PURI tech
Abgastechnik – Exhaust Technology

Clean Air for Generations

Active DPF System (PURImax) for Nanoparticle Filtration and NO_2 Reduction in Practical Use with Low Exhaust Gas Temperatures

Diesel Emissions Conference & Diesel Exhaust Fluid Forum USA 2010, San Diego

Agenda

- Summary
- European Air Quality Standards (PM10, PM2.5, NO_2)
- LEZ Patchwork, Enforcement, Incentives
- NO_2 Exceeding in German Cities
- NO_2 Emissions 1987 – 2004
- UBA List with Homologated Filters
- Nitrogen Oxides Chemistry
- FTF and their Impact on NO_2 & PM
- Systems for NO_2 Abatement (SCR, EGR, FBC, PURImax)
- Components of PURImax System
- Algorhythm of Active Regeneration
- Chemistry in Pre-filter and DPF
- Test Results
- Approvals
- Field Experiences with PURImax

Summary

With the introduction of a 40 g/m3 NO_2-limit in ambient air (January, 2010), the necessity of minimizing NO_2 in European cities became apparent. Currently more than 120 cities exceed the allowed NO_2 concentrations by far – the “leader” is the city of Stuttgart with an annual NO2 average of 120 g/m3. NO_2 is multiple times more toxic than NO and settles at ground level. Hence, tailpipe NO_2 affects especially children but also older people with respiratory problems. NO_2-inducted heart diseases and fatalities are growing with increased emission levels.

Particulate matter emissions in the form of diesel nanoparticles are classified as carcinogenic and massively damage the health of the exposed population because of their mutagenic effect. The financial evaluation of the damage to health exceeds many comparative calculations with the volume of investment for retrofitting Diesel fleets with particulate traps.

Environmental zones have been put in force throughout Europe to reduce particulate matter emissions. By 2012, the relevant EU guidelines for PM reduction must be implemented by all member states. Accordingly, the number of environmental zones in the EU will drastically in the next future. To comply with the EU guidelines, access restrictions to city centers are introduced to prohibit older vehicles without aftertreatment to enter. Unfortunately, national guidelines for the certification of retrofitted filters (in Germany „attachment 27“) allow also FTF „Flow Through Filters” to comply with the regulations. Those systems don’t achieve substantial reductions of nanoparticle emissions from diesel vehicles. An effective abatement of ultrafine PM emissions can only be guaranteed by “closed” filter systems that have particulate number reduction rates of over 99%.

Summary *contd.*

Conventional catalytic coated wall-flow filters very effectively reduce particles, CO and HC emissions. It has been untypical so far that a catalytically active particle filter could also reduce nitrogen oxides and especially NO2 with a high degree of efficiency. PURItech, the exclusive partner for retrofit systems of Mercedes Benz in Europe developed PURImax, an active, self-regenerating particle filter system with a high nanoparticle reduction of 99.7% and a simultaneous decrease of the total NOx emission.

The PURImax system with a high level of NO_2 reduction has proven itself in practical use and works efficiently at exhaust gas temperatures as low as 120° - 230°C.

The performance was recently certified by the Technical University of Graz. They have tested a city bus (Mercedes Benz O530 Citaro) on the roller dynamometer in a low temperature city cycle. The report confirms that PURImax curtails all limited pollutants PM, HC, CO and even NOx. NOx is reduced by 21% in total and NO_2 by impressive 61% compared to the raw emissions. This reduction was recorded in a highly transient cycle with an average exhaust temperature of only 230°C.

Similar test results were documented by ElringKlinger Motec for achieving the German On-Road approval.

The Swiss VERT test protocol demonstrates an almost complete elimination of the NO_2 emissions with the PURImax system in all tested engine operating conditions. The author Dr. Andreas Mayer summarizes: „NO_2 was extremely low, a very impressive result with this filter system, which have not been tested with other DPF systems, so far".

The PURImax system can be retrofitted to vehicles and machines without modifications of the engine and the necessity of adding operating fluids (AdBlue or FBC). With its highly efficient nanoparticle abatement and simultaneous NOx (NO and NO_2) reduction at low exhaust gas temperatures, the filter system offers a cost-effective solution for the control of urban PM and NO_2 emission loads.

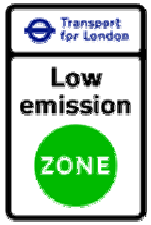
Summary *contd.*

Compared to SCR technology, which requires an exhaust gas temperature of over 230-250°C for the decrease of NOx emissions, the reduction of NO_2 using the PURImax System begins at 120°C and presents a considerable advantage in urban areas. Furthermore, PURImax nearly eliminates ultrafine particulate matter concentration in the ambient air which SCR technology cannot provide.

A considerable portion of the NO_2 emissions in cities is caused by traffic, especially by older commercial vehicles and busses. Until now, attention has been paid to the reduce pollution of CO, HC and PM which can be done by platinum-containing DOC's, diesel particle filters (DPF) or a combination of both.
These purifiers, often referred to as "CRT systems" but also FTF's considerably increase the NO_2 proportion in comparison to engine raw emissions, especially at lower exhaust gas temperatures.

New vehicles often combine DPF systems with SCR catalysts to reduce the NO_2 and nanoparticle emissions simultaneously. The SCR technology requires a urea-water solution as an agent to be able to reduce NOx in the SCR catalyst. The efficiency of the SCR catalyst at temperatures below 230°C is poor. Hence, the urea dosing system remains switched off at temperatures which are typical for urban city driving cycles.
The usage of an SCR system in urban applications with reference to NO_2 reduction is therefore to be viewed critically.

Clean Air for Generations



PM 10 (since 1995)
Annual average < 40 µg/m³
Daily average > 50 µg/m³ max 35 days a year
Latest compliance date: 10th of June 2011

PM 2.5 (since 2010)
Annual average < 25 µg/m³
Latest compliance date: 1st January 2015

NO_2 (since 2010)
Annual average < 40 µg/m³
Hourly average > 200 µg/m³ max 18 days a year
Latest compliance date: 1st of January 2015

Air Quality Standards in Europe and LEZ's

Country	Qty. LEZ	Pass Criteria	Enforcement	Incentives for Retrofit	Percentage Retrofitted
D	40+	EURO 2 EURO 3 EURO 4	Police €60, 1 Point	330 € Cars 3600 € HDV (>12 tons)	Ca. 5%
UK	London	EURO 3 PM	Cameras £200 p. day	none	Ca. 25%
NL	10+	EURO 4	Cameras €150 p. day	150 Mio €	Ca. 75%
I	7	Min. EURO 2	Police Different Fines	Regional 5 – 15 Mio €	Ca. 15%

European LEZ's

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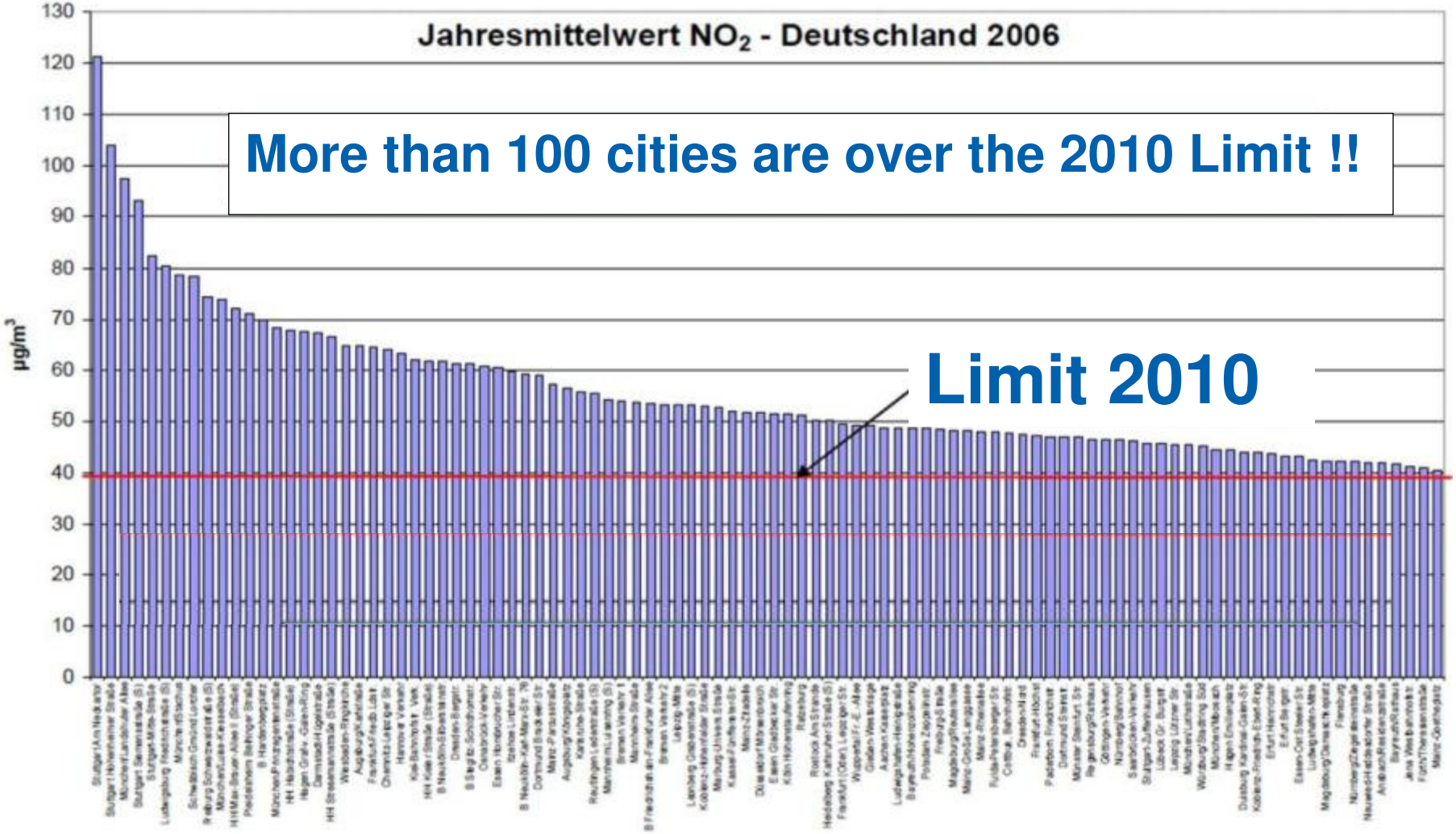
Zeitleiste der Umweltzonen in Deutschland (mit Angabe der für die Einfahrt in die Umweltzonen erforderlichen Plakettenfarben und Schadstoffgruppen)

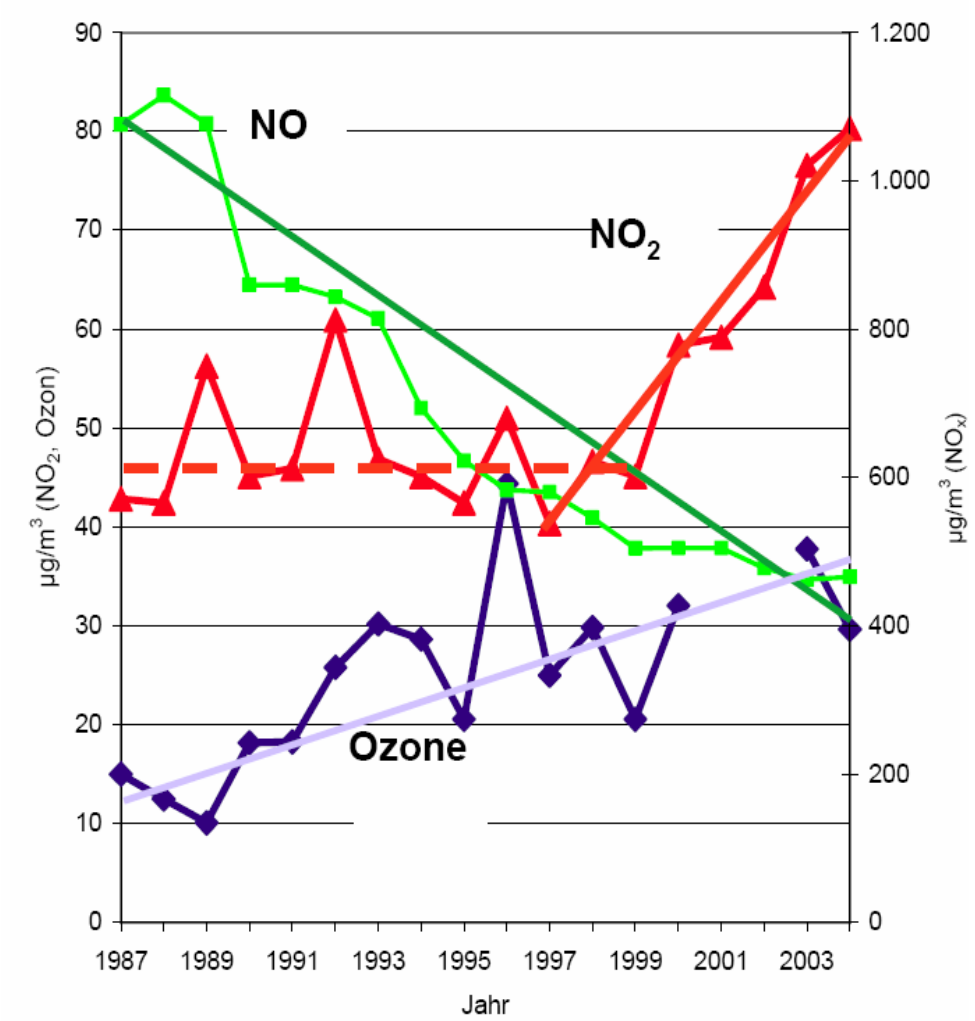
Ort	Bundesland	Status	2008	2009	2010	2011	2012	2013	2014	2015
			J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N
Augsburg	Bayern	aktiv	1	1 2	2 3	3	3 4	4	4	4
Berlin	Berlin	aktiv	2	2	4	4	4	4	4	4
Bochum	Nordrhein-Westfalen	aktiv	1 2	2	2	2	2	2	2	2
Bonn	Nordrhein-Westfalen	inaktiv	1	1	2	2	2	2	2	2
Bottrop	Nordrhein-Westfalen	aktiv	1 2	2	2	2	2	2	2	2
Bremen	Bremen	aktiv	1	2	3	3 4	4	4	4	4
Dortmund	Nordrhein-Westfalen	aktiv	1 2	2	2	2	2	2	2	2
Dortmund (Brackeler Straße)	Nordrhein-Westfalen	aktiv	1 3	3	3	3	3	3	3	3
Duisburg	Nordrhein-Westfalen	aktiv	1 2	2	2	2	2	2	2	2
Düsseldorf	Nordrhein-Westfalen	aktiv	1	1 2	2	2	2	2	2	2
Essen	Nordrhein-Westfalen	aktiv	1 2	2	2	2	2	2	2	2
Frankfurt am Main	Hessen	aktiv	1 2	2	3	3	4	4	4	4
Freiburg im Breisgau	Baden-Württemberg	inaktiv	1	1	2	2	3	4	4	4
Gelsenkirchen	Nordrhein-Westfalen	aktiv	1 2	2	2	2	2	2	2	2
Hannover	Niedersachsen	aktiv	2	3	4	4	4	4	4	4
Heidelberg	Baden-Württemberg	inaktiv	1	1	2	2	3	4	4	4
Heilbronn	Baden-Württemberg	aktiv	1	2	2	2	3	4	4	4

