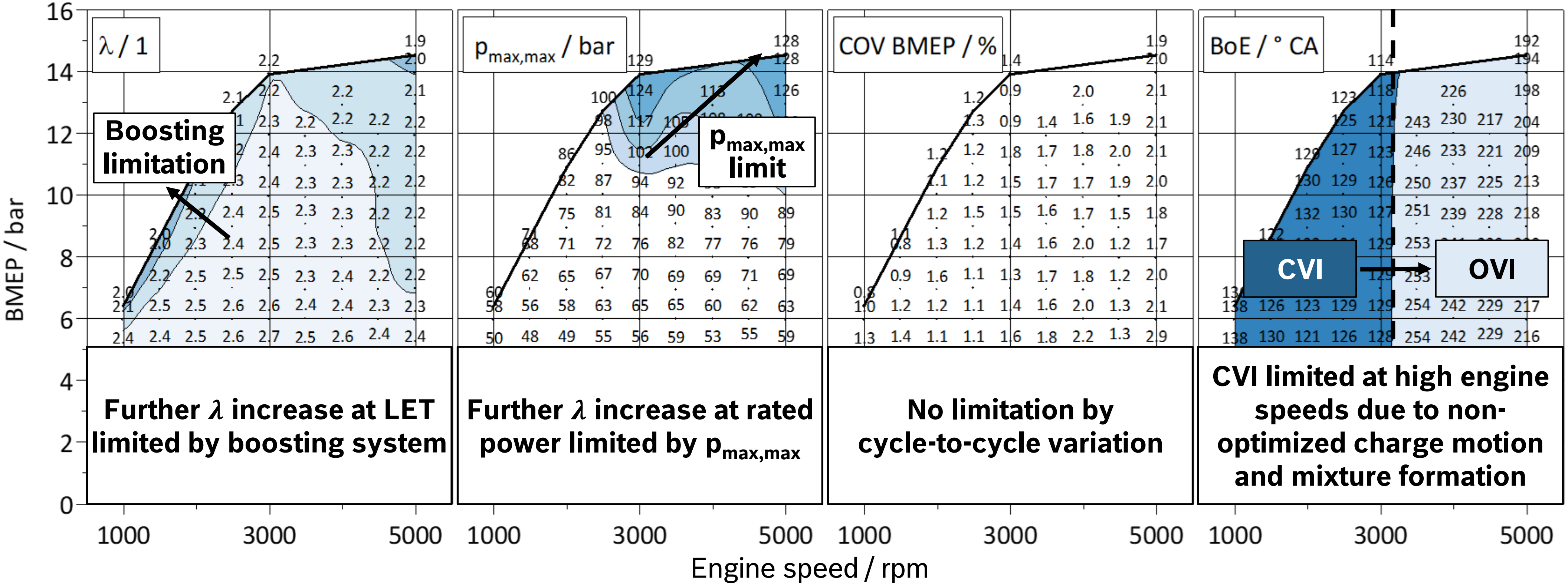

Current 1.0 EcoBoost H_2 engine is limited by boosting system, peak cylinder pressure capability, charge motion and mixture formation.

BMEP: brake mean effective pressure, λ: relative air-fuel ratio, $p_{max,max}$: peak in-cylinder pressure, COV: coefficient of variation (BMEP), BoE: begin of energization, LET: low-end torque, CVI/OVI: closed/open valve injection

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H_2 Engine: Stationary Test Results – Engine-out Emissions

