DAIMLER

Status der Abgasqualität von Nutzfahrzeug-Dieselmotoren
Status of Exhaust Gas Quality of CV Engines

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Daimler Trucks

FREIGHTLINER FUSO WESTERN STAR Thomas BUILT BUSES BHARATBENZ

Overview - „NO_X-free" Exhaust Gas from Heavy-Duty Diesel Engines?

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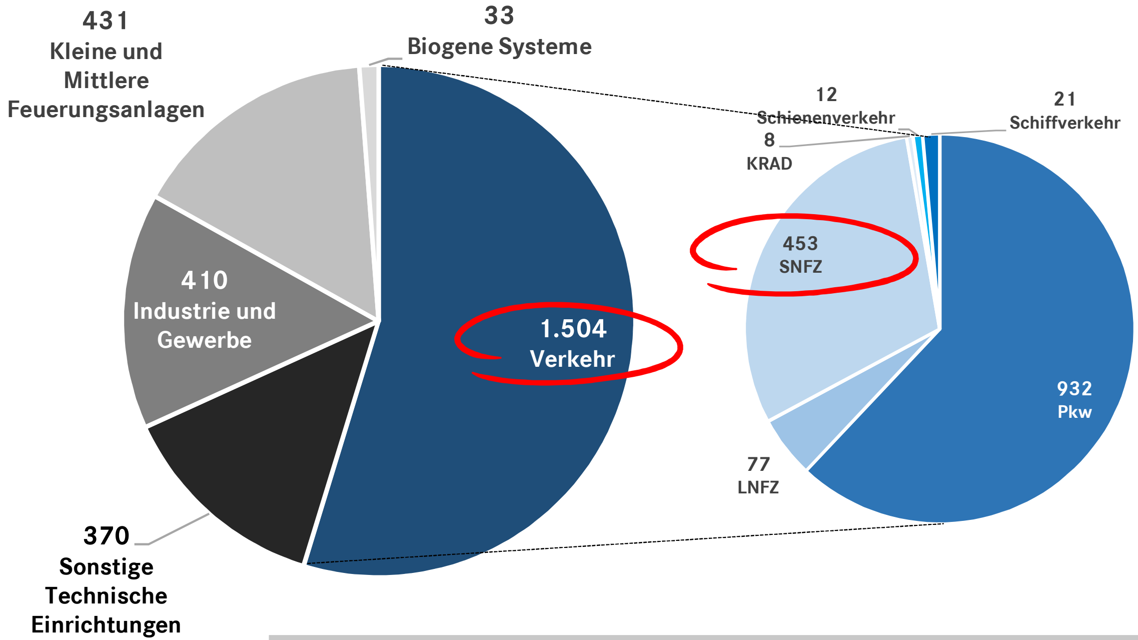
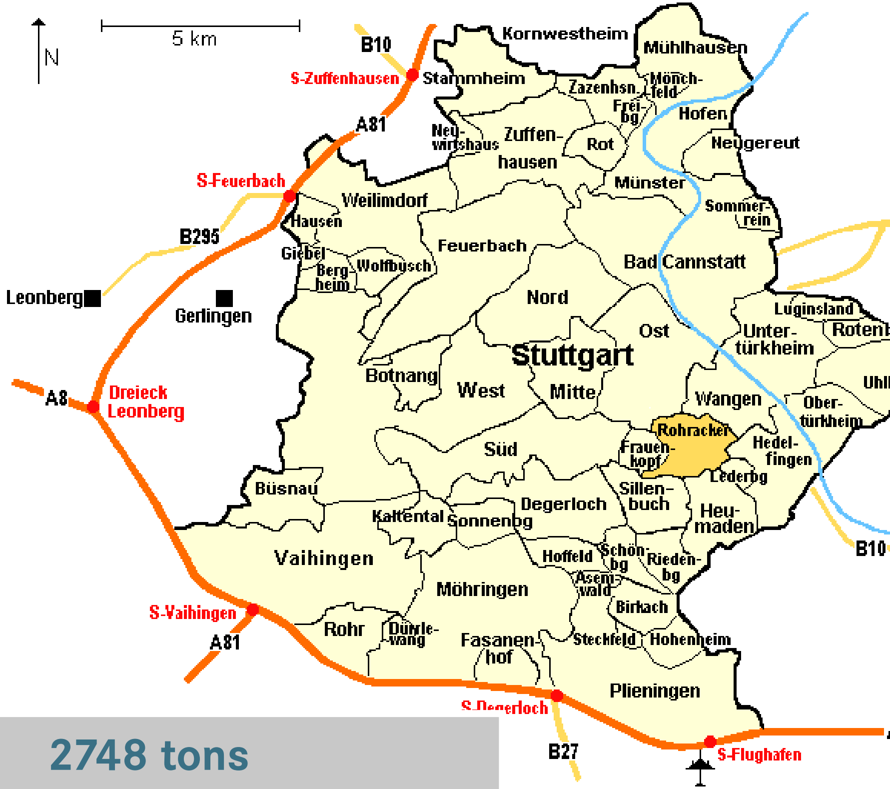
1. Status Exhaust-Gas Quality Commercial-Vehicle-Engines in Traffic [1]





Total NO_x Load in Stuttgart Metropolitan Area: **2748 tons**

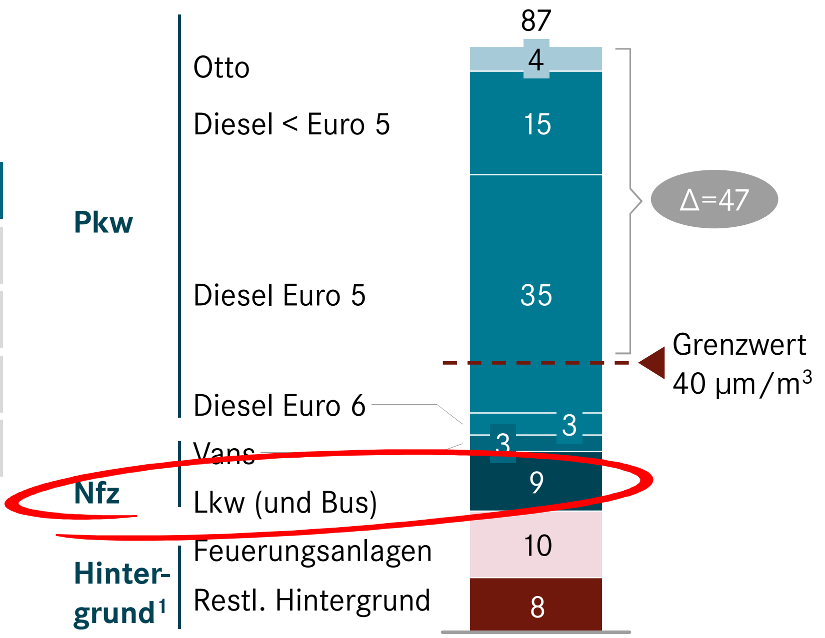
Total Traffic: **1504 tons (54,7 %)**

HD Engines: **453 tons (16,5 %)**

Ref.: LUBW Landesanstalt für Umwelt, Baden-Württemberg, 2014

1. Status Exhaust-Gas Quality Commercial-Vehicle-Engines in Traffic [2]

Ursachen der NO_2-Belastung 2015,
in µg/m³



„Neckartor Stuttgart“ with HOTSPOT Monitoring Station

Traffic Volume[1)]

