Hydrogen-Based Mobility and Power – KAUST’22

Effect Of Different Charging Concepts on Transient and Altitude Performance of Hydrogen Fueled Internal Combustion Engines

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H_2 ICE – a brand **new** invention!

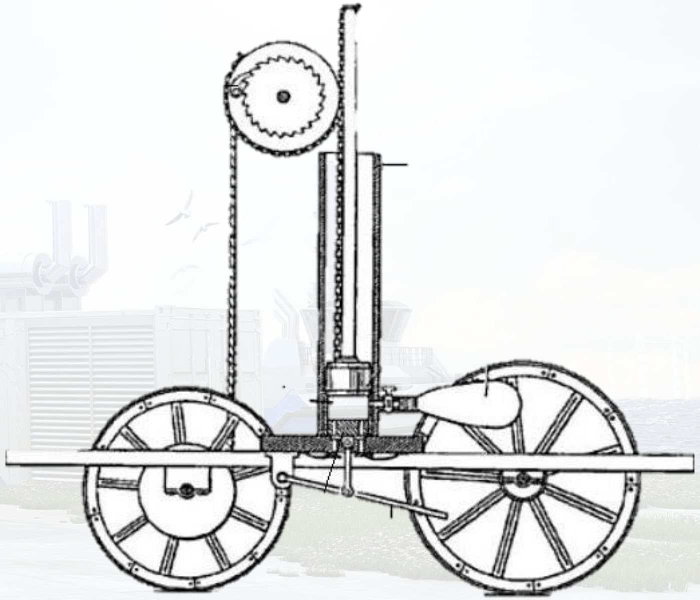
Rivaz engine (~1806)

1813 Isaac de Rivaz tested the first hydrogen powered vehicle

It achieved 25 consecutive ignitions

The vehicle **ran for 26m** with a speed of 3km/h

This was the first drive of a vehicle operated by a gas engine!



https://de.wikipedia.org/wiki/Isaac_de_Rivaz
https://www.automostory.com/first-hydrogen-car.htm

Delivering the European Green Deal

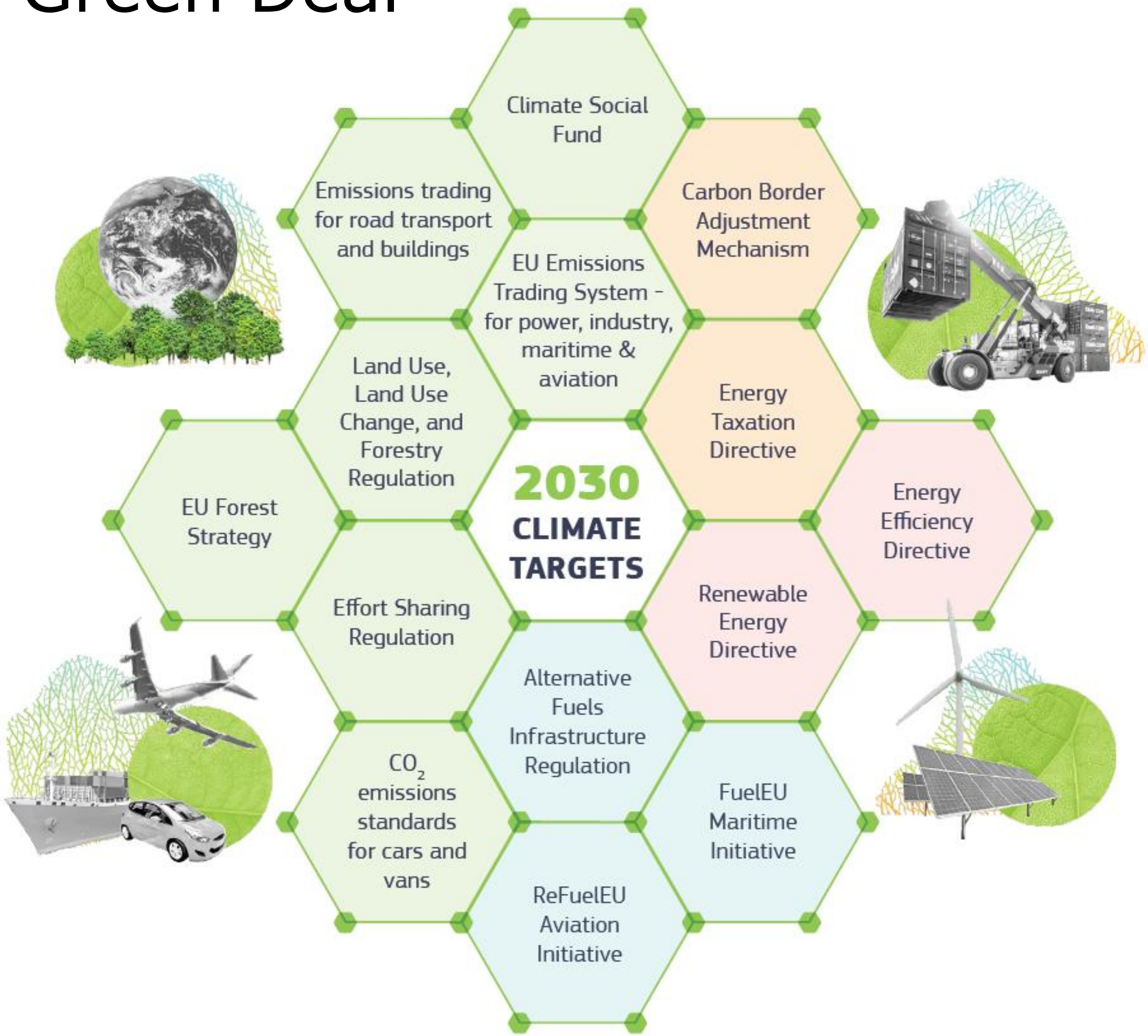
‘The Decisive Decade’

The EU will **reduce its net greenhouse gas emissions by at least 55% by 2030**, compared to 1990 levels, as agreed in the EU Climate Law.

On 14 July 2021, the Commission presented proposals to deliver these targets and make the European Green Deal a reality.

➡ A Prize on carbon and a premium on decarbonization.