German LEZ's

NO_2 Concentrations in German Cities



NO_2 Concentrations 1987 - 2004



Source: IFEU, 2005

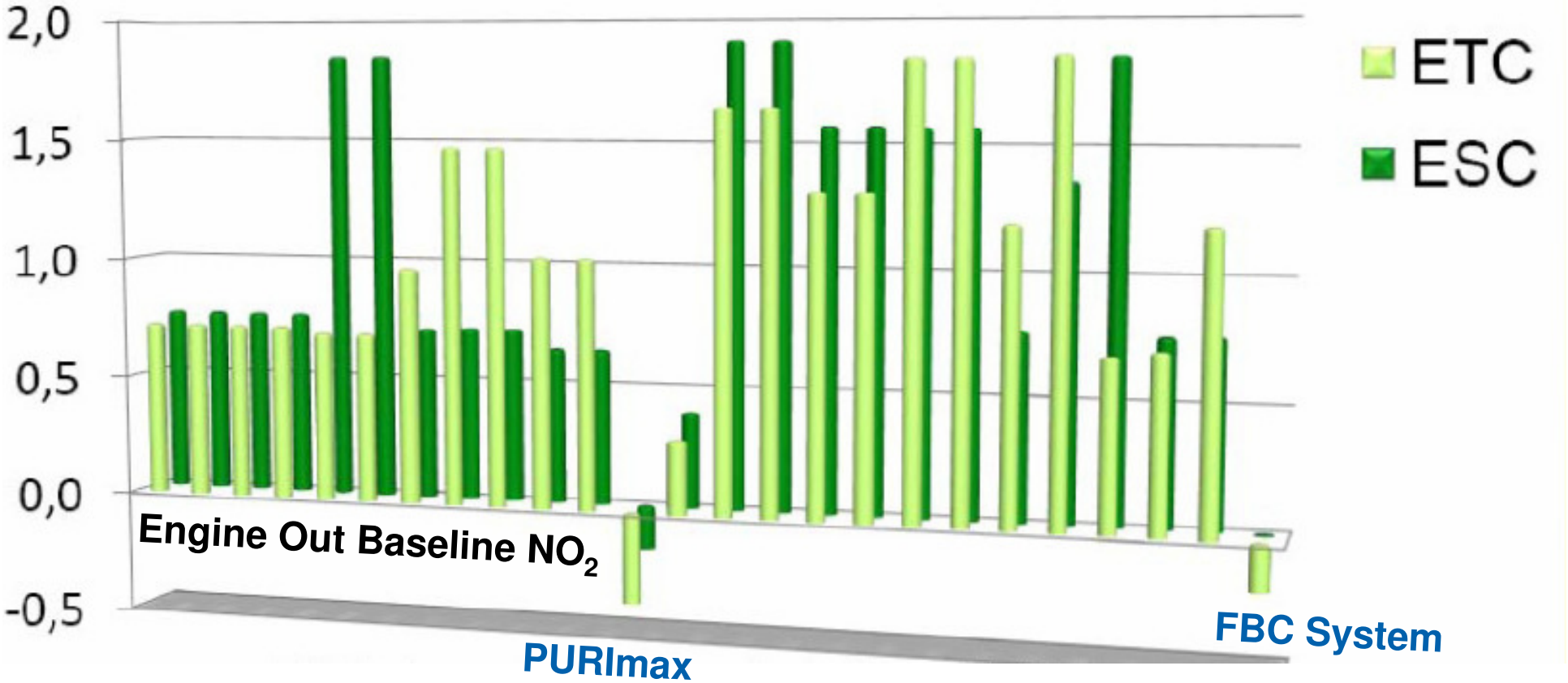
Rapid Increase of NO_2 in Cities after 1999

Reasons:

- **Introduction of Low Sulfur Diesel Fuel**
- **DOC's**
- **Pt-Coated Sootfilters**

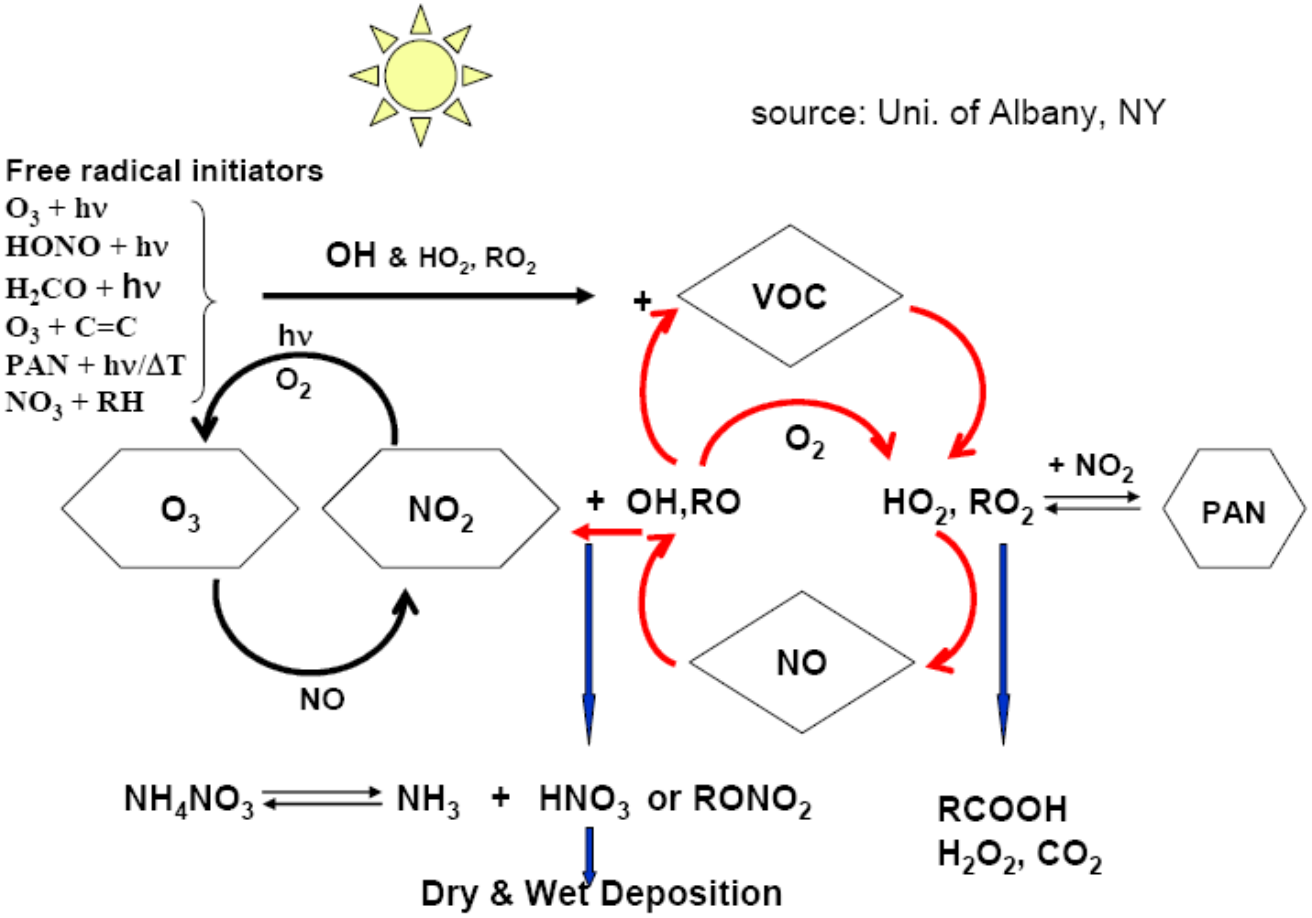
NO_2 Performance of Certified Filters in Germany

NO_2 in g/kWh



Source: UBA, 2010

NO_2 Chemistry in Ambient Air

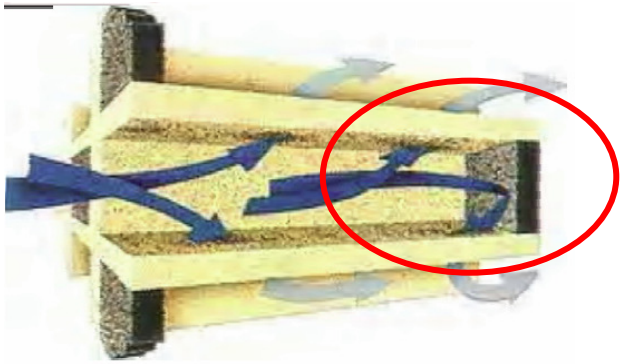


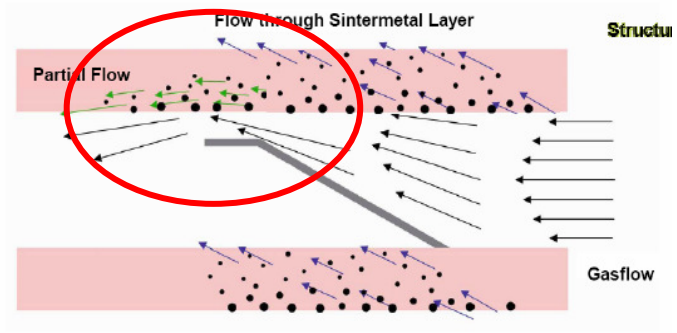
Balance of NO & NO_2 depends on:

- **Ozone Concentration**
  O_3 oxidises NO to NO_2
- **Solar Radiation**
  Light reduces NO_2 to NO

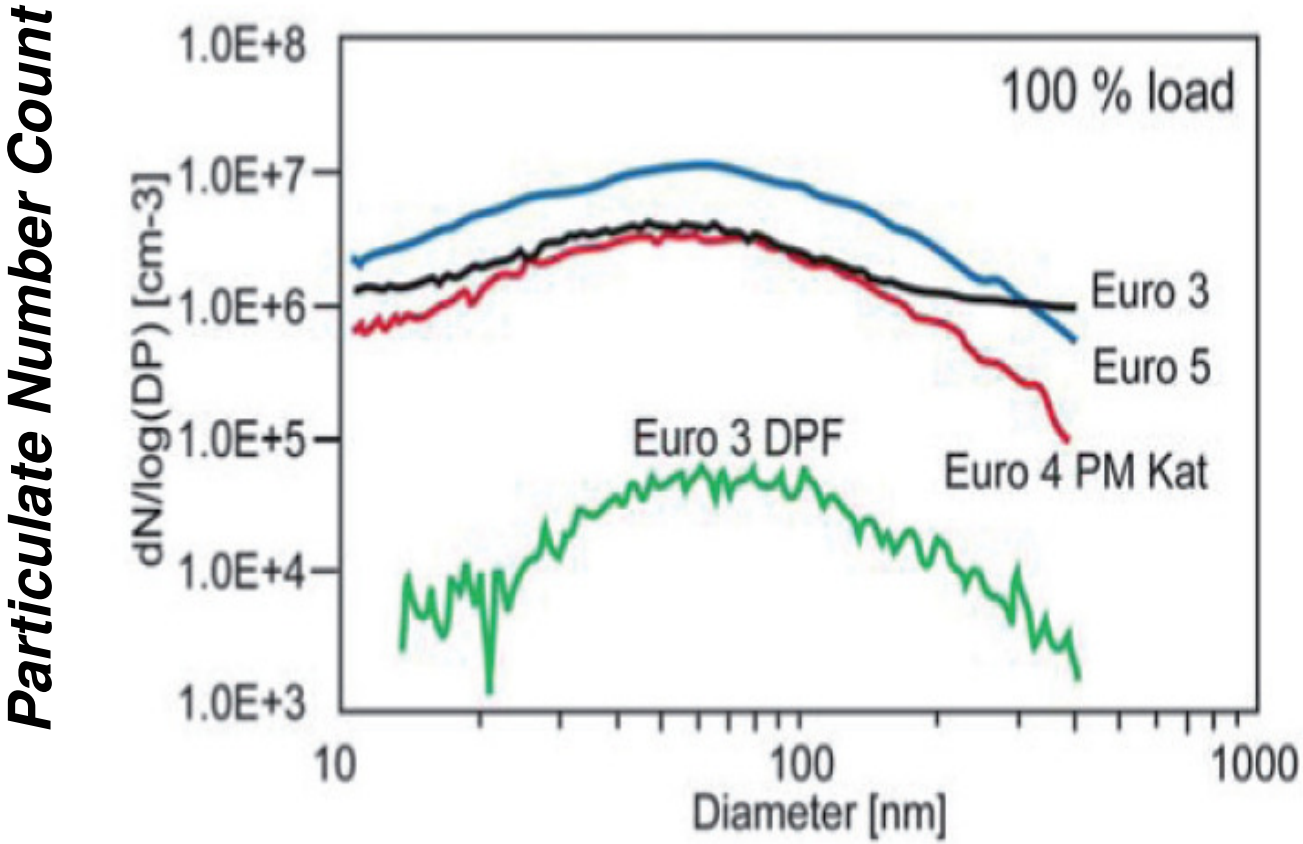
NOx is 90% men-made!

