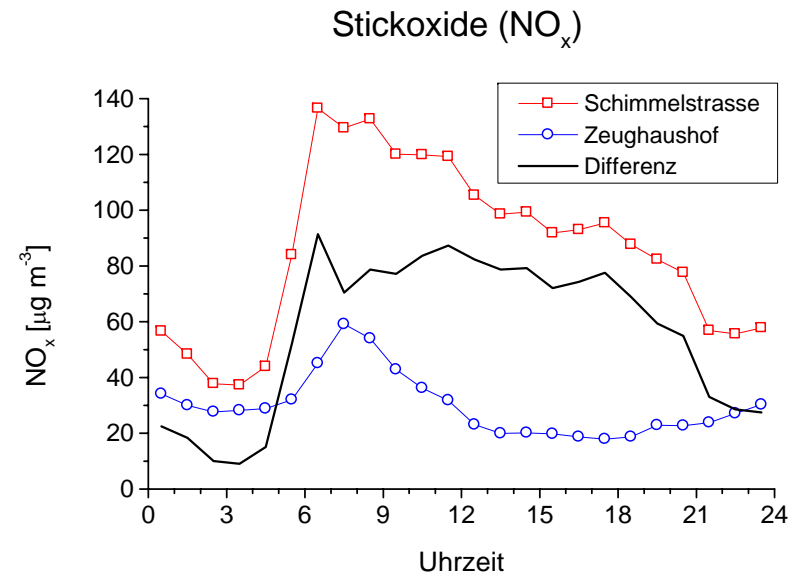
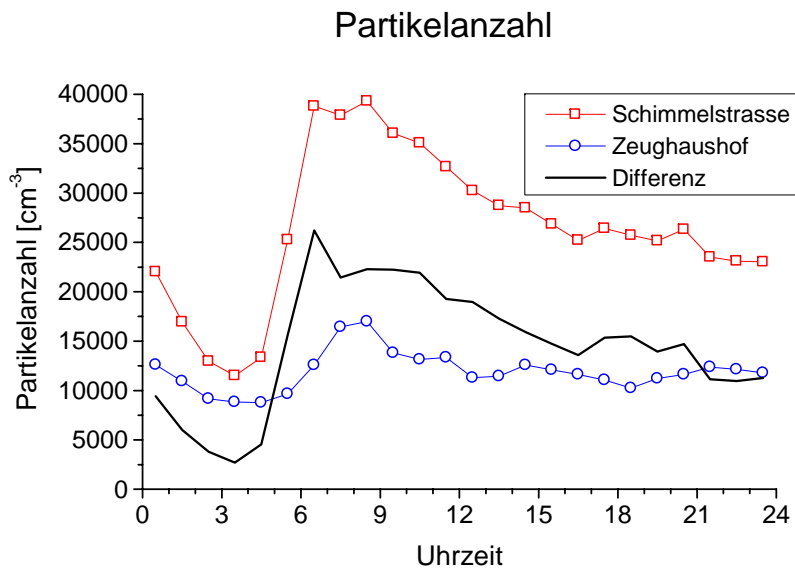
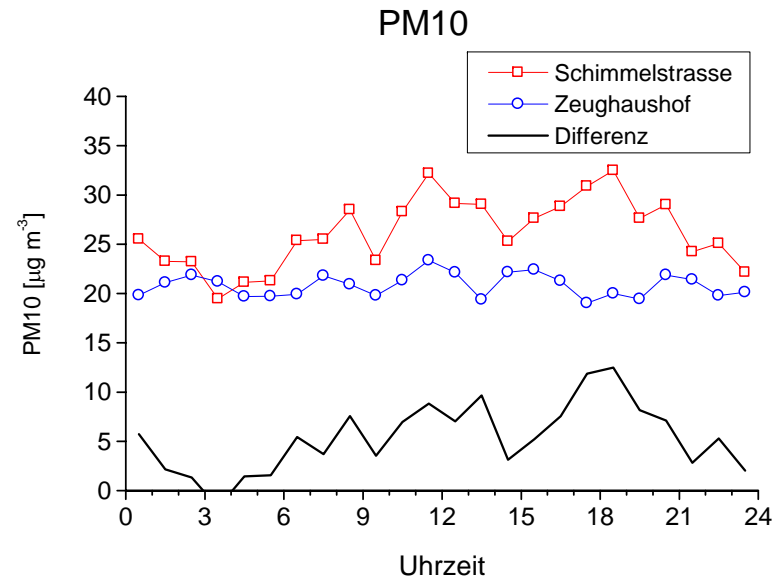


***"NO_x-Reduction on Top of Particle-
Elimination for Offroad Retrofit
today and tomorrow"***

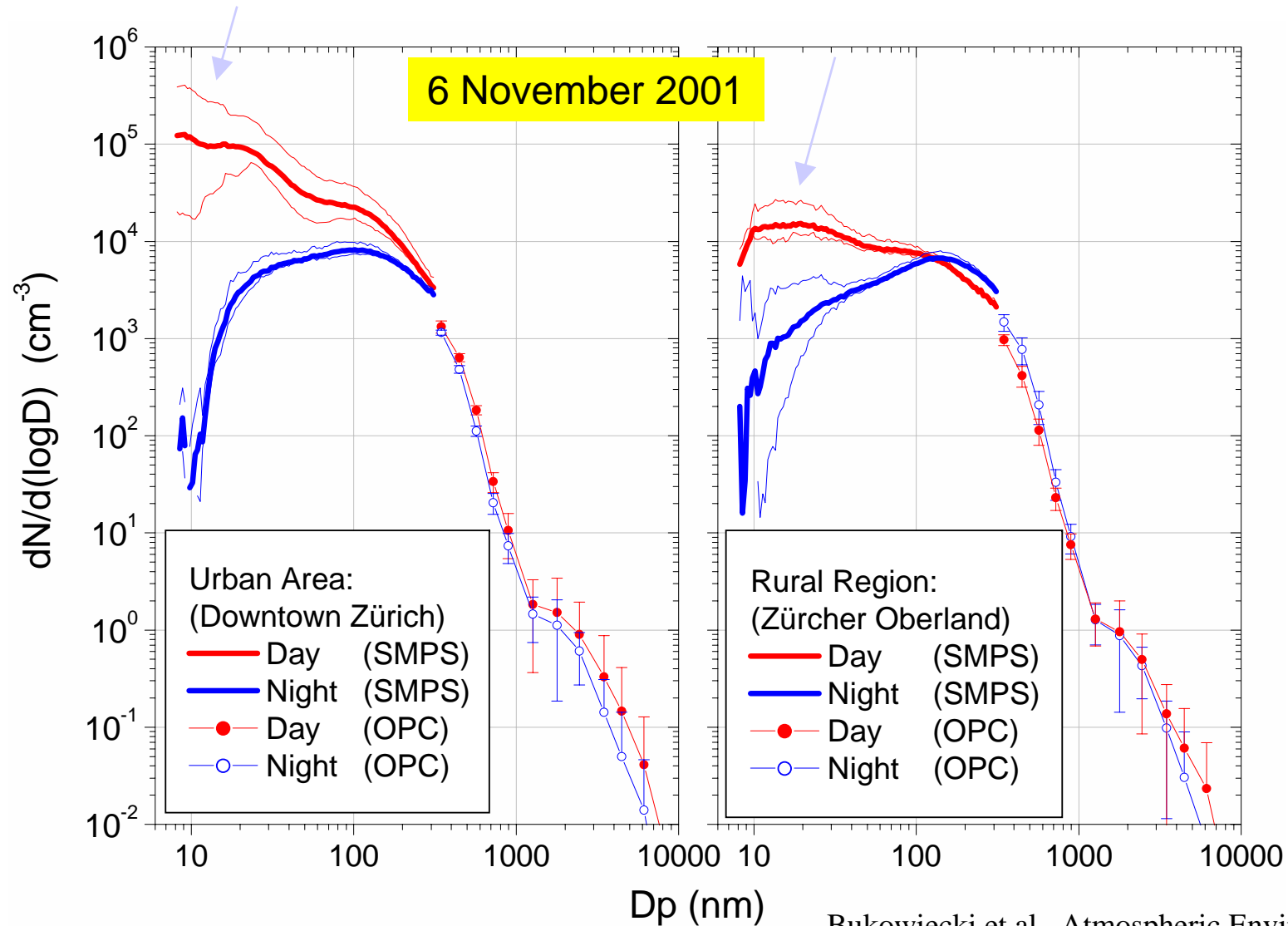
***Open Questions
based on Experience in Switzerland***

