Using SCR on Filter Technology for downsizing future HDD On- and Off road Systems for Euro VI and Stage V

19th ETH-Conference on Combustion Gerenrated Nanoparticles

June 28, 2015

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Outlook

- Current situation / demand for next generation
- Downsizing concept & components test in 9‘‘x10‘‘ size, stationary
- Transient tests: Inline test setup and test in full system
- Optimization
- Summary

Current Situation

- HDD On-Road:
  - EURO VI is established on the market
  - Combination of DPF & SCR can be found using Cu-, Fe-, or Vanadia based SCR technologies
  - Active and passive regenerated DPF
  - 2nd generation EURO VI under development

- Off-Road:
  - Stage IV for >130kW introduced on the market
  - Main solution is SCR only – Vanadia the preferred SCR catalyst
  - Packaging is challenging

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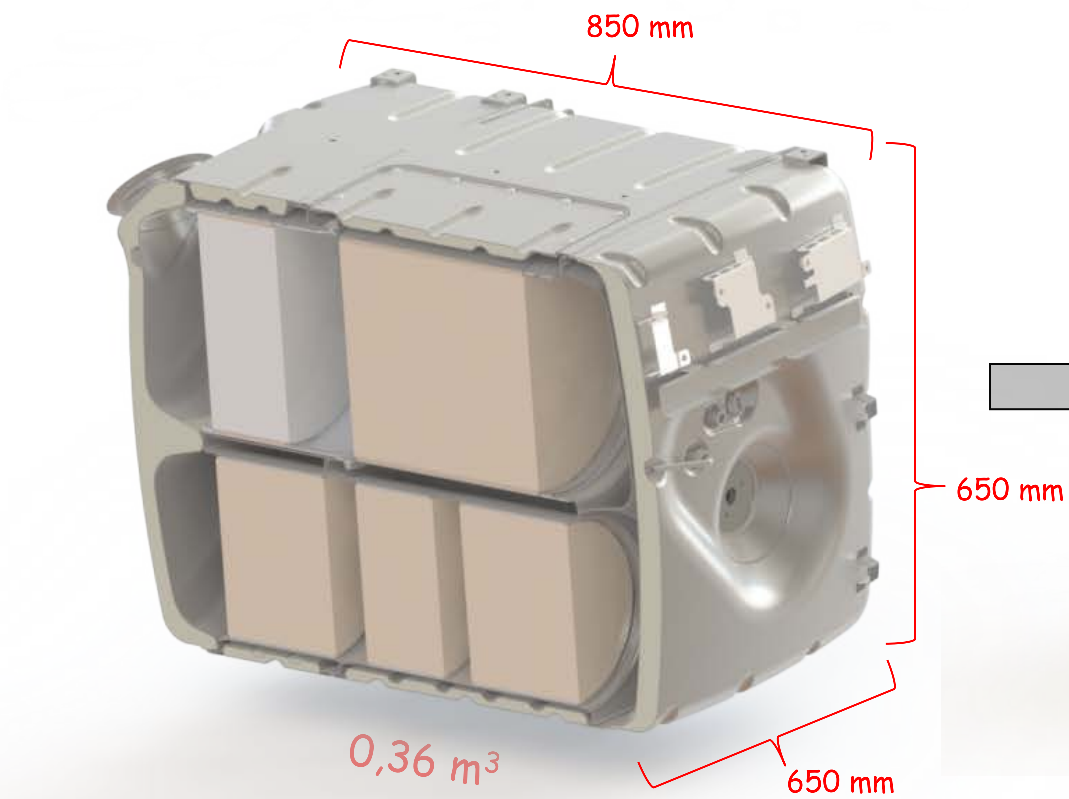
Next Generation

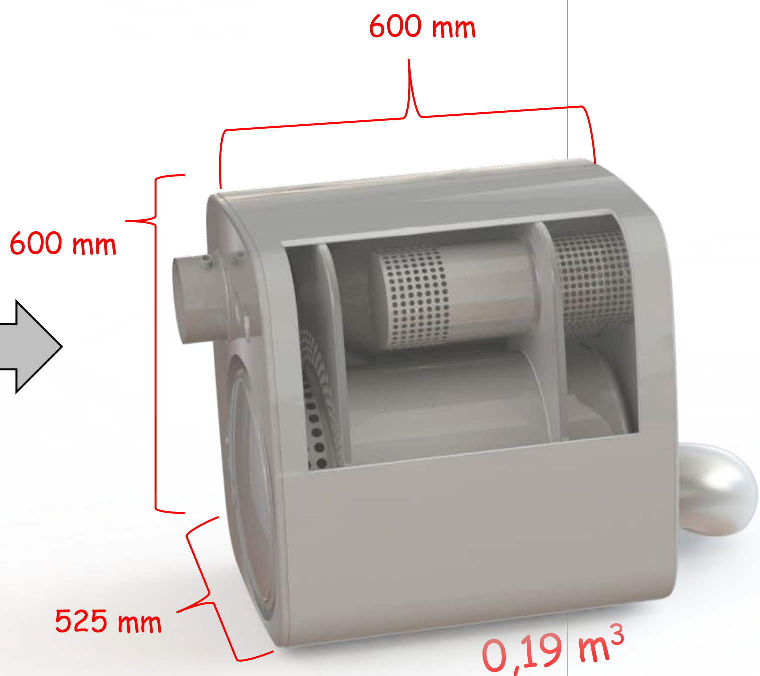
- Fuel efficiency improvements in Diesel engine developments lead to lower exhaust gas temperatures
  - Improvement in system performance needed (low temperature SCR → close coupled 4-way system / ammonia distribution...)

- Off-road Stage V regulation
  → Integration of particle filtration in existing Off-Road ATS concepts
  - Packaging and total system costs become more and more important
  - Downsizing by usage of SCR on Filter

Downsizing strategy HDD

- Existing Euro VI:
  - 1xDOC, 1xDPF, 4xSCR, 2xASC
  - <u>Total 8</u>
- Downsized system:
  - 1xDOC, 1xF-SCR, 1x SCR, 1xASC
  - <u>Total 4</u>





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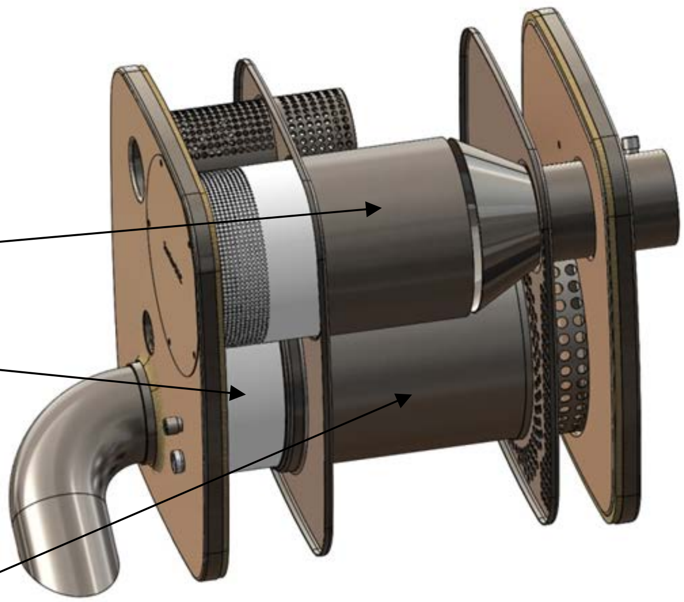
Downsize Concept with F-SCR scalable