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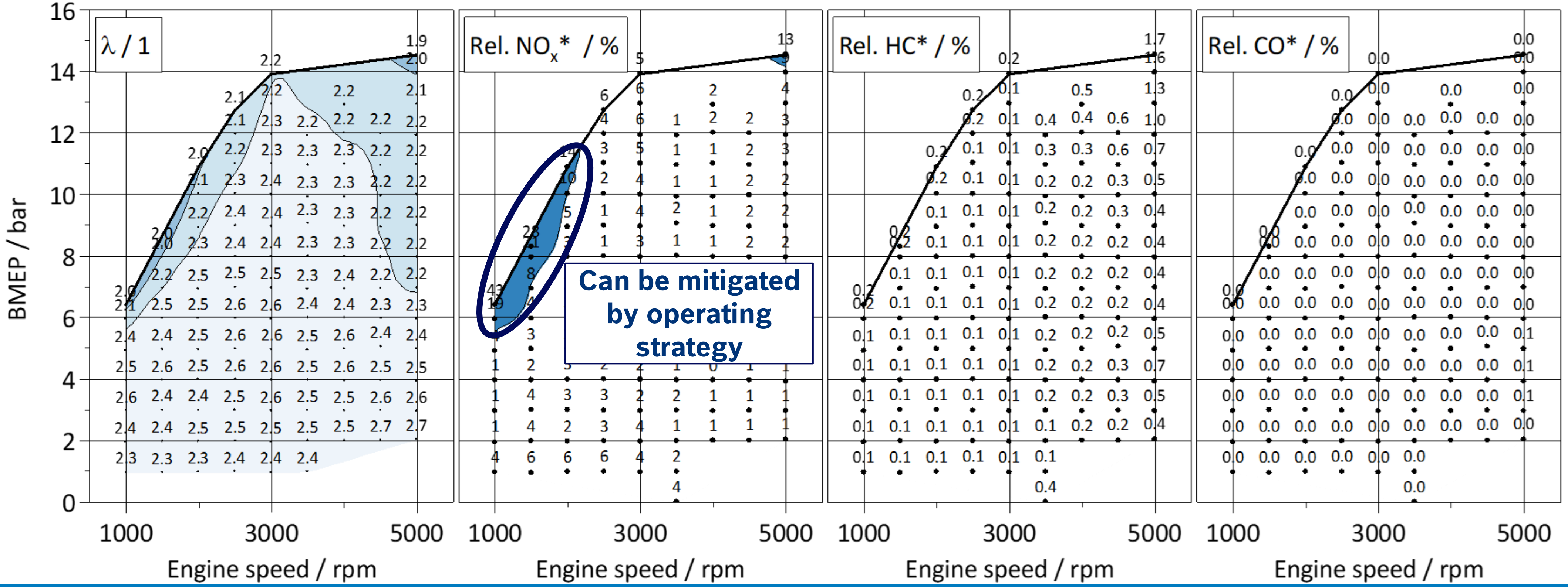

For stationary H_2 operation, engine-out HC and CO emissions < 2 %, engine-out NO_x emissions ≤ 13 % of gasoline related emissions in large area of the engine map.

* Engine-out emission values are normalized to the corresponding mass production gasoline engine, λ: relative air-fuel ratio, NO_x: Nitrogen Oxides ($NO+NO_2$), HC: hydrocarbons, CO: carbon monoxide

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H_2 Engine: Hybrid Operation Strategy