A.Mayer / TTM

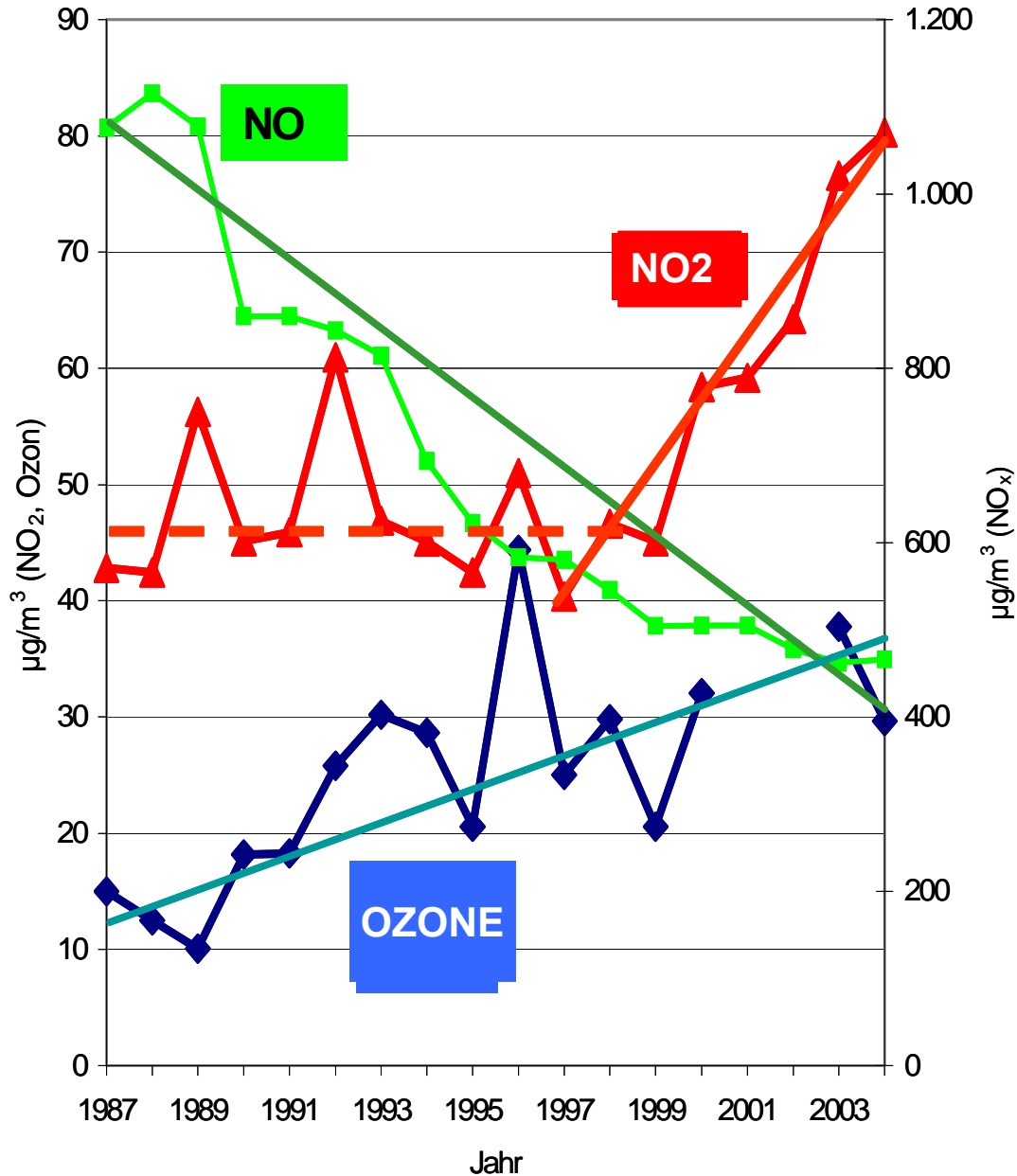
PM, PN and NO₂ Emissions in dense Traffic during a Day



Particle Concentrations and Size Distribution urban (Zürich) and country (Zürcher Oberland)



Konzentration von NO_x, NO₂ und Ozon



**NO₂-Increase
due to DOC
with ULDF**

**Monitoring a
German
Highway**

1987-2004

Source: UBA, Umwelt Bundesamt

Priorities ?

Particle-and/or NOx-Reduction

| Particle-Elimination | NO and NO ₂ -Reduction |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none">• carcinogen – no threshold• cardiovascular mortality• IC-engine-related• reduction efficiency > 99 %• no secondary emissions• retrofit technology proven• health benefit / cost > 5 <p>→ must be enforced</p> | <ul style="list-style-type: none">• no carcinogen - threshold• toxic at concentrations > ??• IC-engine + other sources• reduction efficiency < 70 %• secondary emissions ??• technology for retrofit ??• health cost / cost > ?? <p>→ must be investigated</p> |

Particle-Elimination

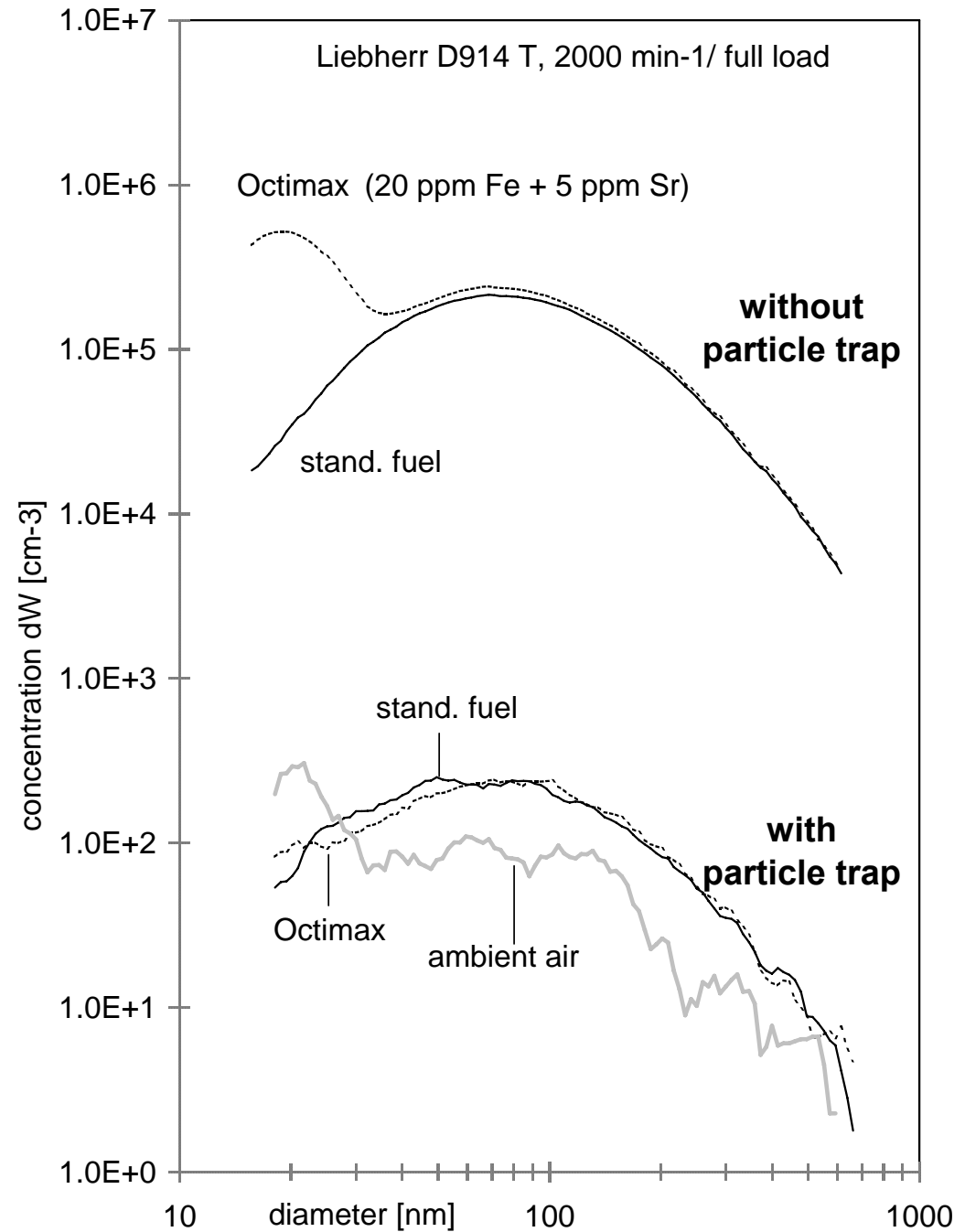
Experience with 15'000 Retrofits in Switzerland ?