Components:

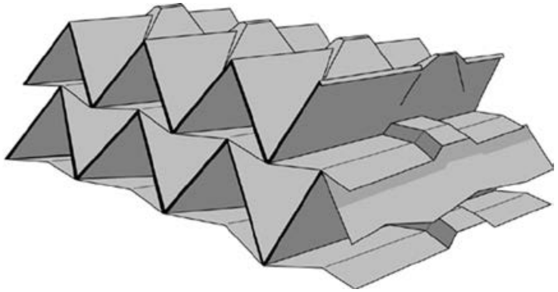
- Metallic substrates for the DOC and the SCR/ASC



- High porous SiC substrate for the F-SCR
- Various SCR catalysts and their combinations in the F-SCR and SCR/ASC
  Volume ratio F-SCR:SCR/ASC 2:1

EcoCat® substrates with self-locking design for DOC & SCR

- Features groove system for substrate locking and improved flow dynamics.
- 100 % stainless steel (1.4767/1.4725 substrate, FeCrAl).
- Easy to integrate into the exhaust system.
- Improved heat and mass transfer rate, low thermal inertia.
- High resistance against thermal and mechanical shocks.



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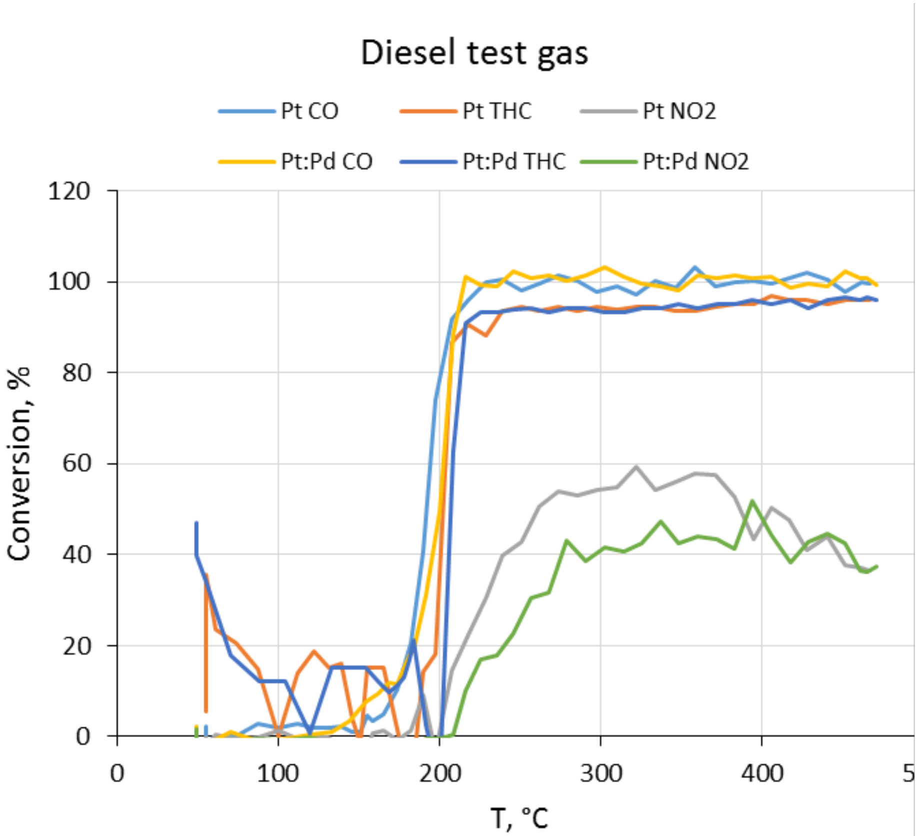
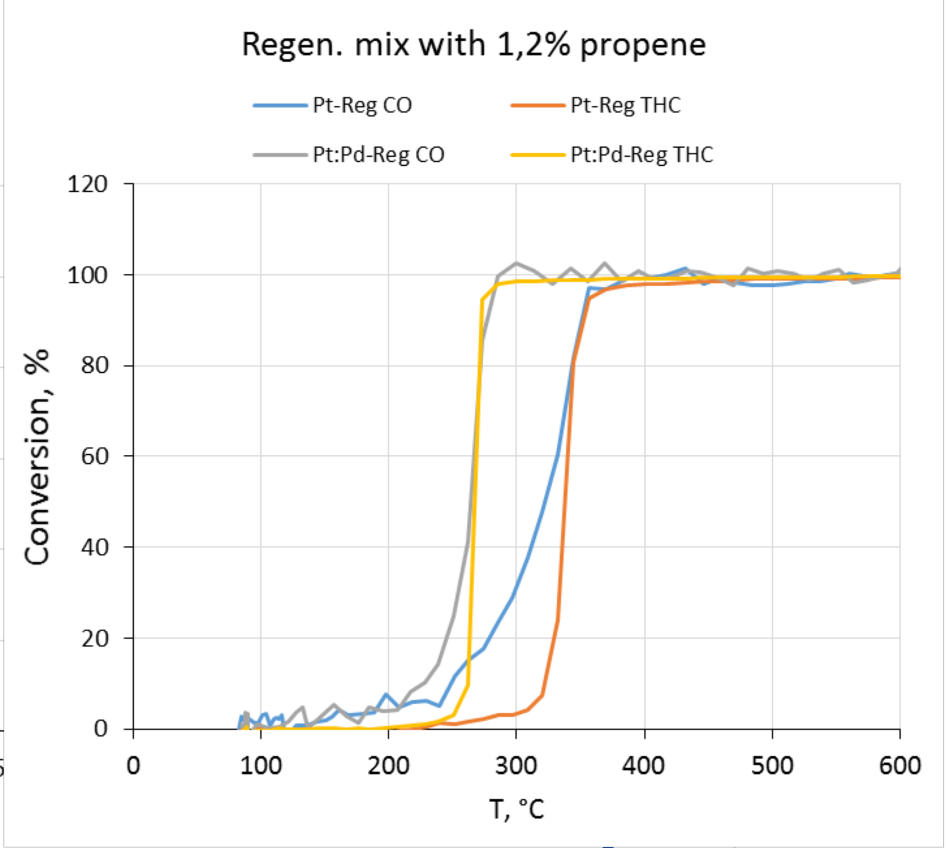
DOC