(Frans Timmermans, Executive Vice-President for the European Green Deal, press conference, 14.07.2021)

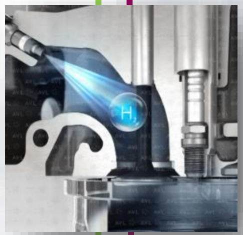


Source: Architecture of the package Factsheet, European Commission, 14.07.2021

H_2 Combustion Concepts - Commercial Applications

MPI or Low Pressure DI

Mixture formation **tumble** based

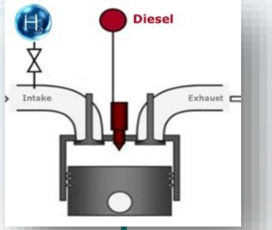



MPI or Low Pressure DI

Mixture formation **swirl** based

H_2 Low Pressure

Homogeneous combustion / spark ignited

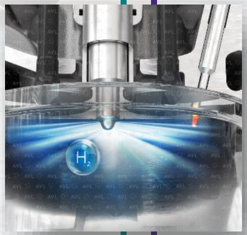


Dual Fuel (Diesel + H_2)

Carry over cylinder head (swirl)

High Pressure DI

Diesel pilot



High Pressure DI

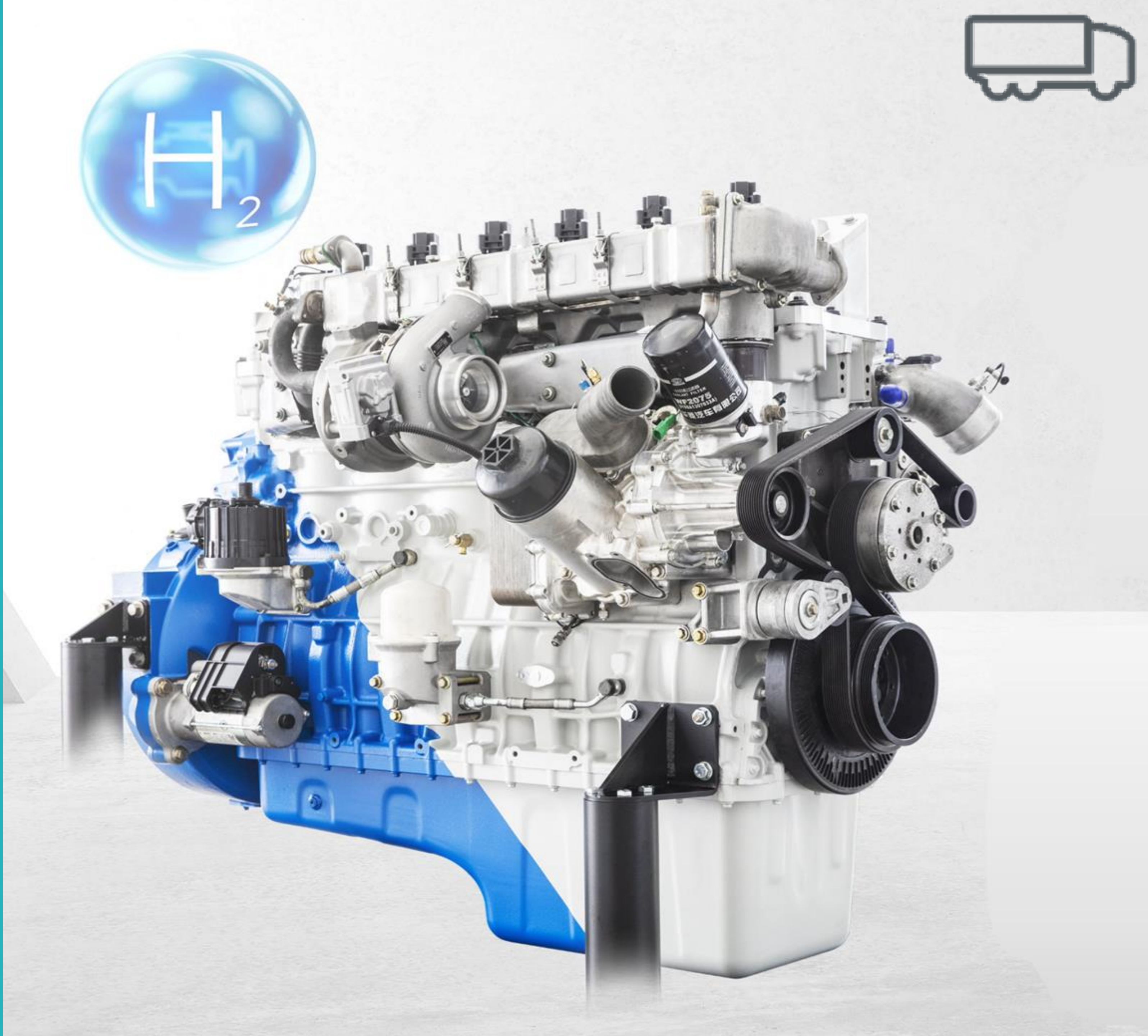
Carbon neutral ignition

H_2 High Pressure

Diffusion combustion / Diesel ignited

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

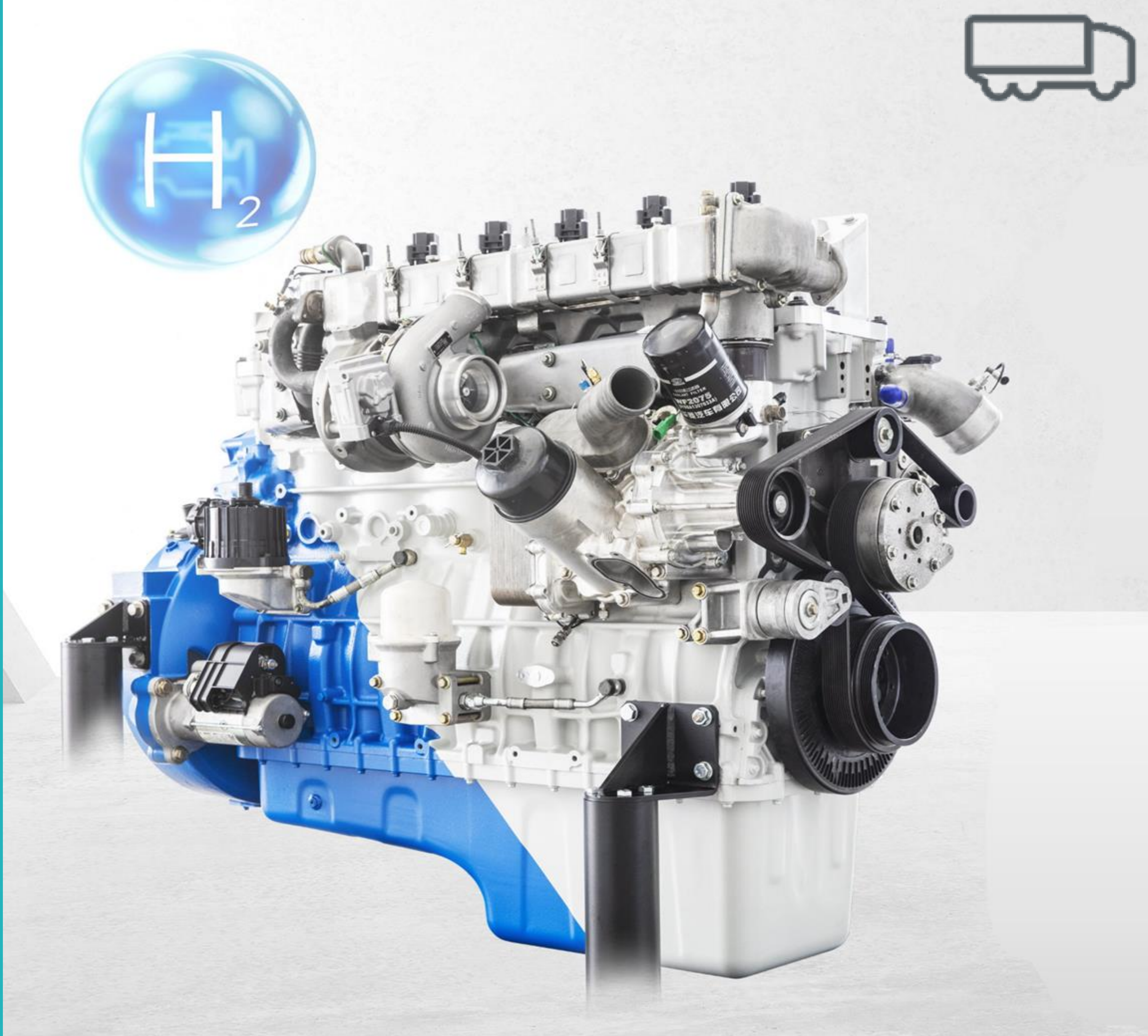


AVL

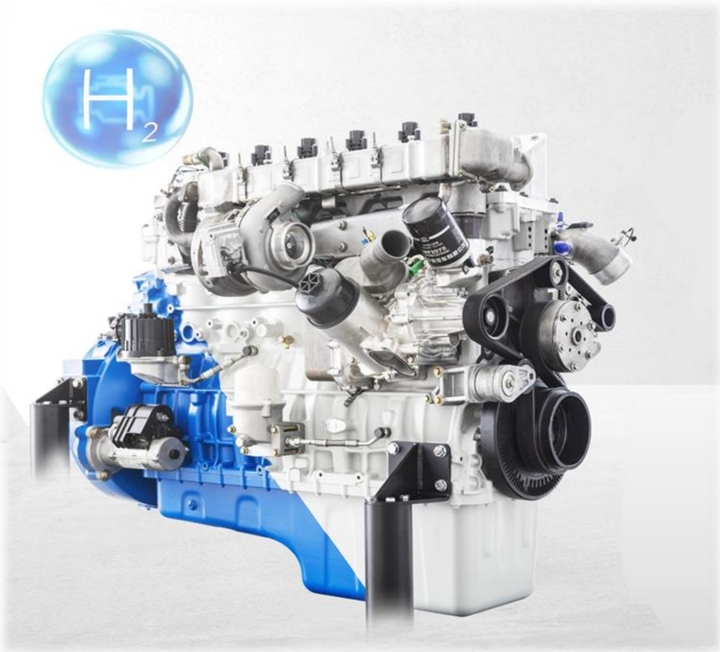
AVL Hydrogen Engine

Main Specifications

- Base Engine: 12,8l Natural Gas
- Hydrogen LP-DI and MPI injection
- Single stage VGT turbocharger
- Cooled EGR for combustion moderation and NO_x reduction
- H_2 spark plugs and coils
- Diesel derived SCR with Urea dosing and PF