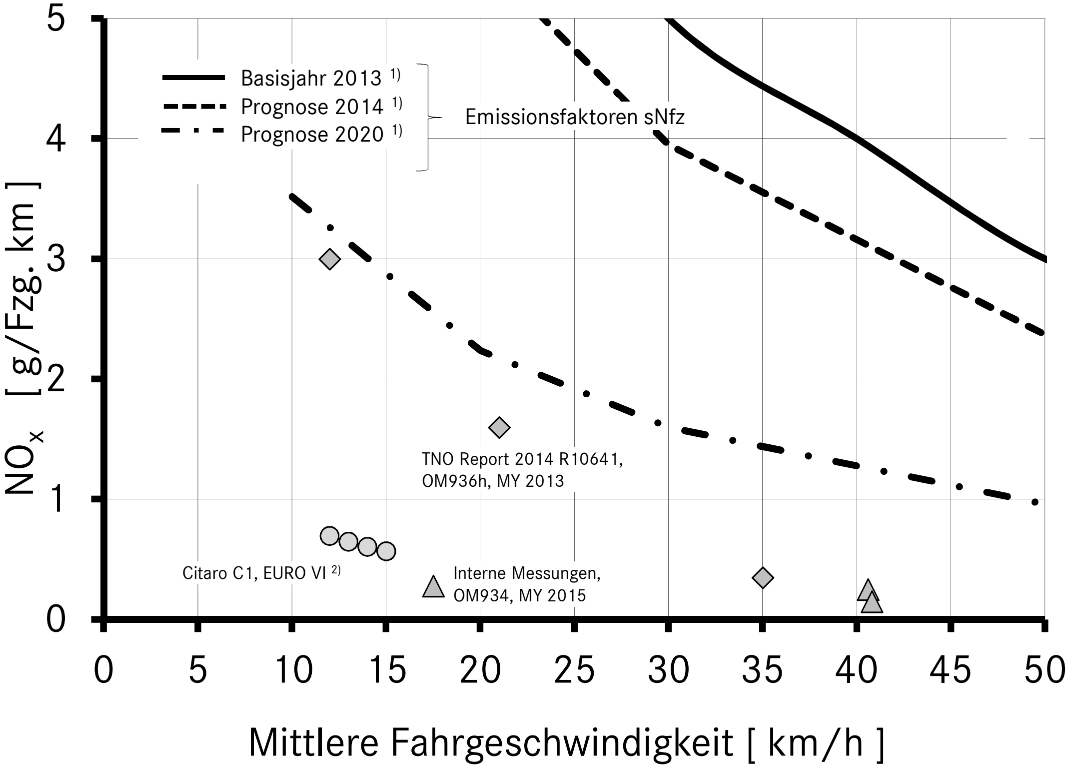
Total 71100 Vehicle/day, thereof

PC	66870 #/day
Heavy Duty	2020 #/day (2,8 %)

[1)] Stand 2013

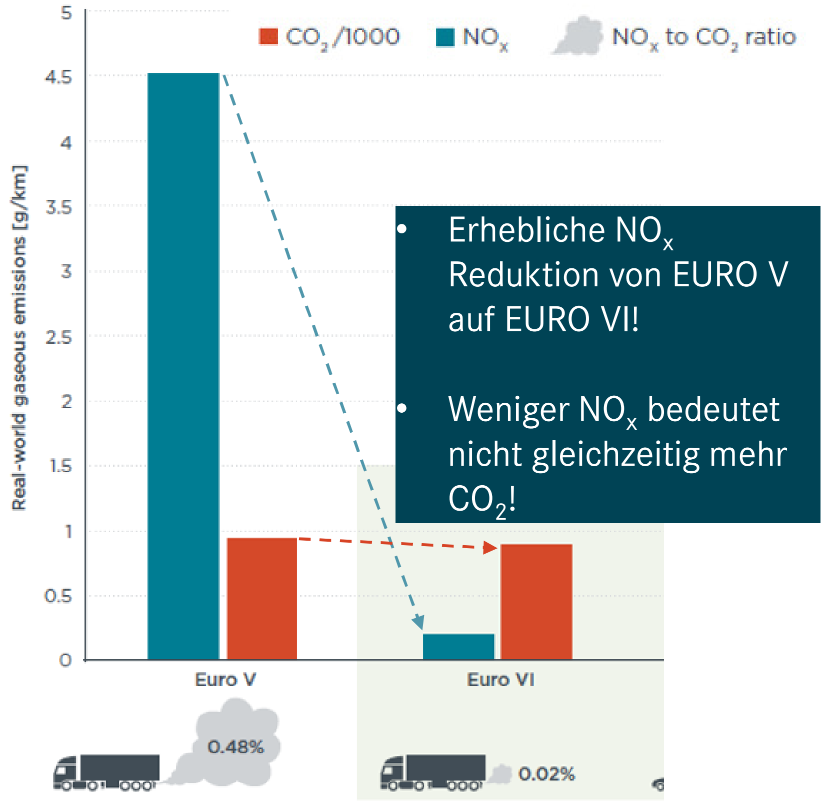
Ref.: a) Norddeutscher Rundfunk NDR (Foto), b) Verkehrsstärke an ausgewählten Verkehrs- und Spotmessstellen Landesanstalt für Umwelt LUBW, 05/2015, c) Dai-Berechnungen auf Datenbasis LUBW/Aviso

1. Status Exhaust-Gas Quality Commercial-Vehicle-Engines in Traffic [3]



[1] Datenquelle: Wirkungsabschätzung weiterer Maßnahmen für den Ballungsraum Stuttgart, Emissionsfaktoren für sNfz, LUBW, 05/2015

[2] Datenquelle: BELICON, Prof. Pütz, FH Landshut, Citaro Linienbusse mit OM 470 in Wiesbaden



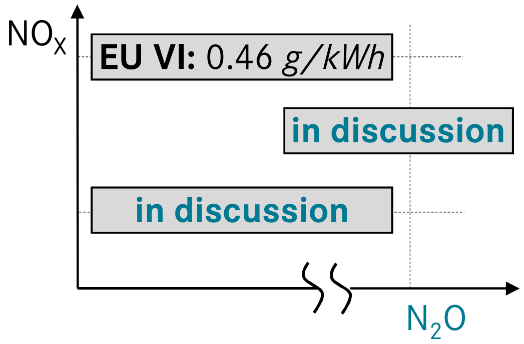
- Erhebliche NO_x Reduktion von EURO V auf EURO VI!
- Weniger NO_x bedeutet nicht gleichzeitig mehr CO_2!