Pt vs. Pt:Pd 4:1 – 30g/cft

Hydothermal aged at 800°C





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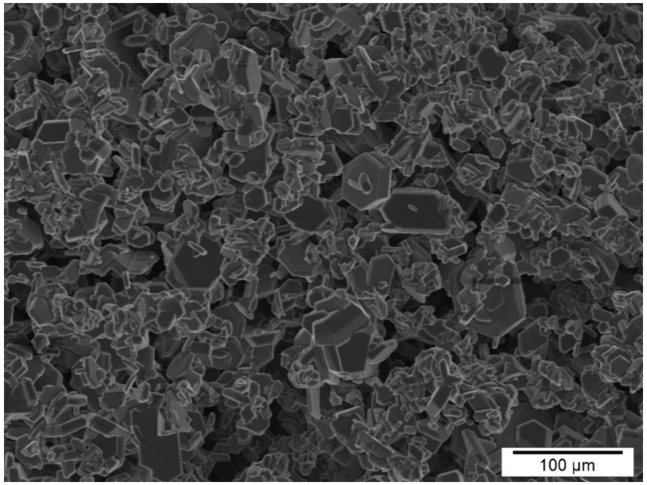
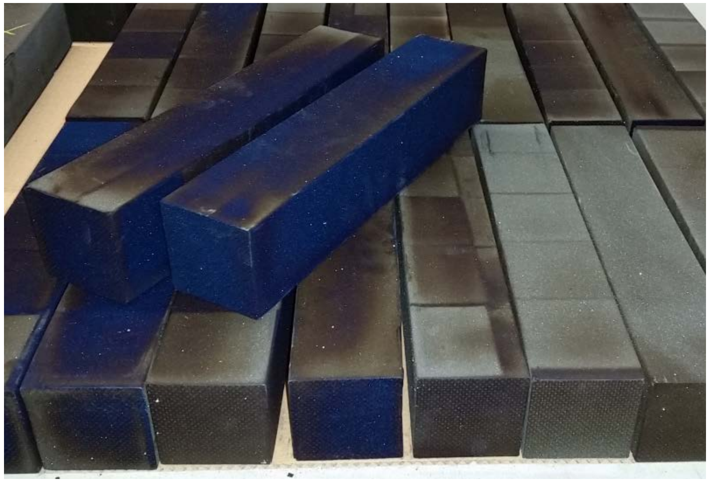
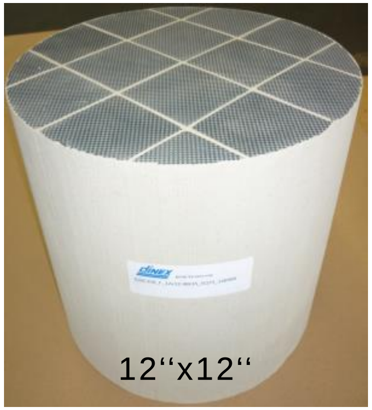
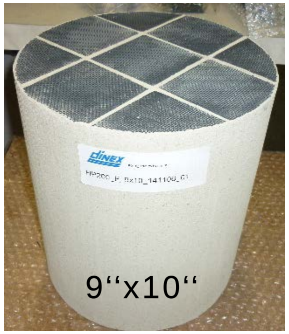
F-SCR - substrate

DiSiC$_{HP}$ with 65% porosity – 20µm pore size
Segments size: 78mm edge length









Current cell design: 200/16
Future: 200/12 & 300/10

DiSiC$_{HP}$ → SAE 2014-01-1484
ETH conference 2014

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F-SCR – catalyst types

Catalyst types

catalyst	SCR activity	S-tolerance	Temp. stability	N_2O formation	cost
Mixed metal oxide Ce/Zr/Nb MMO	T_{50}: ~ 250°C ≥ 90%: ~300°C –500/550°C	very high	up to 850°C	no	+
Fe-β-zeolite	T_{50}: 300°C ≥ 90%: 400°C – 650°C	high	up to 850°C	no	-
Cu-zeolite	T_{50}: 180°C ≥ 95%: 250°C – 400°C	low	up to 800°C	Yes, but low	-

SAE 2014-01-1484 & ETH conference 2014

this presentation

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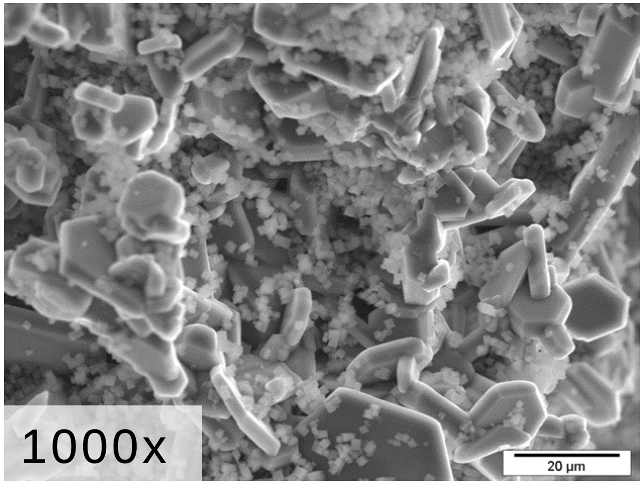
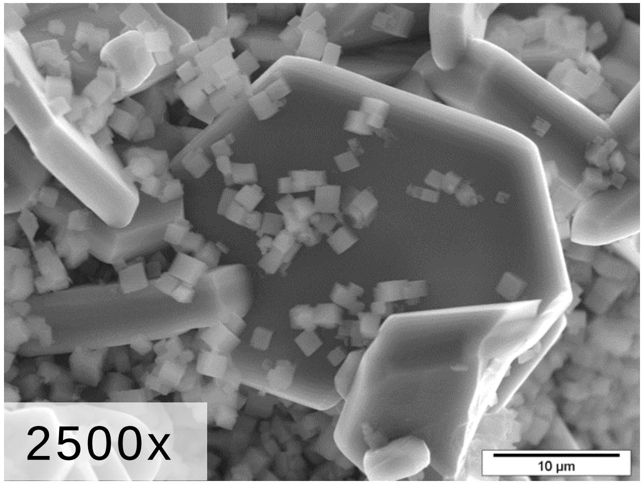
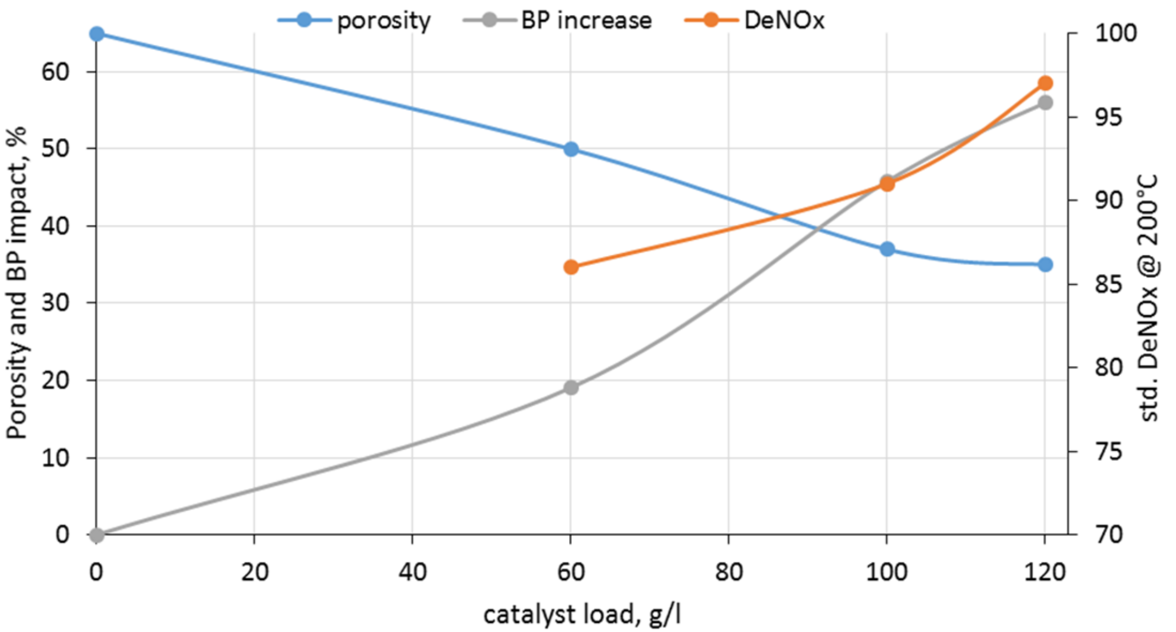
F-SCR – catalyst coatings