Wall-Flow DPF vs FTF (Flow Through)

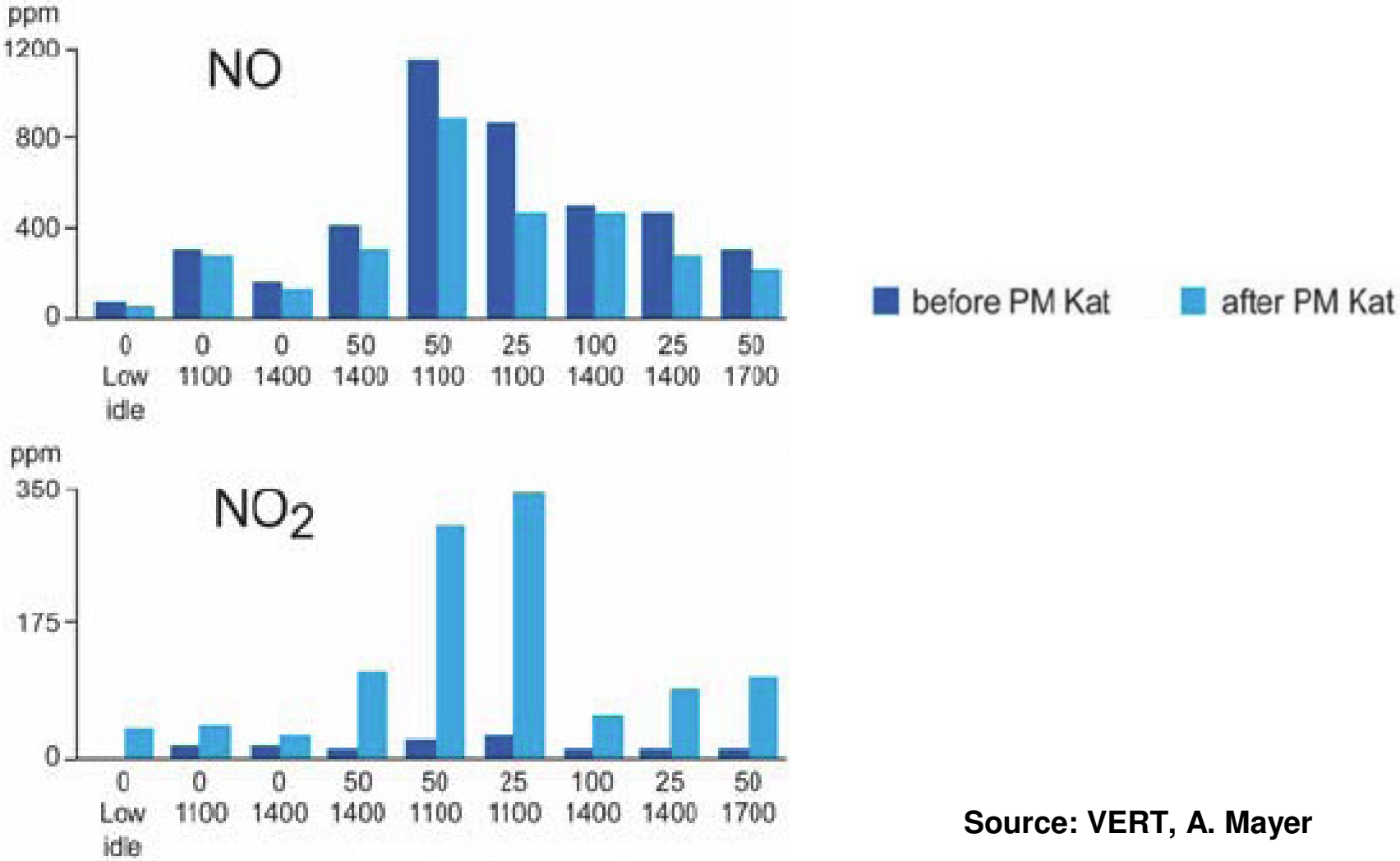




Size Specific Particulate Matter Distribution

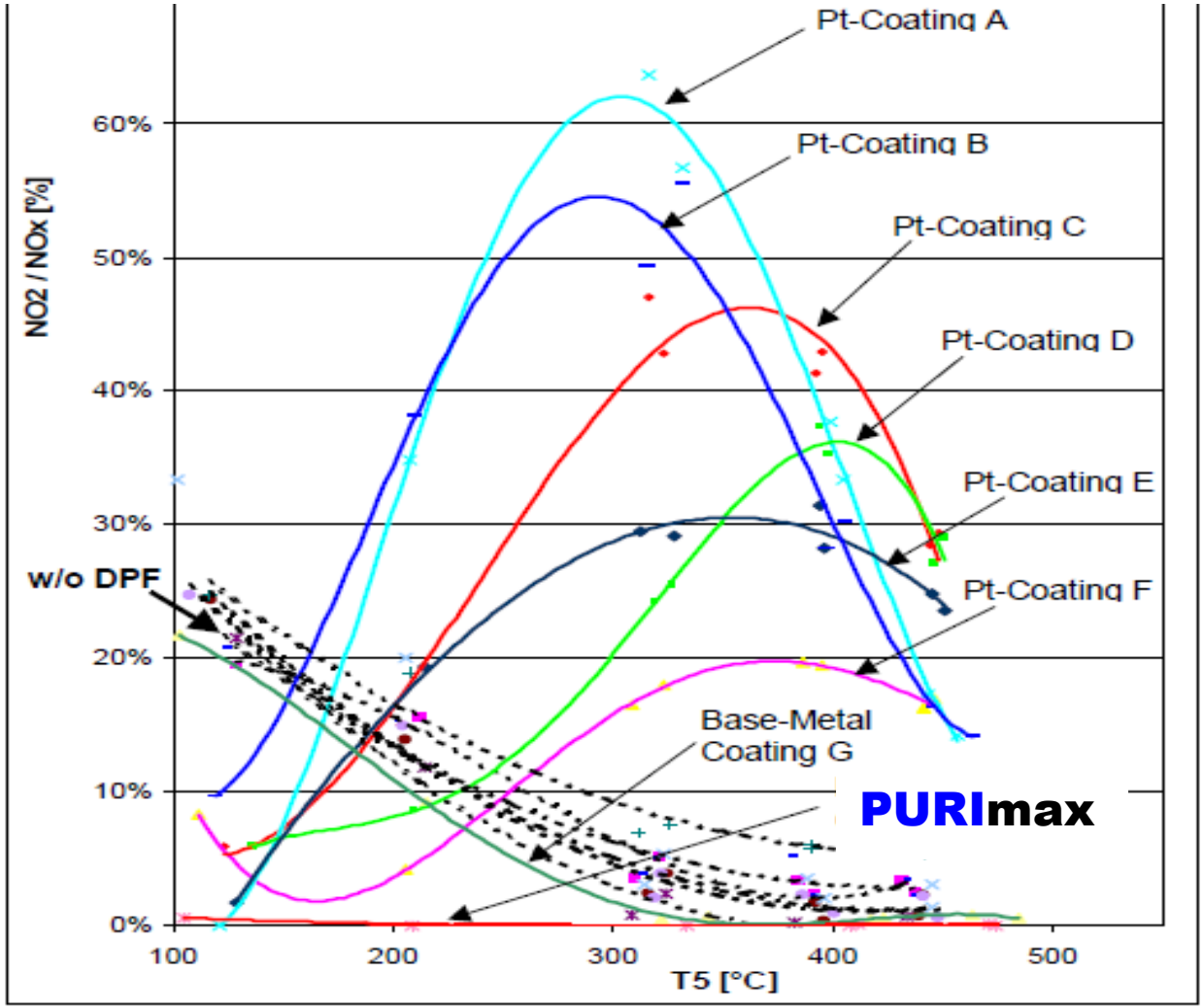


NO / NO_2 Performance FTF



Source: VERT, A. Mayer

NO_2 Formation with Platinum Coated DPFs



Source: VERT, A. Mayer

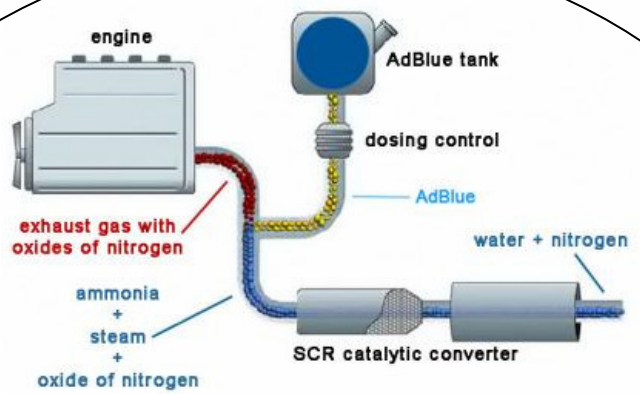
Systems for NOx / NO_2 Abatement

EGR: NOx Reduction max. 35%, difficult to retrofit, suitable for urban driving cycles

PURImax

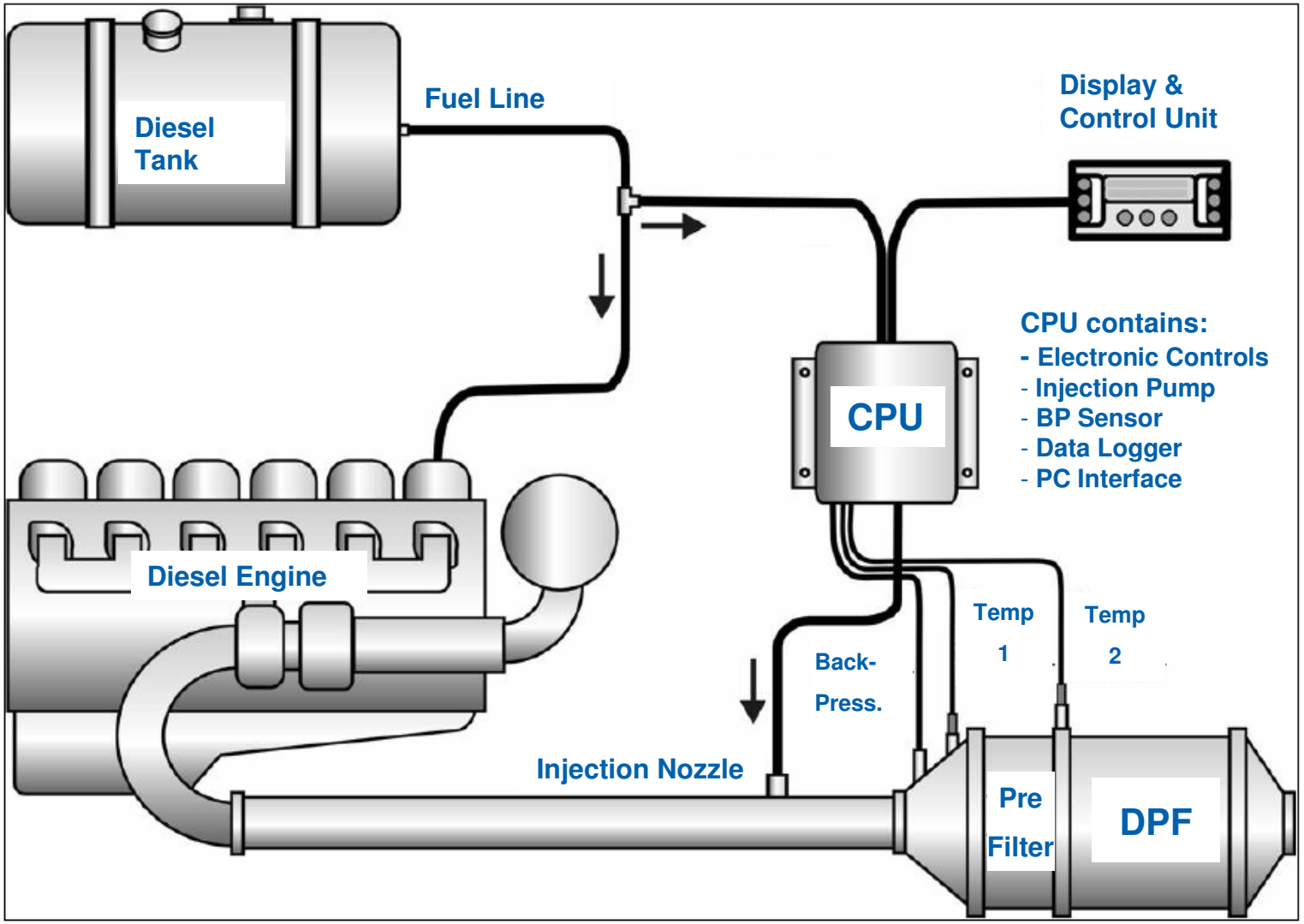
NOx Reduction up to 30%, high NO2 Reduction, good performance in urban driving cycles

→ Only 1 device for PM & NOx



SCR: NOx Reduction up to 90%, complex to retrofit, low performance in urban driving cycles

PURImax System



PURImax System

- Diesel Fuel is injected by a special nozzle upstream of pre-filter (injection pressure: 10 bar)
- Droplet Size < 40µm of fuel mixes with exhaust gas and vaporizes (no static mixer necessary)
- Exhaust/Fuel mixture combusts in the pre-filter (base metal oxides coating) and increases exhaust temperature to > 500 deg C
- DPF rapidly combusts trapped soot
- Fuel Injection can start at exhaust gas temperatures as low as 220 deg C
- HC & CO slip is oxidised in DPF

Active Regeneration

4 different algorhythms can be selected/programmed:

1. **Timer Regeneration → when the system operates at the mandatory exhaust temperature (i.e. 220 deg C), the CPU will start to inject fuel after a pre-set time of operation (i.e. 8 hours)**

2. **Pressure Regeneration → when the system operates at the mandatory exhaust temperature (i.e. 220 deg C), the CPU will start to inject fuel after a pre-set exhaust back-pressure level (i.e. 150 mbar) is reached**

3. **Temperature Regeneration → when the system reaches the pre-selected exhaust temperature, the CPU will start to inject fuel**

4. **Intelligent Regeneration → when the system operates at the mandatory exhaust temperature and is triggered by the back-pressure level, the CPU will inject fuel for a pre-set period of time. It permanently monitors and records the pressure drop, which is also programmable. In case the desired pressure drop cannot be registered, the CPU will continue dosing fuel. Pauses between 2 regeneration attempts can be adjusted.**

Chemical Reactions in the DPF

Special formulation of Base Metal Oxides coated on Pre-Filter & DPF:

Coating reduces NO & NO_2 by utilising HC & CO as a reduction agent (similar to Urea)

$$NO_2 + CO \rightarrow NO + CO_2$$
$$NO_2 + HC \rightarrow NO + H_2O$$
$$NO \rightarrow N2 + O2$$