- Filtration > 99 % (solid particles 20-500 nm)
- Regeneration active and automatic
- many systems without secondary emissions
- VERT-standards and certification in place
- Engine-compatible with backpressure < 200 mb
- Reliability > 98% and life > 5000 hr

BUT

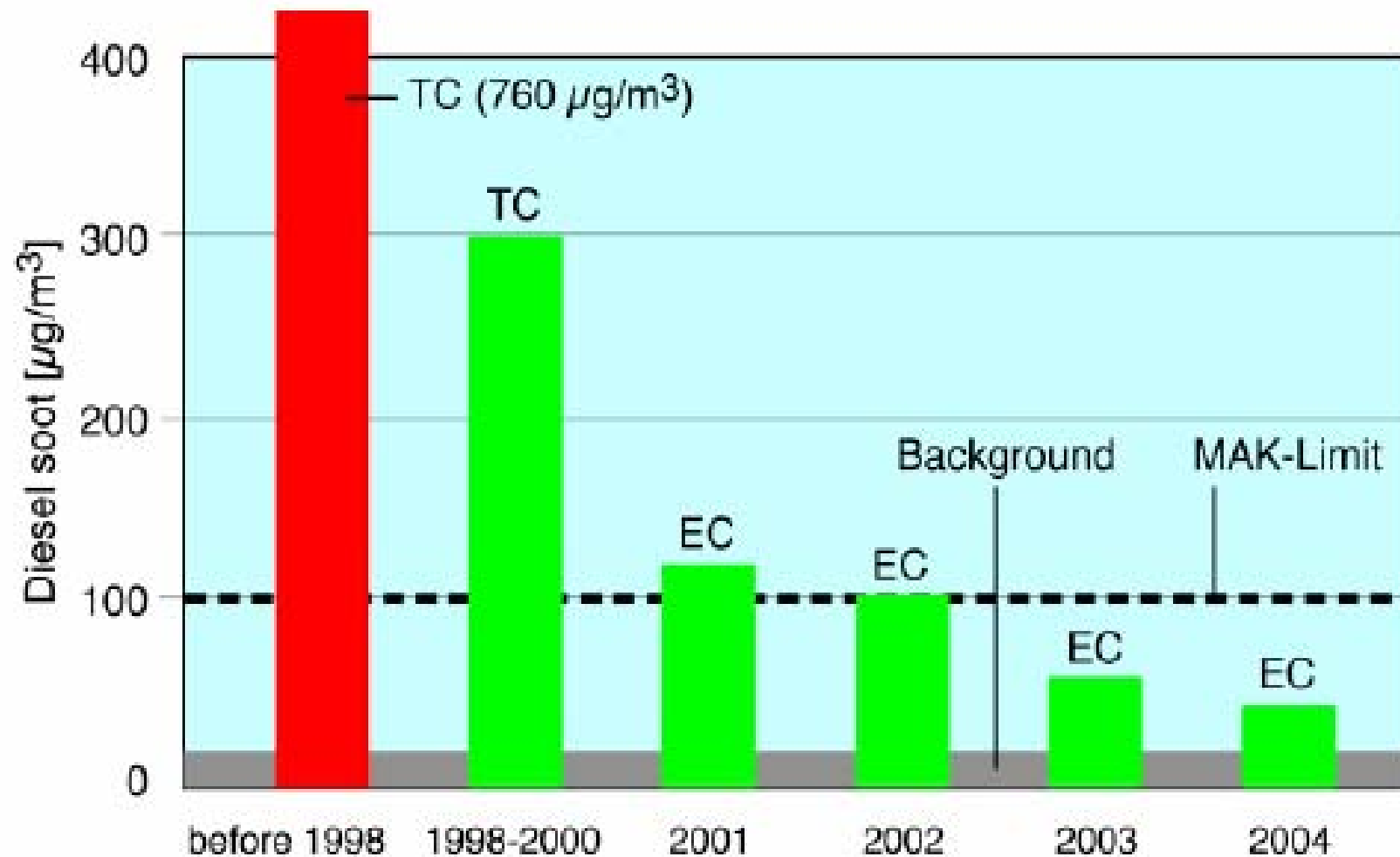
- bulky: needs at least space of replaced muffler
- expensive: 50 (300kW) – 100 (50 kW) US \$/kWh

Particle Elimination with CORNING-Filter and Fe-FBC



VERT-approved PFS

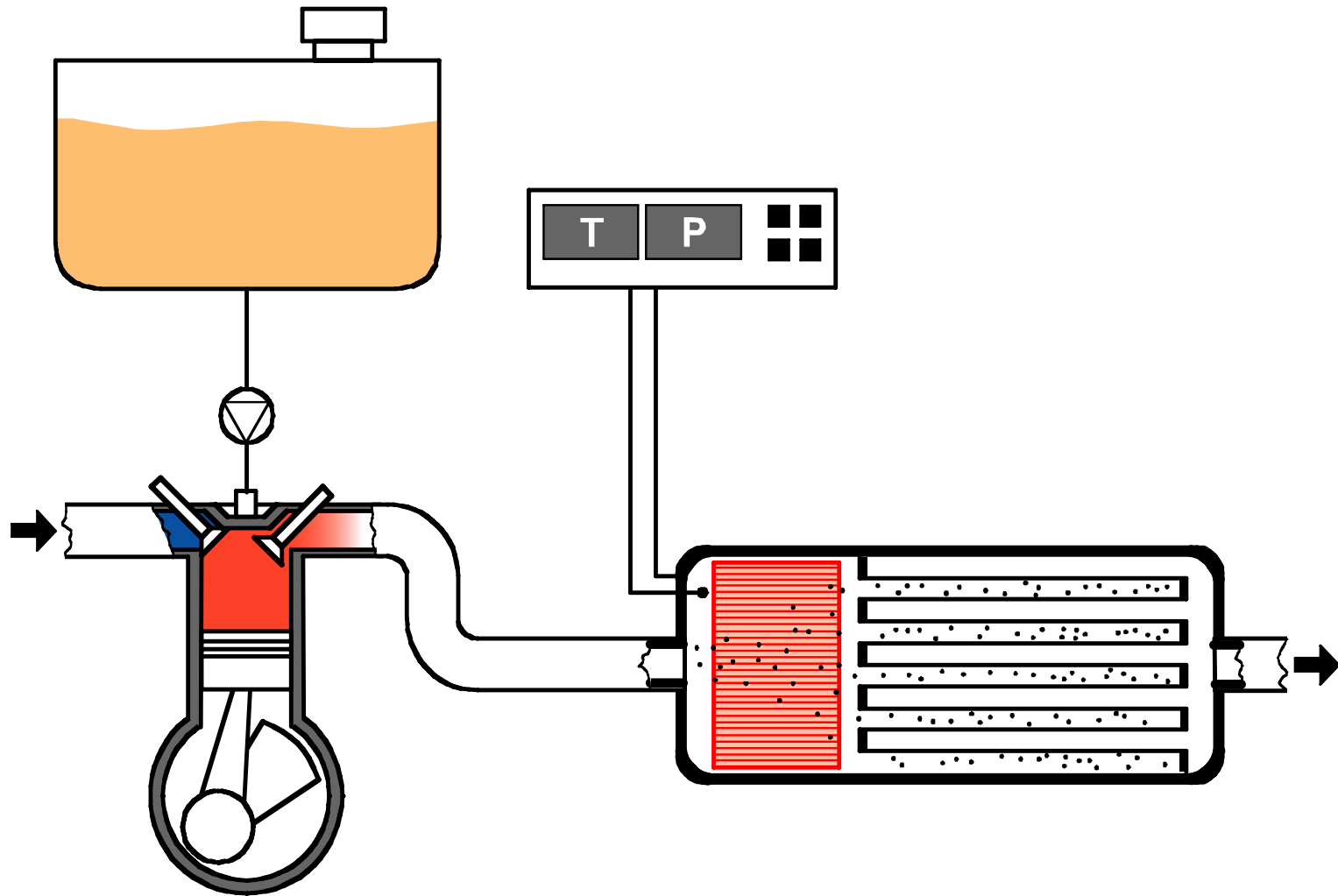
| VERT Test VFT3 | Regeneration Type | PMAG | PZAG |
|----------------|-----------------------------------------------|--------|---------------|
| | | [%] | |
| ADASTRA-OCTEL | FBC | 89.5 | 99.351 |
| AIRMEEEX | FBC | 83.6 | 99.973 |
| ARVINMERITOR | Full Flow Burner | 91.00 | 99.854 |
| ATH | Stand Still Burner | 45.9 | 99.998 |
| COMELA | Heat Storage with twin Filter Set, FBC | -382.9 | 98.310 |
| DCL | Electric External | 81.4 | 99.999 |
| DINEX | Catalyzed, FBC | 93.8 | 99.906 |
| ECS (UNIKAT) | On Board Electric | 91.0 | 99.999 |
| ECS (UNIKAT) | Catalyzed, FBC | 52.0 | 99.955 |