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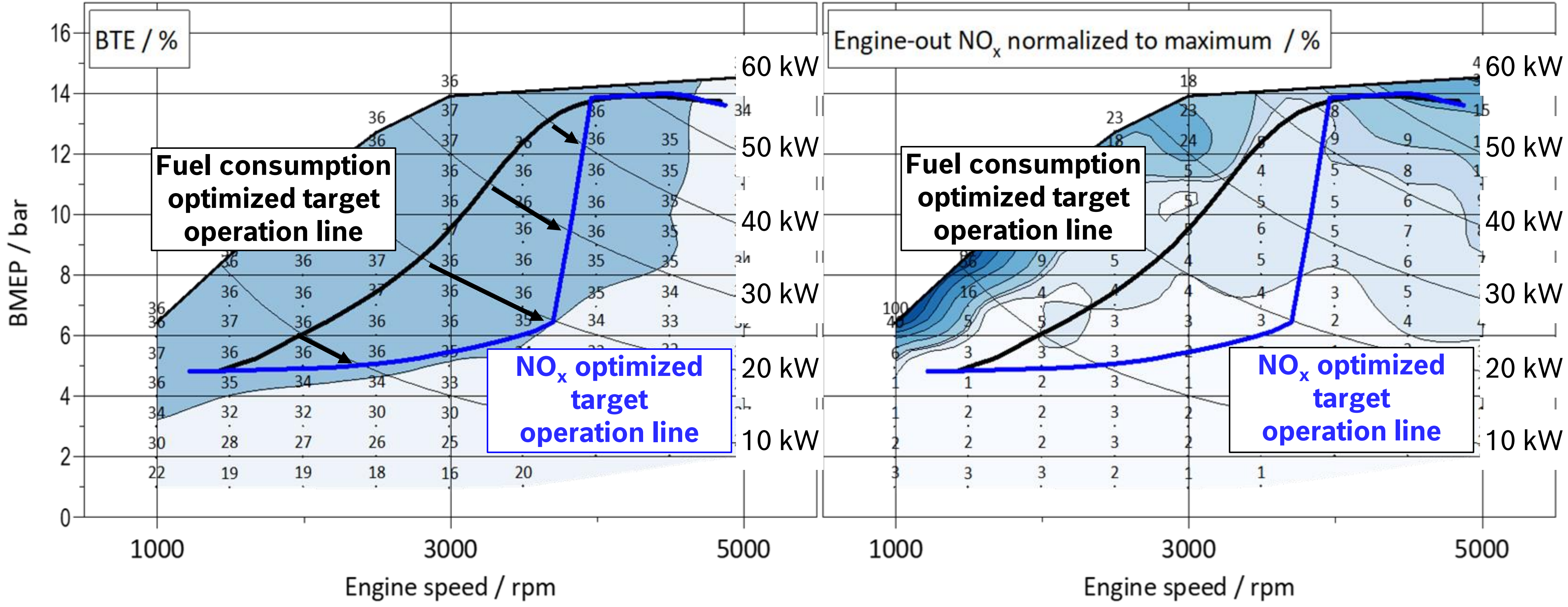

BMEP: brake mean effective pressure, BTE: brake thermal efficiency, NO_x: Nitrogen Oxides ($NO+NO_2$)

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H_2 ICE Democar

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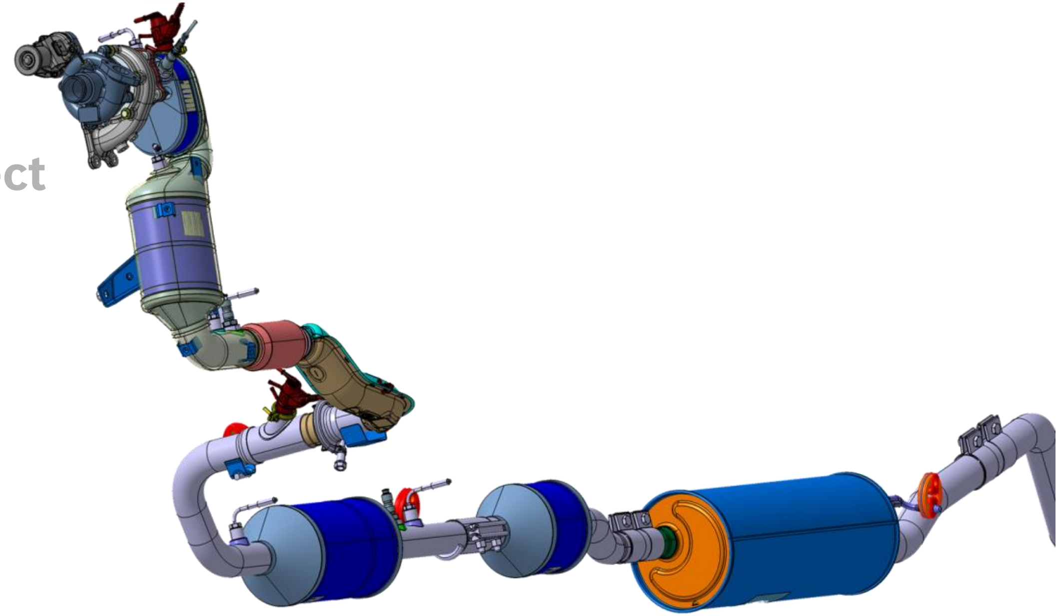
- Project Scope of the “H_2 ICE Democar” Project
- Hydrogen Engine
- **Hydrogen Exhaust Gas Treatment**
- Transient Results
- Status Vehicles and further Use