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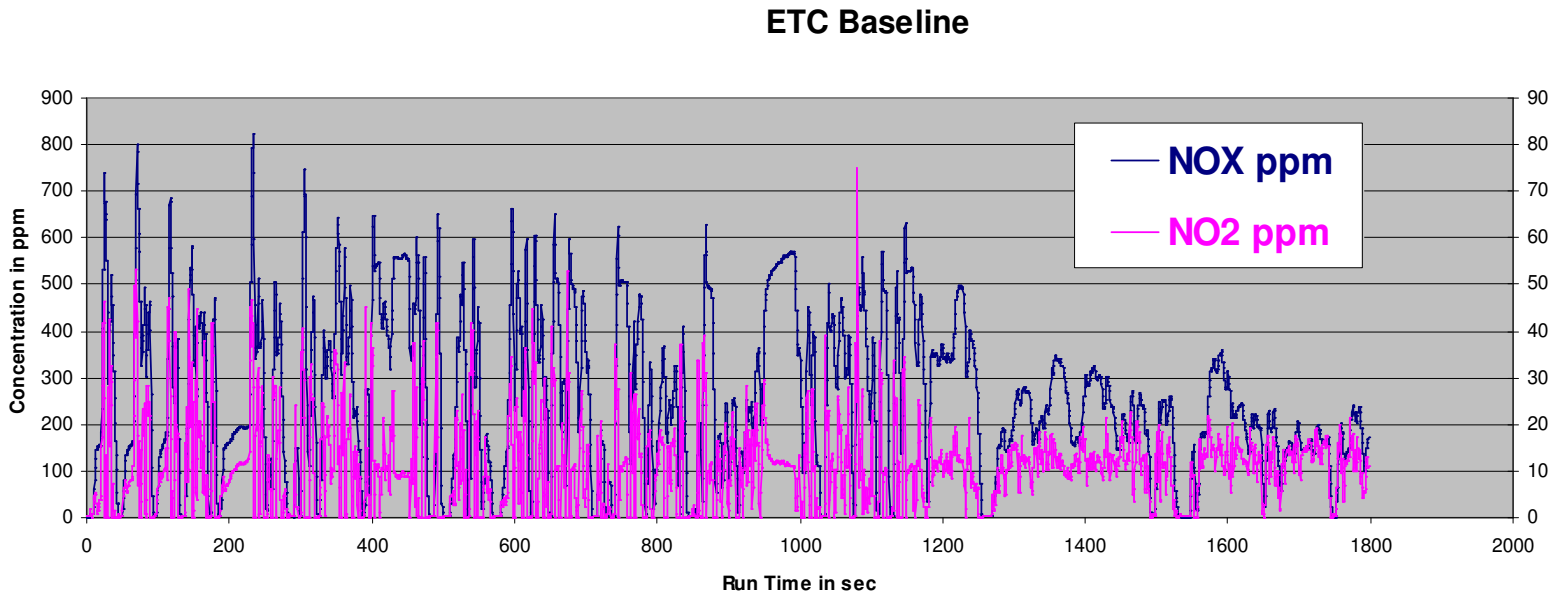
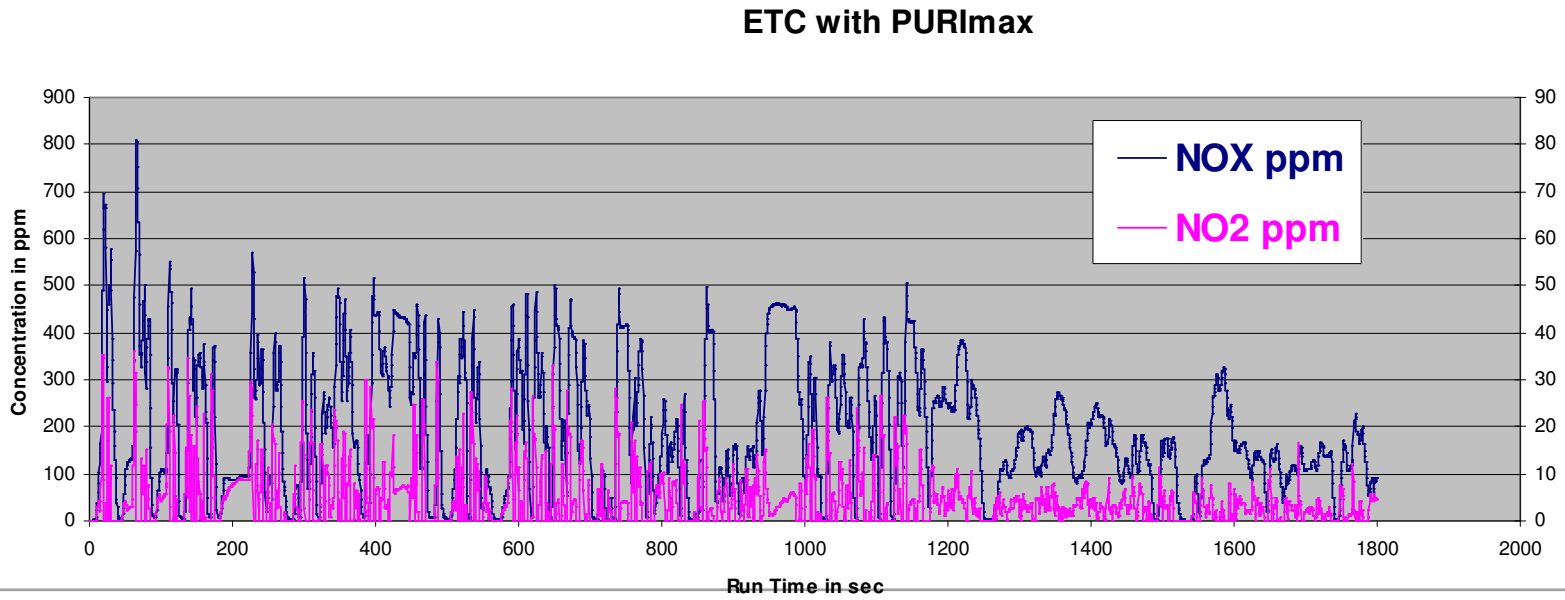
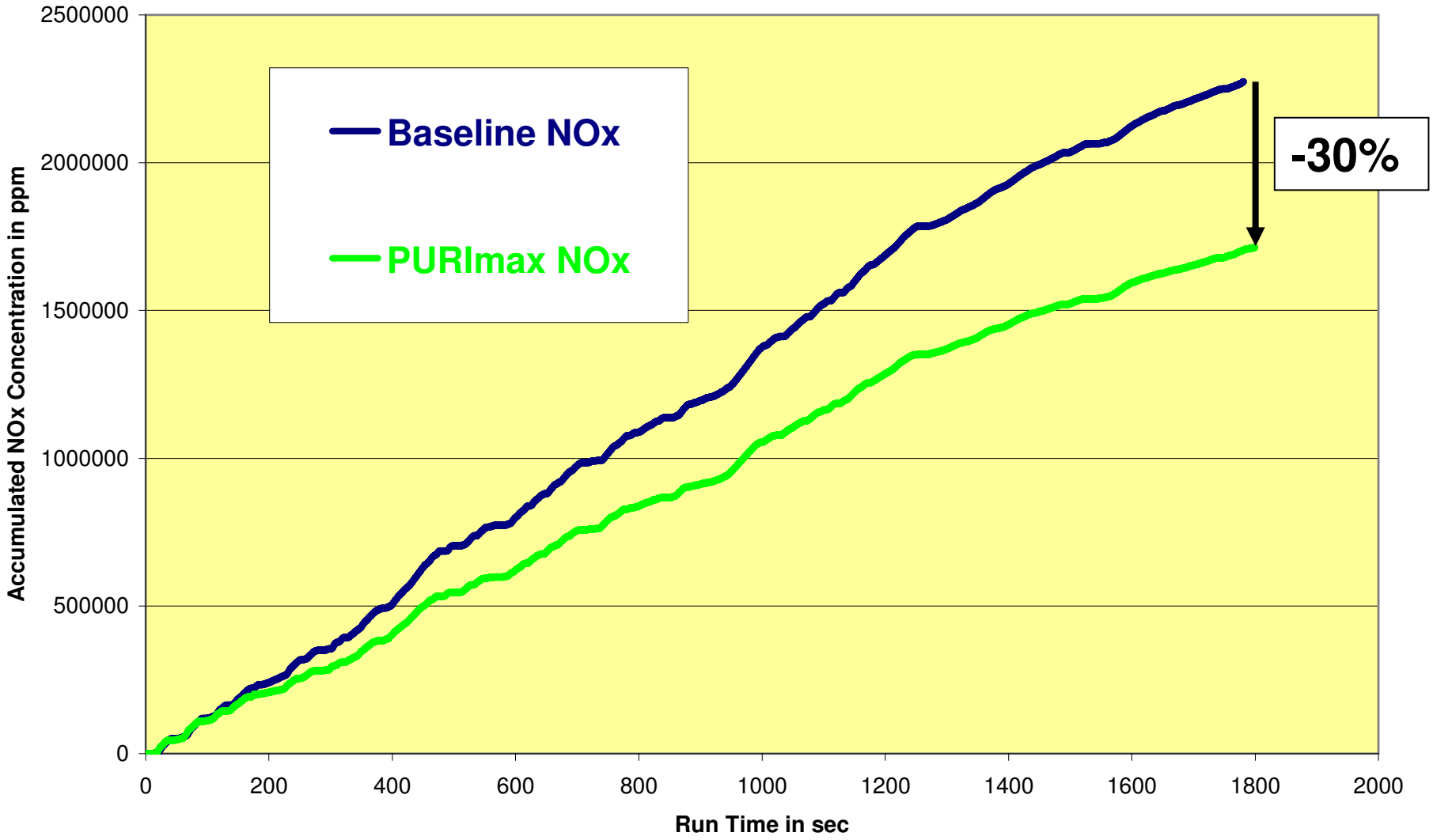
NO_2 & NOx Reduction German Approval

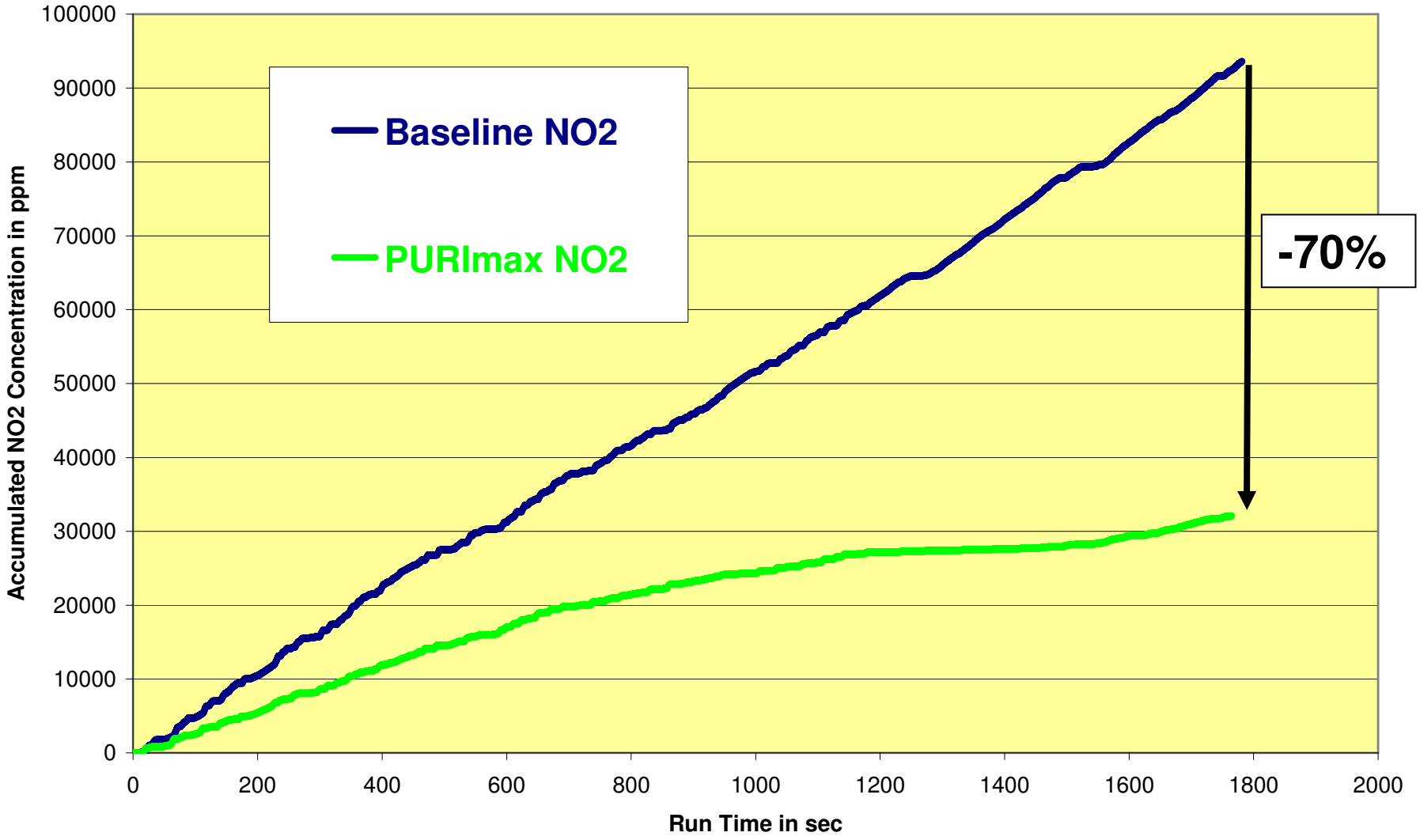




ETC Baseline vs PURImax - Accumulated



ETC Baseline vs PURImax - Accumulated



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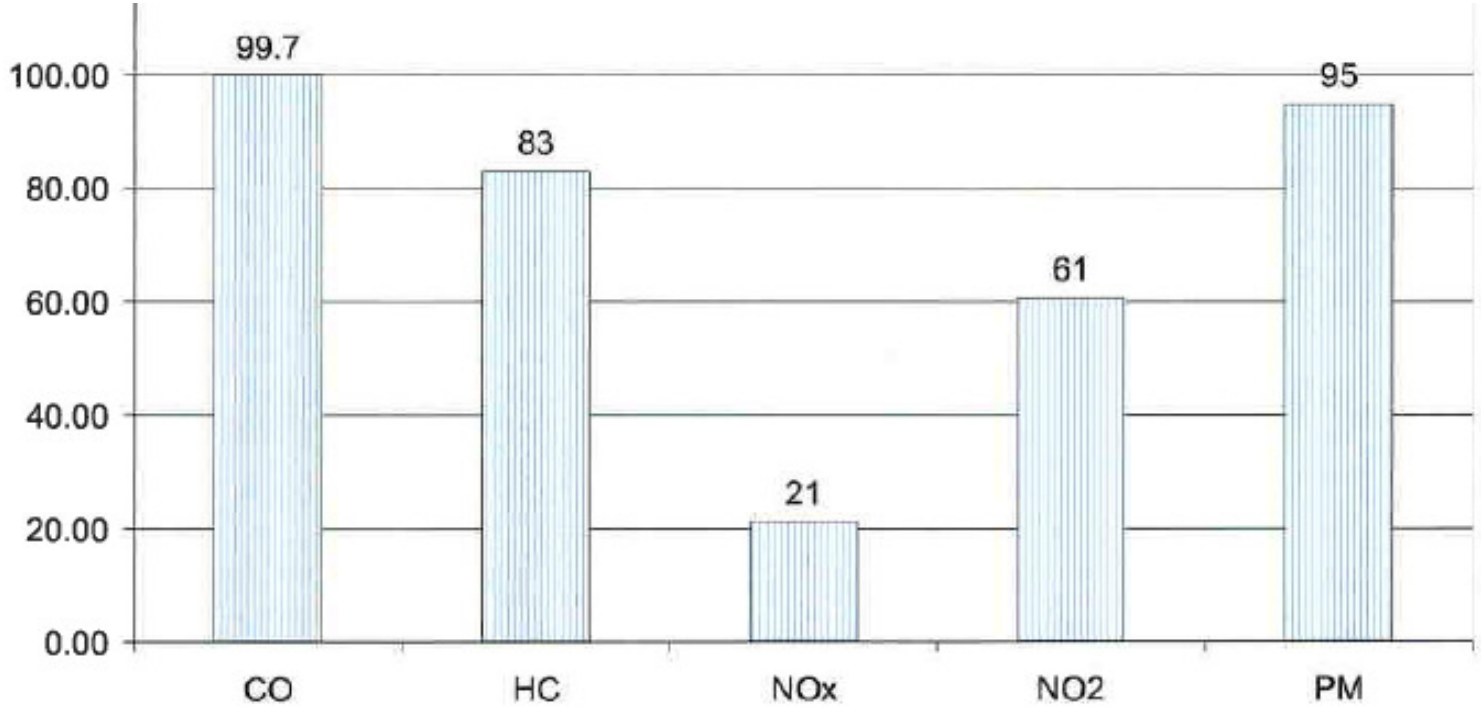
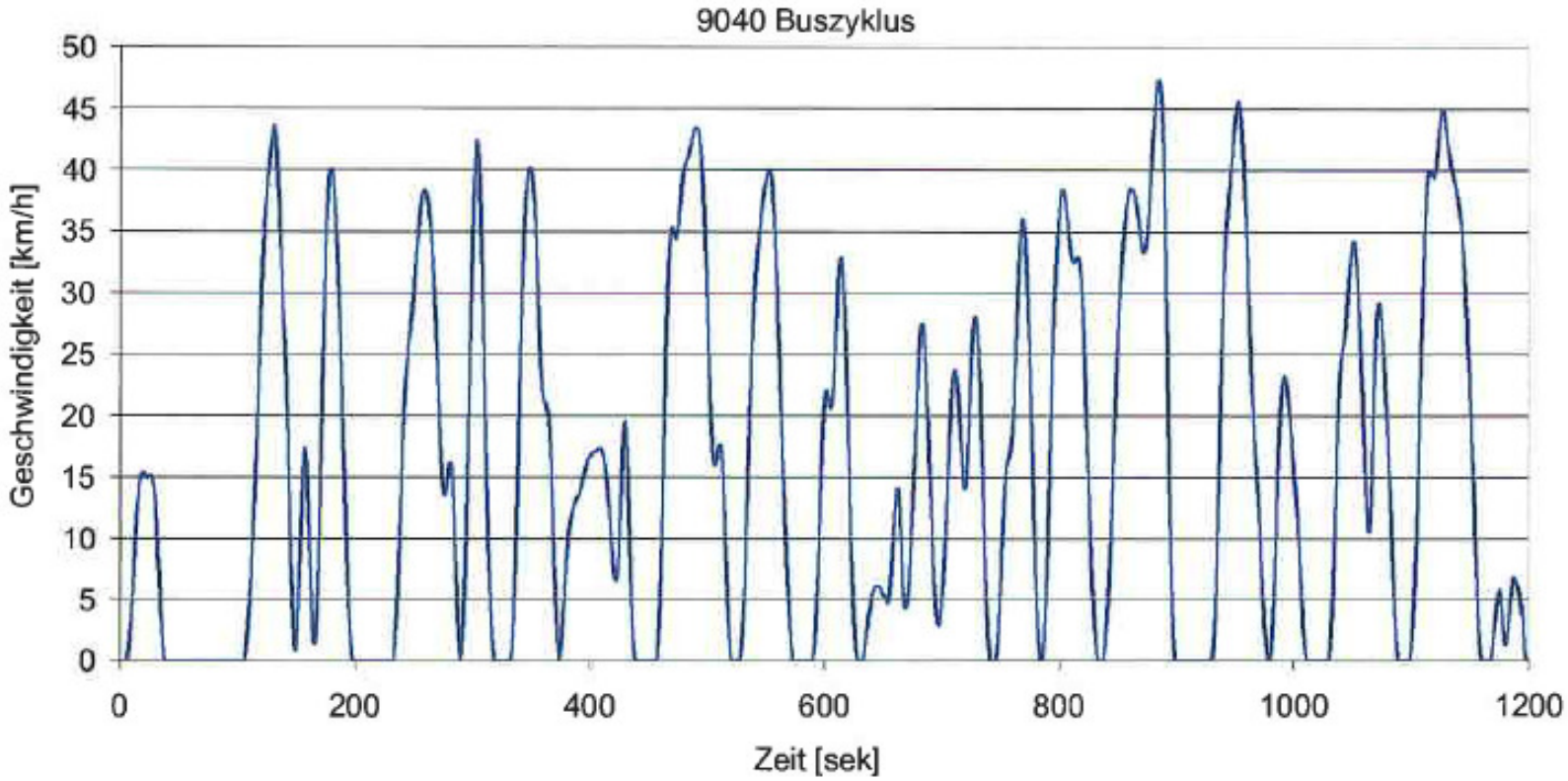
Emission Reduction TU Graz/Austria



