Reaching EU7/BS7 emission limits for Commercial vehicles: a holistic approach by an exhaust aftertreatment system supplier

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ECT-2023
International Conference

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Table of contents

- Eu 7 emission target proposals – EU Comission vs. Council
- The holistic approach / description of components
- Example for a HDD application in Europe
- Assessment of DeNOx functionality for a MDD engine:
  from a BS VI to BS 7 via step by step implementation of
  e-heater, new SCR catalyst, and 2-stage dosing
- Summary & Conclusions

Eu7 proposal EU Commission, counter proposal EU Council

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MOBILITY NOTES

Summary of EU Council proposal for Euro 7 emission standards (mobilitynotes.com)

M2, M3, N2 and N3 Units mg/kWh (gas) #/kWh (PN)	Euro VI	Euro 7 HD : Commission Nov 10th, 2022			Euro 7 HD : Council Sept 22nd, 2023	
	WHTC	Cold 100th percentile	Hot 90th percentile	Budget Trips < 3xWHTC	WHTC	RDE
NOx	460	350	90	150	230	300
PM	10	12	8	10	8	-
PN (#/kWh)	PN_{23} $6x10^{11}$	PN_{10} $5x10^{11}$	PN_{10} $2x10^{11}$	PN_{10} $3x10^{11}$	PN_{23} $6x10^{11}$	PN_{23} $9x10^{11}$
CO	4000	3500	200	2700	1500	1950
NMOG	160 $_{THC}$	200	50	75	80	105
NH_3	10 ppm	65	65	70	65	85
CH_4	500	500	350	500	500	650
N_2O	-	160	100	140	200	260
HCHO	-	30	30	-	-	-

Implementation time after final regulation	**1st July 2027** (all new vehicles)	48months (new types approval) - **July 2028** (estimated) 60 months (all new vehicles) - **July 2029** (estimated)

EU Parliament:

The EU Parliament has cast its vote, siding with the Commission in terms of the stringency of Euro 7.

It supports the stricter limits, inclusion of smaller particles in the PN limit.

There will be "trilogue" discussions between the Commission, Council and Parliament, and then a consensus is expected on the final regulation.

Timeline:

The timing of the regulation will still be delayed compared to the original proposal by the Commission. The proposal calls for heavy-duty vehicles to comply with the regulation 48 months after the final publication of the regulation..

Eu7 Limit definition and calculations

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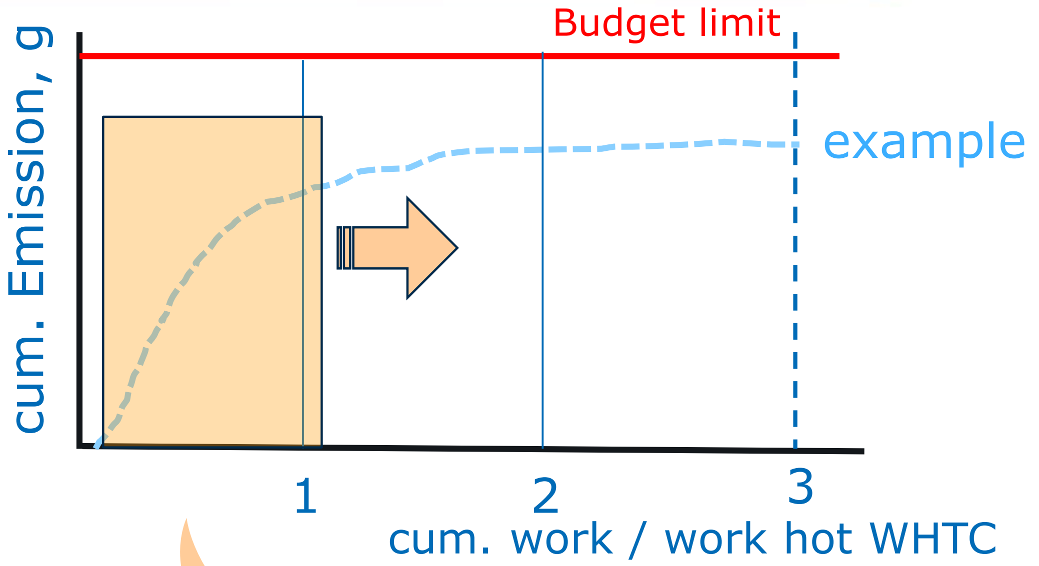
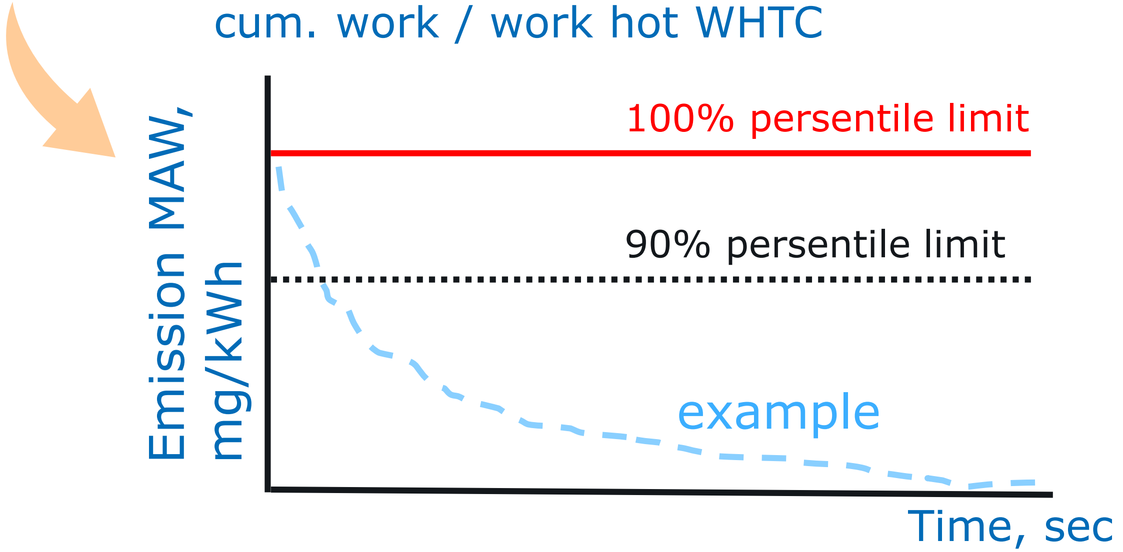
work of trip < 3 times work of hot WHTC
→ Budget view is used
→ Budget Limit x 3 x WHTC hot work
= cummulated limit



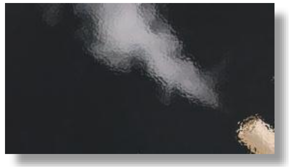
work of trip > 3 times work of hot WHTC
→ percentile limits with moving average windows is used (MAW)

1. length of moving average window (MAW):
   = duration until work of hot WHTC is reached
2. every new second of the trip a new MAW starts
3. from the first second of the trip percentile limits are active
4. the last MAW which has not reached the full WHTC work will not be considered in the evaluation



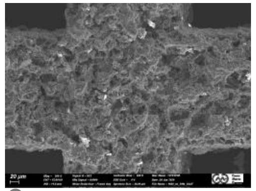
The holistic approach for an Eu 7 Aftertreatment system