Ref.: ICCT, „NOX emissions from heavy-duty and light-duty diesel vehicles in the EU: Comparison of real-world performance and current type-approval requirements“, Dezember 2016

Overview - „NO_X-free” Exhaust Gas from Heavy-Duty Diesel Engines?

2. Future challenges– legal drivers

EU - legislation



NH_3 – mean = 10 ppm
PM = 10 mg/kWh
PN = 6 x 10^{11}
CO = 4 g/kWh
THC = 0.16 g/kWh

Cerfification of WHTC + WHSC on engine test bench
in-use-compliance (IUC) w/- conformity factor = 1.5 (2013)

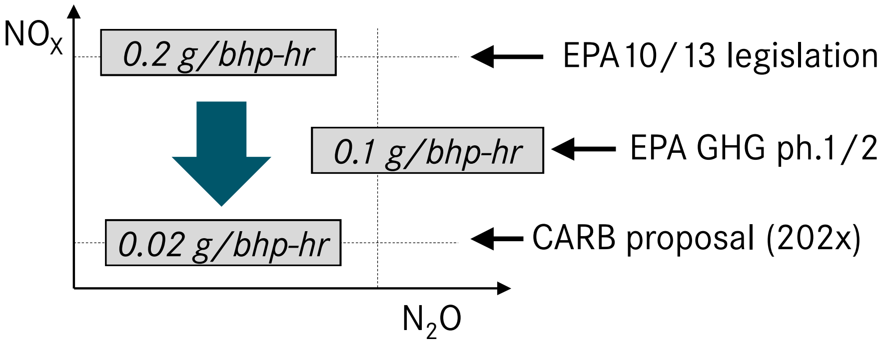
EU6d (2018):

- More stringent *IUC* requirements
- Pay-load reduction from 20 % to 10 %
- **Cold start** emissions still **not relevant**

EU7 (beyond 2018?):

- CO_2 limitation expected 2020
- More strigent IUC legislation?
- N_2O limitation?

CARB / EPA - legislation



no NH3 limit
PM = 10 mg/bhp-hr
no PN limit
CO = 15.5 g/bhp-hr
HC = 0.14 g/bhp-hr
(1 kWh = 1.34 bhp-hr)

Cerfification of FTP + RMC on engine test bench

EPA10/13:

- includes ***in-use-compliance*** *(IUC)* measurements
- ***conformity factor*** (CF) of 1.5 x certification values
- **NOx emissions at T_{SCR} < 250°C not OBD relevant**
- NTE zone at ***high engine-speed / load*** (CF = 1.5)
- **Cold start** emissions **not relevant**

Common CARB / EPA legislation in discussion (202x):

- More strigent FTP NO_X - emission requirements
- IUC in RDE – cycles / OBD

2. Future callenges– environmental drivers

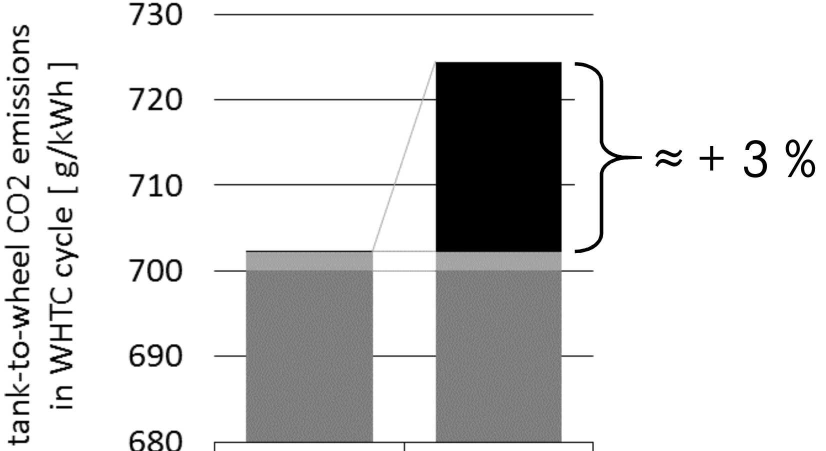
environmental aspects

Global problem:

CO_2 / N_2O (direct emission)

Influence on global climate change:

- N_2O has CO_2 equivalent of 298
- Temperature annomaly + 0.8 K (≈ last 100 years)



	CO2	CO2e
■ CO2 (N2O)	0.0746	22.2
■ CO2 (Adblue)	2.2	2.2
■ CO2 (fuel)	700	700

discussed US limit

approximate data of MD 8 l engine

health aspects

Regional / local problem:

HC + NO_2 + hv → O_3 (indirect emission)

N_2O
NO_2
PM
} (direct emissions)

Influence on human heatlth:

- O_3/NO_2: tear attraction, respiratory ducts stimulation, heat aches
- N_2O: only health critical at very high concentrations
- PM: cancerogenic effects, respiratory ducts stimulation

→ NO_2 has priority in California against climate gases N_2O

emission values (2015)

[µg/m³]		PM2.5	NO_2
Stuttgart (Neckartor)	mean.	17	**87**
	max.	40	**264**
Beijing (U.S. embassy)	mean.	**65**	-
	max.	**684**	
Central L.A.	mean.	12	**45**
	max.	56	**162**

summer smog (Los Angeles)

winter smog (Peking)

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1 Status exhaust-gas quality commercial-vehicle-engines in traffic

2 Future challenges

3 Measures for NO_X - reduction

4 Proof of concepts

5 Summary

3. Measures for NO_X - reduction

1
2
3
4
5

catalysis

catalysts	applications	NOx-reduction performance
PNA	future	100°C - 300°C $NO_{X,storage}$=0.2-1.0 g/l
NSC	pass-car	200°C - 450°C $NO_{X,storage}$=0.5-2.0 g/l
Va-SCR	EU4+5(+6)	$\eta_{SCR,200°C} \approx 50\%$
Fe-SCR	EU6	$\eta_{SCR,200°C} \approx 60\%$
Cu-SCR	EU6	$\eta_{SCR,200°C} \approx 85\%$