Forschungsgesellschaft für Verbrennungskraftmaschinen und Thermodynamik mbH

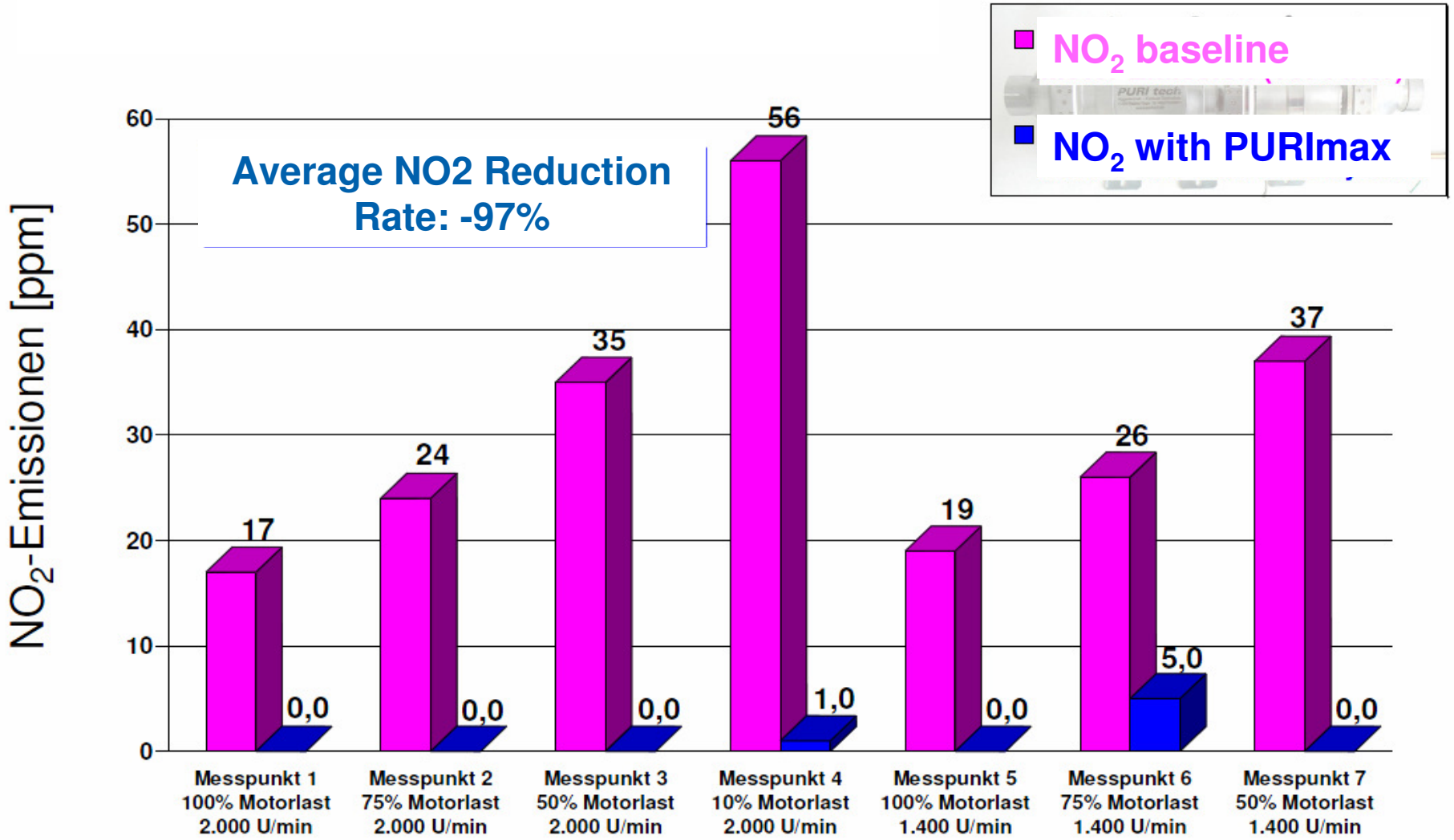
Emission Reduction TU Graz/Austria



Mercedes Citaro
OM457, 185 kW, 12 ltr
Euro III
Transient Urban Cycle
with max. Speed of 33 mph

Forschungsgesellschaft für Verbrennungskraftmaschinen und Thermodynamik mbH

NO_2 Reduction VERT Test



Quelle: *VERT Sekundäremissionsmessung (VSET) mit PURI tech DAS-DBS / Abgasprüfstelle (AFHB) - Messung nach ISO 8178 - gemäß VFRT Verfahren*

Head-to-Head: PURImax vs. SCRT System

Criteria	**PURImax**	SCRT
NOx/NO_2 Reduction in Urban Cycles	30% / 70%	No reduction below 220 deg C
Operating Cost	Low (filter cleaning)	High (filter cleaning, AdBlue refill & maintenance)
Installation Space	Replaces Muffler	Replaces Muffler & Needs Additional Space for SCR Catalyst
Investment	100%	Minimum twice the price

Approvals

Qualitätsmanagement DQS ISO 9001

QUALIFIED PRODUCT VERT

TÜV

KBA

Færdselsstyrelsen
TEKNOLOGISK INSTITUT

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Bundesamt für Umwelt BAFU

Transport for London

U.S. Department of Labor
MSHA
Mine Safety & Health Administration

In-Field Experiences

2000 hrs VERT Test

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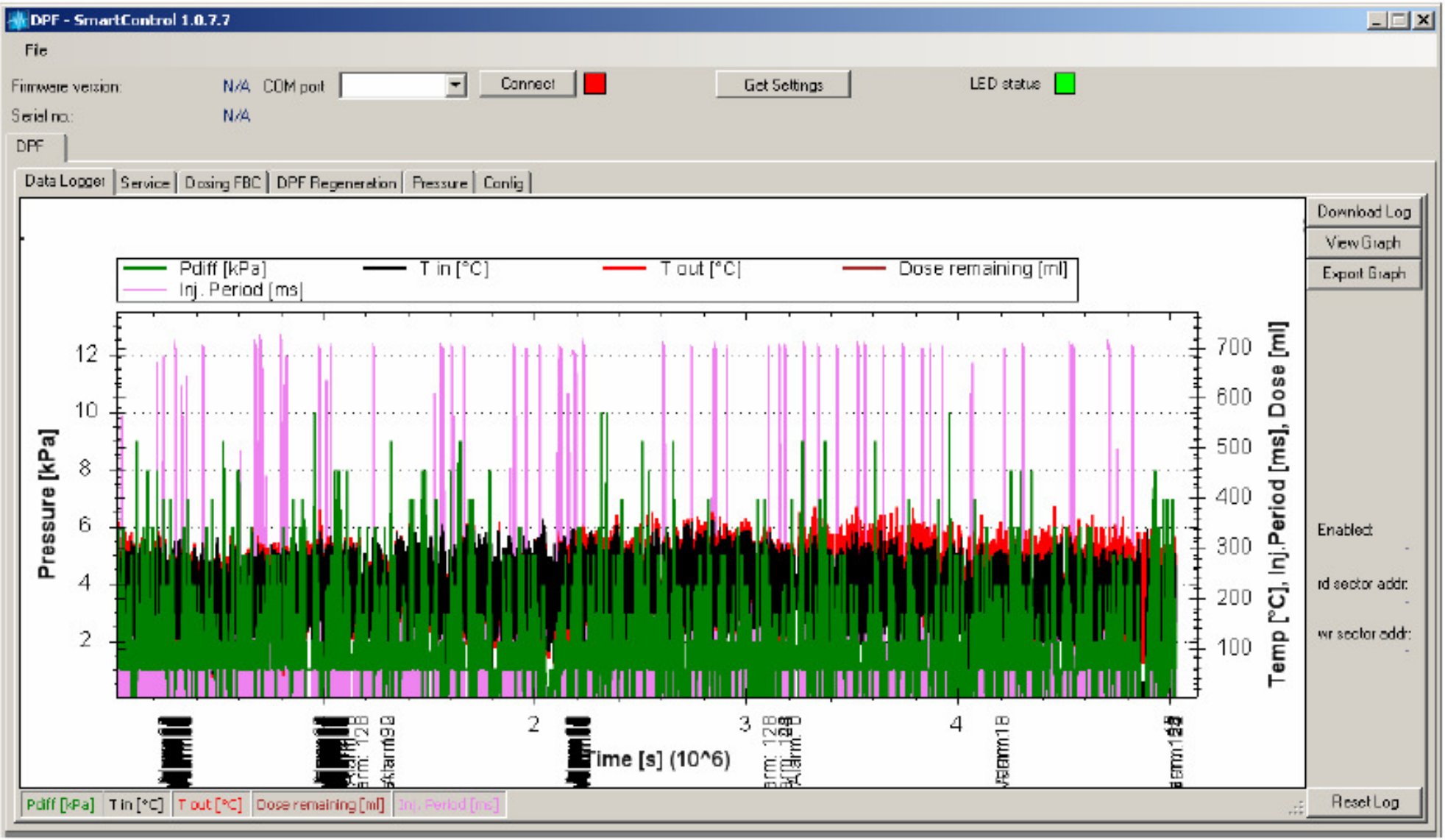
In-Field Experiences 2000 hrs VERT Test



Many thanks for your attention!

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PURIclean

Clean Air for Generations

Erstellt von: PURItech Marketing

14.02.2011

PURItech
ABGASTECHNIK – EMISSION TECHNOLOGY

Introduction

1. Company Portrait

2. PURImax – DPF-System with PM, CO, HC, NO_x and NO2 Reduction

1. PURItech – Company Portrait

Head Office:	Waldshut-Tiengen / Germany
Activities:	Research, Development and Distribution of Systems and Components for Diesel Emissions Control
Products:	- Active / passive Emission Reduction Systems - Catalytic Converter - Control- and Monitoring-Systems / Data logger
Certifications:	- QS9000 / ISO9001:2000 - KBA / TUEV / Anlage XXVII STVZO (Germany) - VERT / BAFU (Switzerland) - RDW (Netherlands) - Denmark - MSHA (USA) - CARB (USA – in progress) - LEZ (UK) - Others

1. PURItech – Company Portrait

Germany:	Waldshut, Leipzig, Siegen, Dortmund, Wiesbaden, Nuernberg
Switzerland:	Zurich
Austria:	Linz, Vienna
Italy:	Milan, Bolzano
Belgium:	Brussels
Denmark:	Copenhagen (PURItech Nordic ApS)
Estonia:	Tallin
Great Britain:	London
Slovenia:	Ljubljana
Hungary:	Budapest
Canada:	Toronto
USA:	Santa Monica, CA (PURItech US Llc.)