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



Main Limitation

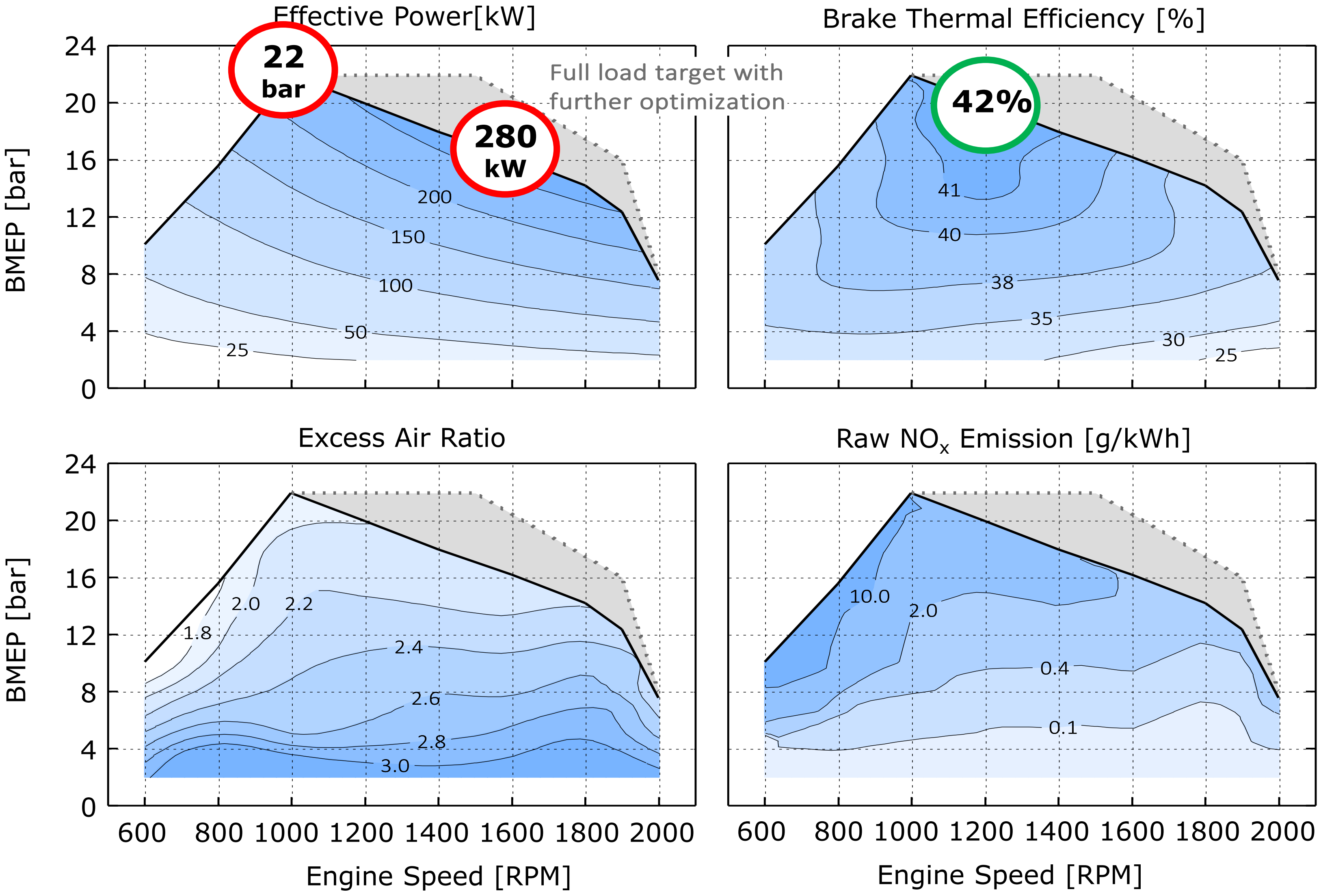
Backfire

Preignition

Knocking

Homogenization

High reaction willingness of hydrogen