PNA, NSC: 1; Va-SCR, Fe-SCR, Cu-SCR: 2

1 **Discontinious** NOx – adsorption / absorption
Disadvantages: ageing, $\lambda < 1$

2 **Continious** NOx – reduction
Disadvantages: low temp. activity

engine based measures

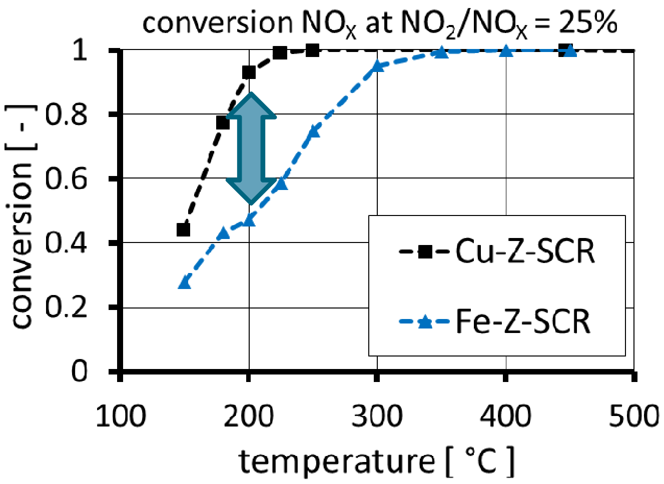
technology	NOx-reduction performance
combustion-design	most efficient, but trade-off CO_2
exhaust-gas-recirculation	most efficient up to – 50 %
charge-air-cooler	Efficient up to - 20 %, but driven by power demand
H_2O-injection	most efficient up to – 50 % (only steady-state applications)
NO_X-reburn	Efficient, but complex
controlled-auto-ignition	Most efficient up to -80 %, but very complex
in-cylinder Adblue dosing	efficient, but complex

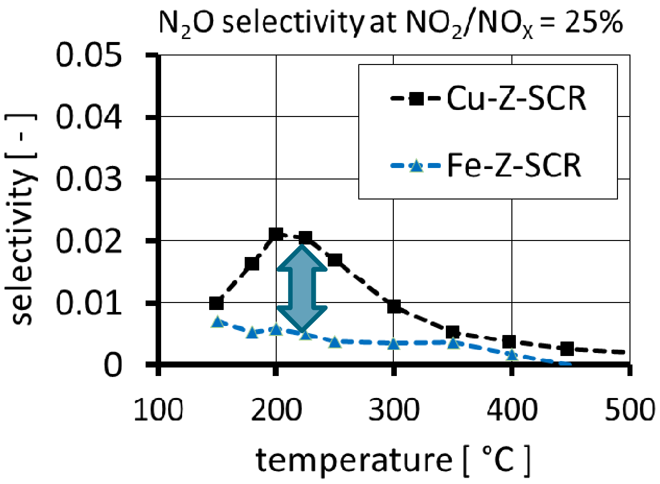
combustion-design, exhaust-gas-recirculation, charge-air-cooler: A; H_2O-injection to in-cylinder Adblue dosing: B

A **State of the art** technologies

B **Exotic** technologies

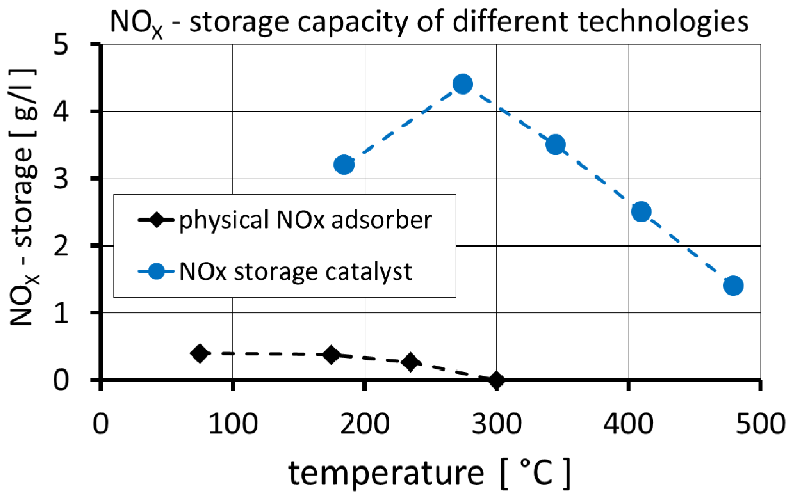
3. Measures for NO_X – reduction - catalysis





NO_X vs. N_2O

$NH_{3,storage}$ vs. NO_X-control



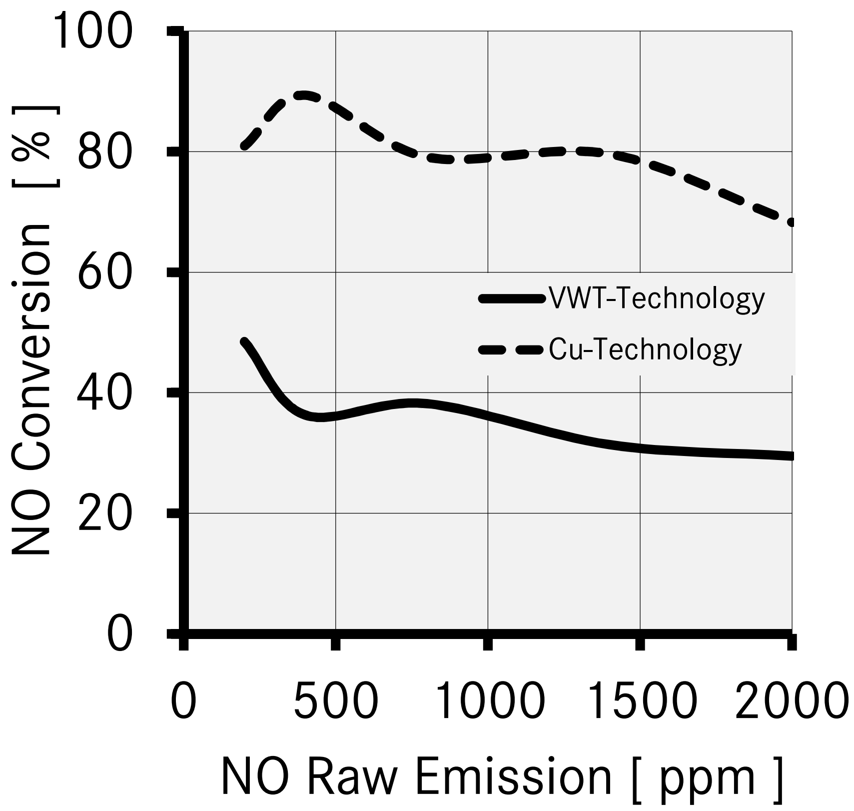
regeneration (λ<1)