Cu-zeolite







DeNOx based on synthetic gas bench
on 1‘‘x3‘‘ filter samples
back pressure on 78mmx78mmx304mm segments
in 100m³/h cold flow

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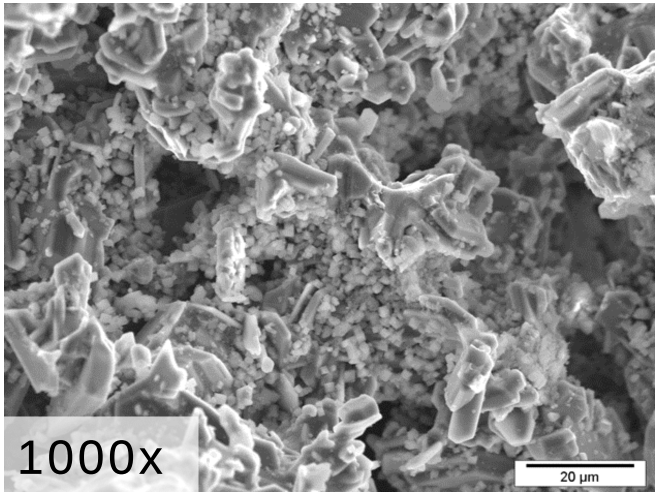
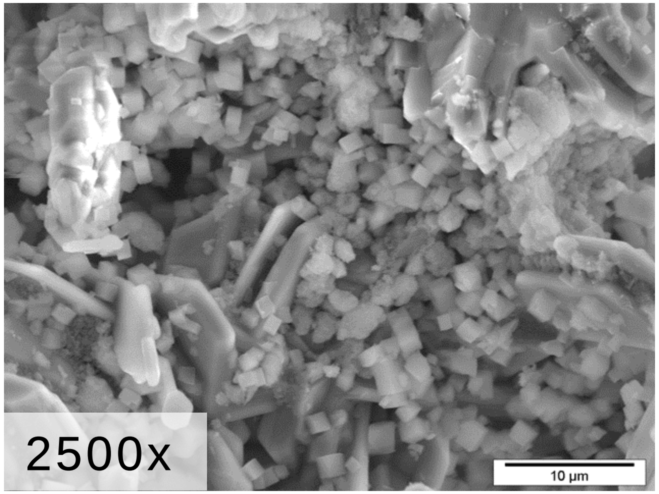
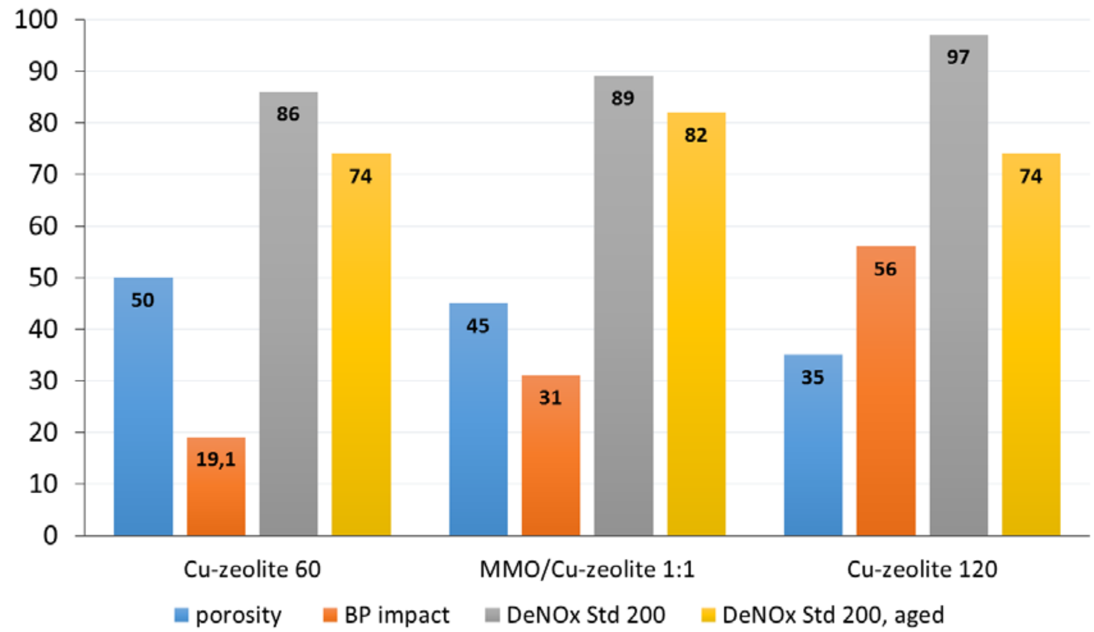
F-SCR – catalyst coatings

MMO + Cu-zeolite







DeNOx based on synthetic gas bench
on 1''x3'' filter samples
aged = hydrothermal 700°C, 20 h
back pressure on 78mmx78mmx304mm segments
in 100m³/h cold flow

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Stationary tests

F-SCR_1: Mixed Metal Oxide with Cu-Zeolite, 1:1

DOC 2 - 1.9L	FSCR - 10,4L
200cpsi	DiSiC-HP 9'' x 10''
25g/cft Pt	MMO + Cu-zeolite 120g/l

F-SCR_2: Cu-Zeolite

DOC 2 - 1.9L	FSCR - 10,4L
200cpsi	DiSiC-HP 9'' x 10''
25g/cft Pt	Cu-zeolite 120g/l

System 1

DOC 2 - 1.9L	FSCR - 10,4L	SCR - 4.1L
200cpsi	DiSiC-HP 9'' x 10''	350cpsi - 9.5'' x 90mm length
25g/cft Pt	MMO + Cu-zeolite	Cu-zeolite

System 2

DOC 2 - 1.9L	FSCR - 10,4L	SCR - 4.1L
200cpsi	DiSiC-HP 9'' x 10''	350cpsi - 9.5'' x 90mm length
25g/cft Pt	Cu-zeolite	Cu-zeolite

Stationary SCR test setup

Engine experiments used for development purposes

- Agco Power 4.9 L diesel engine
- Low-S diesel fuel (<10 ppm S)
- Bosch/AGCO POWER air-free urea dosing system with standard Adblue solution
- Steady engine points with urea/NO_X variations to detect SCR operation window
- α experiments: concentrations as a function of urea $(NH_3)/NO_X$
- Criteria NO_X conversion: NO_X efficiency corresponding to 20ppm NH_3

Table 1. Engine conditions in SCR experiments (ISO 8178 points).