H_2 ICE Hybrid Powertrain for LCV Application
Hydrogen Exhaust Gas Treatment

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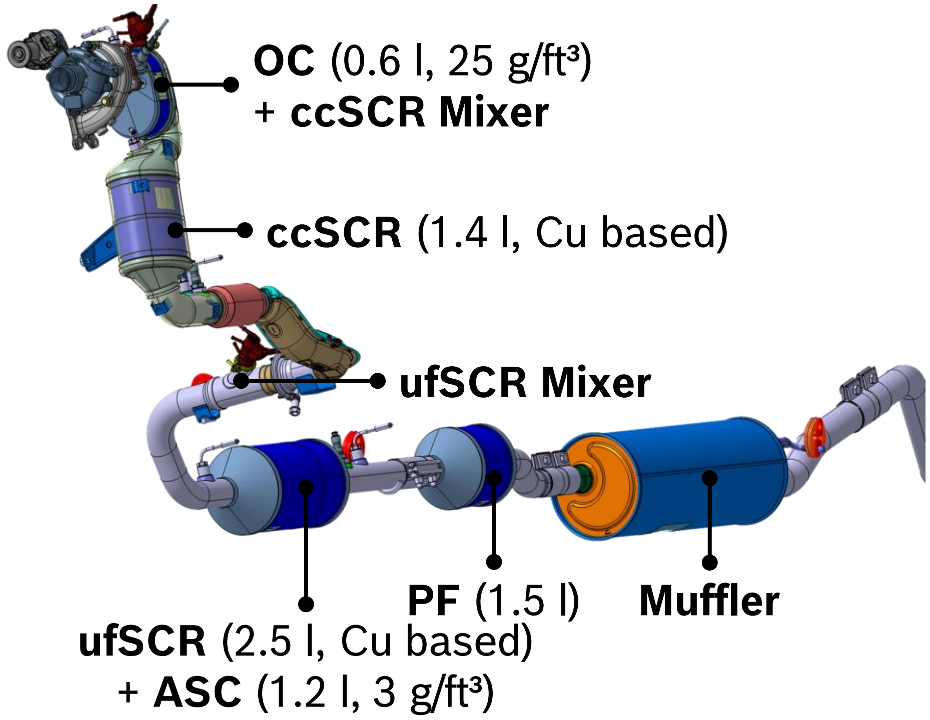

- **Oxidation Catalyst (OC):**
  - Oxidation of H_2, residual CO and HC
  - Heating function at cold start conditions
  - Oxidizing NO to NO_2 for efficient NO_x conversion in SCR catalyst
- **Selective Catalytic Reduction (SCR) catalyst:**
  - Reduction of engine-out NO_x-emissions
- **Ammonia slip catalyst (ASC):**
  - Prevent NH_3 emission slip in case of NH_3desorption
- **Particle filter (PF):**
  - Addresses potential PN emissions over lifetime

Challenging package in demonstrator vehicle, especially for close-coupled catalyst:
EGT system is a compromise between required installation space and function.