Low temperature urea dosing for earlier deNOx

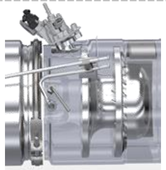


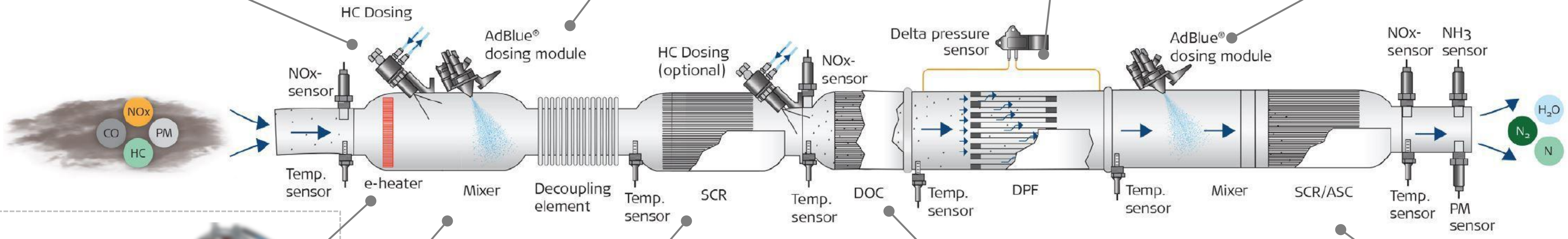
Hydrolysis coating for mixer/pipe

Advanced DPF substrates for higher PN filtration

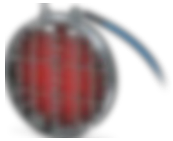


Compact & low thermal mass mixing



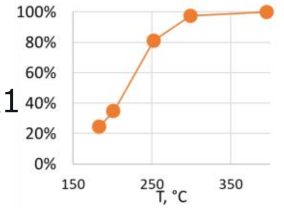


Active thermal management

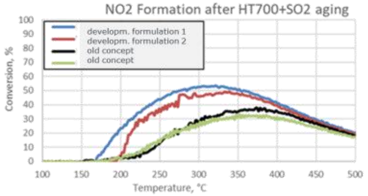


Pipe mixing for dual urea dosing

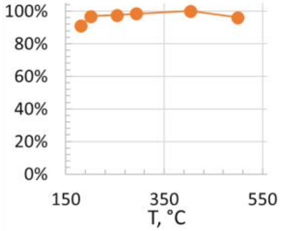
SCR1



Advanced DOC washcoat for improved PGM utilisation & S resistance



SCR2

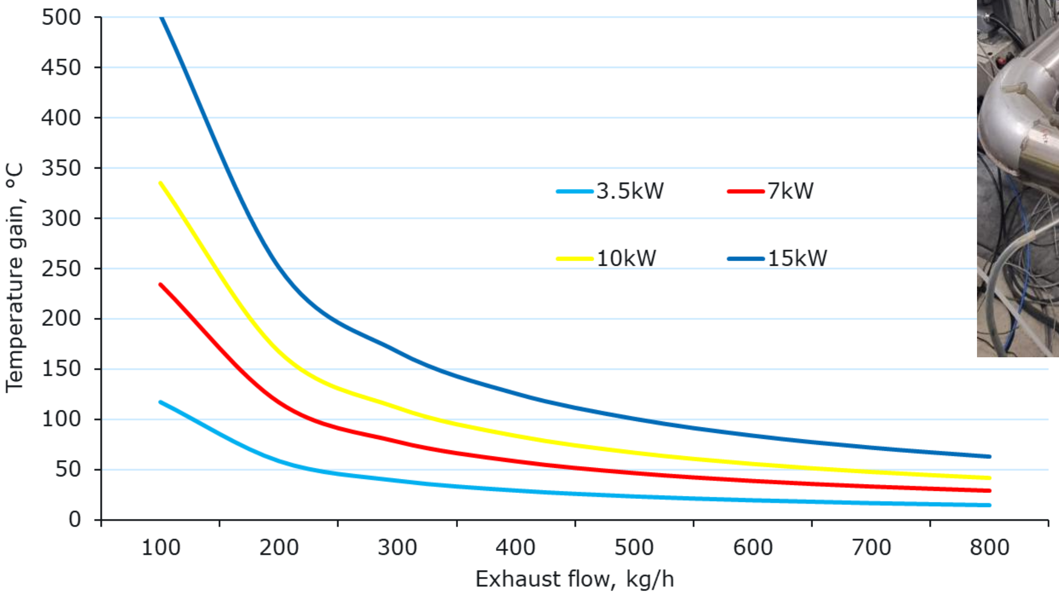


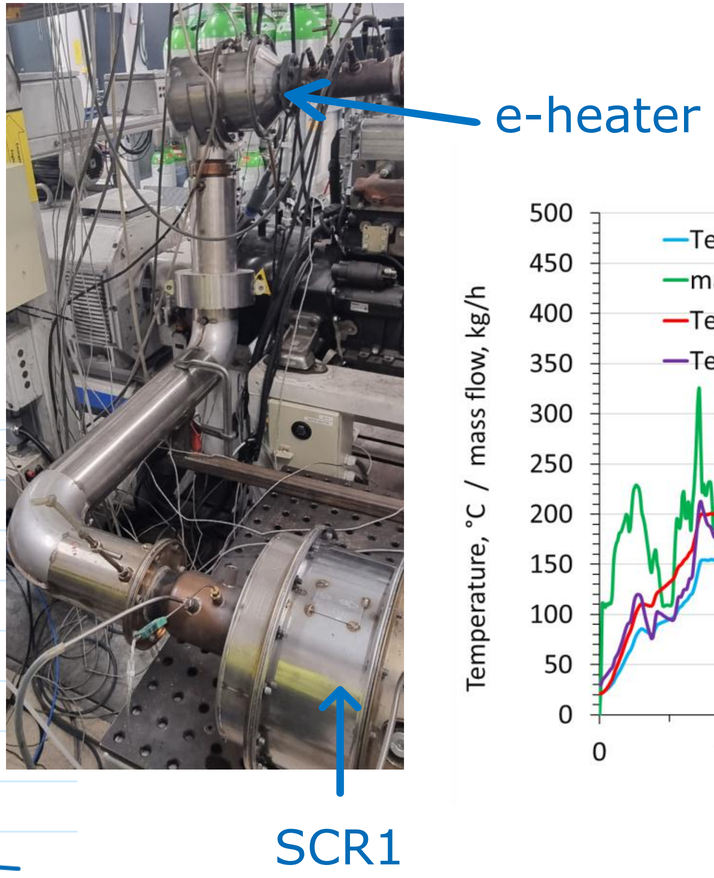
2-stage SCR to utilize early light off in combination with e-heater

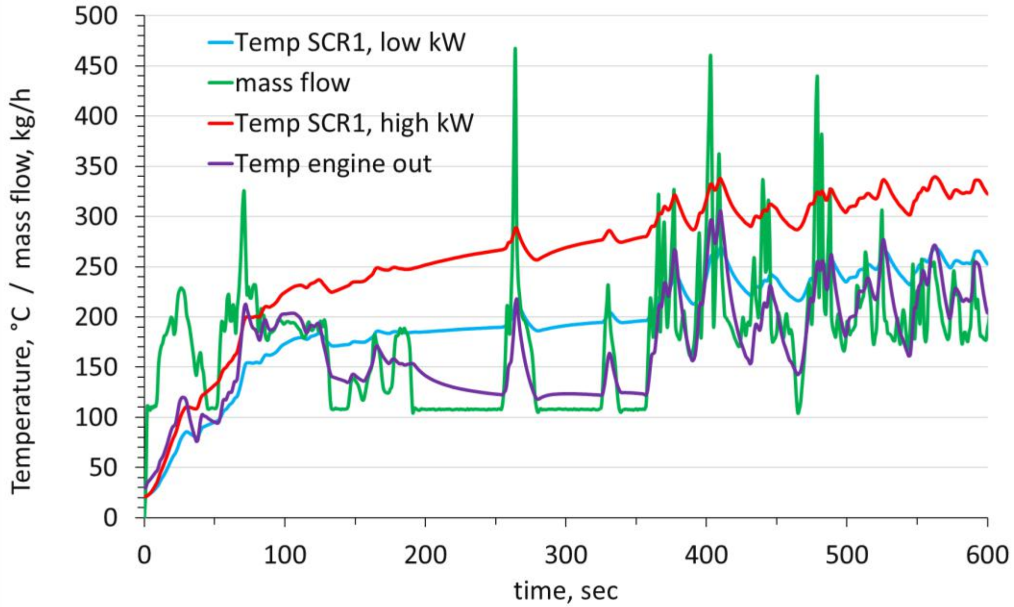
e-Heater design on the test bench

Maximal available power:

System	Power, kW
12V	3.6
24V	7.2
48V	14.4







Impact on temperature at SCR1:

- length of front pipe
- thermal weight
- thermal management engine

Measures at AdBlue dosing / NH3 preparation: heated nozzle and hydrolysis catalyst

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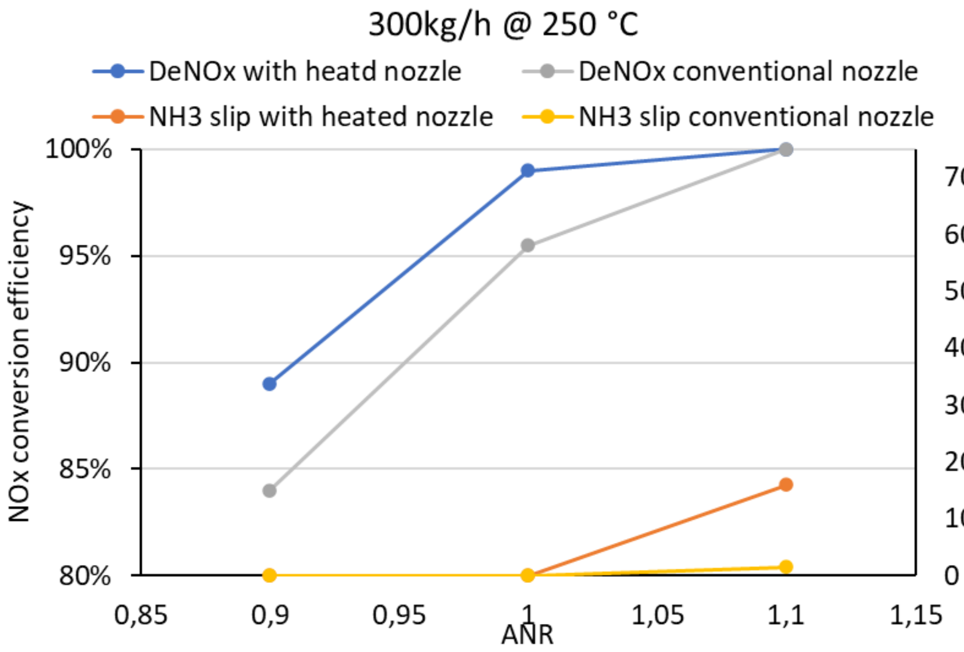
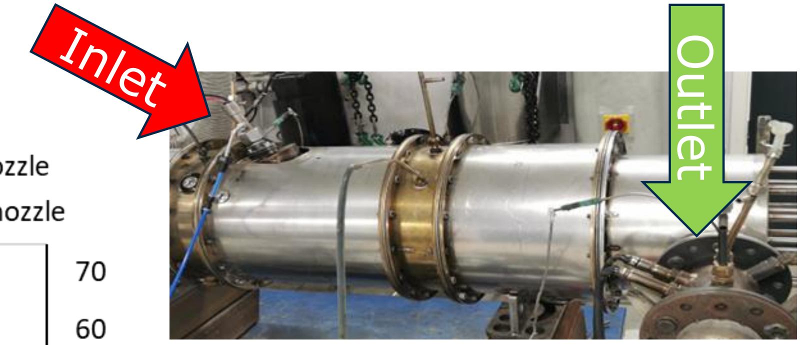
Heated Nozzle