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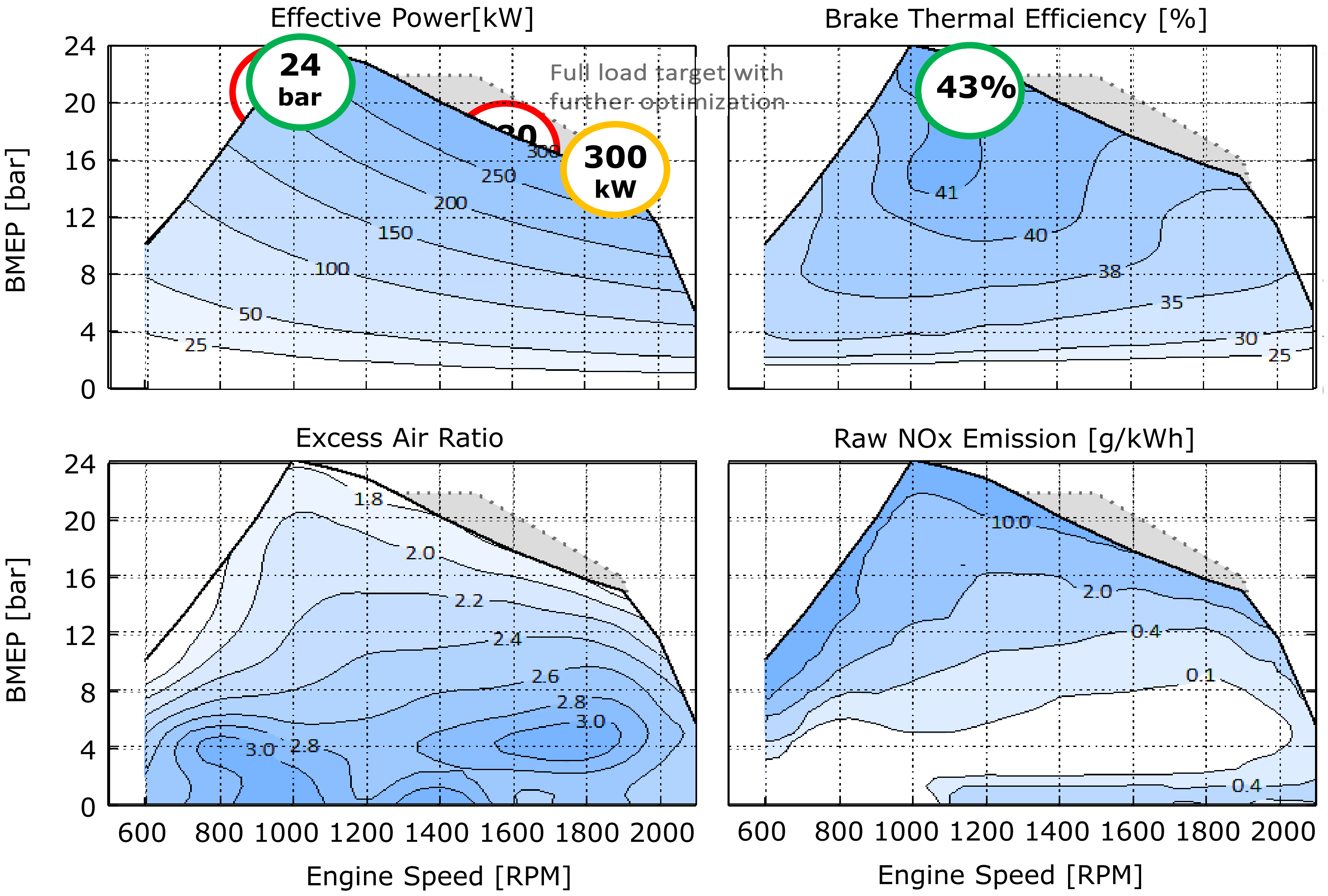

Main Limitation

Backfire

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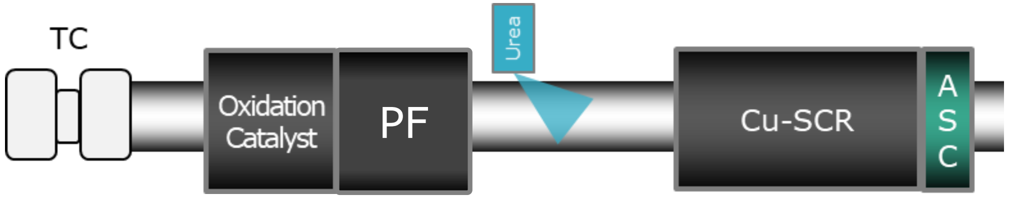
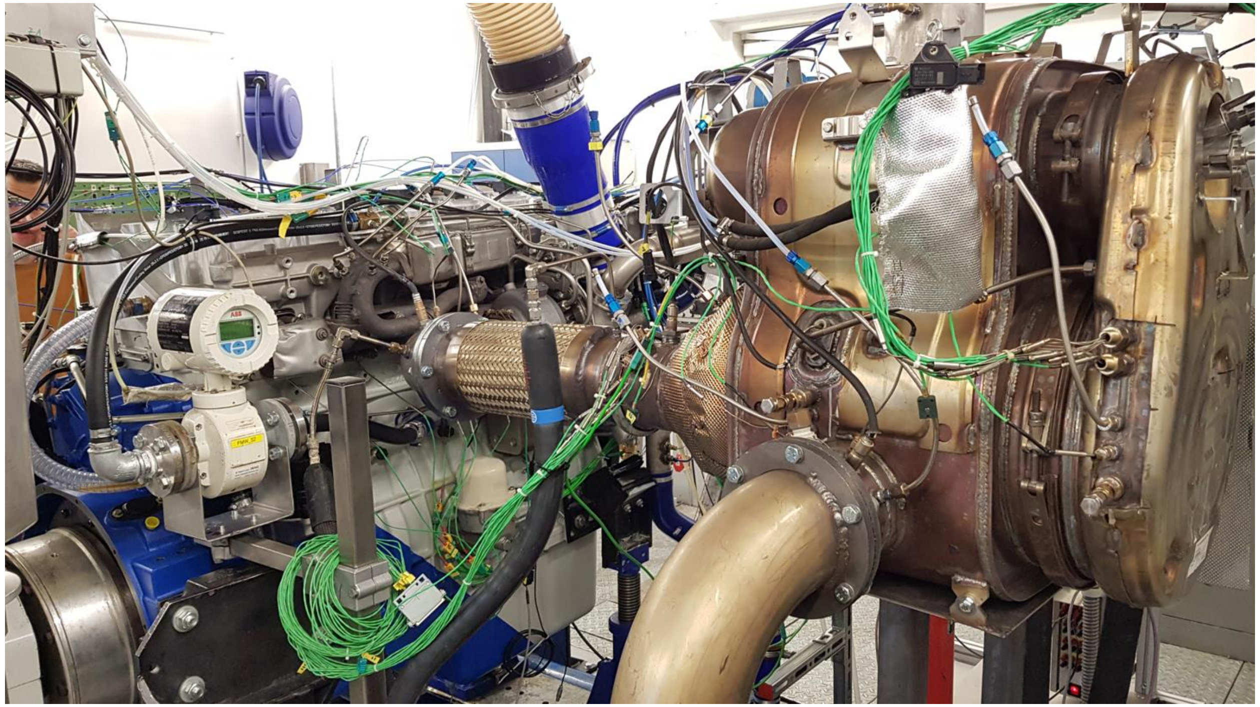
Homogenization