1. PURItech – Experience & Know-How

Application experiences:
> 15,000 DPF Systems
> 30,000 operating hours
> 800,000 km

Competence in Innovation:

- 2005: Active DPF-System for trucks – cooperation with DaimlerChrysler AG

- 2007: Combined DPF-System (active/passive) with NO_2-Reduction > 97%

- 2010: First emission reduction system for engine-upgrade from (NOx reduction > 30%)
  a) Euro-3 to Euro 4
  b) Euro-4 to Euro 5

1. PURItech – Experience & Know-How

Product Range for:
- LDD/HDD Trucks
- Mining Equipment
- Tractors
- Busses
- Construction Machines / Fork Lift Trucks
- Diesel Locomotives / Ships / Yachts

Customer base:
- Exclusive europe-wide supplier for Mercedes-Benz retrofit filter systems
- Exclusive supply partner of Daimler AG for MD and HD retrofit filter systems

> 50 OEMs with releases for PURItech products

1. PURItech – OWM References

DAIMLER
Mercedes Benz
VANHOOL
NEOPLAN
CATERPILLAR®
FENDT
SCHMIDT
Ein Unternehmen der Aebi Schmidt Gruppe
MULAG
TERBERG
Rofan
macchine edili ed agricole dDIECI
BOMAG

LIEBHERR
TEREX
VOLVO
kramerALLRAD
WACKER NEUSON
BELL EQUIPMENT
FAUN KIRCHHOFF GRUPPE
GHH FAHRZEUGE
LISSMAC
KLEMM Bohrtechnik
AMMANN
HYDREMA

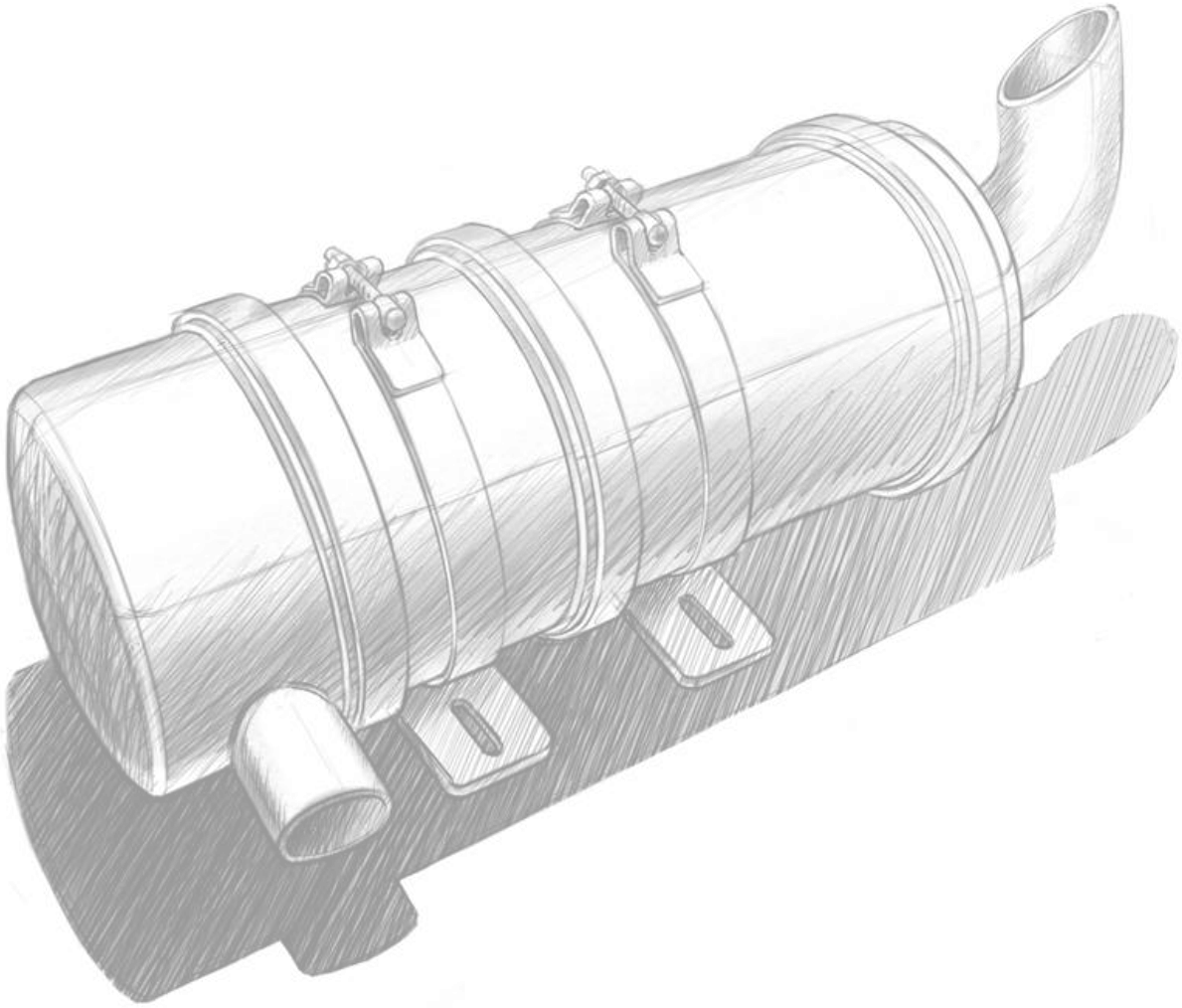
Atlas Copco
CompAir
HERRENKNECHT Tunnelling Systems
Putzmeister Mörtelmaschinen
mtu
HAMMEL
WILLIBALD
TENNANT

HanseLifter
JUNGHEINRICH
RMF
MORA
MKF
PAUS ...the people who care
JANO
SCHOPF
deilmann-haniel mining systems

VOLK
ABI
MFL
CASE CONSTRUCTION

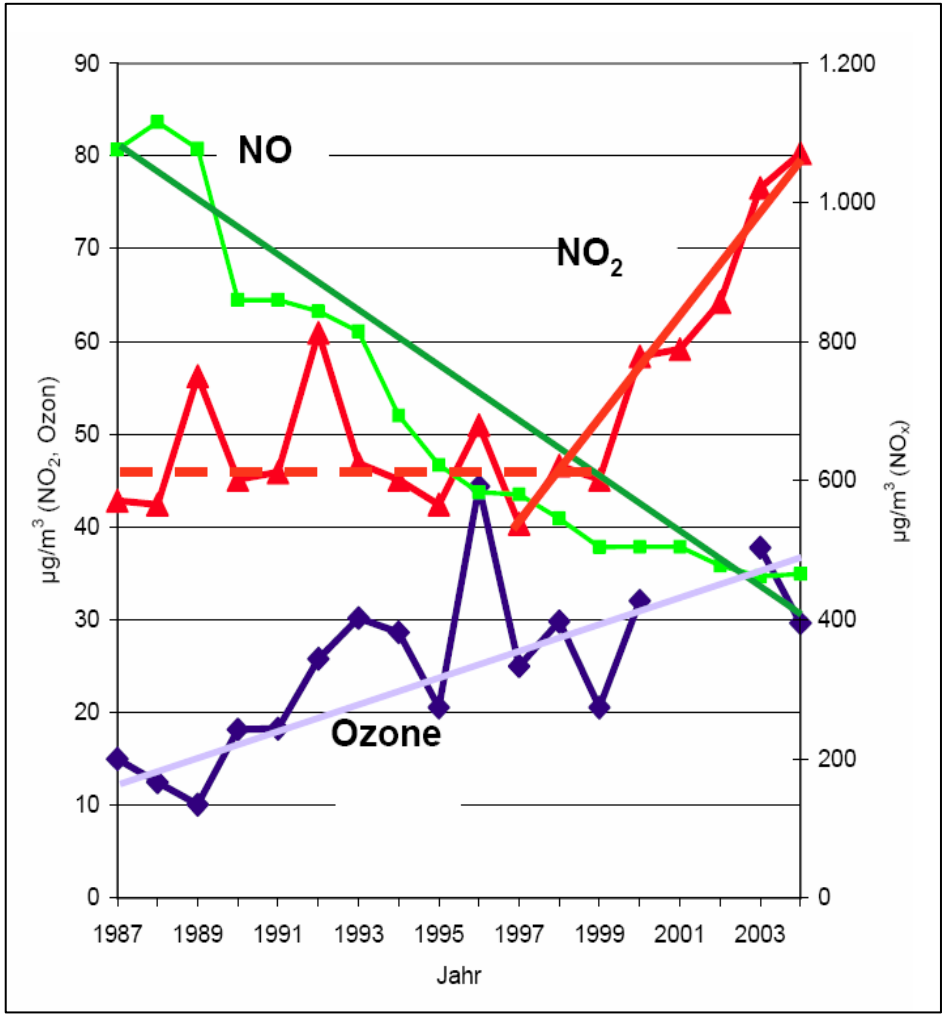
1. PURItech – Application Examples

2. PURImax



2. NO_2 increase in ambient air

NO_2 concentrations in ambient air 1987 - 2004



Source: IFEU, 2005

Rapid increase of NO_2 beginning of 2001

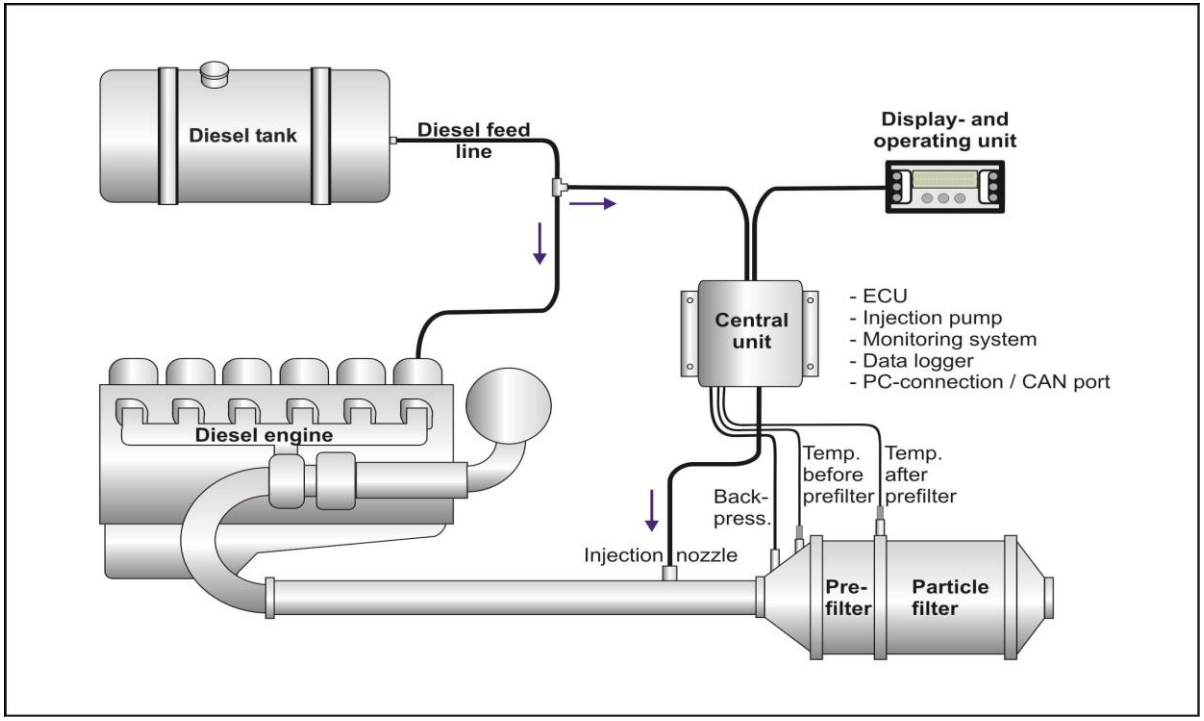
<u>Reasons:</u>

- Introduction of Low Sulfur Diesel Fuel
- Pt-Coated DOCs
- Pt-Coated DPFs

2. PURImax-System with NO_2 and NO_x Reduction

PURIMAX System:

- Active DPF regeneration at 220º C, Regeneration by catalytic coating and HC-dosing
- Components : a) exothermal converter / catalytic coated pre-filter
  b) catalytic coated DPF / ceramic wall-flow substrate
  c) HC dosing system / automatic self-controlled system



2. PURImax-System with NO_2 and NO_x Reduction

PURIMAX System:

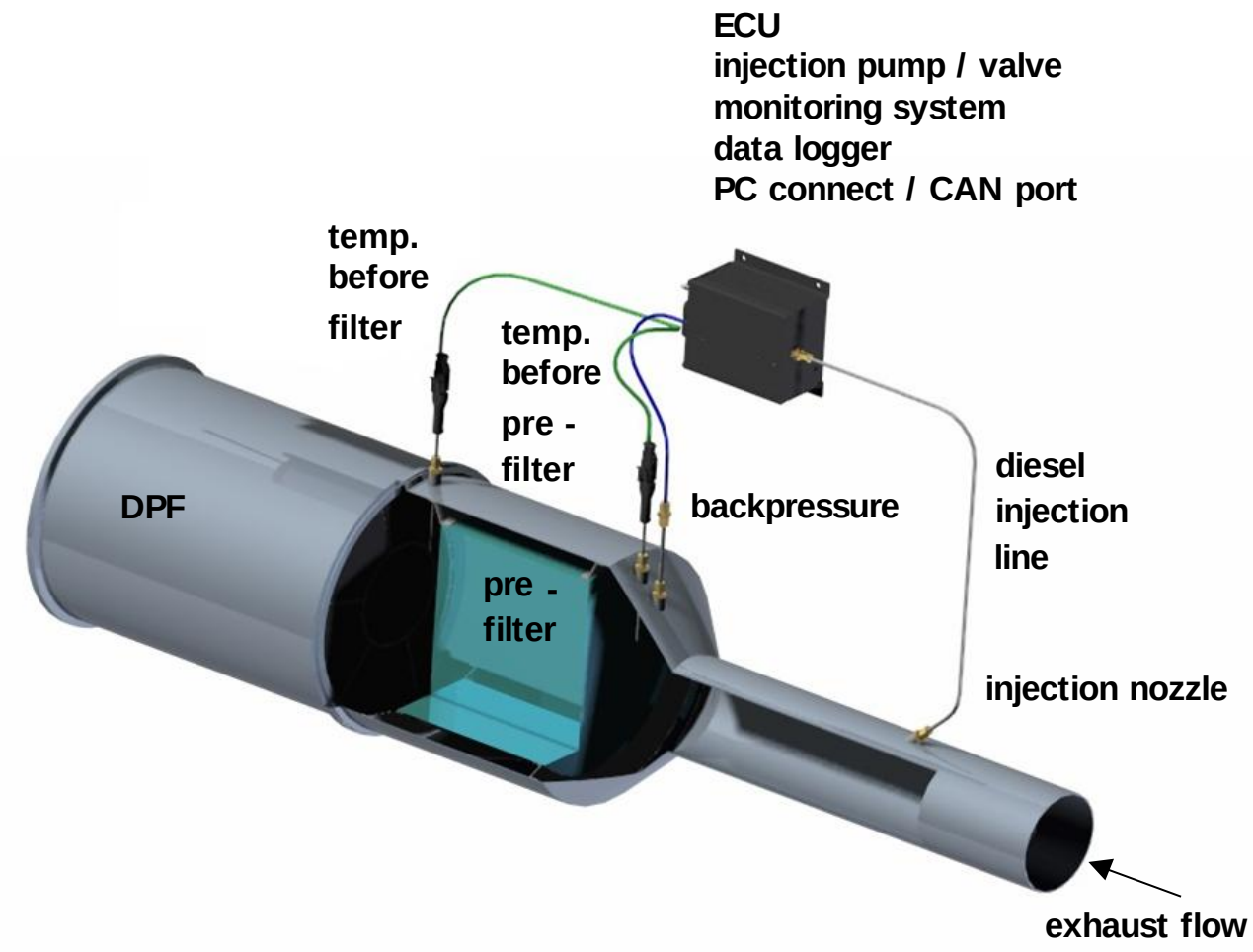
a) Catalytic coated pre-filter

- Matrix: stainless steel metal foil
- Catalytic coating for reduction of NOx and NO_2
- Exothermal converter / light-off for HC-Dosing starts at 220° C

b) Coated particulate filter (DPF)

- Monolith: silicon carbide / cordierite (200 cpsi)
- Catalytic coating for reduction of NOx- and NO_2
- Additional catalytic coating for DPF regeneration
- DPF regeneration (balance point) at ~ 320° C
- Regeneration temperature depending on soot emission and space velocity