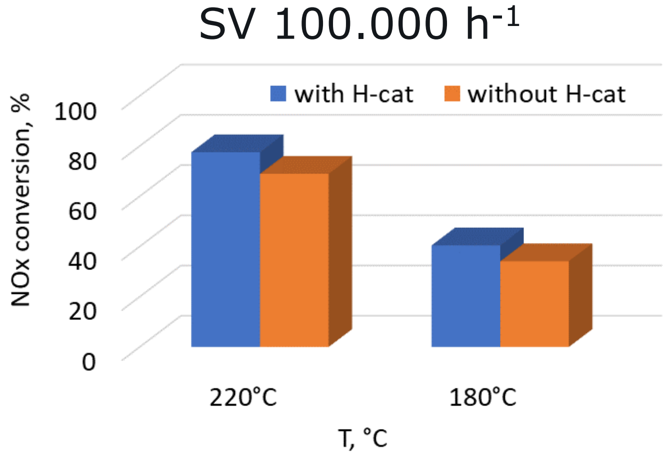
Heated and conventional nozzles have been compared back-to-back on the same aftertreatment system (pictured above).

Measurements have indicated a higher NH3 production and increased conversion rates at same ANR

Measurements have shown comparable NH3 distribution and neglible difference in temperature upstream SCR.

NH3 slip indicates a faster Urea decomposition.
→ Saving potential for DEF/AdBlue.

Hydrolysis catalyst



DOC solution for passive and active regenration

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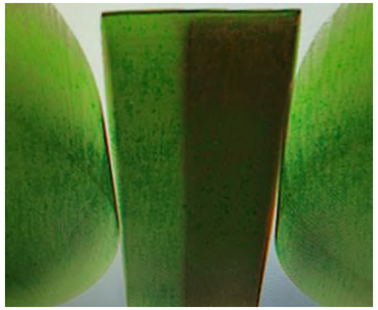
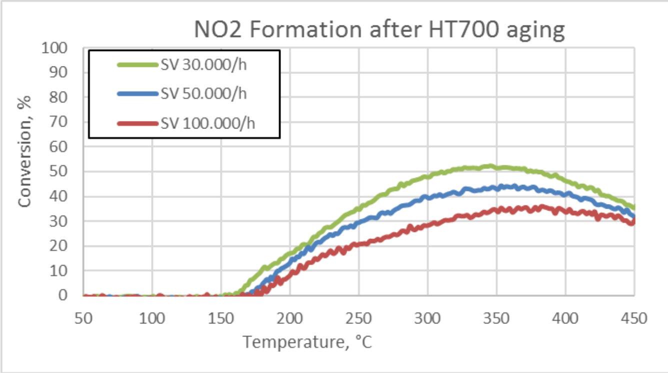
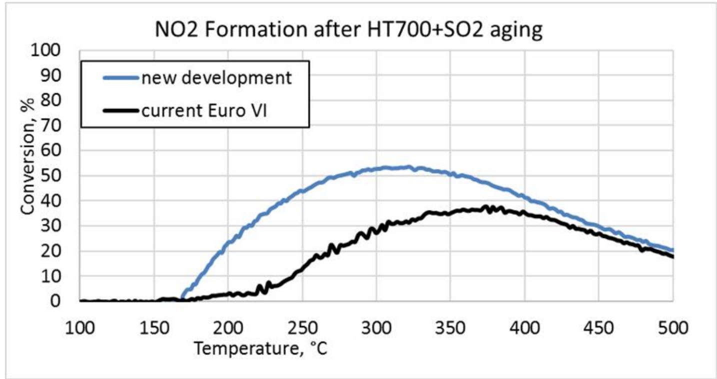
high thermal stable wash coat formulation with low CO and THC light off and high NO_2 formation.

Example:
PGM load: 25g/cft
Pt:Pd (2.6:1)
Pd rich inlet, Pt rich outlet

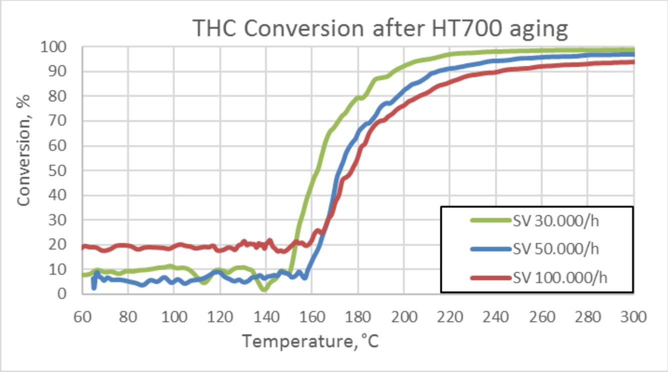


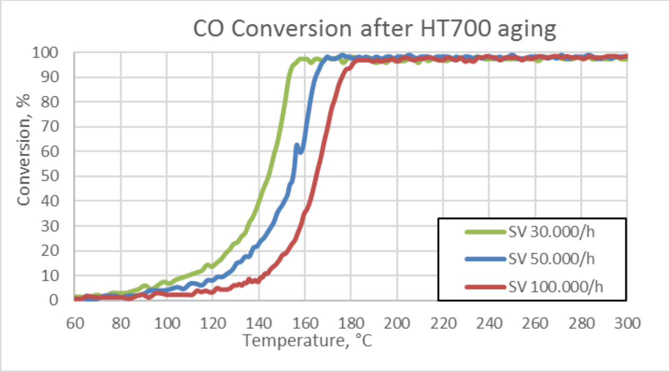


Wash coat modification



gas mixture:
10ppm $C_{10}H_{22}$,
10ppm C_7H_8,
40ppm C_3H_6,
300ppm CO,
500ppm NO,
10%O_2, 6%H_2O,
6%CO_2, balance N_2.