H_2: hydrogen, HC: hydrocarbons, CO: carbon monoxide, NO_x: nitrogen oxide emissions (NO+ NO_2), PN: particle number, cc: closed-coupled, uf: underfloor

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Hydrogen Exhaust Gas Treatment

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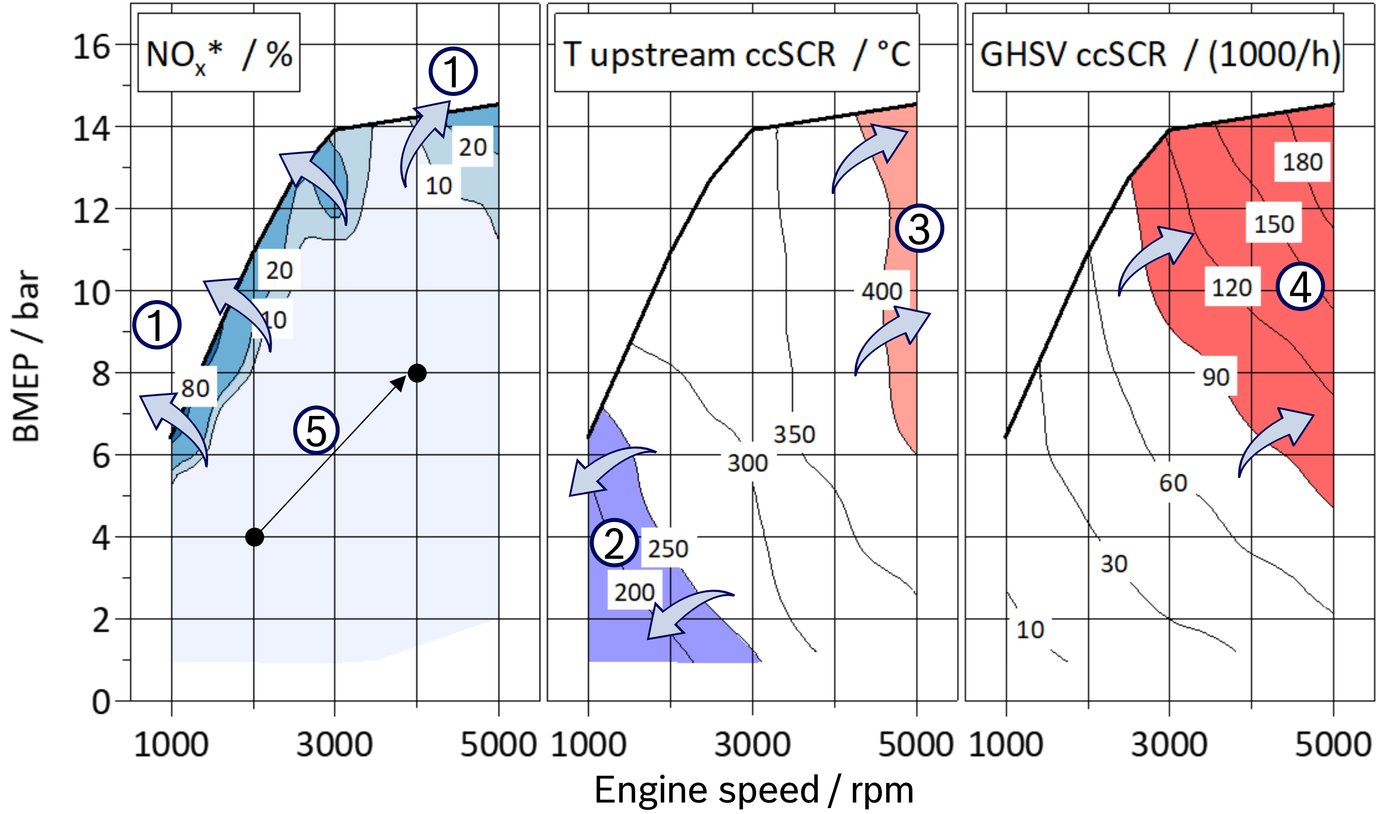

Challenges:

① **limited air supply**
-> engine-out NO_x ↑

② **Low exhaust temperature**
-> SCR NO_x conversion efficiency ↓

③ **High exhaust temperature**
-> SCR NO_x conversion efficiency ↓

④ **High exhaust mass flows / velocities**
-> SCR NO_x conversion efficiency ↓

⑤ **Transient operation**
-> engine-out NO_x ↑

Challenging package in demonstrator vehicle, especially for close-coupled catalyst: EGT system is a compromise between required installation space and function.