2. PURImax-System with NO_2 and NO_x Reduction



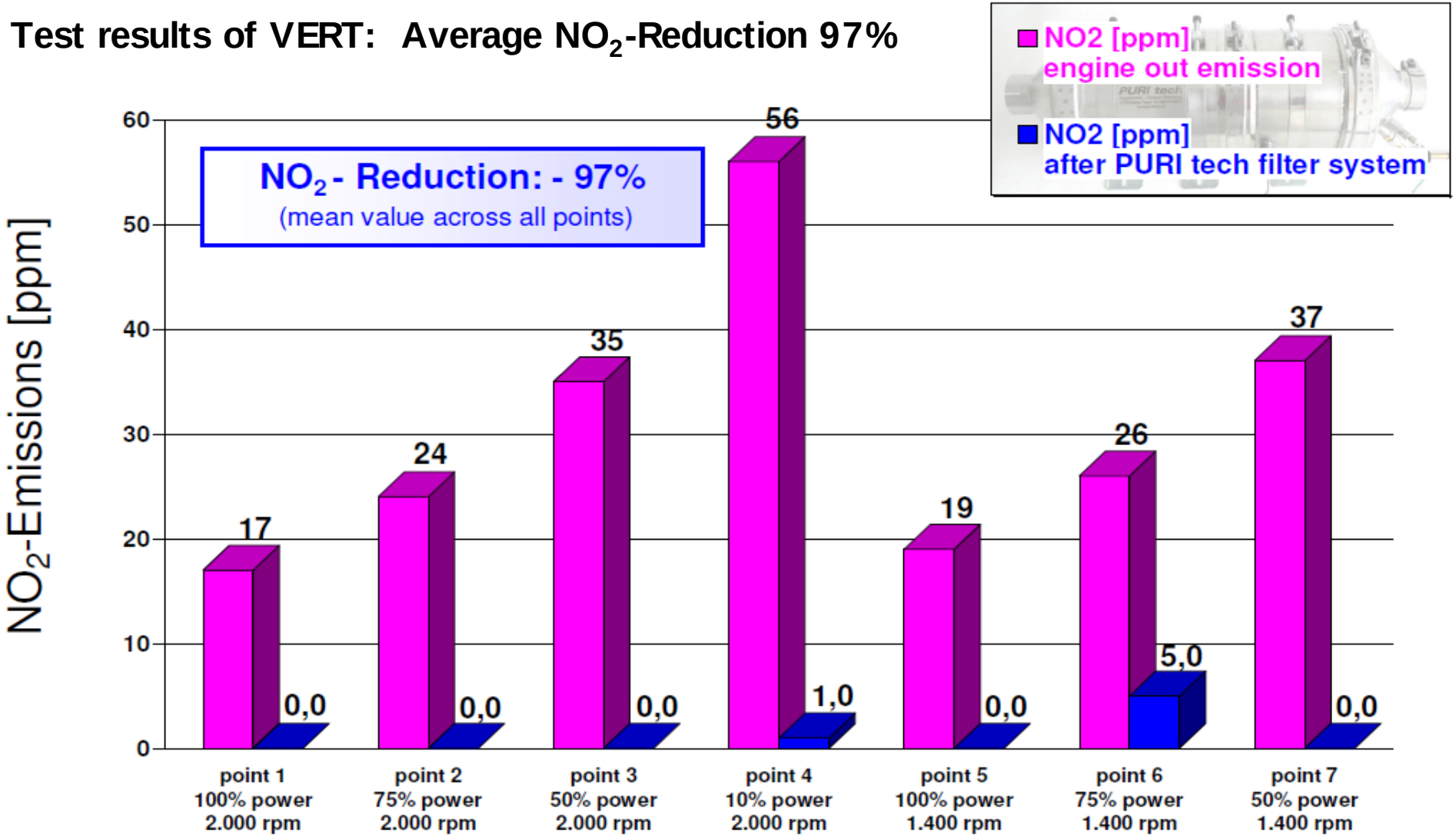
2. PURImax-System with NO_2 and NO_x Reduction

System description:

- Reduction of NO_2 Emission: - 97 % (even at engine idle)
- Reduction of Particulate Emissions: - 99.9 % (for nanopartice counts)
- Reduction of CO- / HC-Emissions: - 99 % (100% light-off at around 230 degC)
- Reduction of NO_x: - 30 % (even at engine idle)
- Combined active / passive DPF regeneration
- Fully automatic control of filter regeneration (HC dosing)
- self-cleaning process even at low load / stop-and-go operation
- System tests at DEUTZ / DAIMLER / MBtech / AVL / VERT / TUEV/ University of Graz (FVT)

2. PURImax-System with NO_2 and NO_x Reduction

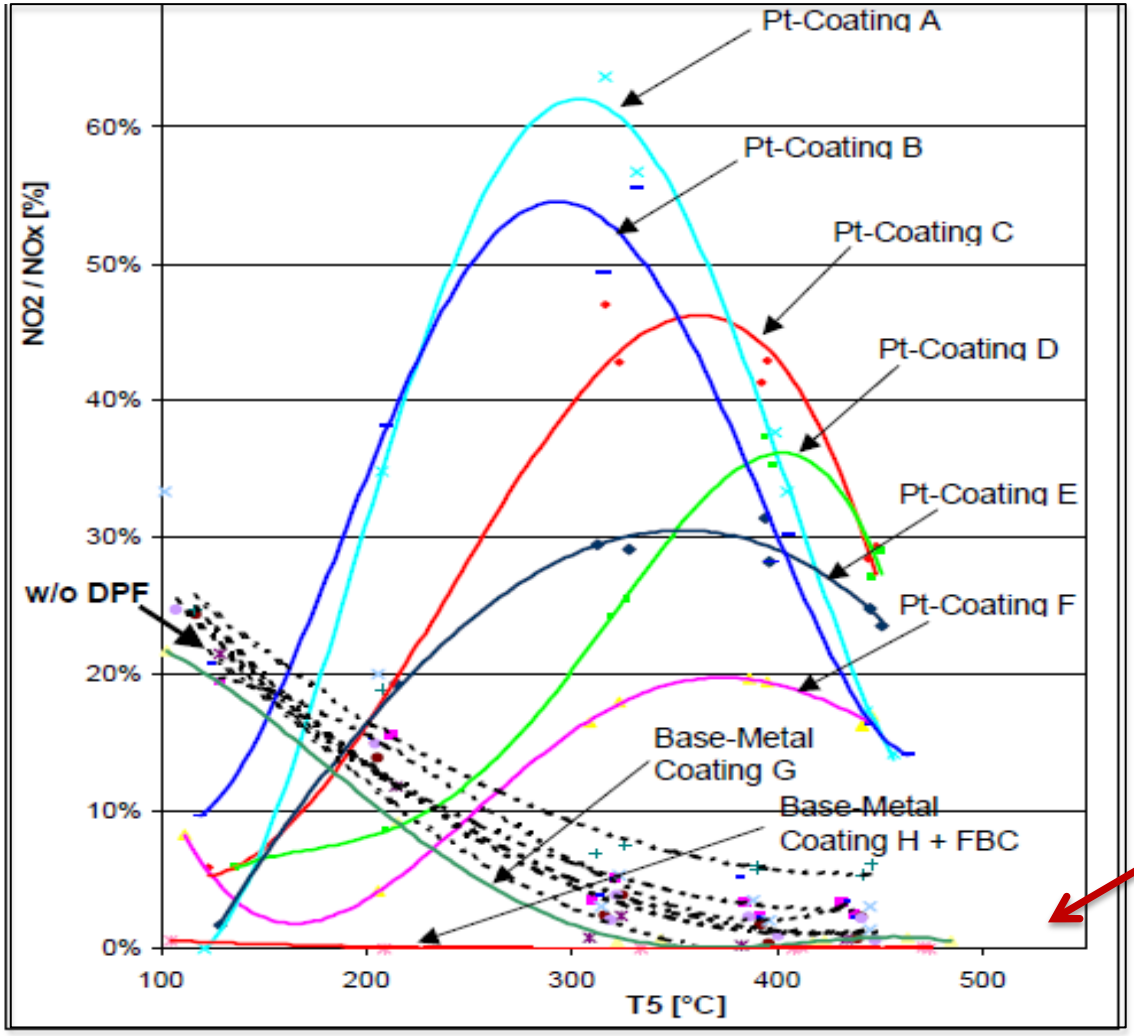
Test results of VERT: Average NO_2-Reduction 97%



Data Source: *VERT Secondary Emissions Test (VSET) with PURI tech DAS-DBS / emission test institute (AFHB) - measuring according ISO 8178 - VFRT procedure*

2. PURImax-System with NO_2 and NO_x Reduction

Test Results of VERT: Average NO_2-Reduction 97%



Source:

VERT-tests of different DPF systems in terms of NO2 formation (from 120° C to 450° C)

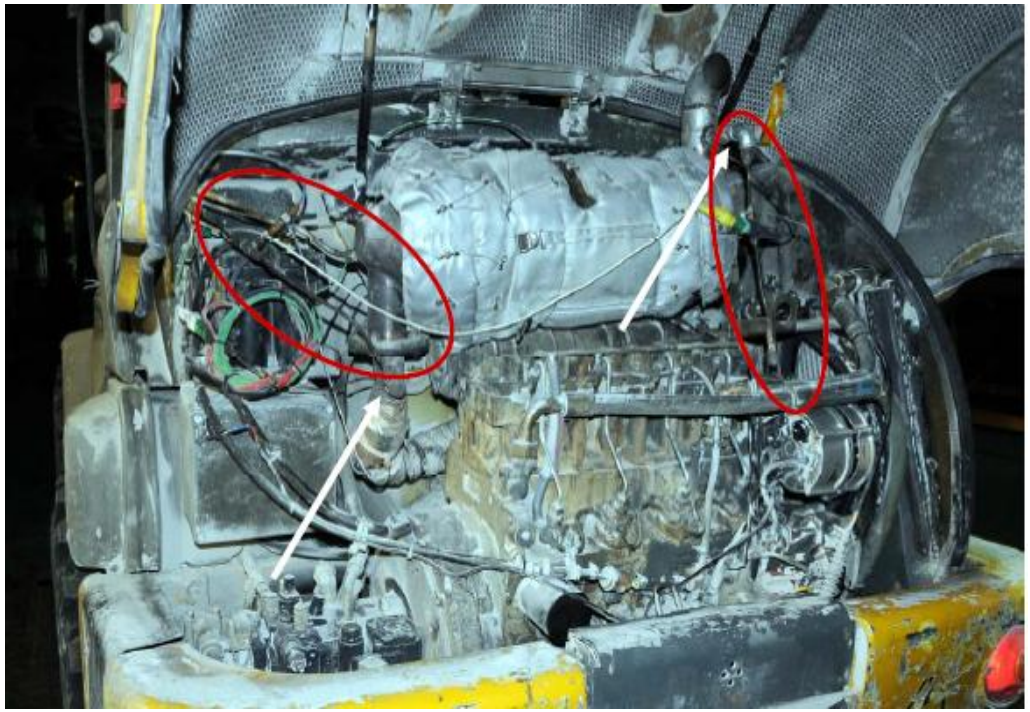
Red line (H) = PURItech DPF System

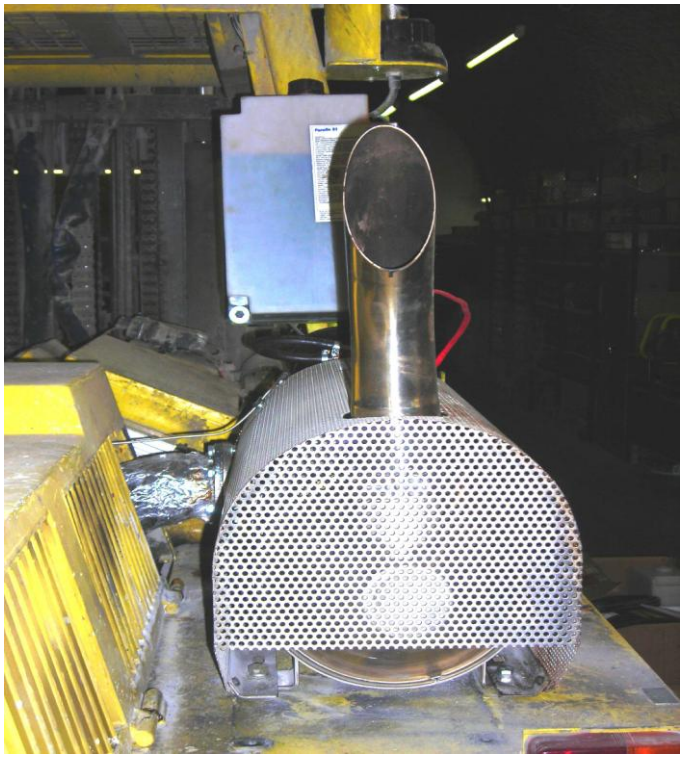
2. PURImax-System Validation Off-Road

In-field system validation w/ online measurement of NO - NO_2 at "Schachtanlage Asse", Germany

a) wheel loader "Kramer 480"
engine: Deutz F5L 912 W
displacement: 4.7 l
engine power: 52 kW (2.300 rpm)

b) fork lift "Herbst Arktur II"
engine: Deutz F4 M 2011
displacement: 3.1 l
engine power: 44 kW (2.400 rpm)





2. PURImax-System Validation Off-Road

Results of online NO_2 measurement at "Schachtanlage Asse", Germany

Online measurement / October 07th 2008

"Kramer 480" - DPF-System Puritech "0708"

average values	pre DPF	post DPF	result
[ppm] NO_2	30	9	NO_2 - Reduction - 70%

"Herbst Arktur II" – DPF-System Puritech "0908"

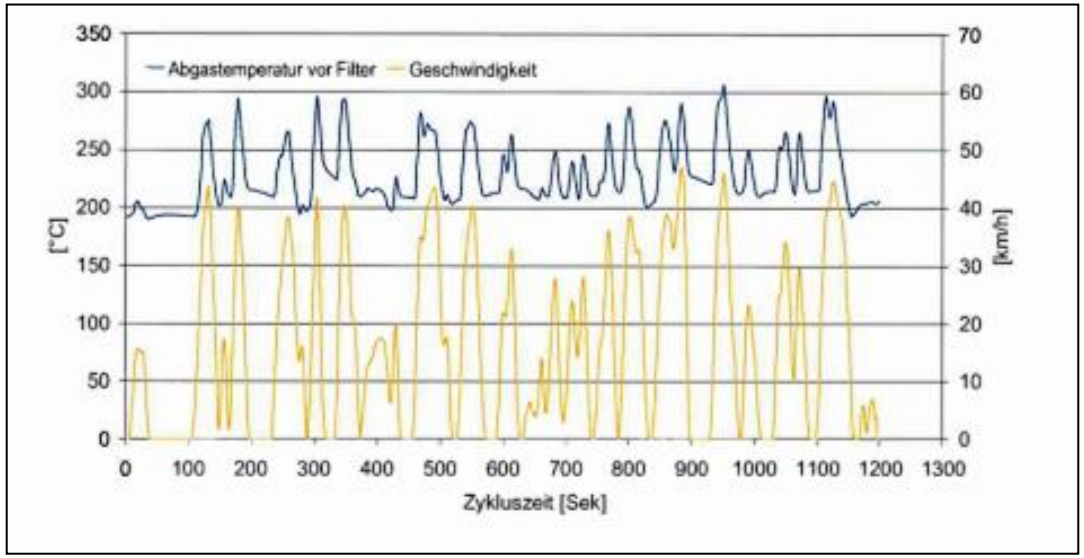
average values	pre DPF	post DPF	result
[ppm] NO_2	21	10	NO_2 - Reduction - 54%