$NO_{X,storage}$ vs. NO_X-control

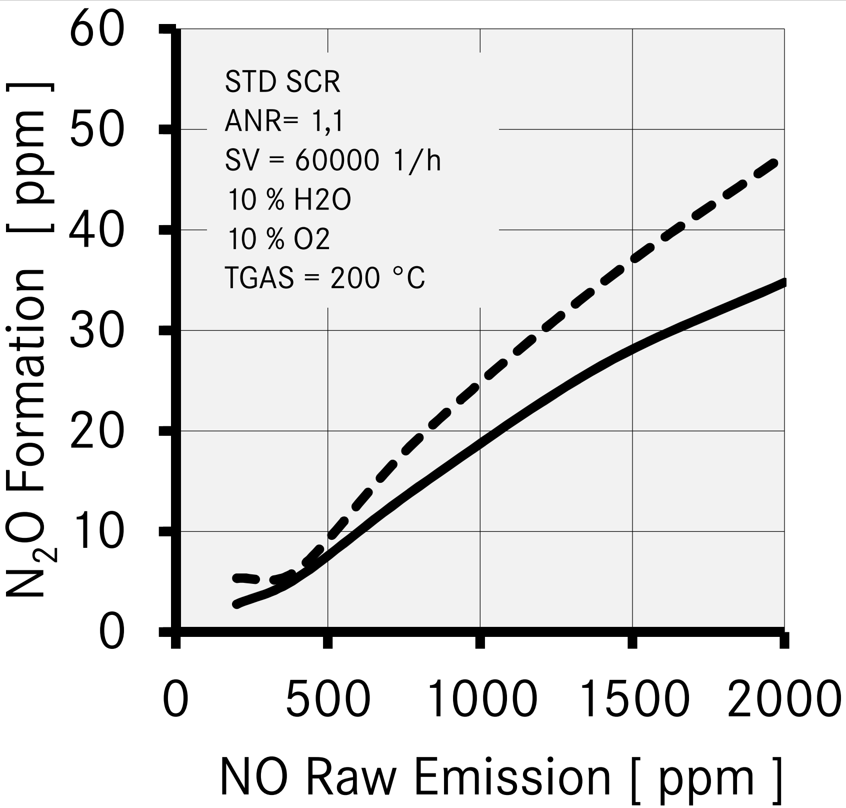
efficiency=f(end of test cycle)

3. Measures for NO_x-reduction – basic investigations of NO_x- catalysis

- CO_2 Reduction will increase NO Raw Emission. Exhaust Gas Temperatures will drop.
- DeNOx Benefit of SCR Catalysts on Cu Base
- More Catalyst Volume with higher NO Raw Emission



- Increasing NO Raw Emission causes higher N_2O Formation
- Cu Technology causes higher N_2O Formation



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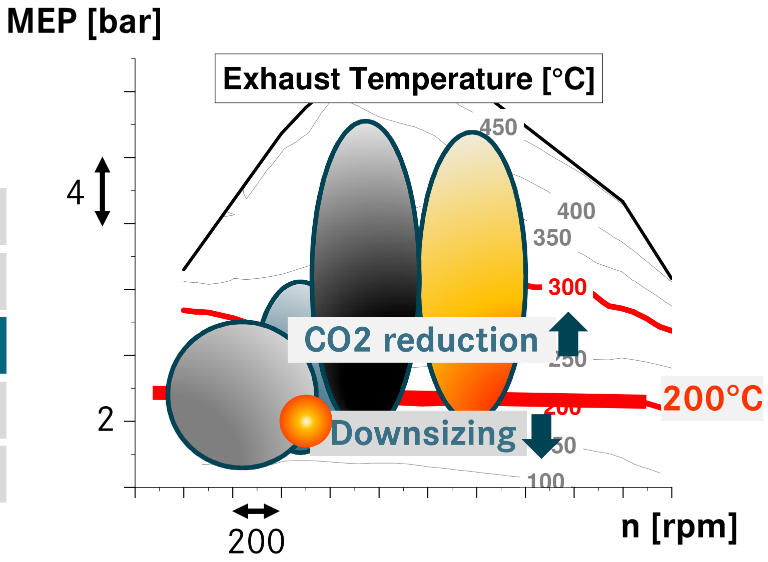
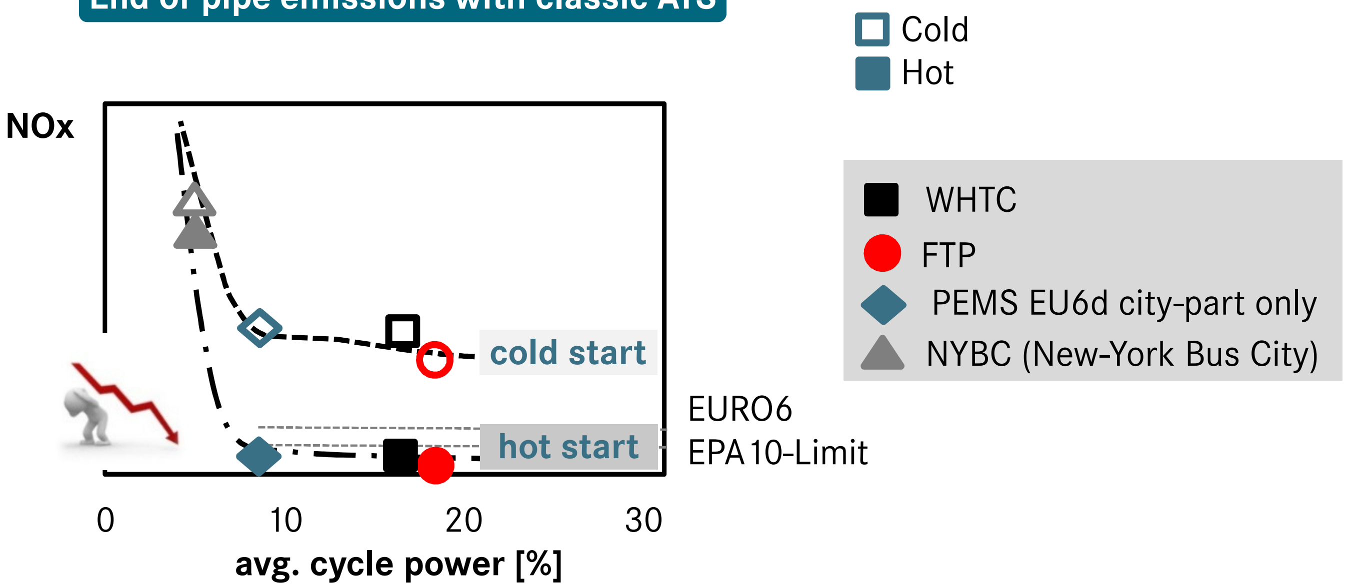
3. Measures for NO_X – reduction – system analysis