Mode	Speed rpm	Load Nm	Flow rate m^3/h (NTP)	Temperature °C	3+2 exp.	6+2 exp.
1	2100	670	600	530	x	x
2	2100	503	570	450	x	x
3	2100	335	500	350	x	x
4	2100	67	338	190		
5	1500	830	461	480		x
6	1500	623	404	400		x
7	1500	415	326	340		x
8 idle	850	16	102	130		
9 extra	1500	200	230	290	x	x
10 extra	1500	140	220	250	x	x

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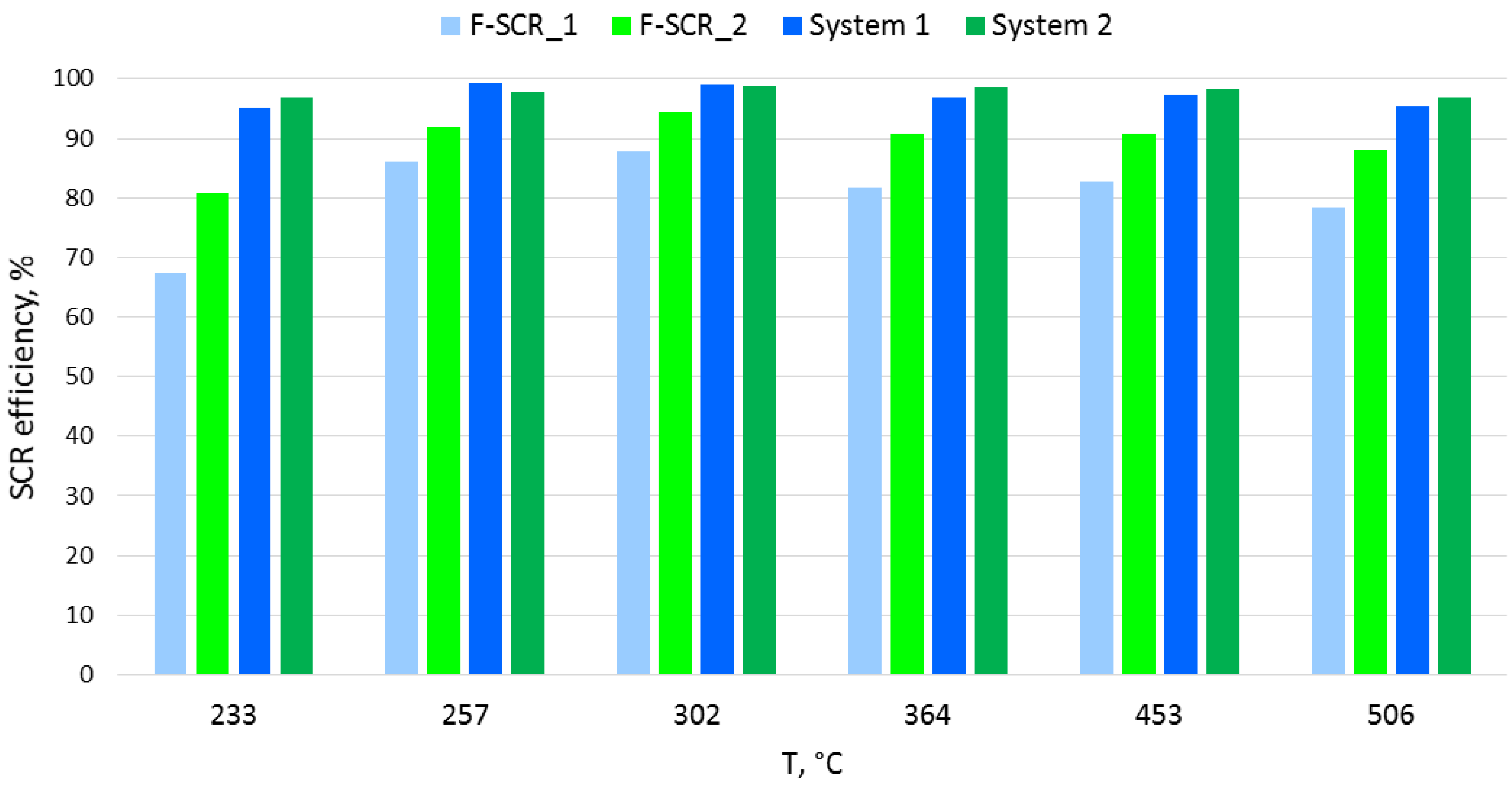
SCR efficiency- stationary



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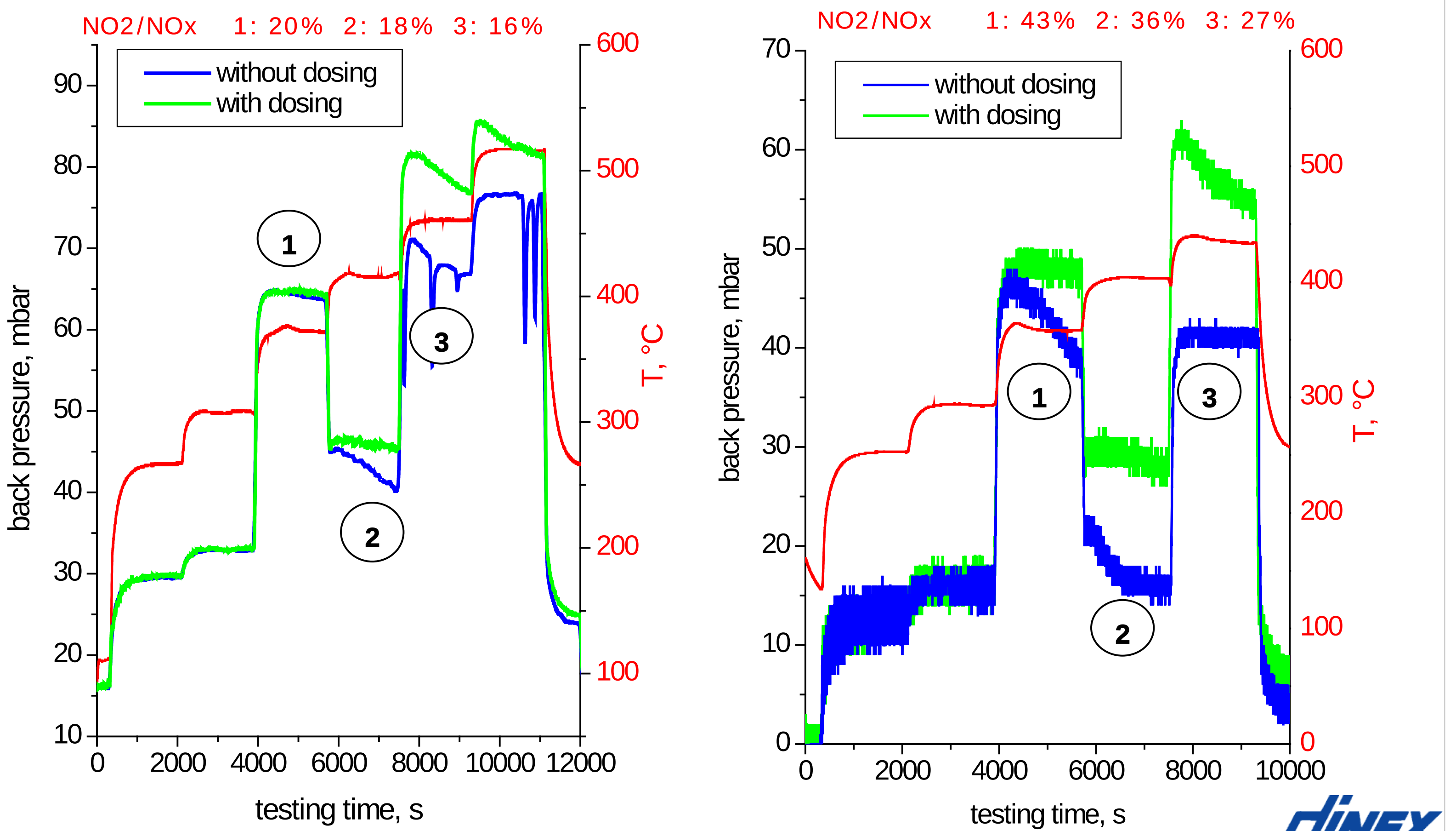
Impact of SCR on passive regeneration