AVL Hydrogen Engine: EAS Layout for Euro VI

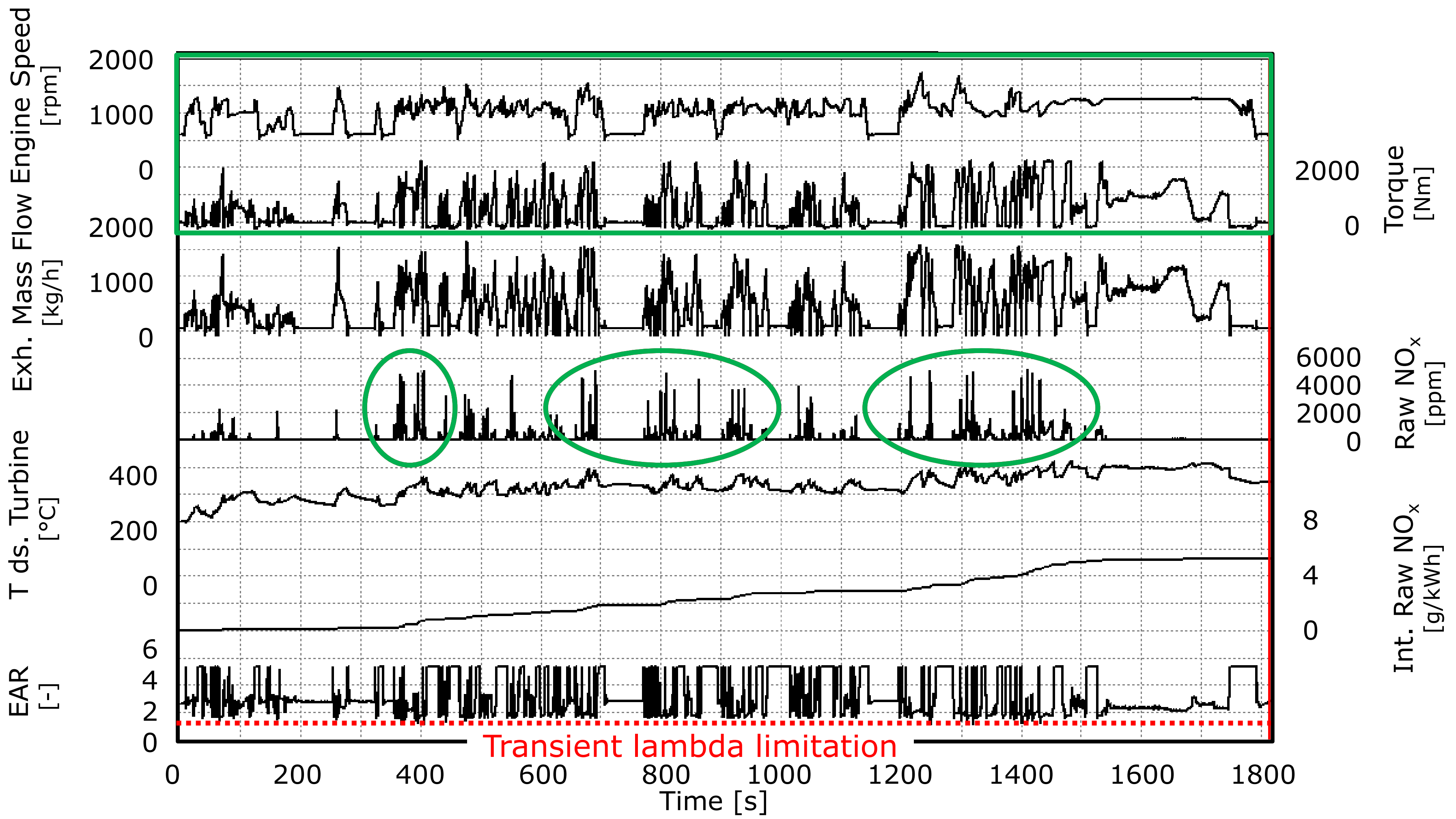




EAS specifications

Diesel derived EAS

WHTC Test Results – Emitted NOx



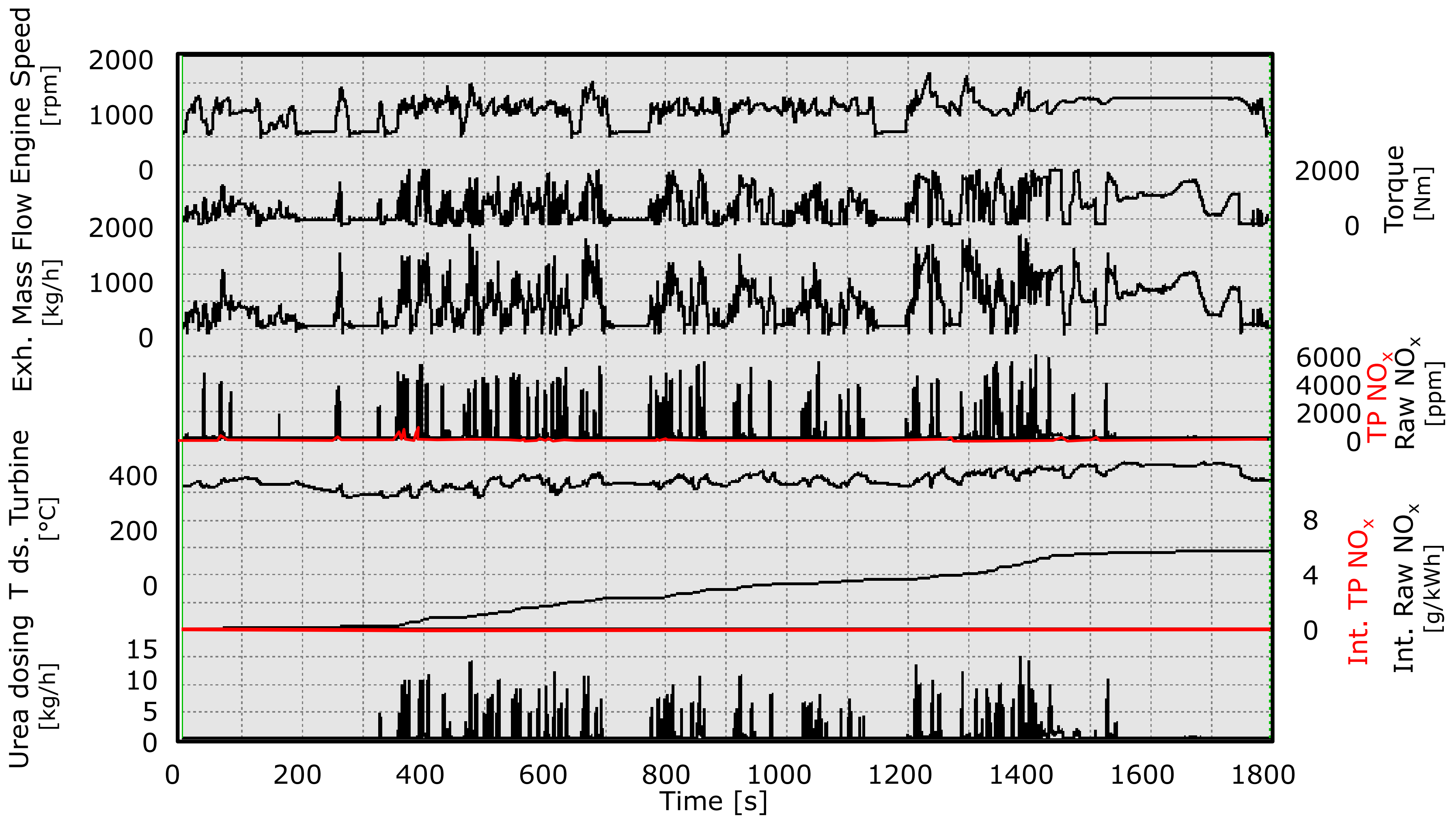
22 bar BMEP
300 kW

WHTC characteristics

Work:	**29 kWh**
Avg. power:	**57 kW**
Avg. speed:	**1000 rpm**

Lambda limit: 1,8
for transient NO_x limitation

Reduction Strategy of Emitted NOx with EAS



Urea dosing activated

WHTC characteristics

Work: **29 kWh**

Avg. power: **57 kW**

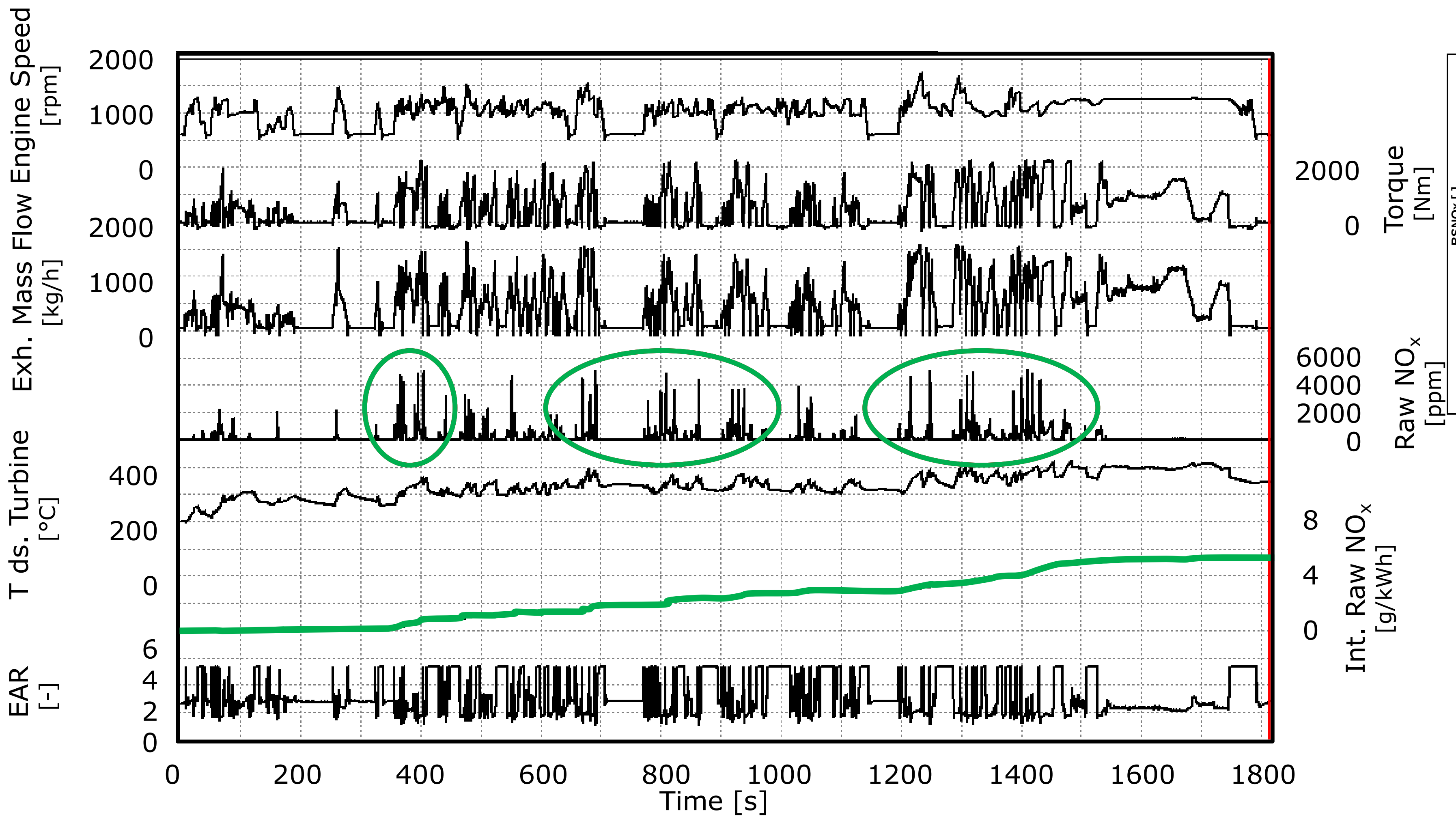
Avg. speed: **1000 rpm**

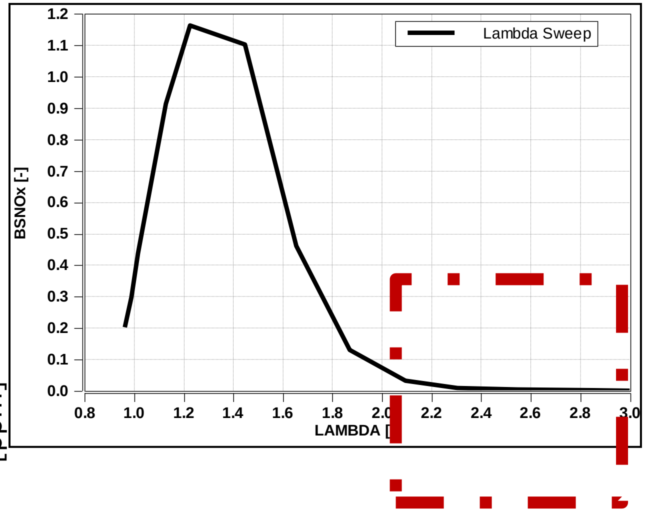
Results EO

NOx	H2O	H2	CO2_Oil	THC	CO	BSFC
g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh
5.84	802.90	1.23	0.23	0.005	0.01	83.33

NOx Tailpipe
g/kWh
0.06

Reduction Strategy of Emitted NOx without EAS





→ If the lambda value can be kept at **> 2.4**, emitted NOx will be minimum without EAS.

Effect Of Different Charging Concepts on Transient and Altitude Performance of Hydrogen Fueled Internal Combustion Engines

Boosting Strategies

Conventional turbocharging concepts are considered for H_2 engine in terms of performance in **high altitude and transient conditions**. In addition, effect of **electric turbocharger assist** concepts are also investigated.