* Engine-out NO_x normalized to the maximum, BMEP: brake mean effective pressure, NO_x: Nitrogen Oxides ($NO+NO_2$), T: temperature, GHSV: Gas Hourly Space Velocity, ccSCR: closed-coupled selective catalytic reduction

Power Solutions | Dr.-Ing. Jan Niklas Geiler | 2025-11-13 | The presentation does not include any legal advice. Information regarding legislative and other regulatory requirements should be checked carefully on an independent basis.
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Transient Vehicle Results – WLTC (charge sustaining mode)

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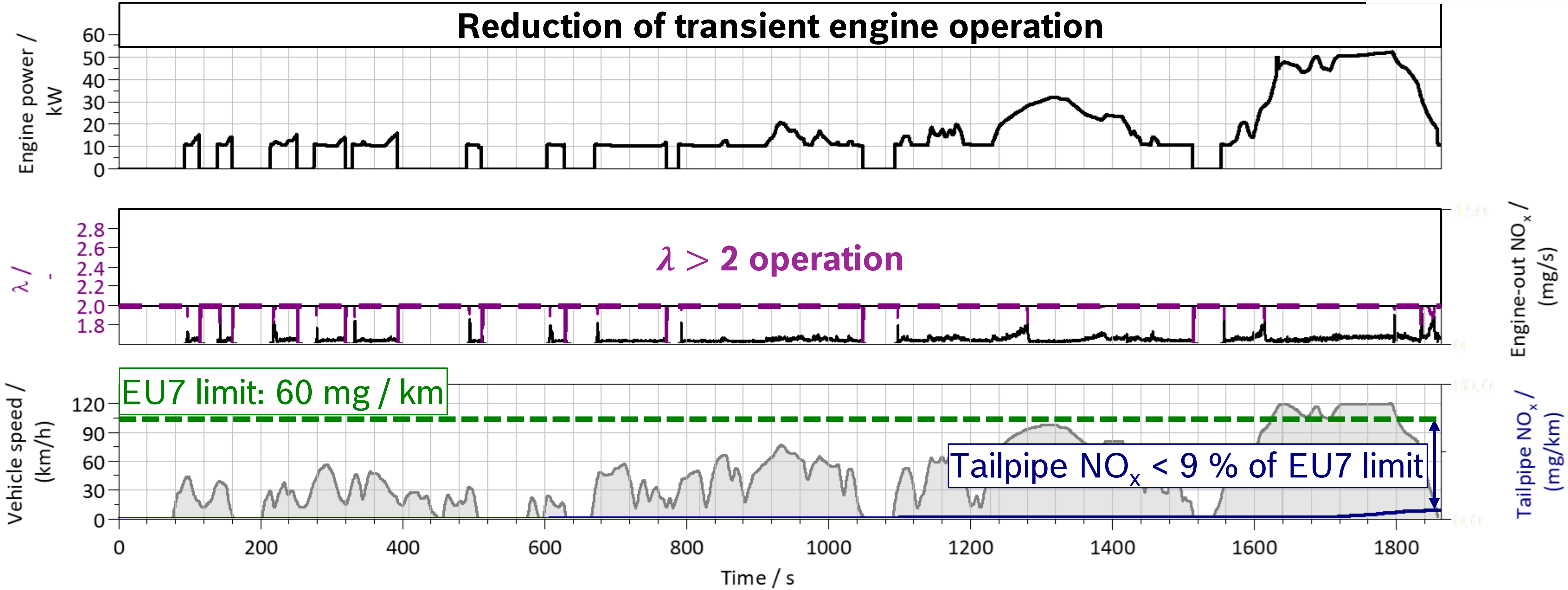

Vehicle test: very low engine-out NO_x emissions for λ > 2 operation, further improvement potential at engine start/stop feasible, tailpipe NO_x emissions significantly below EU7 limit.