F-SCR_1
soot load: 5g/l

Ex. Mass flow 1: 578kg/h 2: 380kg/h 3: 690kg/h



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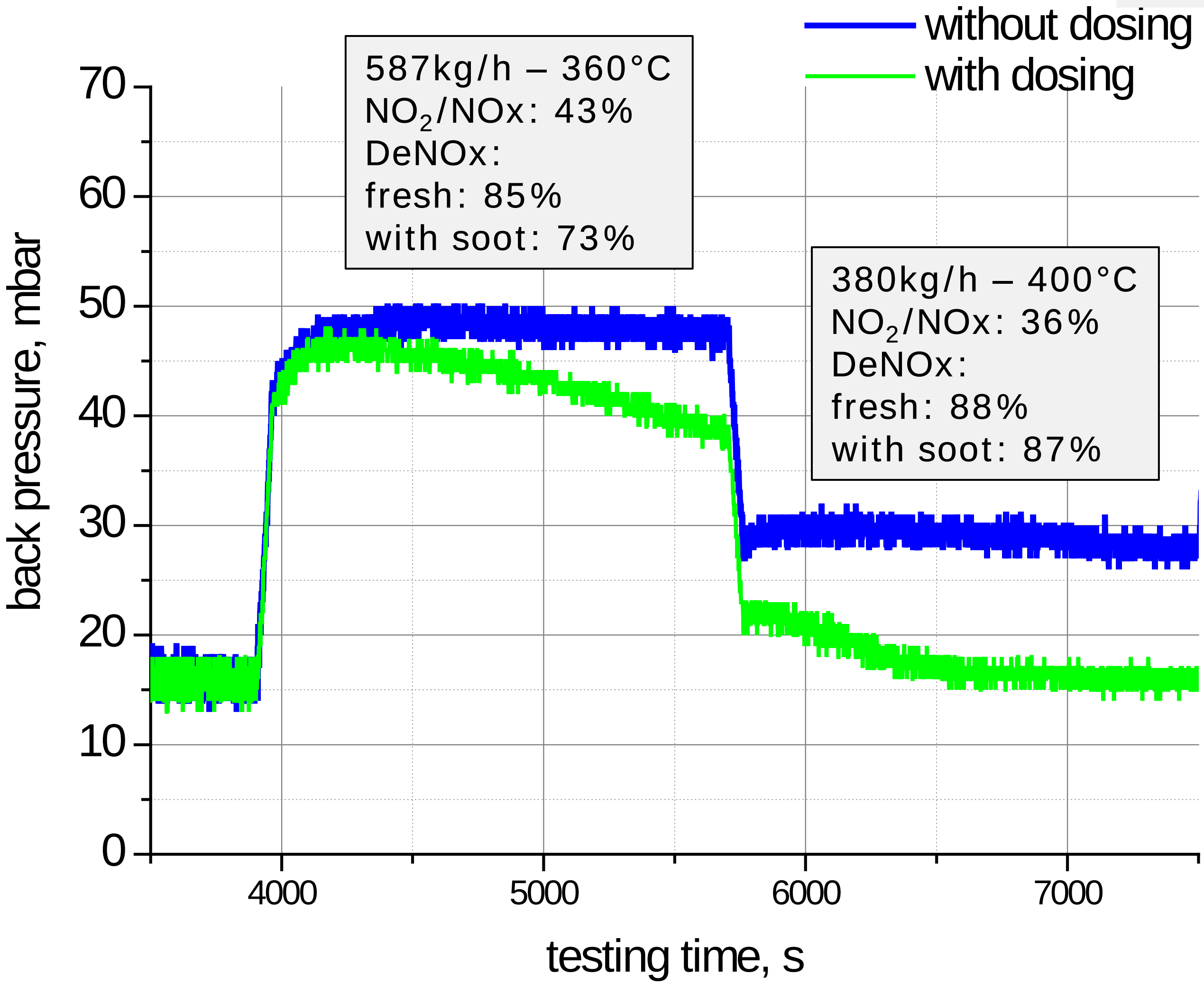
Impact soot load on DeNOx