<u>Conventional concepts:</u>

1. Fixed geometry turbocharger (FGT)
   - ✓ With active wastegate control
2. Variable geometry turbocharger (VGT)
3. 2-stage Turbocharger
   - ✓ High pressure side is VGT
   - ✓ Low Pressure side is FGT
   - ✓ With mid-stage cooler

<u>Electric Turbocharger Assist (ETA):</u>

1. Electrified Compressor (2–stage)
   - ✓ High pressure side is electrified compressor
   - ✓ Low Pressure side is FGT
2. Electrified Turbocharger
   - ✓ Electrified VGT

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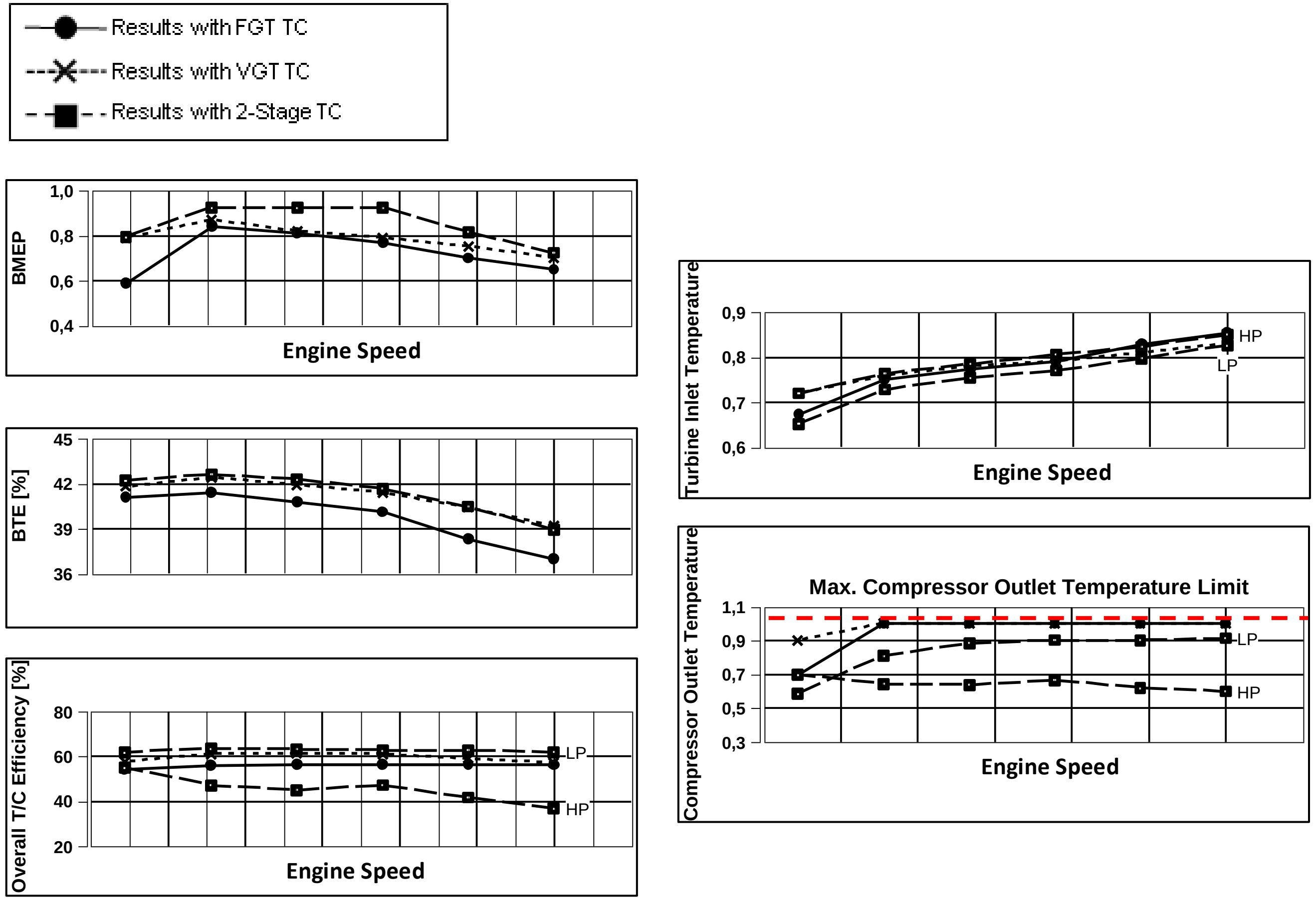
Altitude Performace



! Analyses were run at 1000 m altitude and 35°C ambient temperature conditions.

- √ Torque was derated to satisfy compressor outlet temperature limit with both FGT and VGT.
- √ The highest turbine inlet pressures, **FGT** had **the highest pumping losses** and **lowest BTE** at high altitude.
- √ **FGT and VGT** were already **at the limit** of compressor outlet temperature, whereas **2-stage TC** had still **margin for tougher conditions.**

Speed	FGT	VGT	2-Stage TC
-	%	%	%
1.000	10.8	2.8	0.0
0.889	14.4	8.5	0.0
0.778	16.7	14.1	0.0
0.667	12.7	10.9	0.0
0.556	8.7	5.4	0.0
0.444	25.6	0.0	0.0

Torque Derate Comparison of Turbochargers

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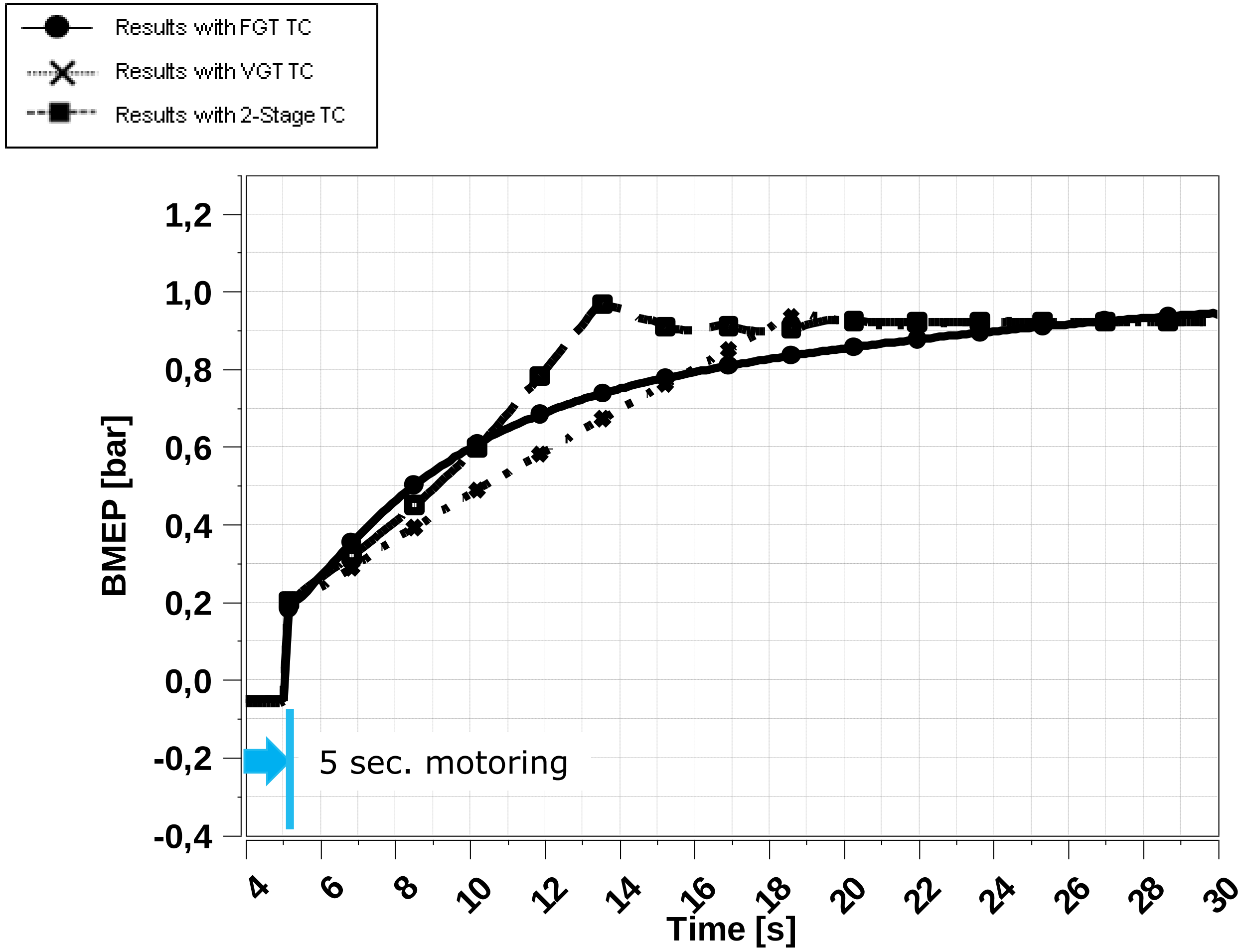
Transient Performace of Convetional Systems