Filter technology for high PN efficiency & low back pressure

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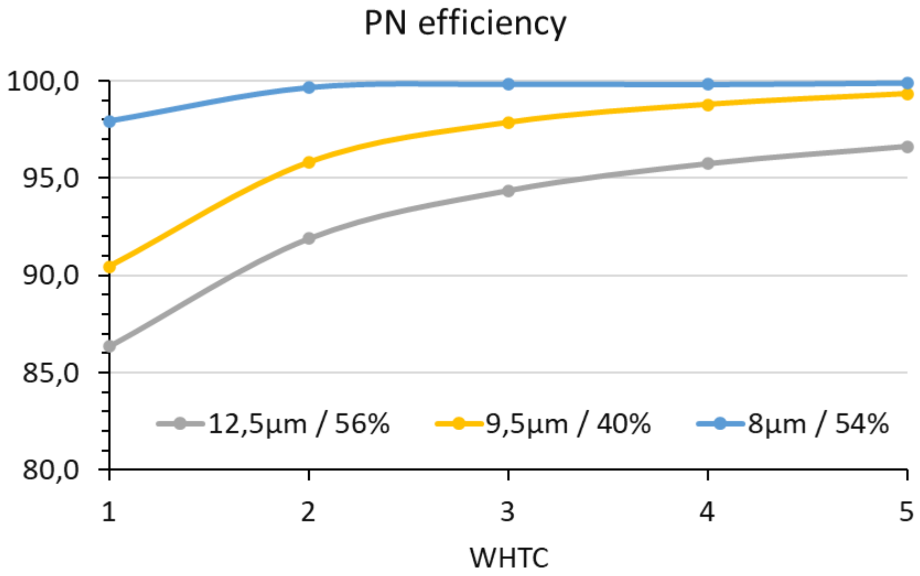
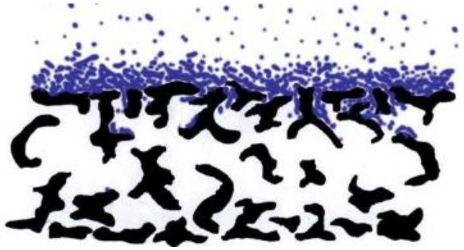
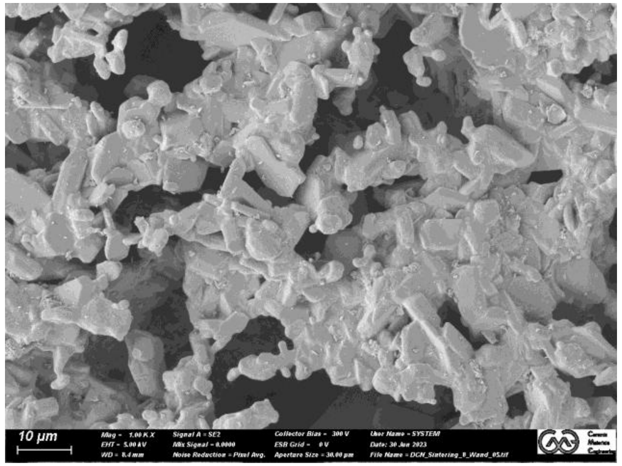
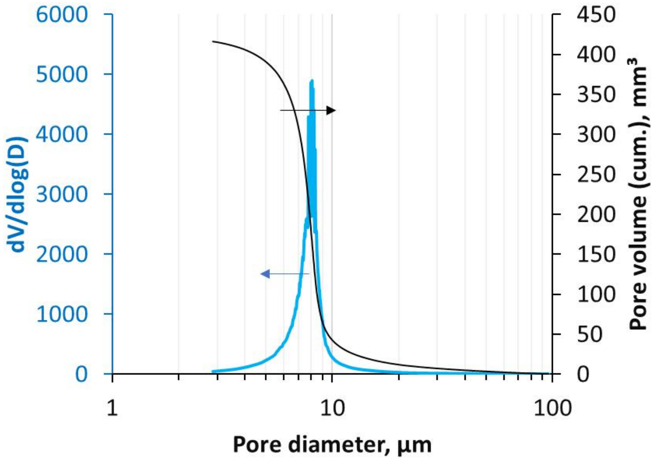
rf CHP-SiC Dinex

Low pore size ensures high PN efficiency

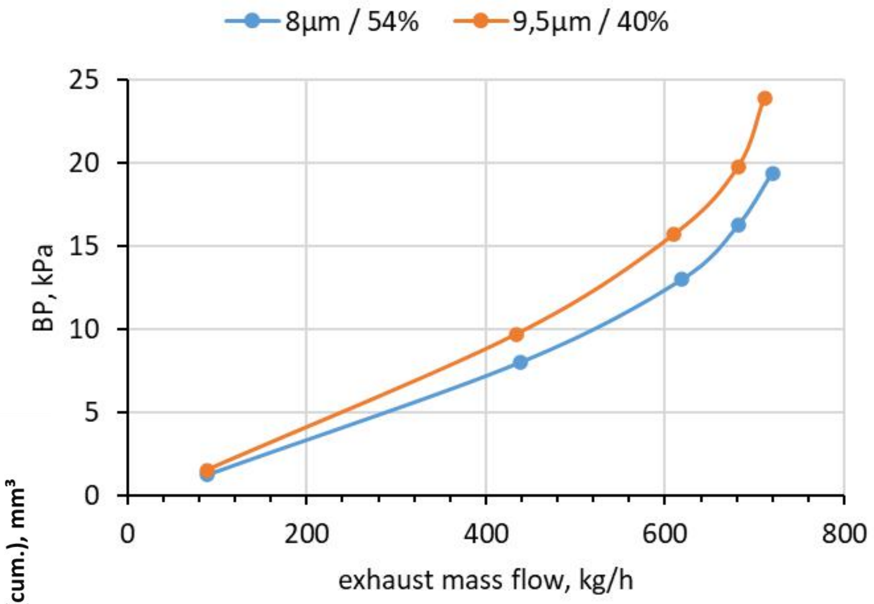






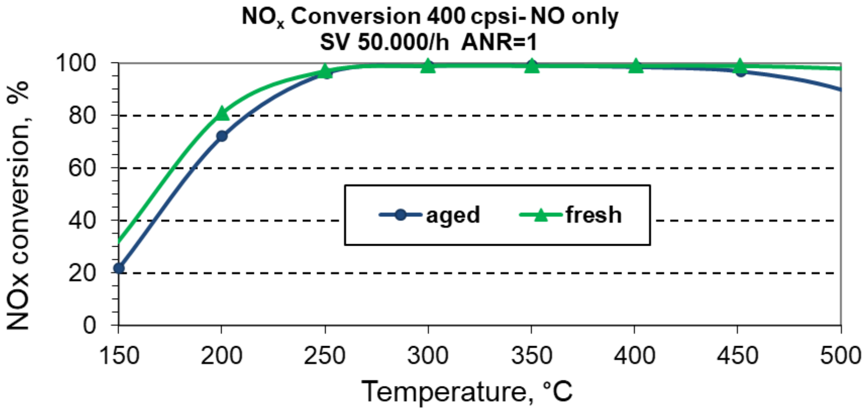


High porosity ensures low back pressure

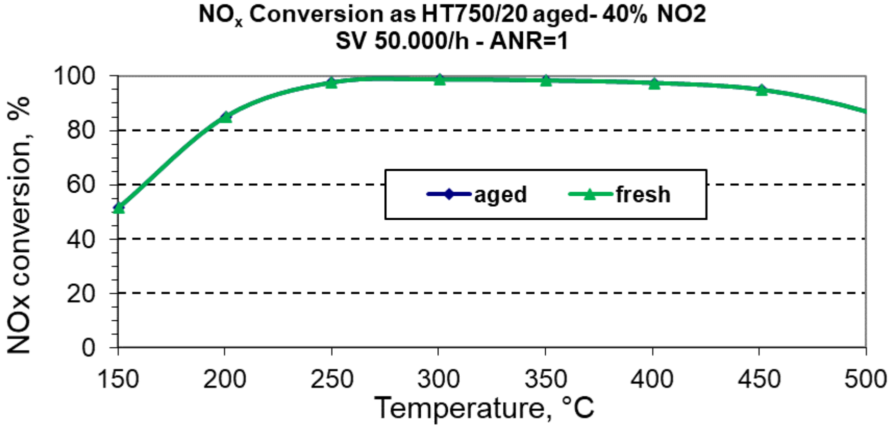


SCR catalysts: Cu-SCR or V-SCR

Cu-SCR, HT stable up to 800°C



aged: HT750/20h



SV 40.000 h^{-1}, 40% NO_2

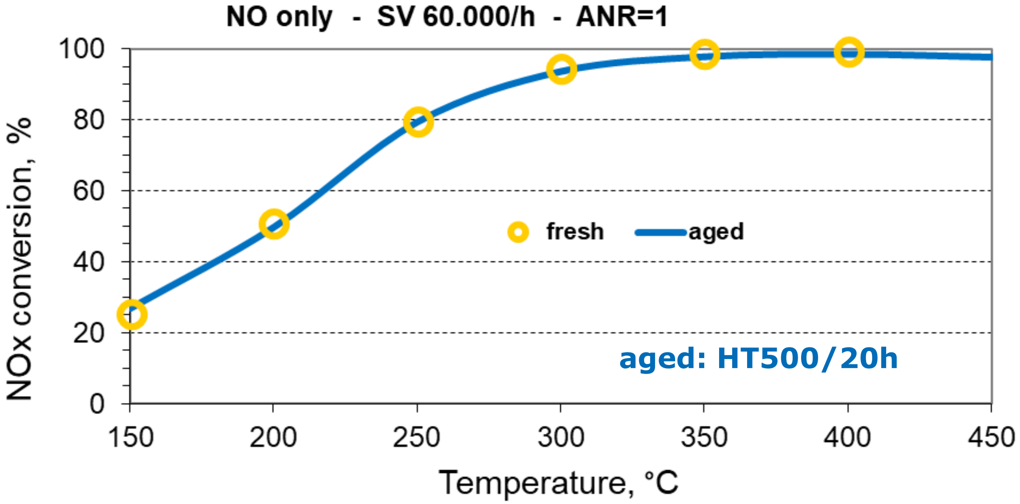
N_2O/NOx, %

T, °C	Cu-SCR	V-SCR
250	2,5	0,5
350	3,5	0,5
450	3,0	0,5

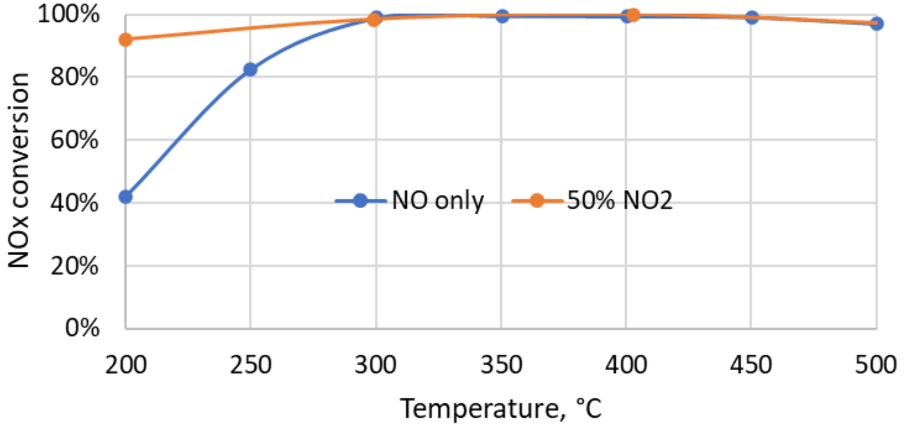
Hydrothermal ageing for calibration data:

Cu-SCR: 650°C/100h
V-SCR1: 500°C/100h
V-SCR2: 580°C/100h

V-SCR1:HT stable up to 500°C



V-SCR2: HT stable up to 600°C



Design of an Eu 7 system for a HDD 13L engine with e-heater and 2-stage V-SCR

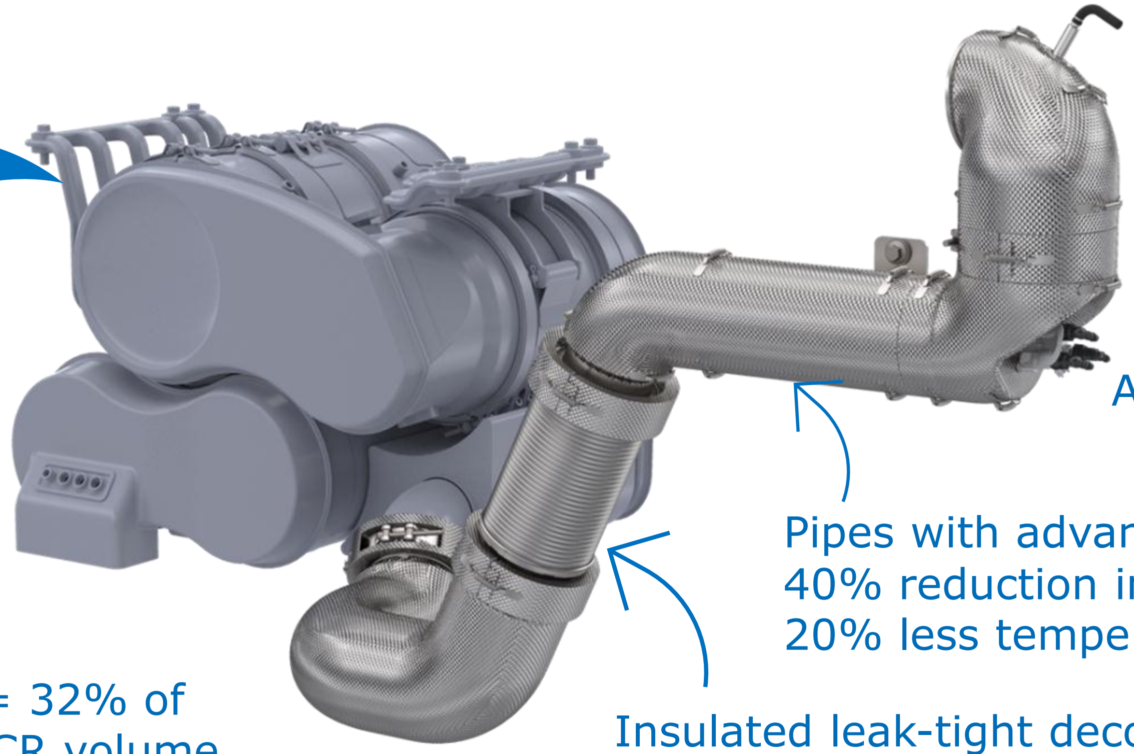
Concept study with
V-SCR1 and V-SCR2

DPF

DOC

SCR2 with ASC

SCR1 = 32% of
total SCR volume



Integrated
e-heater, 48V
need up to 10kW

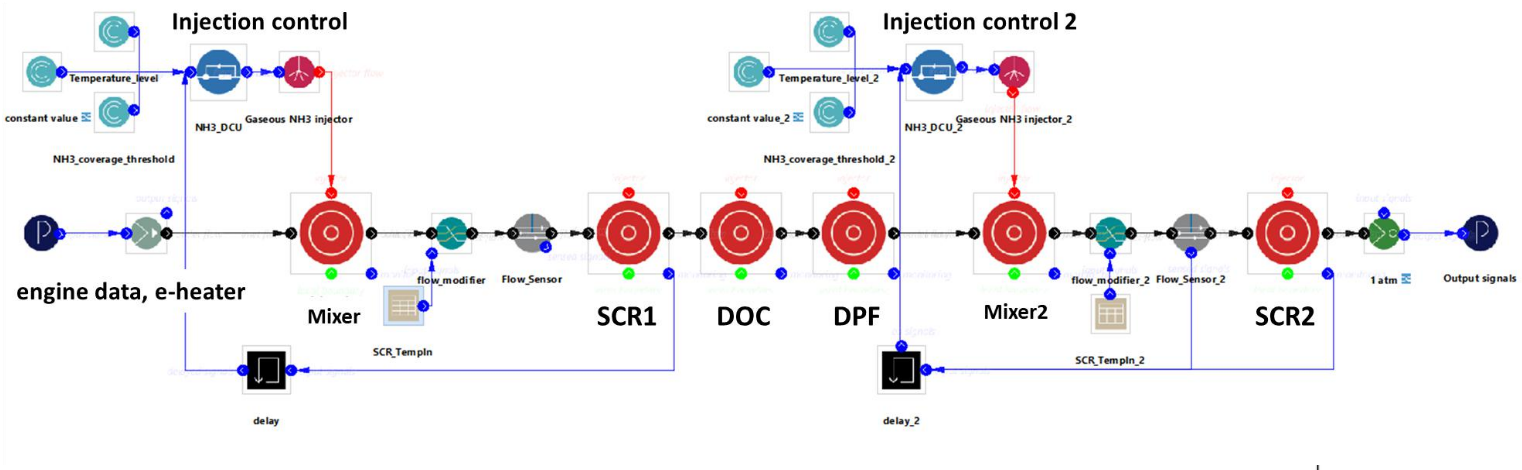
AdBlue-dosing

Pipes with advanced insulation
40% reduction in thickness
20% less temperatur loss per meter

Insulated leak-tight decoupling
up to 25% less temperaure loss

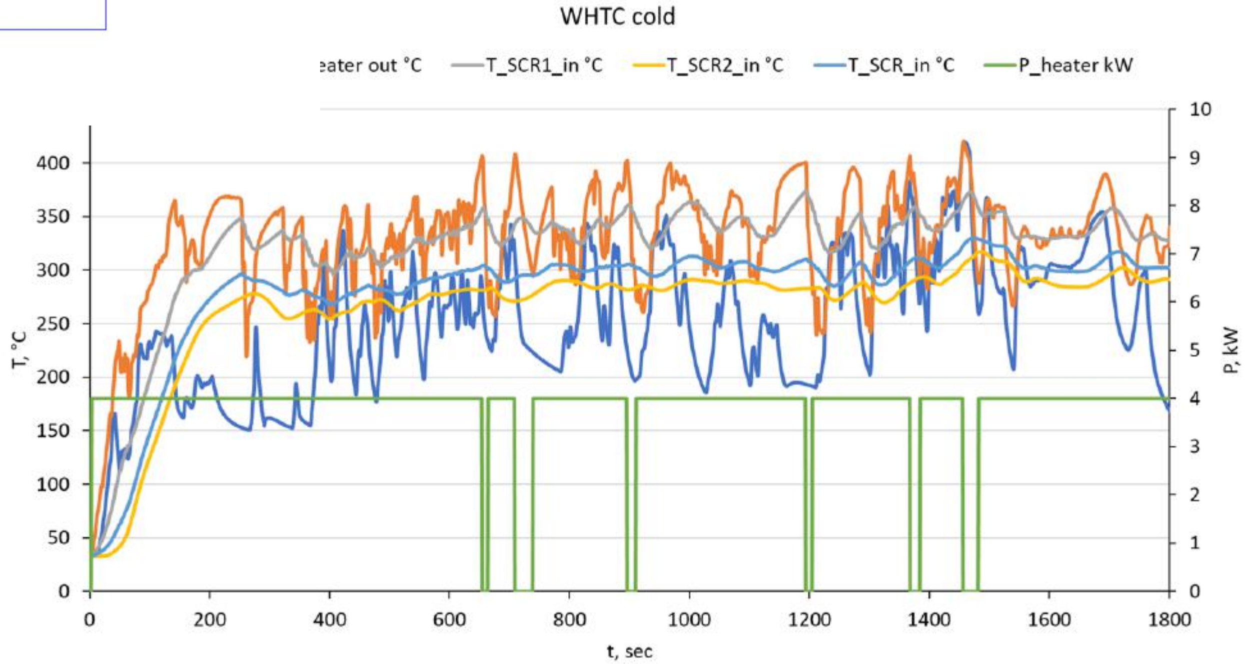
Assessment:
budget view: 1x cold WHTC + 2x hot WHTC
Percentile view: use of low load cycles, work > 3x WHTC