Engine Temp. / Duty Cycles



End of pipe emissions with classic ATS

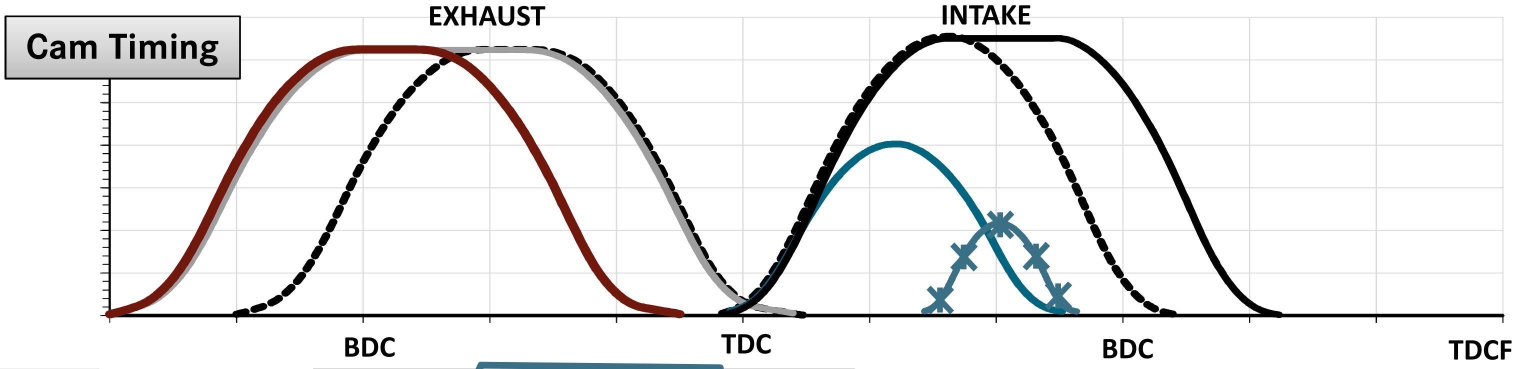


- Critical area MEP < 2 bar
- CO_2 opt. thermal-management
- Close couple ATS

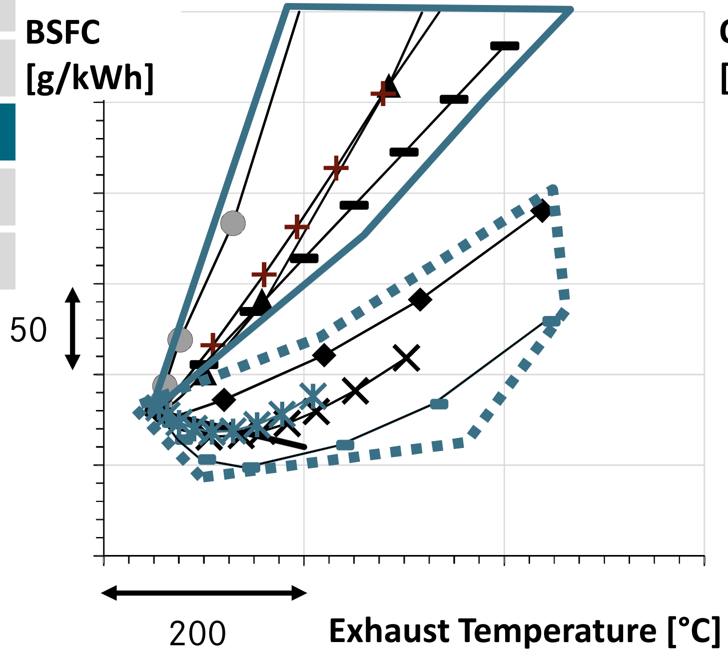
- right engine type and size for appl. ?
- fast SCR light-off

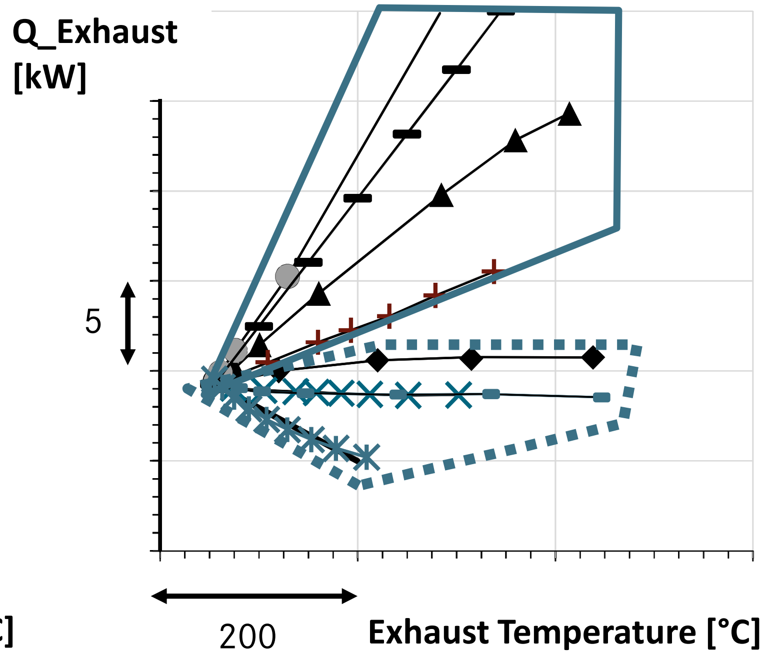
3. Measures for NO_X reduction – thermal management