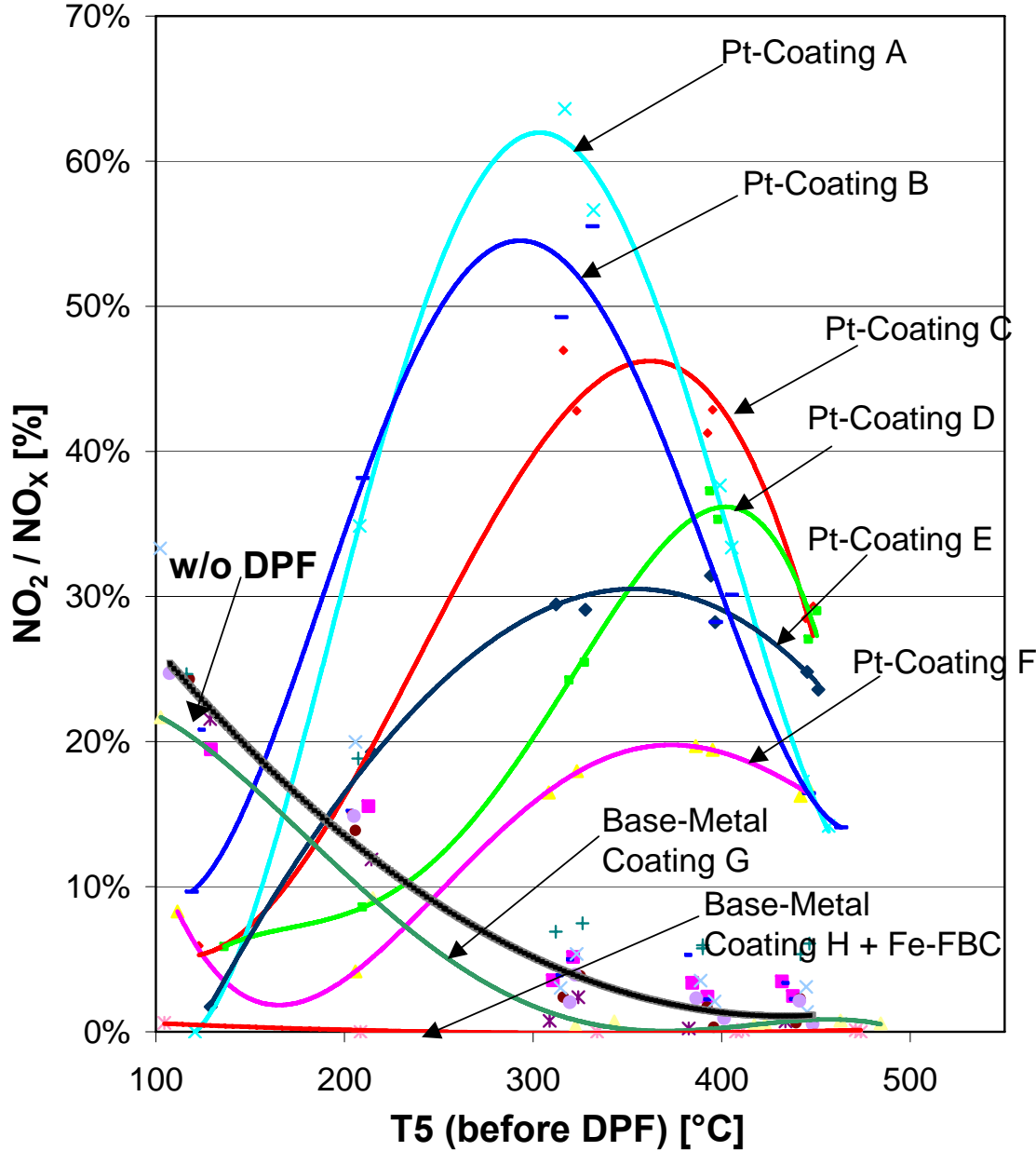


Cleaning the Air in Swiss Tunneling

CRT+DPX: NO₂ regeneration with Pt-catalyst

JM / HJS / EMINOX / PSA / ENGELHARD et.al.

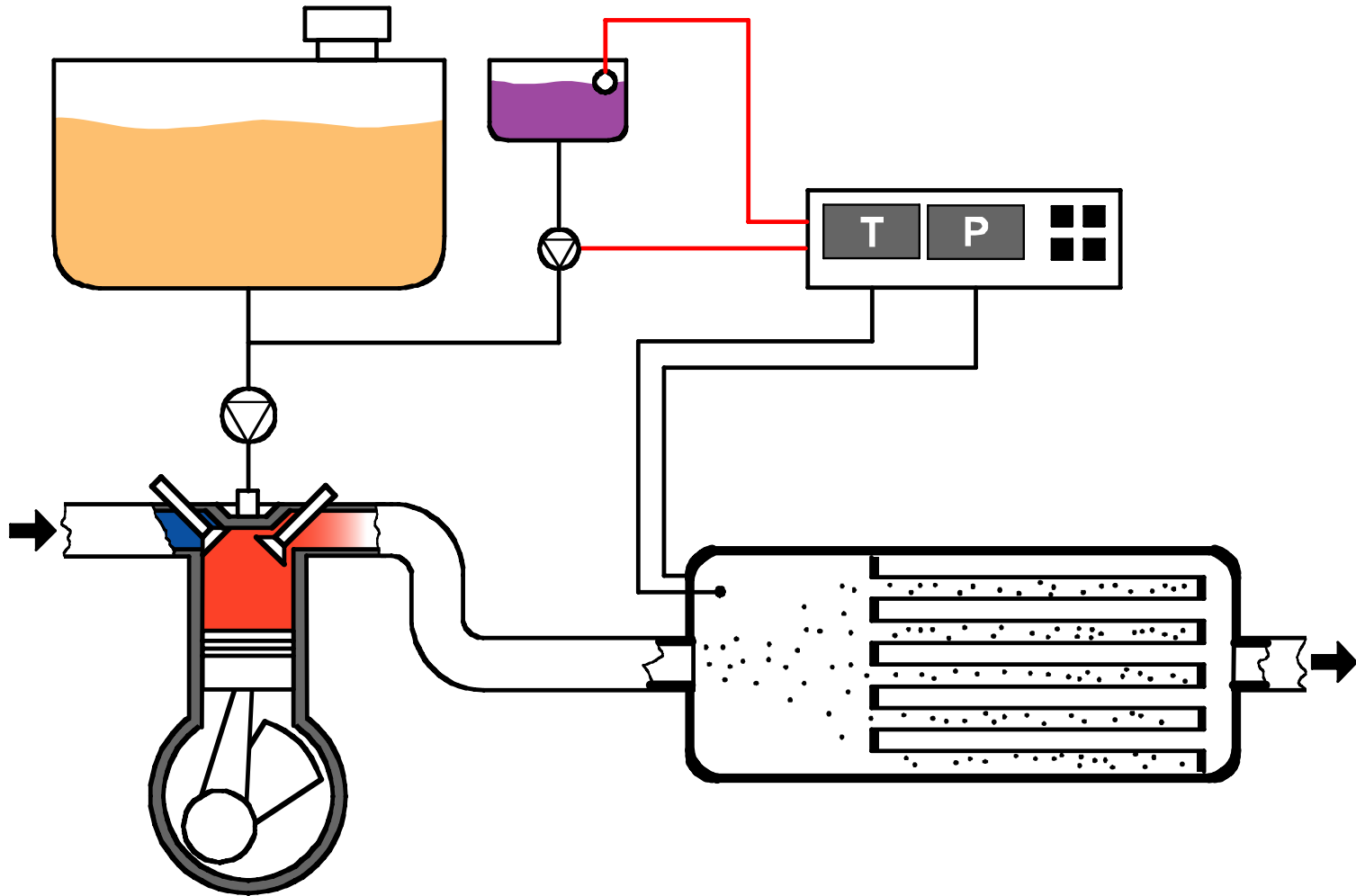




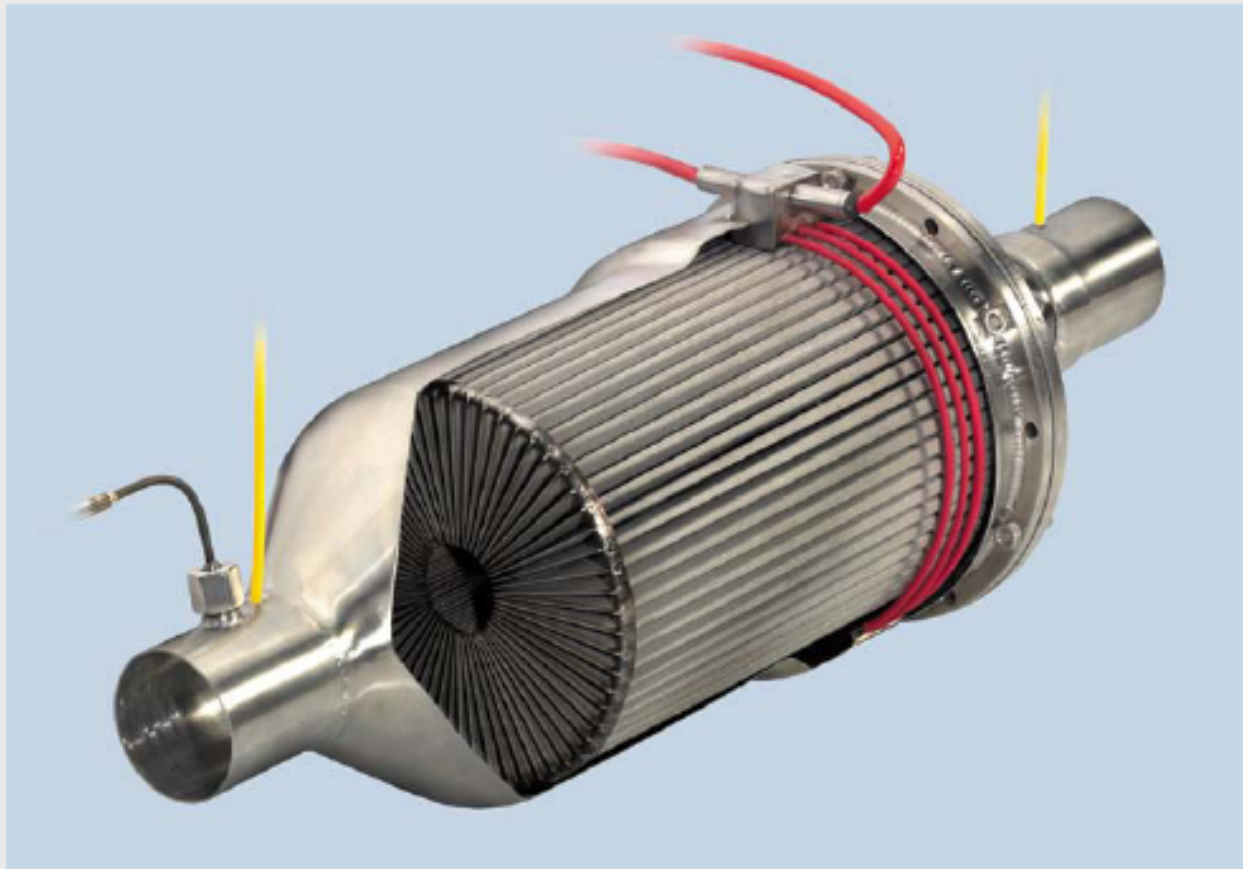
$\text{NO}_2 / \text{NO}_x$ ratio with Pt-coatings

versus FBC and base-metal-coating

Regeneration with fuel borne catalysts (FBC) EMINOX/AIRMEEEX/ HUSS/EXOCLEAN/JM/HJS