√ Elapsed time **from 10 to 90% of max BMEP** with **CMR 2.4** was compared. (Minumum CMR was limited to 2.4)

√ **FGT** had **the longest build-up time** to reach 90% of BMEP and it was **followed by VGT and 2-stage TC**.

TC Concepts	Time 0%-90% [s]
FGT	13.1
VGT	11.4
2-Stage TC	7.2

Transient Response Time Comparison of Different Turbocharger Concepts

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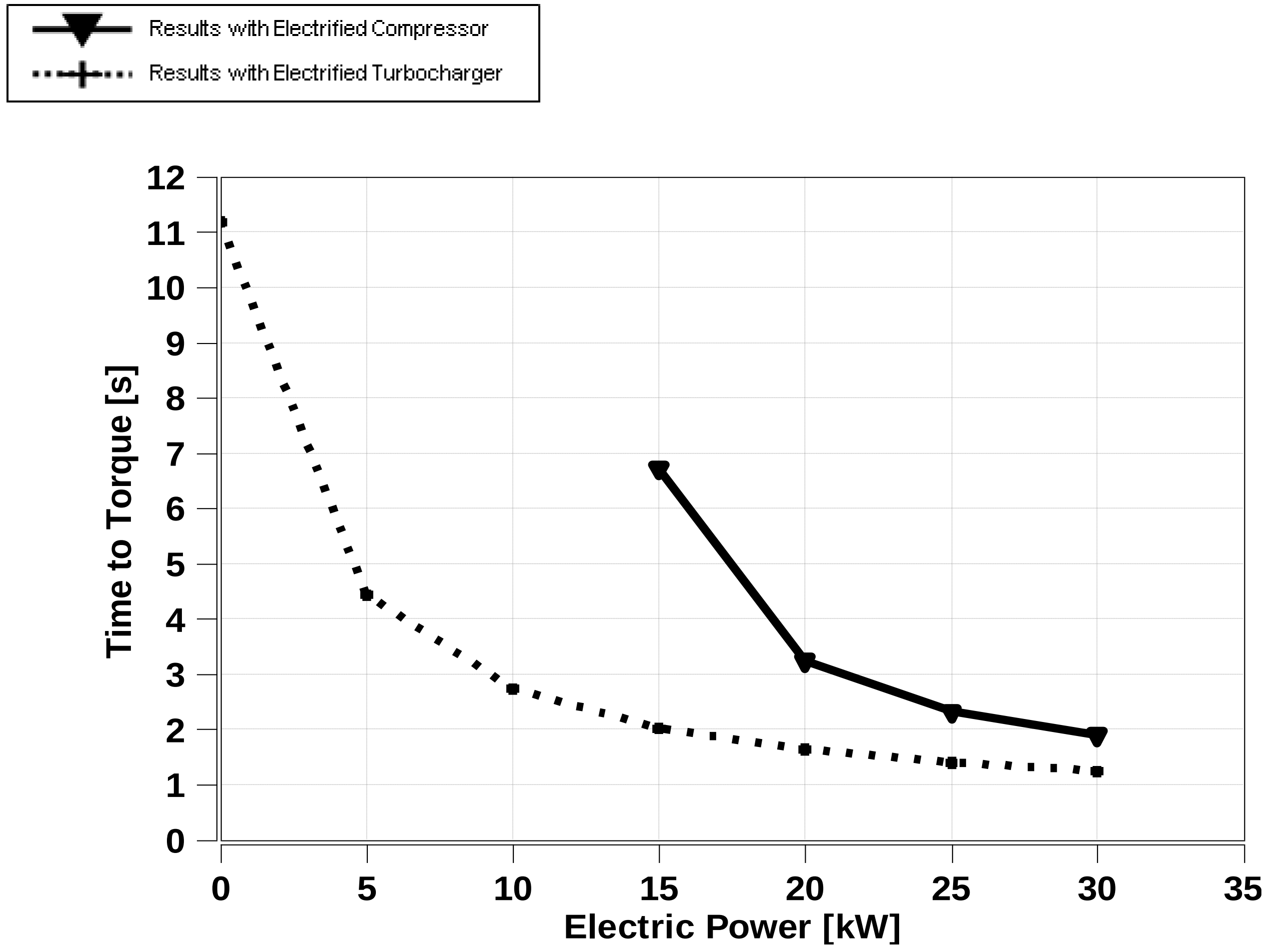
Transient Performace of Elecrified Systems



√ **Electrified turbocharger** and **electrified compressor** were utilised to improve response times further **to reach diesel like response time**.

√ For the electrified turbocharger, **5 kW** of electric assistance reduced **response time of VGT from 11.4 seconds to 4.4 seconds**.

√ Electrified compressor **with a 15 kW** electric assistance **reached 90% BMEP in 6.7 seconds**. There is only a 0.5 s improvement.

√ Electrified turbocharger had better response times than that of electrified compressor concept for this arthitecture.

! Although electrified compressor has a satisfied performance in this study, it holds more potential.
As a further study, research for better performance can be conducted by different structures and optimized strategy.

Summary and Conclusions

- **Hydrogen** will play an **important role in carbon neutral** mobility
- The **AVL Hydrogen Engine** demonstrated **high torque and power levels, high efficiency** – even in transient operation – and **low emissions** (post EU VI capability)
- **Low NOx** emissions at all conditions were secured by limiting the **CMR to 2.4**
- **At altitude condition, Only 2-stage** concept **satisfied** the target torque **for all speeds** with CMR 2.4
- **At transient condition,** performance of **2-stage turbocharger was the best**, followed by VGT and FGT. Despite the best performance of 2-stage turbocharger, **the response time was more than diesel**
- Depending on the supplied electrical power, **response time** was **similar or even better** than diesel **by the use of electrified turbocharger**.
- **Theoretically,** the approach of **lean lambda (λ≥2.4)** operation, is promising in order to be zero emission engine, but **extra caution is required** in commercial application **to ensure zero emission and extra effort is required for final evaluation**.

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Thank you….