Simulation tool Exothermia
Data from hydrothermal aged catalysts

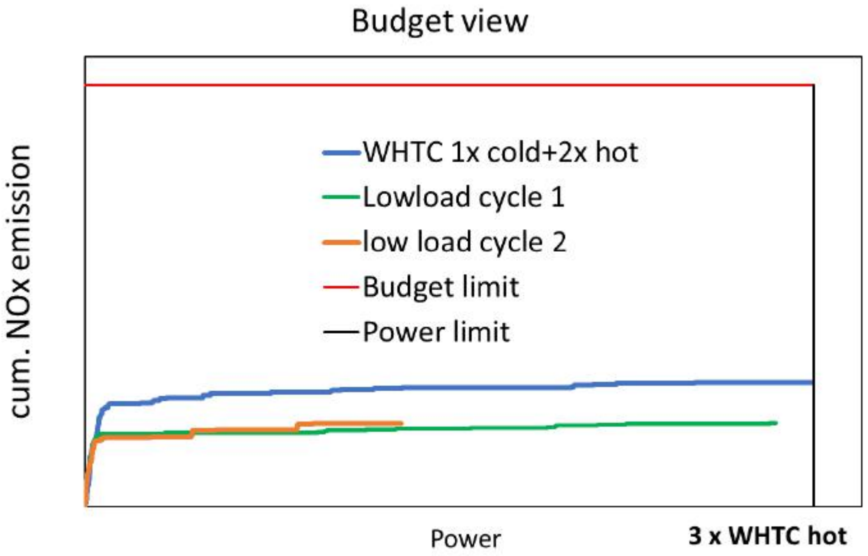


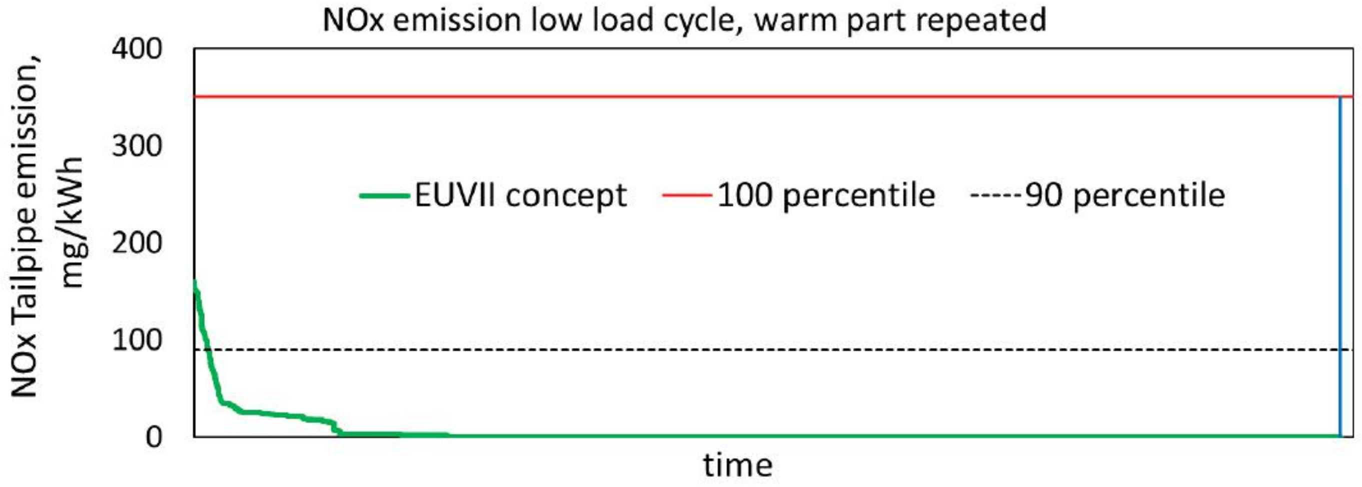
settings e-heater:
T @ e-heater outlet < 300°C → ON,
T @ e-heater outlet > 400°C → OFF

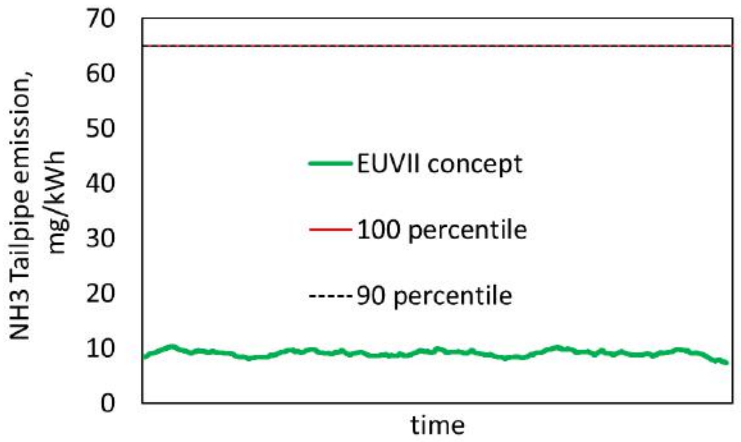
kinetic parameters for model calibration taken from SGB measurements
(Arrhenius factor & Activation Energy)

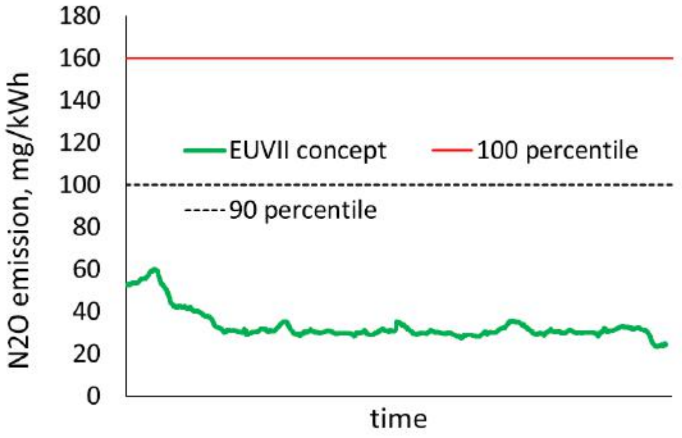


Eu7 system with e-heater & 2-stage V-SCR
Example 13L engine

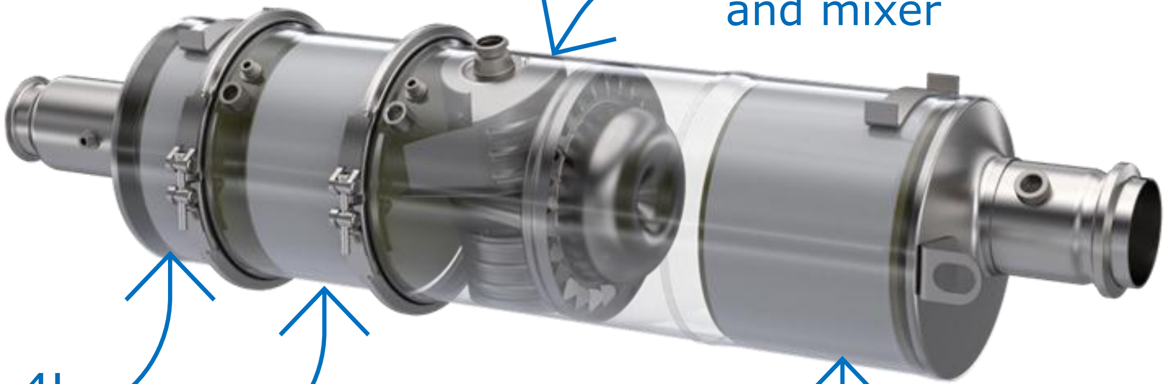








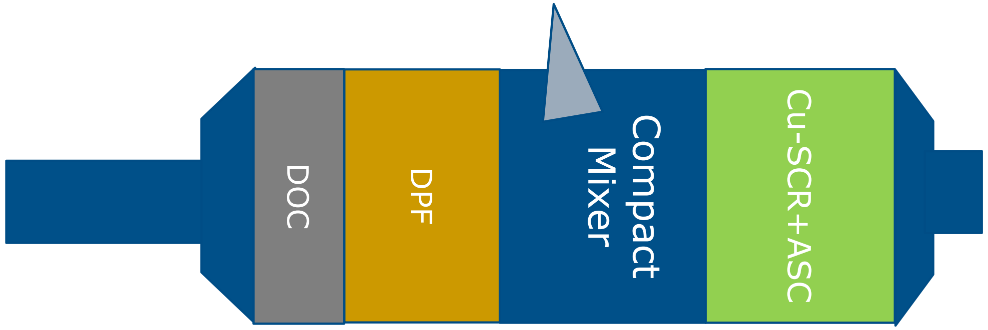
BS VI: series ATS for a MDD engine
Power range: 140 – 160 HP