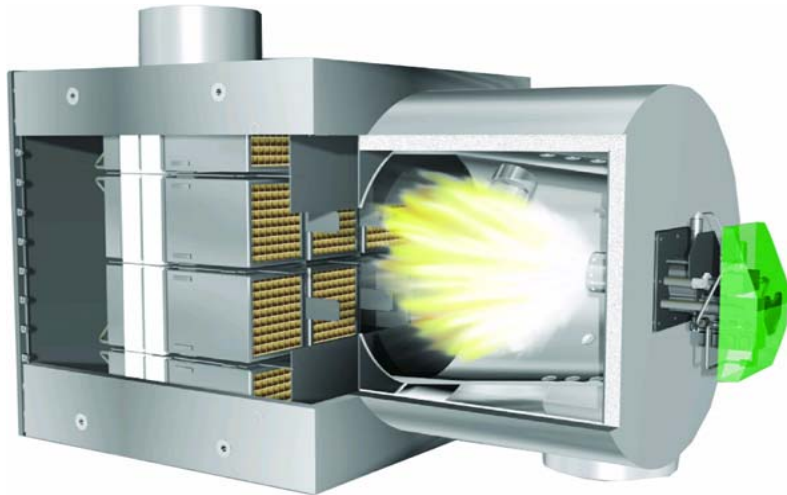


HJS SMF[®] – System mit autarker Regeneration

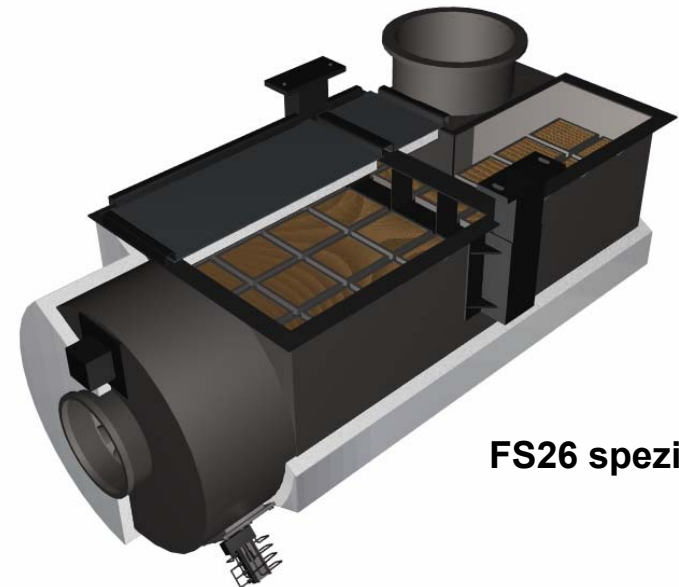


PFS for large engines in locomotives and ships

300 locomotives 200-3000 kW – 15'000 hrs in operation
Full Flow Burner and **base-metal coating (HUG)**

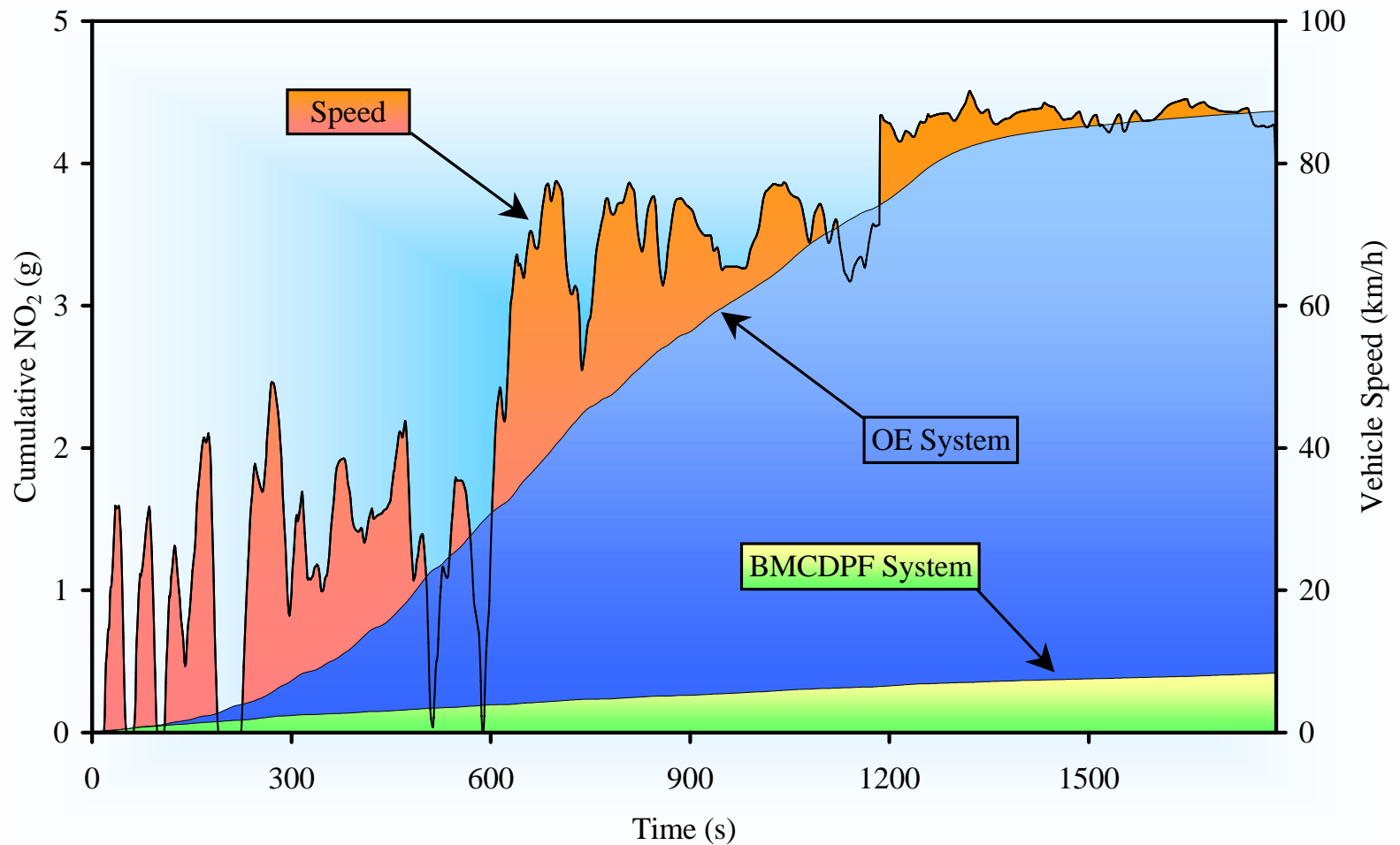


Restsauerstoff im Abgas: > 8%
Heizleistungen: 30 – 400 kW
Druckluft > 5 bar: 20 Nm³/h
Dieselkraftstoff: 3 – 40 l/h
Stromversorgung: 24 VDC



FS26 spezial

Cumulative NO₂ on a bus, with base metal coating and FBC (ADASTRA, EMINOX)