WLTC: Worldwide harmonized light vehicles test procedure, λ: relative air-fuel ratio, NO_x: Nitrogen Oxides ($NO+NO_2$)

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H_2 ICE Hybrid Powertrain for LCV Application
Transient Vehicle Results – WLTC (charge sustaining mode)

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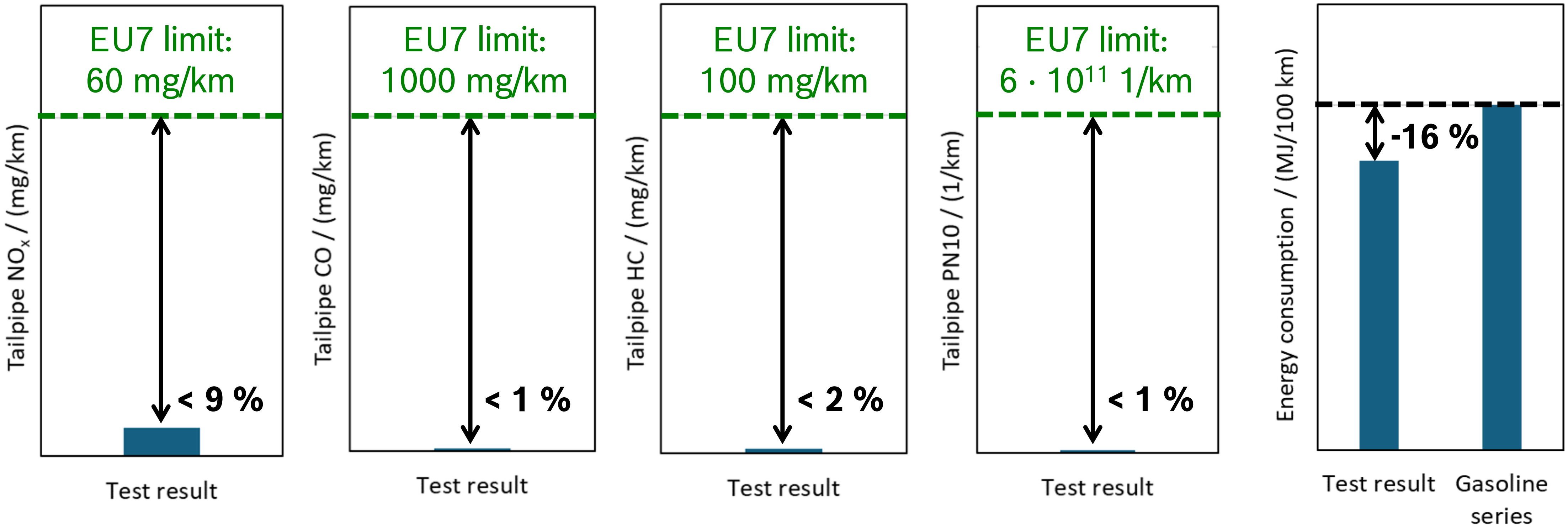

Vehicle test: NO_x, CO, HC, PN10 tailpipe emissions significantly below EU7 limit.
Energy consumption reduced by 16 %.

WLTC: Worldwide harmonized light vehicles test procedure, NO_x: Nitrogen Oxides ($NO+NO_2$), CO: carbon monoxide, HC: hydrocarbons, PN10: particle number > 10 nm

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H_2 ICE Hybrid Powertrain for LCV Application
Transient Engine Results – WLTC (charge sustaining mode)