F-SCR_1
soot load: 5g/l



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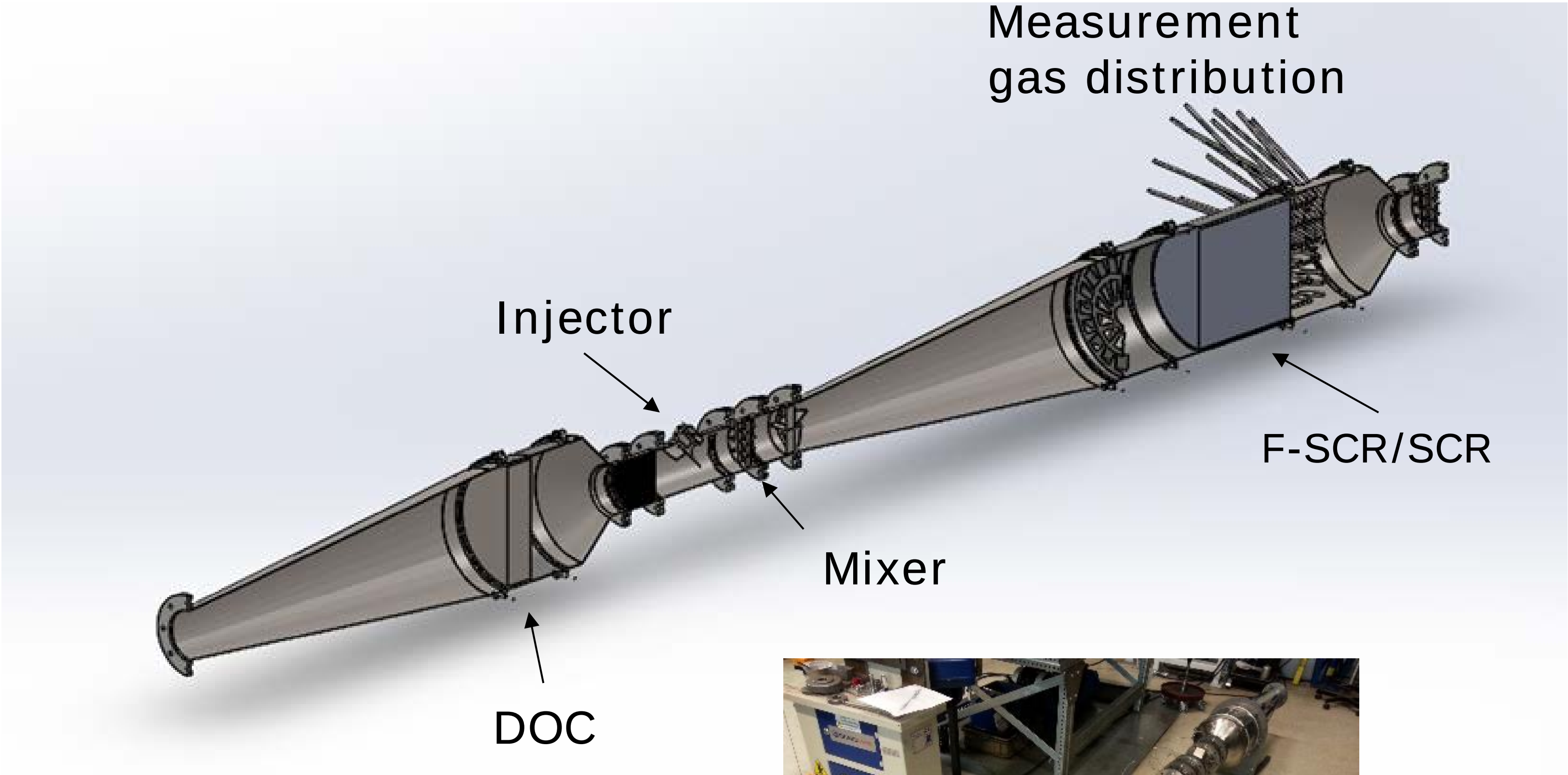
Component testing in full size



Engine:
Liebherr D936 10.5 L

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Components for inline tests

DOC
12“ diameter, 3“ length
Volume 5.5 L
catalyst:
KDN1.3 Pt only
substrate:
metallic 350cpsi/50µm

F-SCR
12“ diameter, 12“ length
Volume 22 L
SCR catalyst:
MMO + Cu-zeolite 1:1
substrate:
SiC 65%, 200cpsi/16mil

SCR
12“ diameter, 3.5“ length, 2x
Volume 13 L
SCR catalyst:
Cu-zeolite
substrate:
metallic 350cpsi/50µm

Load point B: 310°C, 1100kg/h, ANR=0.7

Efficiency [%]

			70			
		68	66	74		
	67	66	68	74	77	
67	67	68		67	75	72
	69	69	68	73	76	
		70	73	72		
			71			

All:	70	%
UI:	0,98	

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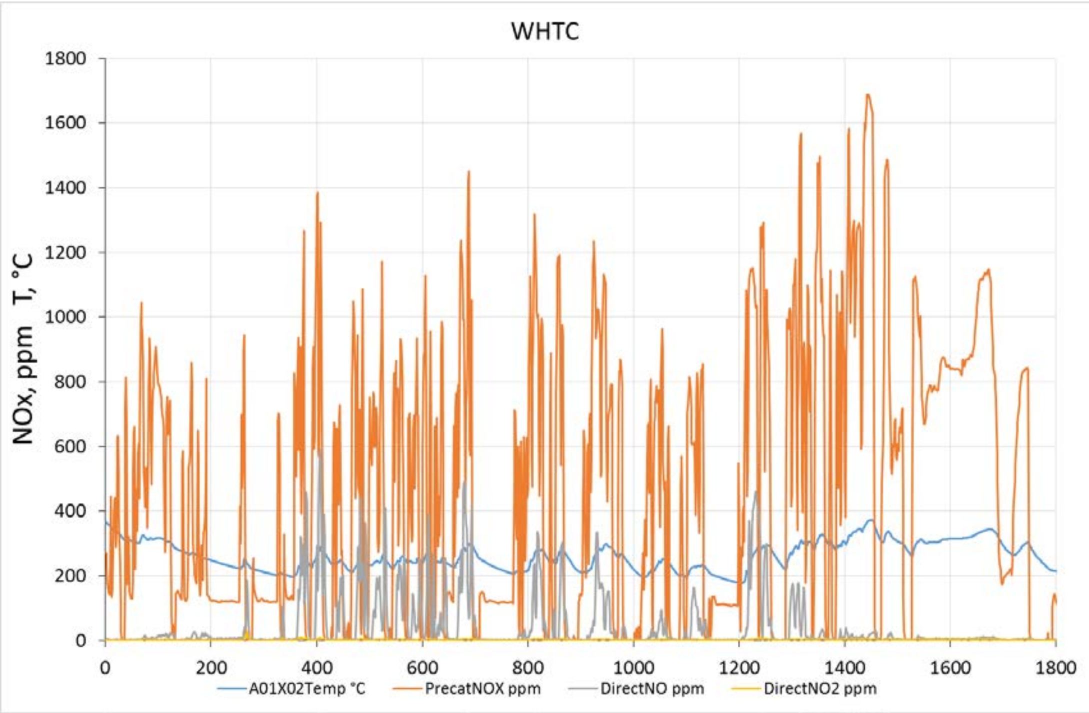
Results SCR-Efficiency



Setup	ESC	WHTC	NRTC
DOC + F-SCR	79%	74%	78%
DOC+F-SCR+SCR3.5‘‘	89%	79%	87%
DOC+F-SCR+SCR7‘‘	95%	90%	94%

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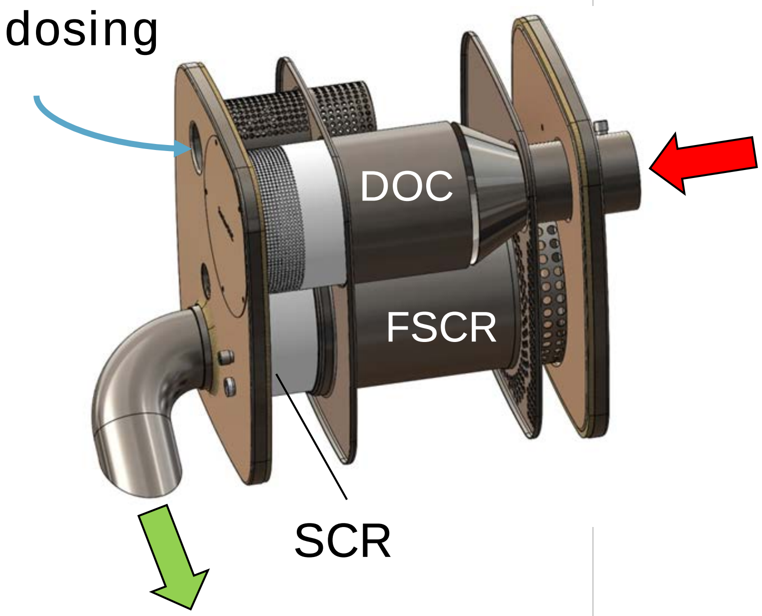
Corresponding first system concept HDD – 12l