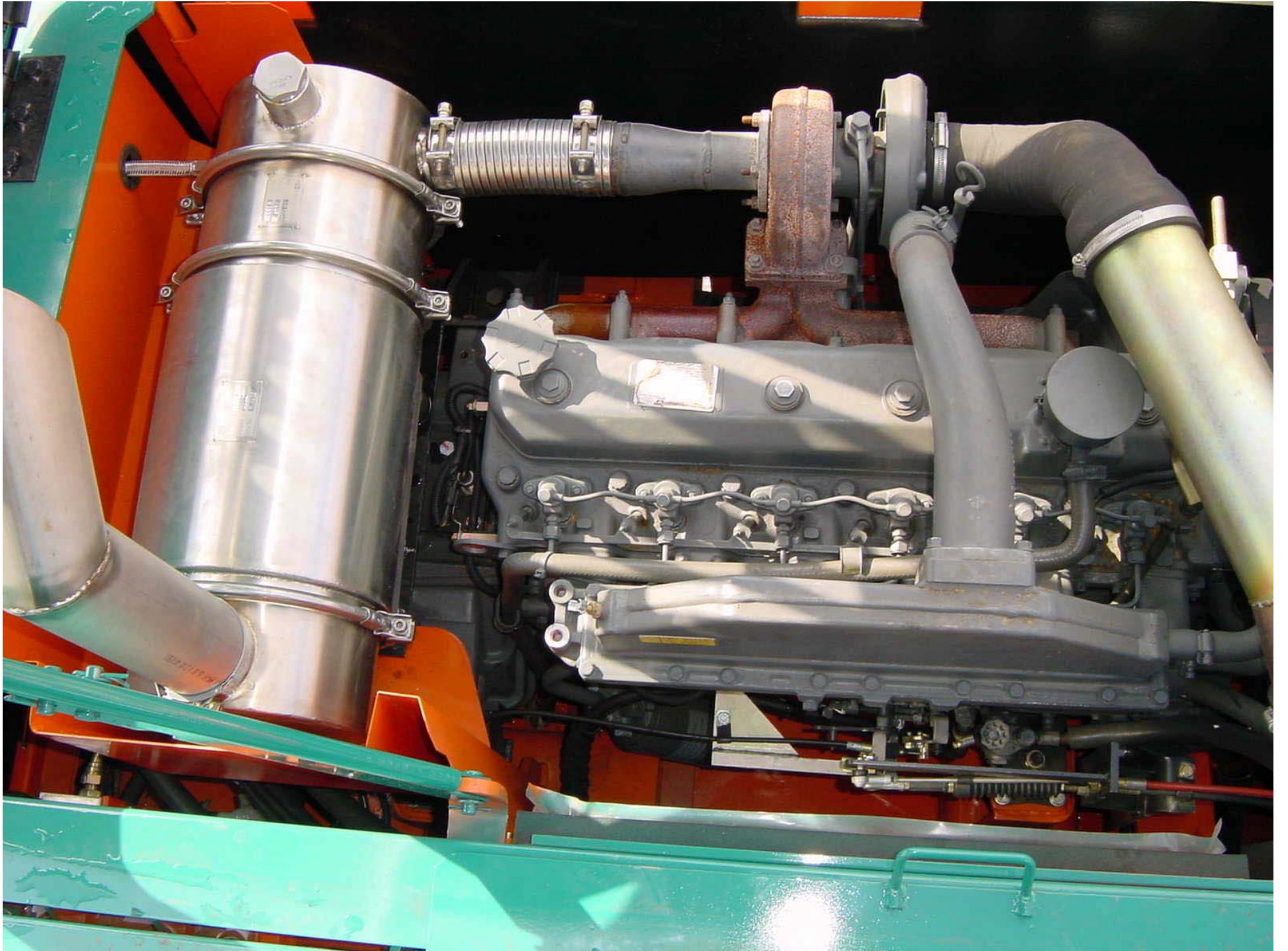




Postauto Schweiz

Busbetrieb: Ivo Matt AG, Mauren







Torre probe SW10
P/N: Typ. RW12
Motor Inco 91AE 435



Bagger Neuson 6583 - 42.5 kw
Motor Yanmar 4TNV98-VNS
PR.mobiclean Typ R 5.4

Traktor Fendt 308 C 69 kw
Motor Deutz BF4M2012C
PR-mobiclean Typ K 4.086/400

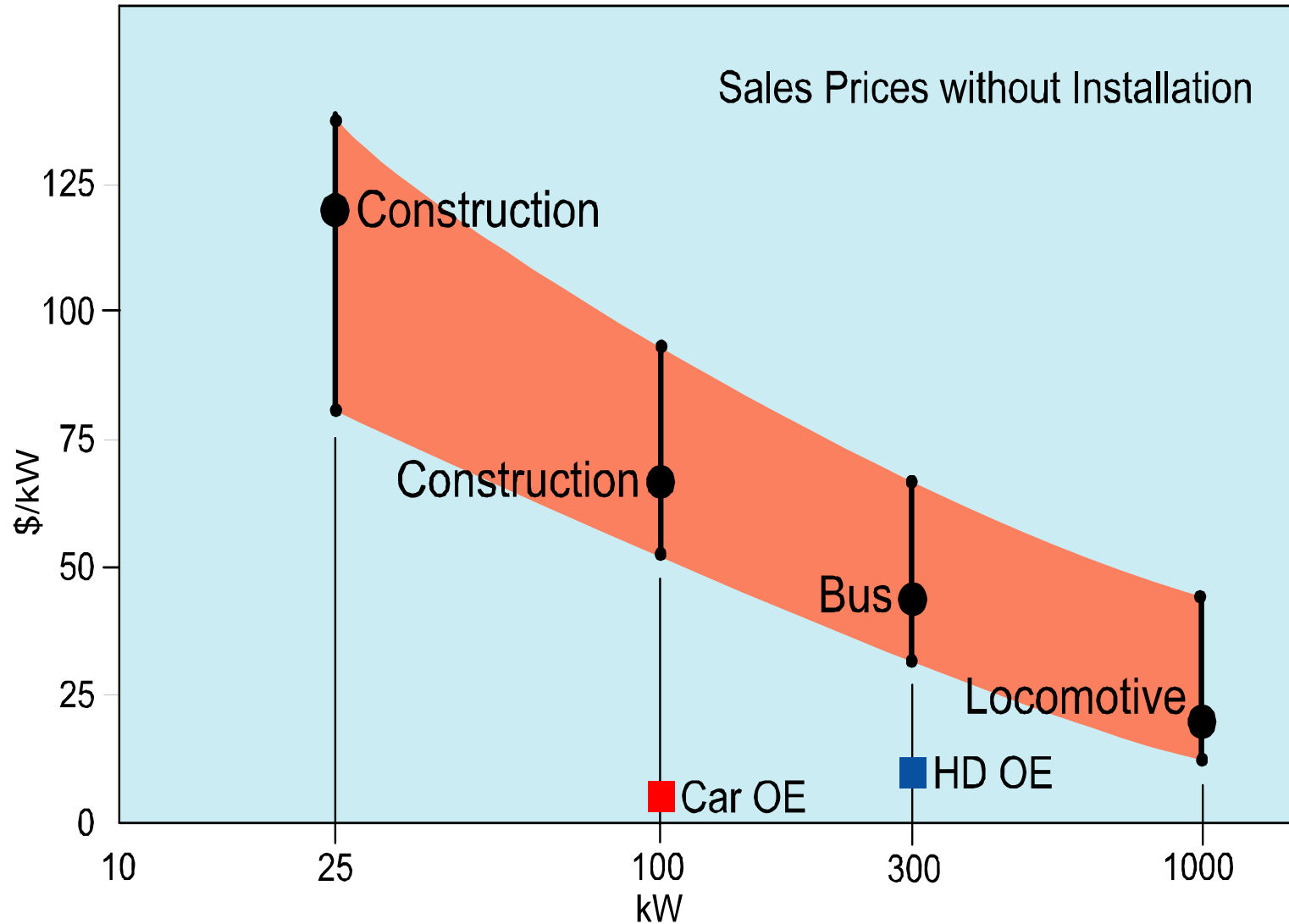




Radlader Caterpillar 950 G II 137 kw
Motor Caterpillar 3126
PR.mobiclean Typ R 18



Cost is still high but Helath-Benefit/Cost – Ratio is > 5



SCR-DeNOx

where do we stand ?

- NOx-Reduction 70 – 90 (95) % > 300 °C
- Catalysts, system elements and reactant available
- Engine-compatibility proven
- Reliability proven

BUT

- No NOx-Reduction < 220 °C
- Generation of Ultrafine Particles ?
- Secondary emissions ?
- as bulky as Particle Filter and needs muffler
- as expensive as PFS + Adblue-cost = 5% of fuel cost
- Standards and certification no ready yet