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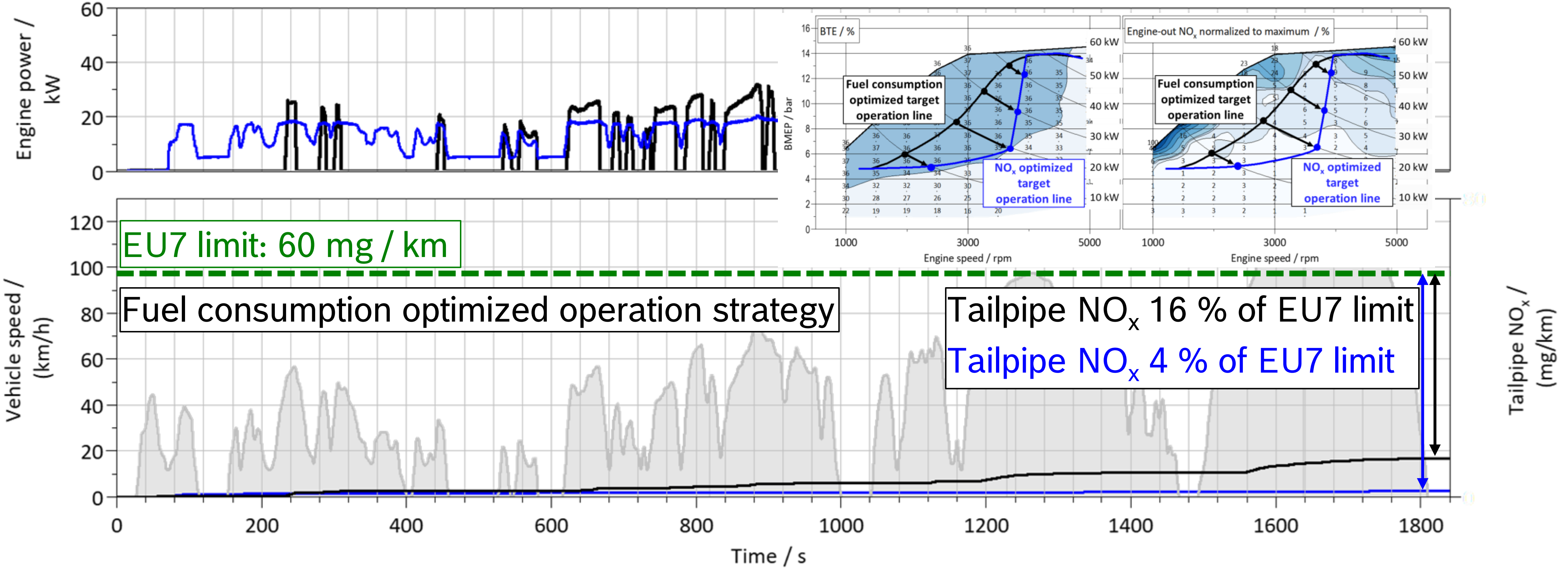

NO_x optimized operation strategy leads to a tailpipe NO_x emission reduction down to 4 % of EU7 limit.

WLTC: Worldwide harmonized light vehicles test procedure, NO_x: Nitrogen Oxides ($NO+NO_2$)

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H_2 ICE Hybrid Powertrain for LCV Application
Summary

- Successful **conversion of gasoline mass production engine to H_2 operation**
  - modification of FIE, ignition system, boosting system and crank case ventilation;
  - expectation: H_2 engine robustness comparable to gasoline operation.
- H_2 engine combined with an efficient EGT system provides **“zero-impact” capability** of CO, HC, PN10 and NO_x according to [1].
- Hybrid operation strategy enables additional degrees of freedom to combine **high efficiency** and **low engine-out NO_x emissions**.
- **Low tailpipe emissions** were verified in **high and low dynamic drive cycles,** e.g., “Transport for London”, dynamic RDE driving.

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H_2 ICE Hybrid Powertrain for LCV Application
Outlook

- Enhance H_2 engine operation limits and increase engine efficiency by further optimization of
  - **boosting system,**
  - **peak cylinder pressure capability,**
  - **charge motion and mixture formation**.
- **Optimization of electrical powertrain**
- Further **optimization of hybrid operation strategy**

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H_2 ICE Hybrid Powertrain for LCV Application

H_2 ICE Democar

+ CO_2 neutral mobility
+ Potential for “zero-impact“-emissions
+ Fast H_2 refuelling
+ High uptime
+ Suitability for daily use

The authors would like to thank the Federal Ministry for Economic Affairs and Climate Action, TÜV Rheinland and all project partners for their support and contributions to this work.

Thank you for your attention!

CO_2: carbon dioxide, H_2: hydrogen

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