BS VI	limits	series ATS degreened	series ATS, simulation HT650°C/100 hours
CO	4000 mg/kWh	120 mg/kWh	260 mg/kWh
THC	160 mg/kWh	30 mg/kWh	60 mg/kWh
NOx	460 mg/kWh	110 mg/kWh	250 mg/kWh

Check of BS VI series ATS in respect to Eu 7 limits – EU Commission

going the extra mile



EU 7	budget limits*, g	series ATS, g
CO	67.230	6.545 ✓
NMOG/THC	1.867	1.569 ✓
NOx	3.735	6.275 ✗
NH3	1.743	0.053 ✓
N2O	3.486	2.328 ✓

*WHTC work 8,5g/kWh

check of Budget limits using
1x cold WHTC
+ 2 hot WHTC
Catalysts HT aged

BS VI ATS concepts with e-heater
Eu 7 limits – EU Commission

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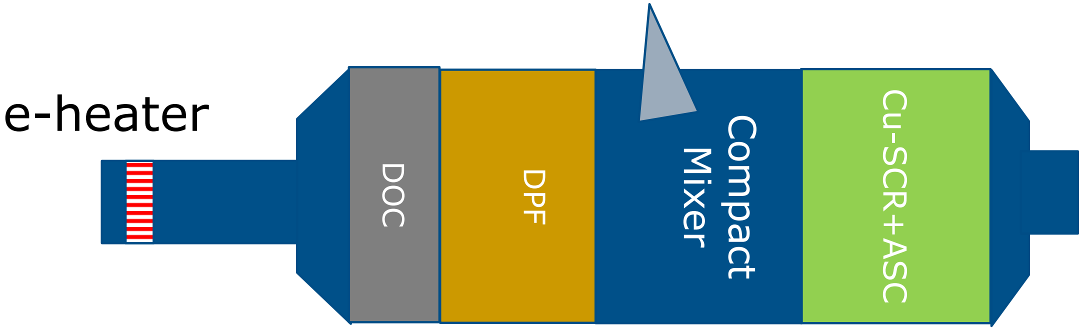
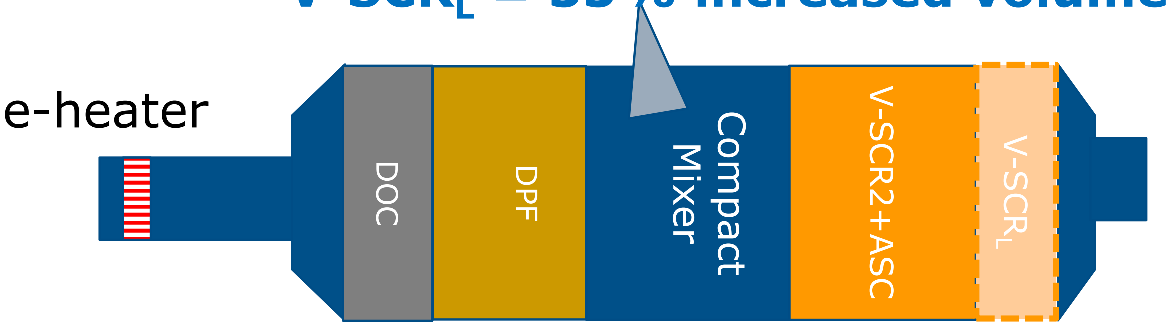
BSVI + e-heater



BSVI with V-SCR + e-heater
V-SCR_L = 33% increased volume



Budget emission	BSVI series	BSVI + e-heater	BSVI + with V-SCR + e-heater	BSVI + with V-SCR_L + e-heater
CO	6.545 g ✓	0.490 g ✓	0.490 g ✓	0.490 g ✓
THC	1.569 g ✓	0.118 g ✓	0.118 g ✓	0.118 g ✓
NOx	6.275 g ✗	1.871 g ✓	4.629 g ✗	4.514 g ✗
NH3	0.053 g ✓	0.053 g ✓	0.330 g ✓	0.250 g ✓
N2O	2.328 g ✓	4.167 g ✗	1.156 g ✓	1.156 g ✓

check of Budget limits using 1x cold WHTC + 2 hot WHTC, Catalysts HT aged

BS 7 concept with e-heater, 2-stage SCR Eu 7 limits – EU Commission

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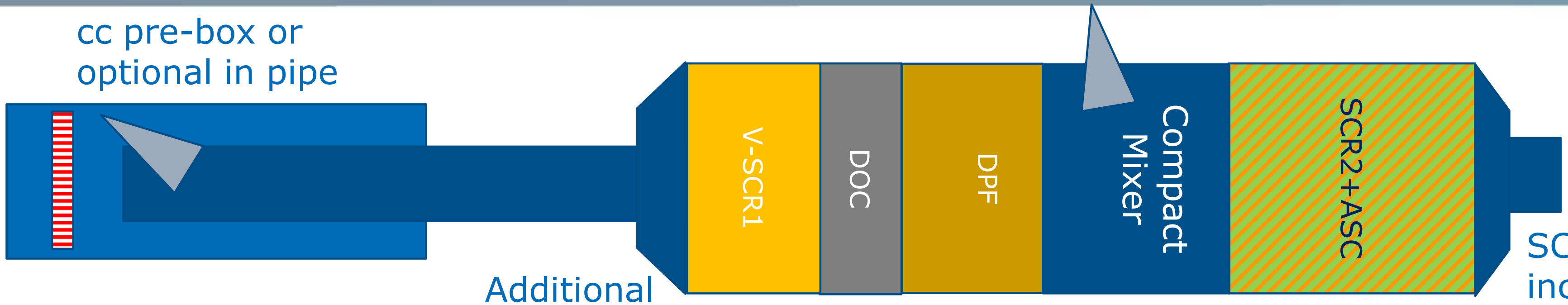
cc pre-box or
optional in pipe



Additional
V-SCR1 with 33%
of totale SCR volume

SCR2+ASC 20%
increased Volume,
either V-SCR2 or Cu-SCR

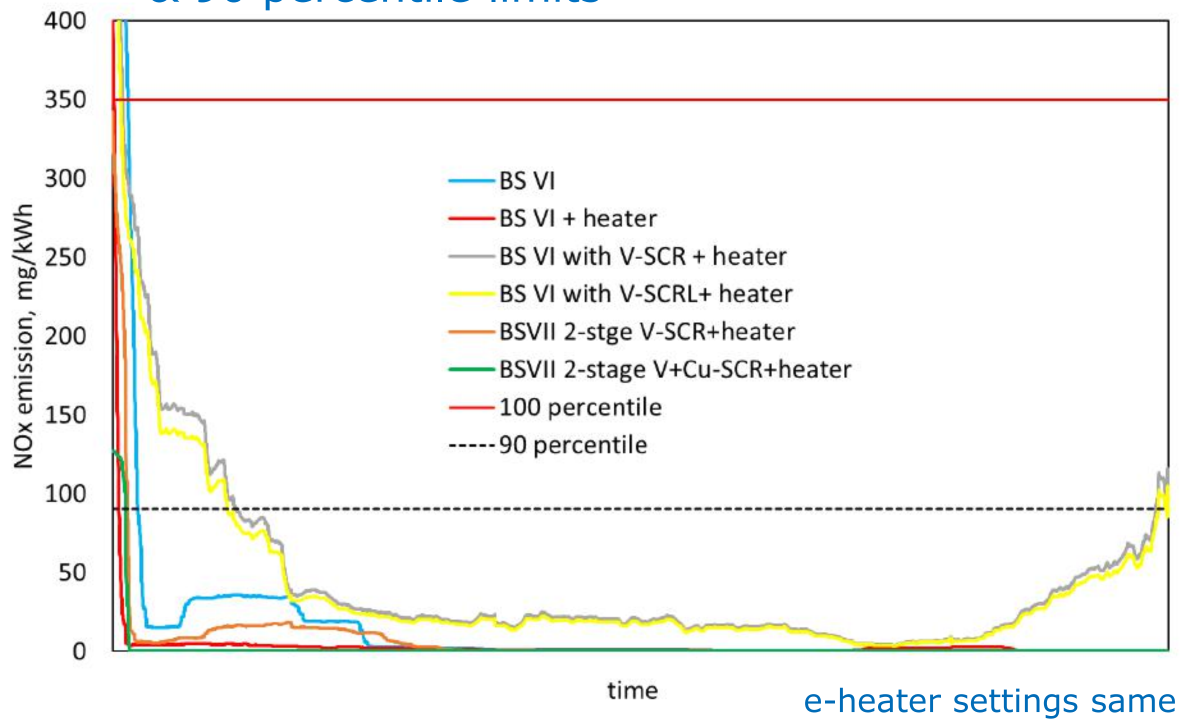
Budget emission	BSVI + e-heater	BSVI + with V-SCR_L + e-heater	BS 7 concept V-SCR1+V-SCR2	BS 7 concept V-SCR1+Cu-SCR2
CO	0.490 g ✓	0.490 g ✓	0.490 g ✓	0.490 g ✓
THC	0.118 g ✓	0.118 g ✓	0.118 g ✓	0.118 g ✓
NOx	1.871 g ✓	4.514 g ✗	2.014 g ✓	0.994 g ✓
NH3	0.053 g ✓	0.250 g ✓	0.112 g ✓	0.056 g ✓
N2O	4.167 g ✗	1.156 g ✓	0.983 g ✓	2.408 g ✓