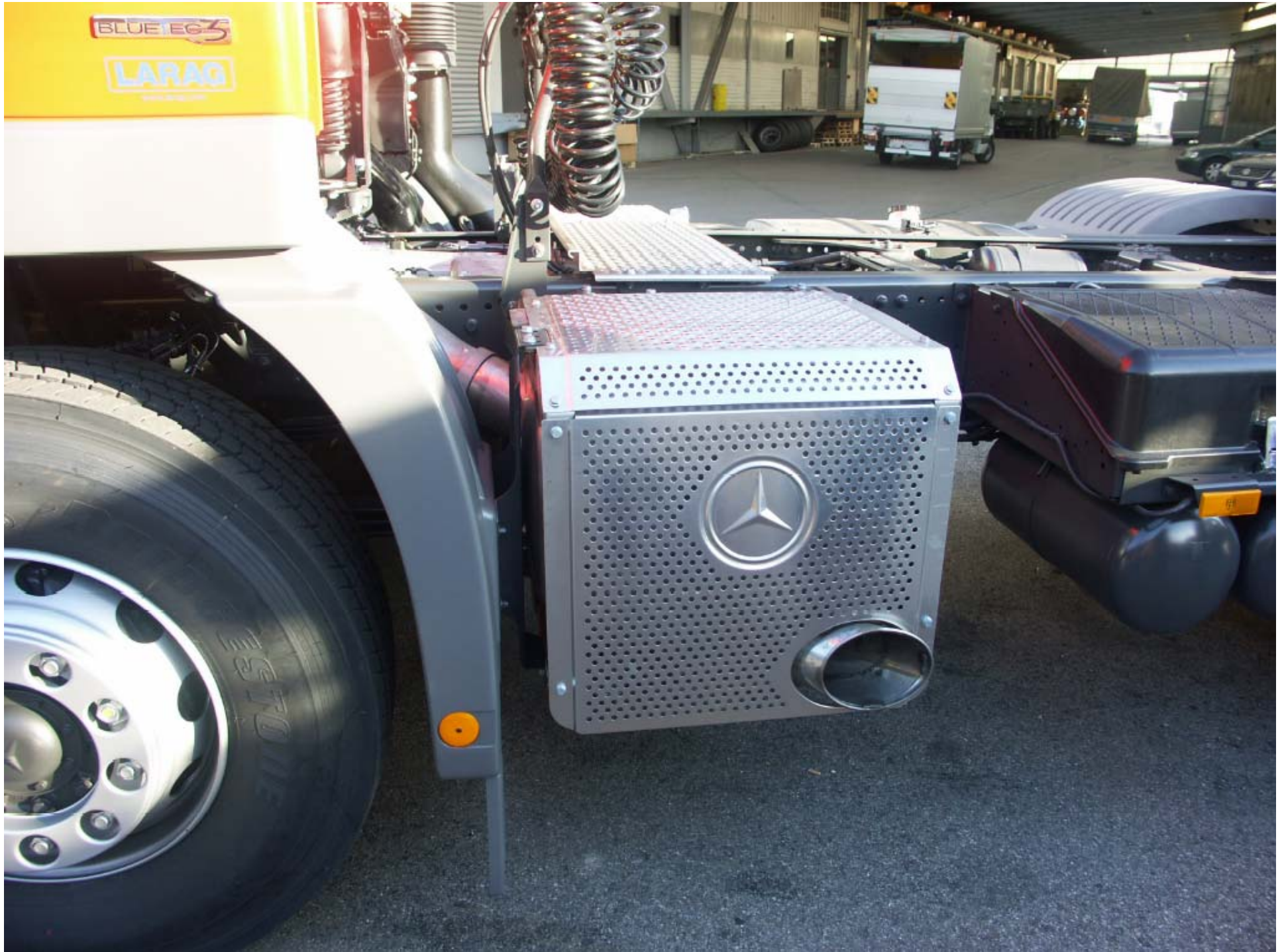
SCR-DeNOx (1)

OE with Euro 4 and Euro 5

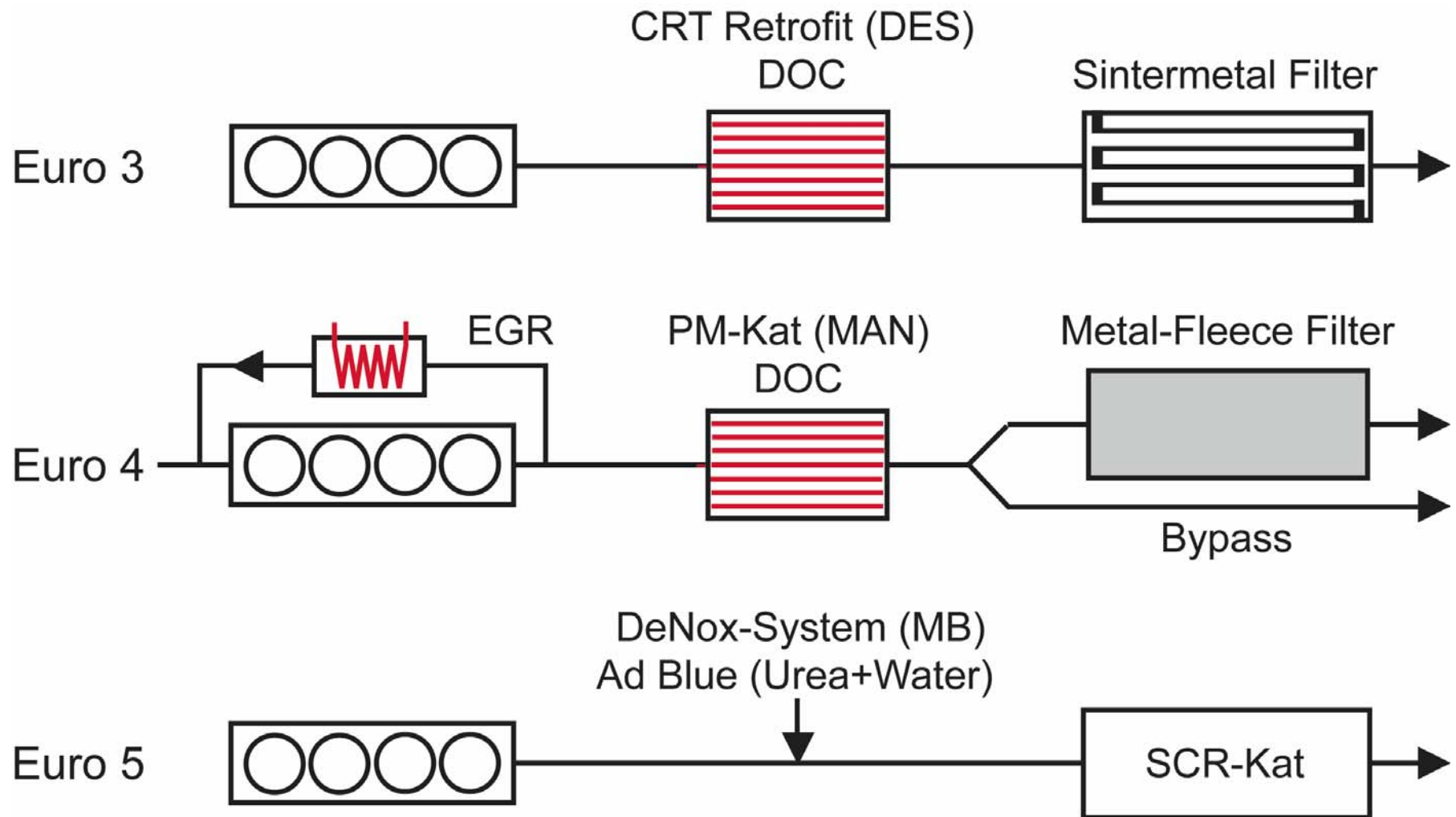
about 100'000 HD vehicles on the road

Problem areas:

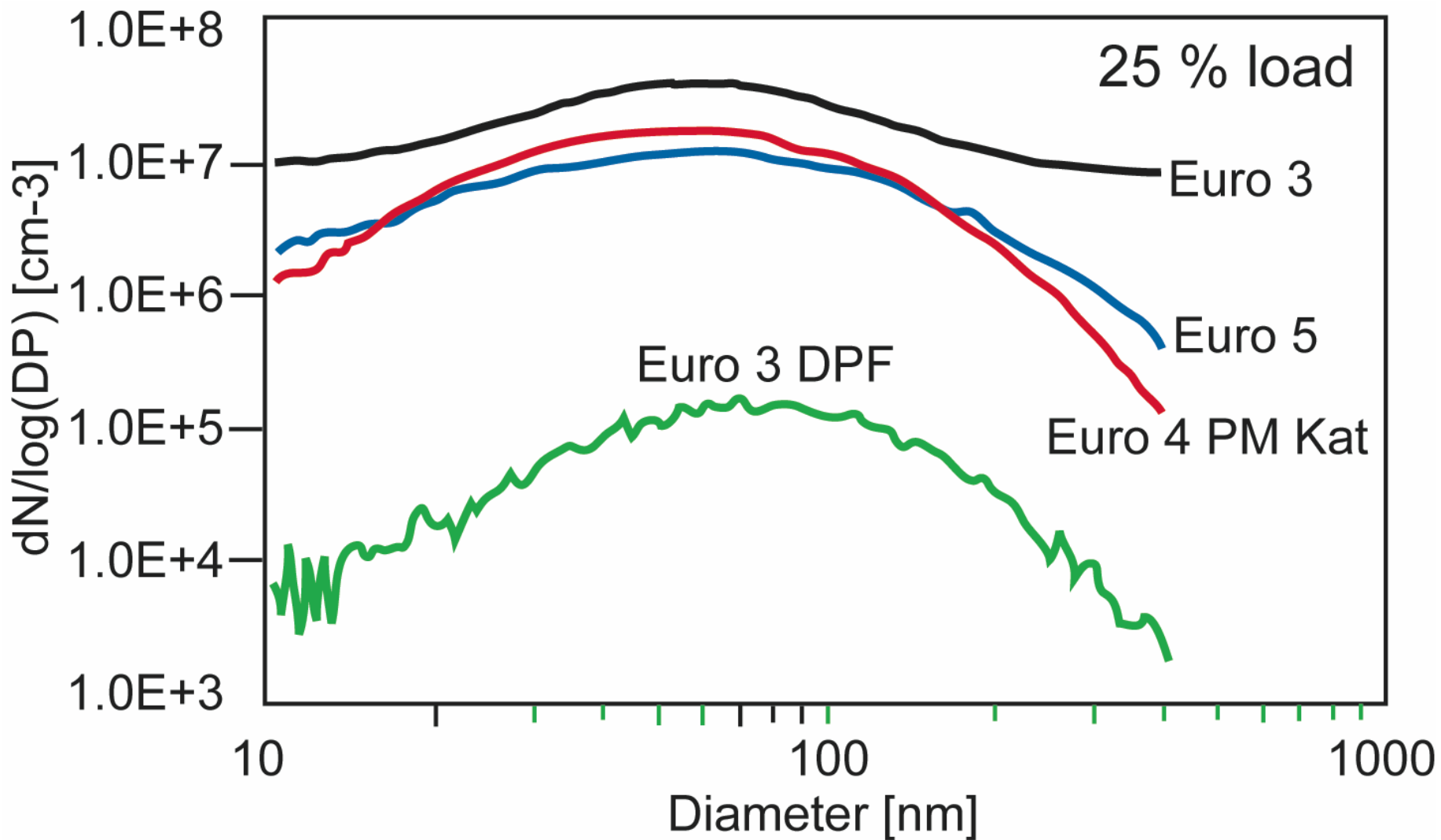
- city driving cycle conversion**
- nanoparticle generation**
- control technology still under development**
- secondary emissions unknown**
- no technical standards**
- no certification procedure available**