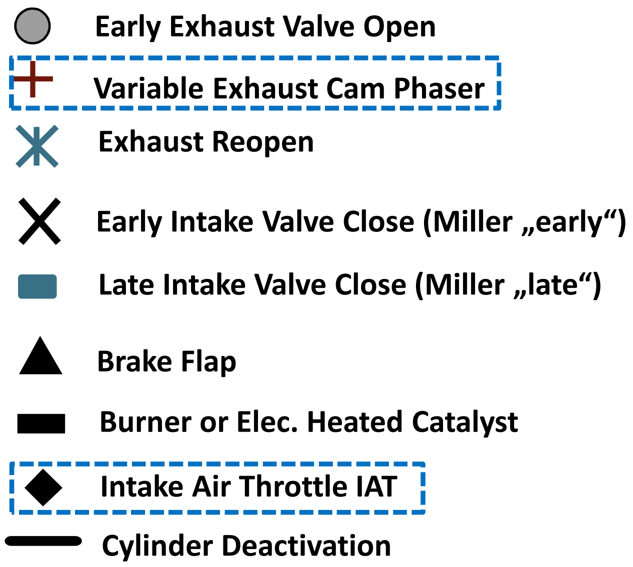
5 Liter MD
N =1200 rpm
MEP = 2 bar



Heat-up | **Keep warm**







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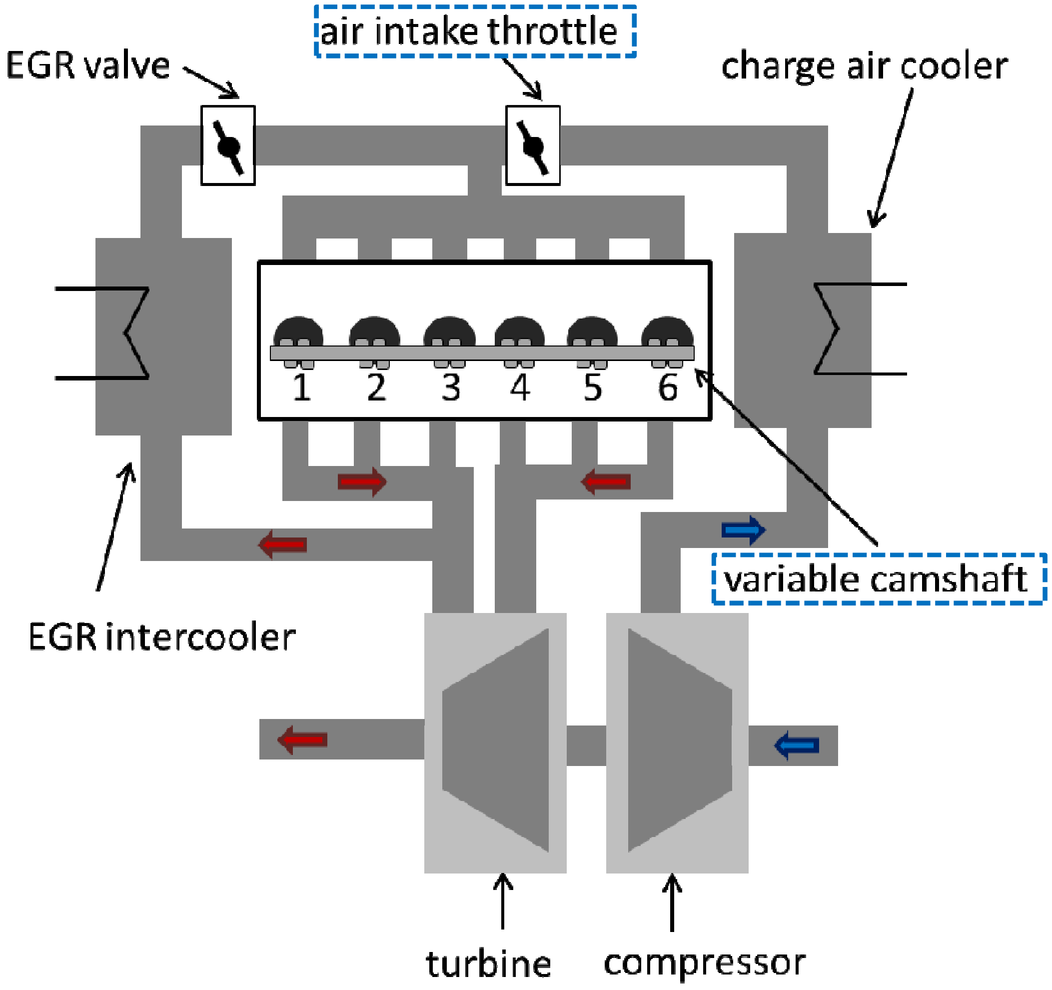
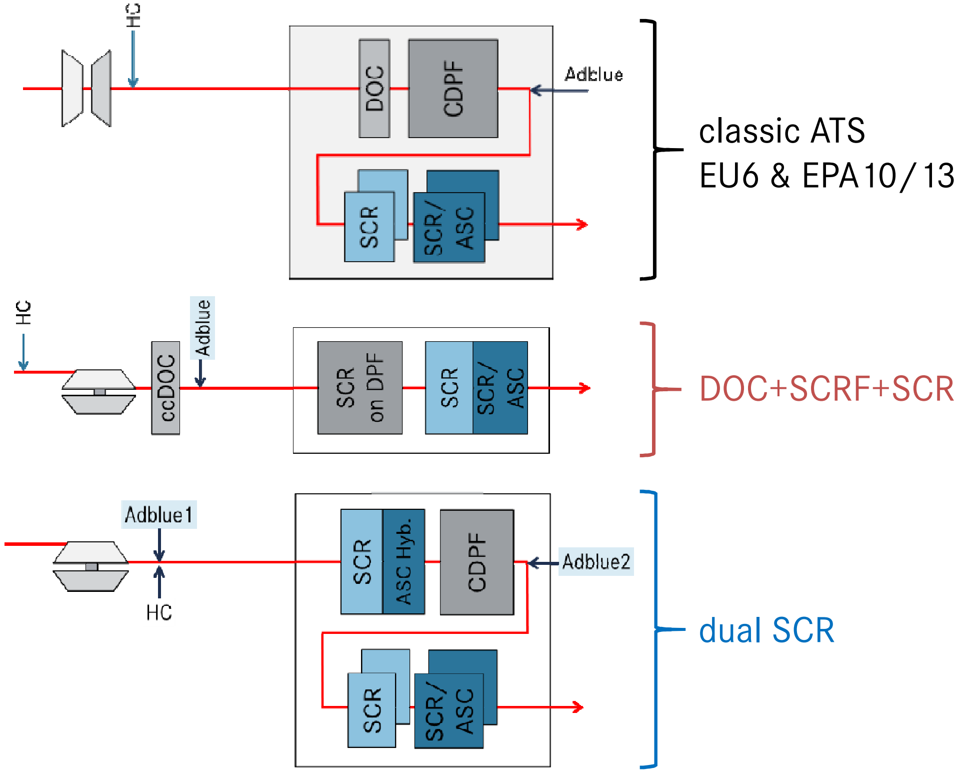
4. Proof of concepts – layout of tested systems