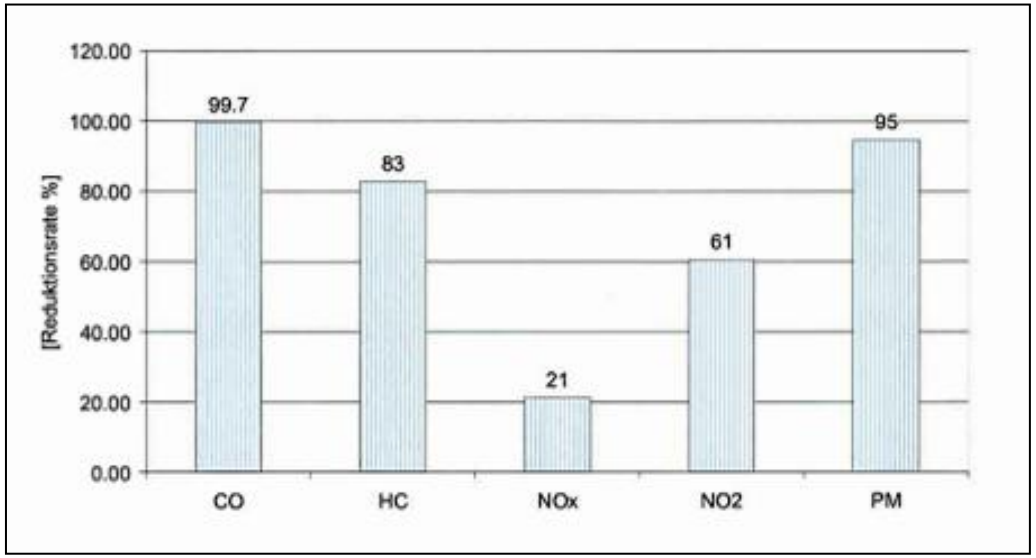
2. PURImax-System Validation On-Road

NO_2 NOx measurement / worst-case low-temp. cycle / University of Graz / chassis dyno

City bus "Mercedes Benz Citaro O530" (EURO-3)

engine:	MB OM 457 hLA	test cycle:	9040
displacement:	12 liter	average temp.:	230 degC
engine power:	185 kW (2.000 rpm)	test date:	12 / 2009





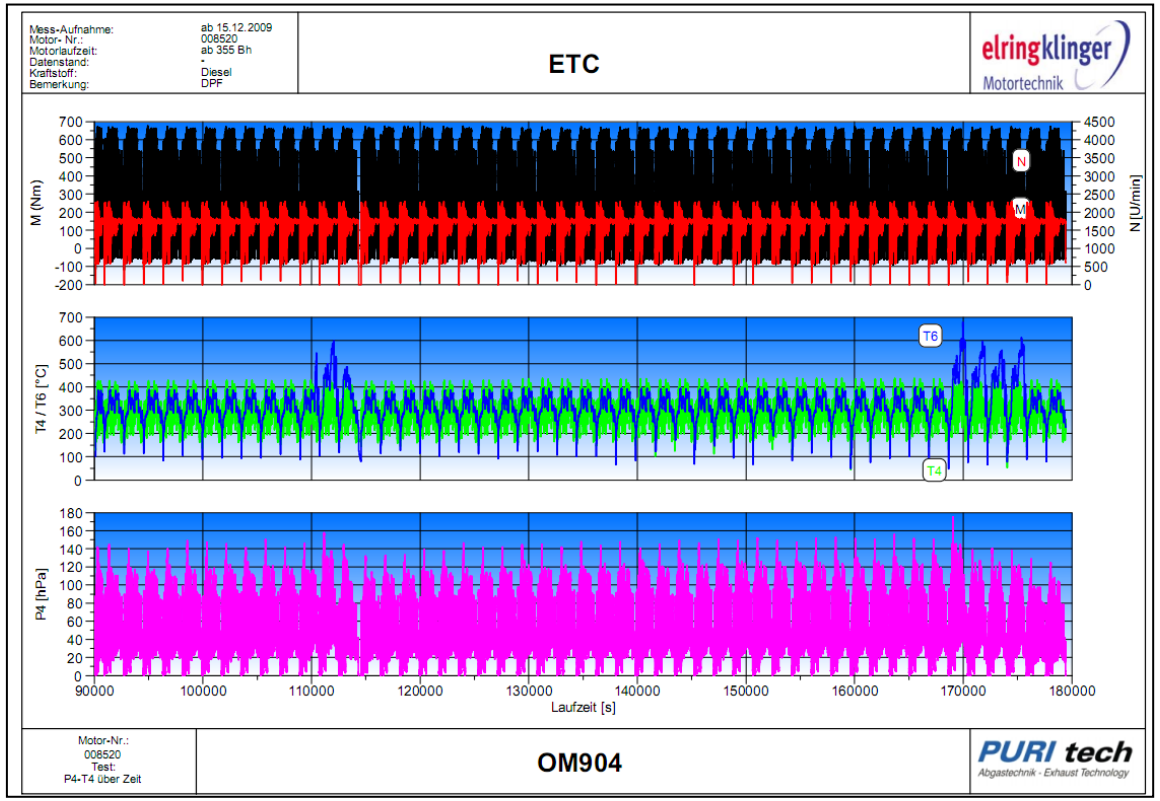
	NO_2	NO_x
Reduction	**- 61 %**	**- 22 %**

2. PURImax-System Validation On-Road

NO_2 - NOx measurement / ETC test cycle (99/96/EG) / TUEV Nord / engine test bench

HDD Engine "MB OM904"

engine: MB OM 904 LA
displacement: 4.3 liter
engine power: 130 kW (2.200 rpm)



	NO_2	NO_x
Reduction	**- 79 %**	**- 30 %**

2. PURImax-System Validation On-Road

Endurance test on different on-road vehicles / in-use testing

-> no failures detected

a) Omnibus "SETRA S417 UL"
engine: MB OM457hLA
displacement: 12 liter
engine power: 260 kW

3,200 operating hours / 130,000 km

2. PURImax-System Validation On-Road

Bern University of Applied Sciences, Engineering and Information Technology Control n°: 500'071-3 Laboratory for IC-Engines and Exhaust Gas Control

VERT Filter Test 3k - measured values

client:	PURI tech	vehicle:	Bus	manufacturer:	Setra	serial no.:	WKK63310313105115	engine type	MB OM 457h LA
additive:	Infineum F7991: 25ppm Fe in fuel	type:	S 417 UL			hours or km :	130'090 km	date of adm. for traffic:	2007
measurement:	without DPF (reference)	particle trap:	-			op. hours/km:	-	date of installation:	-

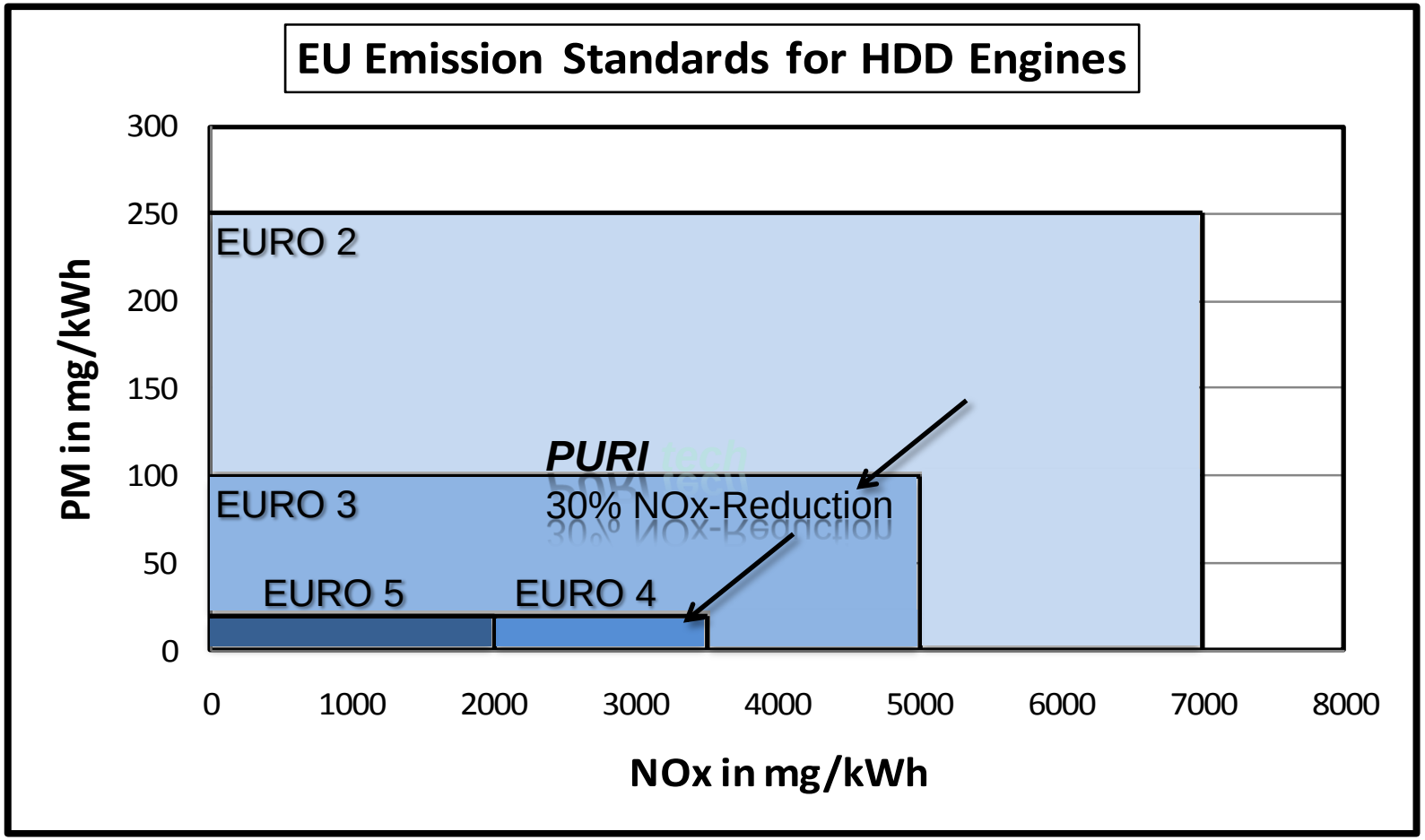
pt.	5)	n	P_e 7)	O_2 1)	CO 1)	NO 1)	NO_2 1)	HC_{IR} 1)	NO_x 1)	CO_2 1)	λ 1)
		[rpm]	[kW]	[%]	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]	[%]	[-]
8.1	idle speed	560	-	18.1	93	683	84	9	767	2.1	7.01
8.2	idle speed	560	-	18.0	97	690	85	11	775	2.1	6.92
8.3	idle speed	560	-	18.1	99	676	85	12	761	2.2	6.85

client:	PURI tech	vehicle:	Bus	manufacturer:	Setra	serial no.:	WKK63310313105115	engine type	MB OM 457h LA
additive:	Infineum F7991: 25ppm Fe in fuel	type:	S 417 UL			hours or km :	130'090 km	date of adm. for traffic:	2007
measurement:	with DPF	particle trap:	DAS/DBS 071224-1-20			op. hours/km:	129'310 km	date of installation:	29.12.2007

pt.	5)	n	P_e 7)	O_2 1)	CO 1)	NO 1)	NO_2 1)	HC_{IR} 1)	NO_x 1)	CO_2 1)	λ 1)
		[rpm]	[kW]	[%]	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]	[%]	[-]
8.1	idle speed	560	-	19.3	9	184	1	4	185	2.0	7.95
8.2	idle speed	560	-	19.3	9	187	1	3	188	1.8	8.38
8.3	idle speed	560	-	19.4	8	183	1	3	184	2.0	7.73

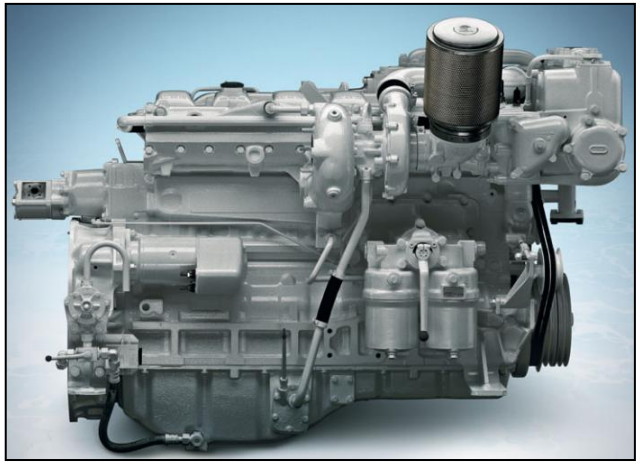
5)	pt.	temperature [° C]	with SCR (MB Blue Tec)			with PURItech DAS/DBS 071224-1-20			reduction rates DPF vs. SCR	
			NO 1)	NO_2 1)	NOx 1)	NO 1)	NO_2 1)	NOx 1)	**NO_2 1) reduction**	**NOx 1) reduction**
8.1	idle speed	163° C	683	84	767	184	1	185	**99%**	**76%**
8.2	idle speed	163° C	690	85	775	187	1	188	**99%**	**76%**
8.3	idle speed	163° C	676	85	761	183	1	184	**99%**	**76%**

2. PURImax-System – NO_x Reduction



2. PURImax-System – NO_x Reduction

MAN D2866 LXE 40



cylinder: 6
displacement: 12 l
engine power: 190/279 kW (1.800 rpm)

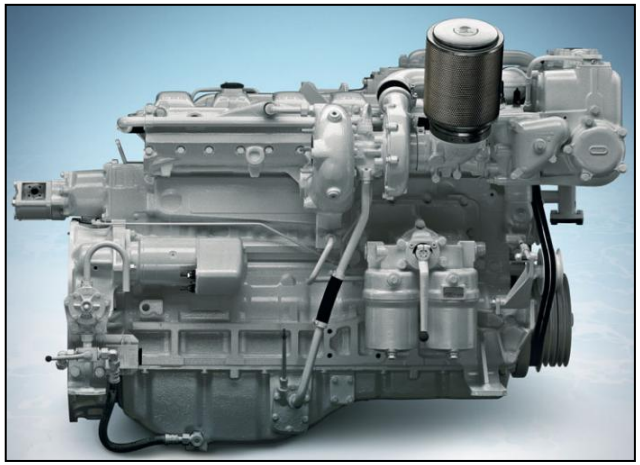
US EPA (marine engines)

Tier 2	**Tier 3**
HC+ NO_x: **7,2 g/kWh**	HC+ NO_x: **5,6 g/kWh**

22% HC+ NO_x-Reduction required

2. PURImax-System – NO_x Reduction

MAN D2866 LXE 40



cylinder: 6
displacement: 12 l
engine power: 190/279 kW (1.800 rpm)

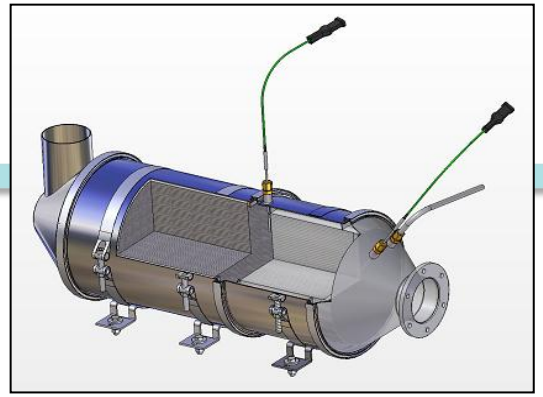
US EPA (marine engines)

Tier 2

HC+ NO_x: **7,2 g/kWh**

Tier 3

HC+ NO_x: **5,6 g/kWh**



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Thank you for your attention!