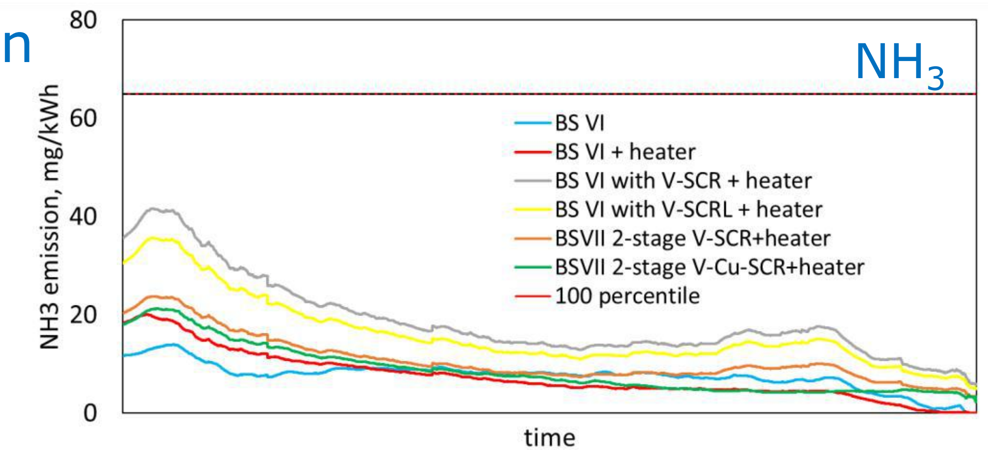
check of Budget limits using 1x cold WHTC + 2 hot WHTC, Catalysts HT aged

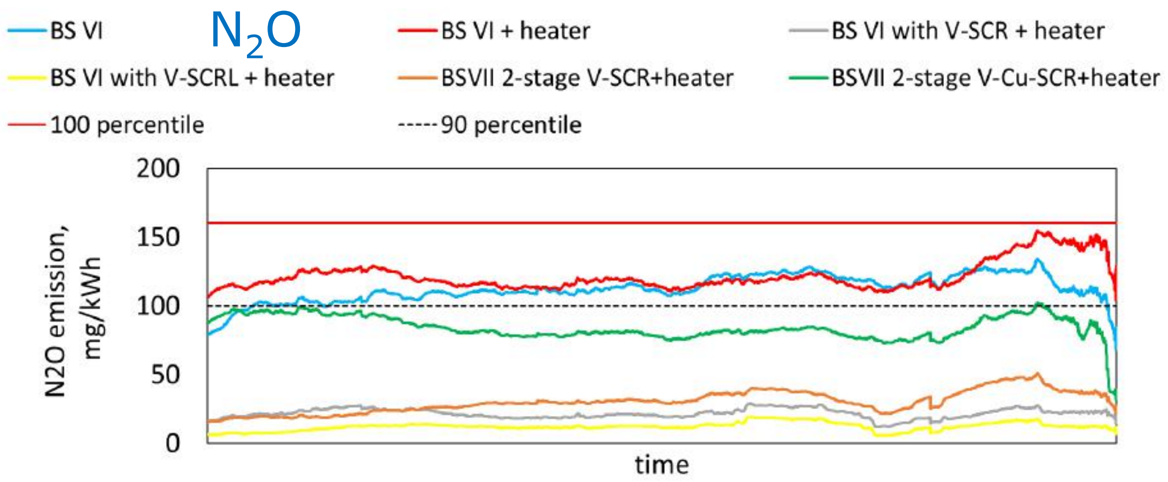
BS 7 concept with e-heater
Percentile limit view

Real PEMS data of a RDE cycle of the BS VI application was used to calculate the emissions in the MAW

only BS VII 2-stage SCR concepts below 100 & 90 percentile limits







e-heater settings same as in WHTC

Check of the different systems in respect to Eu 7 limits – EU Council (22.07.2023)

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Proposed WHTC-Limits:
CO: 1500 mg/kWh
NMOG: 80 mg/kWh
NOx: 230 mg/kWh

NH3: 65 mg/kWh
N2O: 200 mg/kWh

BS 7 concpet
2-stage SCR

cum. Em. mg/kWh	BSVI series	BSVI + e-heater	BSVI + with V-SCR + e-heater	BSVI + with V-SCR$_L$ + e-heater	V-SCR	V- + Cu-SCR
CO	262.9 ✓	19.7 ✓	19.7 ✓	19.7 ✓	19.7 ✓	19.7 ✓
NMOG/THC	63.0 ✓	4.7 ✓	4.7 ✓	4.7 ✓	4.7 ✓	4.7 ✓
NOx	252.0 ✗	75.1 ✓	185.9 ✓	181.2 ✓	80.9 ✓	43.2 ✓
NH3	2.1 ✓	2.1 ✓	13.3 ✓	10.0 ✓	4.2 ✓	2.2 ✓
N2O	93.5 ✓	167.3 ✓	46.4 ✓	46.4 ✓	39.5 ✓	95.3 ✓

Values in table: WHTC cold (20%) + WHTC hot (80%)

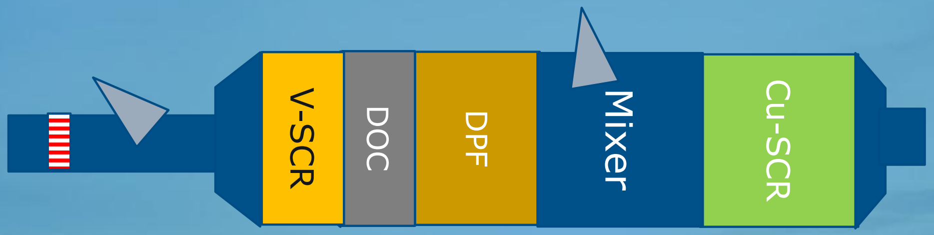
Summary & Conclusions

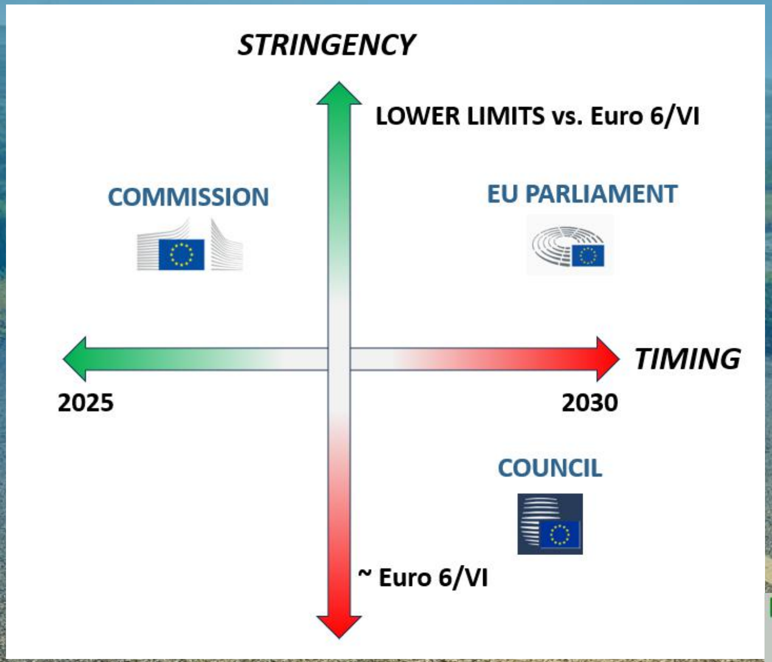
going the extra mile

- A holistic concept for an EU 7 system based on an electric heater upfront the ATS with a 2-stage SCR system was shown - additional measures like heated nozzle or a hydrolysis catalyst can improve the DeNOx performance
- An example for a 13L HDD engine with e-heater and 2-Stage SCR has shown, that it is feasible to meet the Eu7 limits proposed by the EU comission – low thermal mass, thermal management and insulation have a huge impact
- The assessment of an existing MDD BSVI ATS in respect to the discussed Eu 7 limits for NOx, N_2O, and NH_3 was done.
  - Engine bench & RDE emission data was evaluated using 1D simulation
  - The step by step implementation of e-heater, V-SCR, and 2-stage SCR was investigated.

  Outcome:
  - e-heater combined with 2-stage SCR is needed to fulfil the targets proposed be the EU Commission
  - The utilization of a V-SCR type at the first position after the heater is needed to get the N_2O emissions significant down
  - EU Council targets could potentially be reached with e-heater and existing ATS with some optimizations (thermal mass, thermal management,…)

e-heater





THANK YOU
for your attention!