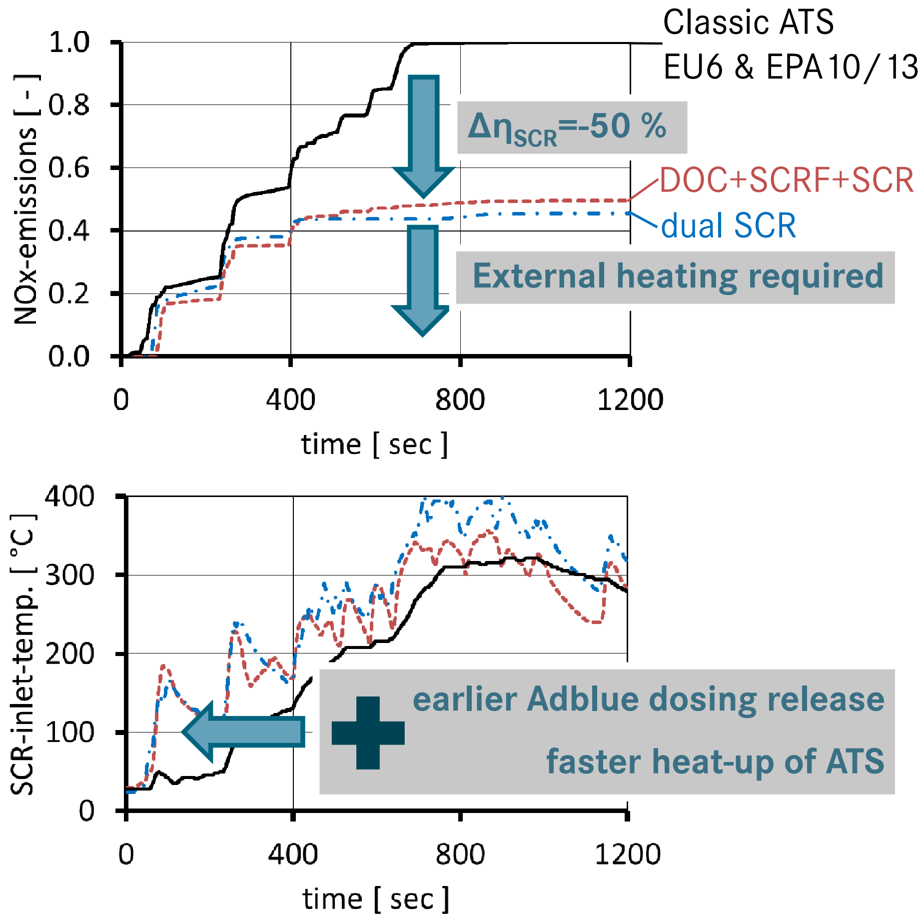


Abbreviations:

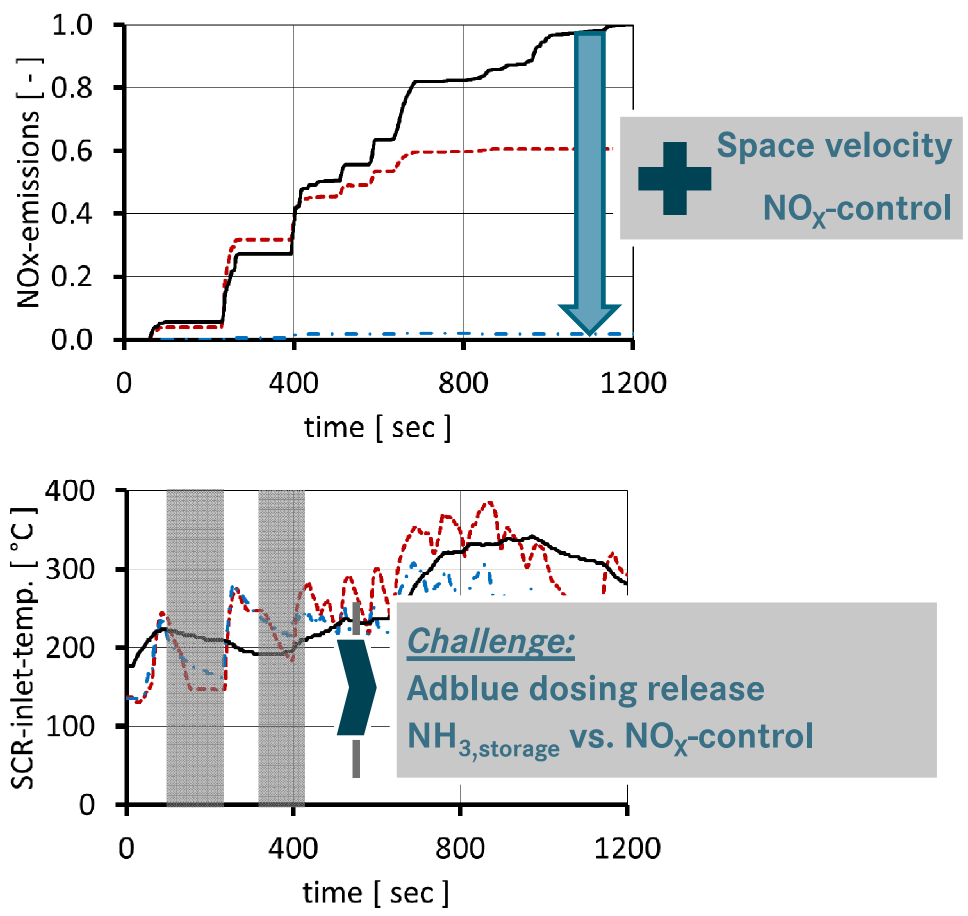
ASC	Ammonia Slip Catalyst
Aftertreatment System	ATS
CSC	Cold Start Catalyst
DOC	Diesel Oxidation Catlayst
DPF	Diesel Particulate Filter
HC	Hydro Carbon
SCR	Selective Catalytic Reduction

4. Proof of concepts – Federal Test Procedure FTP

Cold start emissions



Hot start emissions



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5. Summary

- **Contribution of CV Diesel engines to NO_2 Immission** on very low level. Big benefit from EURO V → EURO VI Technology

- **Cold start** & **low-engine-load** are most critical for CV Diesel engines

- **New ATS technologies / layouts** and/or **external heating devices** are required for **cold start** → **fast heat-up** of ATS

- **New Engine technologies** required for low-load operation → **never light-out** of ATS

- Trade-Off **N_2O-emission vs. NO_X-conversion-rates** of SCR‘s → non-EGR engine concepts has **risk of higher N_2O-** and **CO_2-emissions from Adblue**

- Promising proof of concepts, which could fulfill future **CARB / EU limits**

1
2
3
4
5