DOC	F-SCR	SCR
9“ x 8.3“	12“x12“	12“X7“
8.6 l	22 l	13 l
200cpsi	200cpsi	350cpsi
Pt only	120g/l MMO+Cu-Z	110g/l Cu-Z

Engine:
OM460 12.7 L
high NOx 8.8g/kWh

Cycle	NO_x	PN
ESC	94,0	99,8
ETC	97,5	99,8
NRTC	97,5	99,4
WHTC	91,0	99,9



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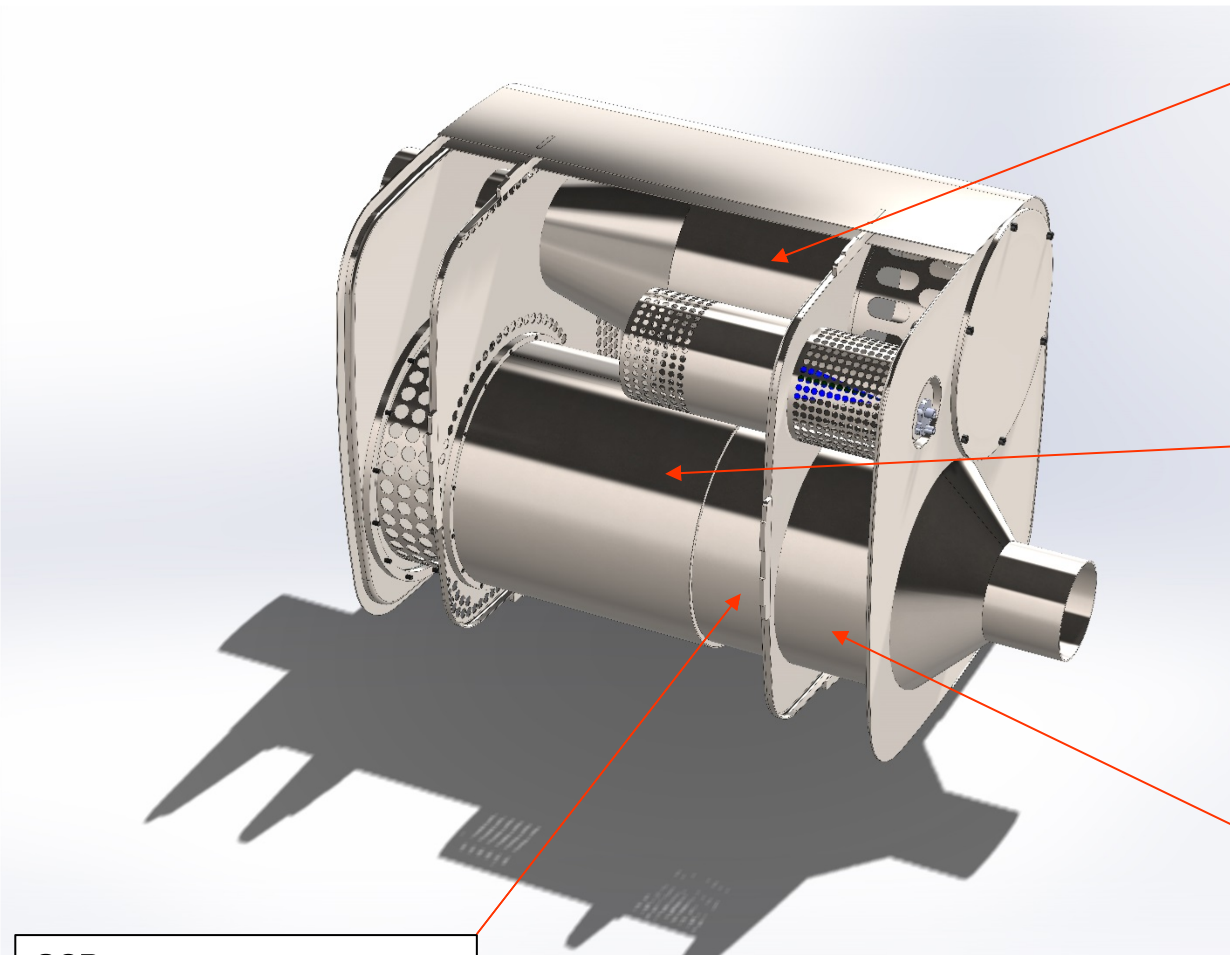
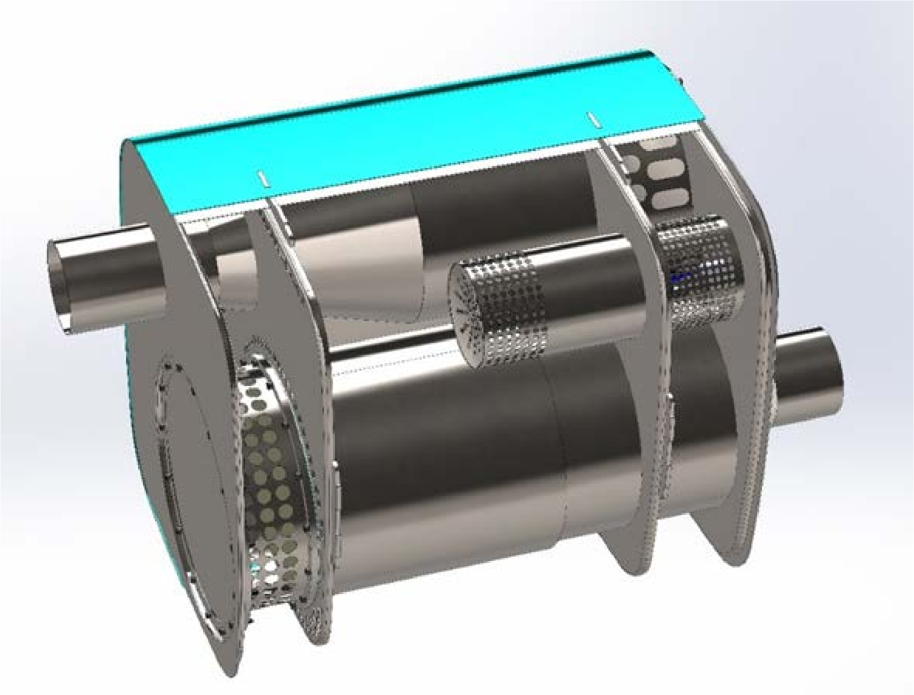
Optimized design HDD 12L



Summary and outlook

- Components for a downsized system for HDD developed – basic system design is
  DOC – F-SCR – SCR+ASC,
  Volume F-SCR/SCR 2:1
- SCR on DPF based on MMO+Cu-Z mixture
- PGM composition of DOC need to be adjusted for high NO2 formation → compensate DeNOx impact on passive regenetarion
- Additional SCR to compensate impact by high soot load on DeNOx
- First test in downsized system showed DeNOx up to 97% - further optimization for Euro VI

Thank you for your attention



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