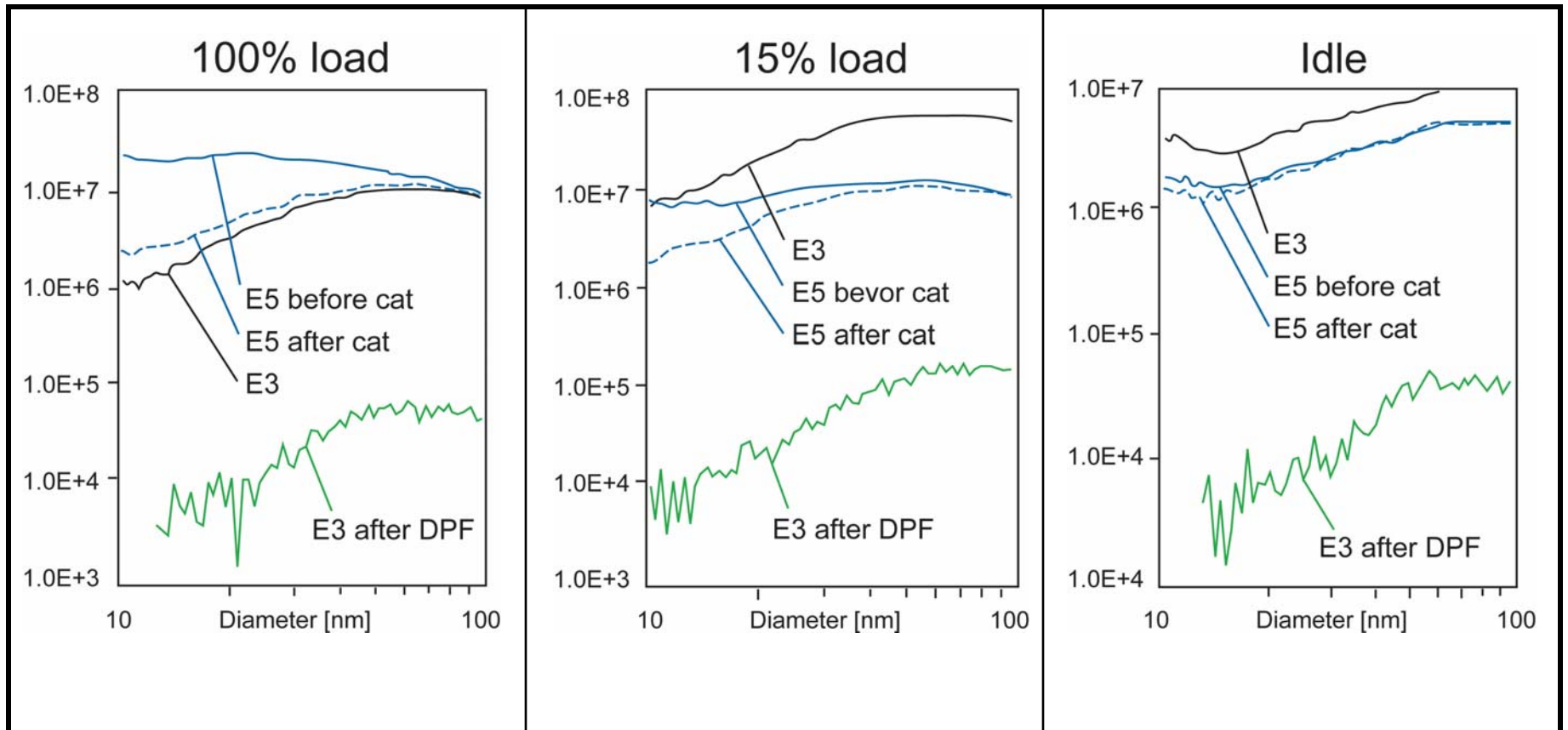
Exhaust Aftertreatment Concepts



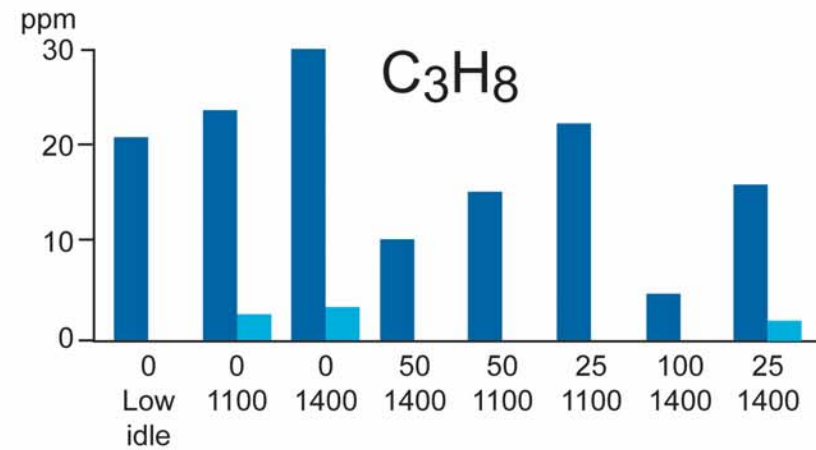
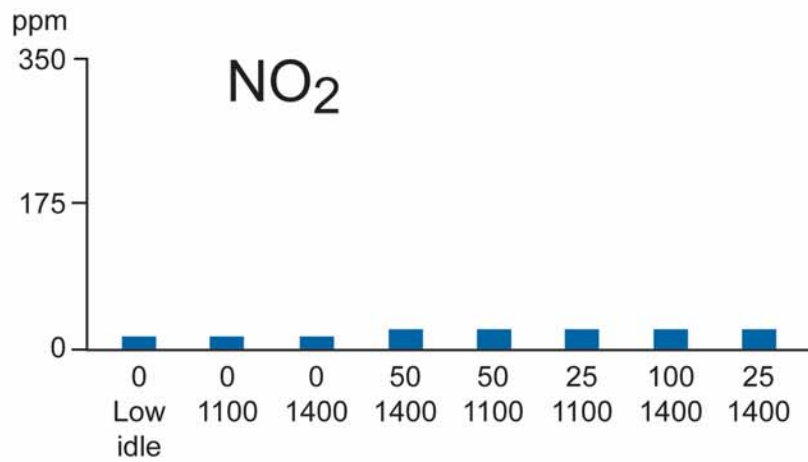
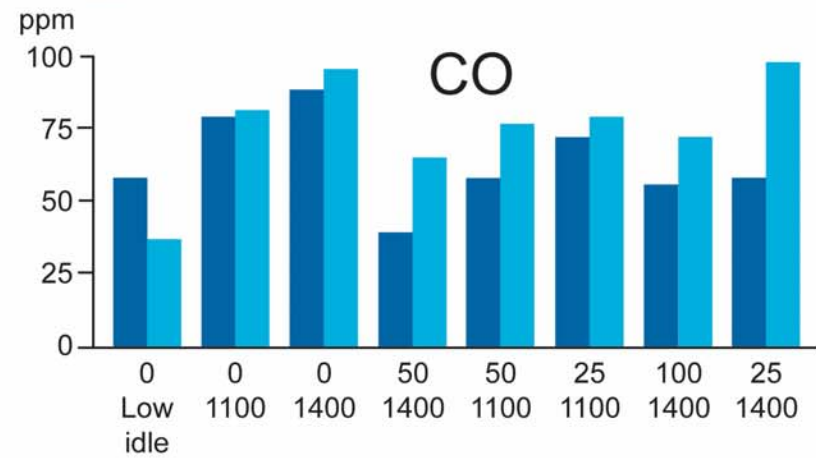
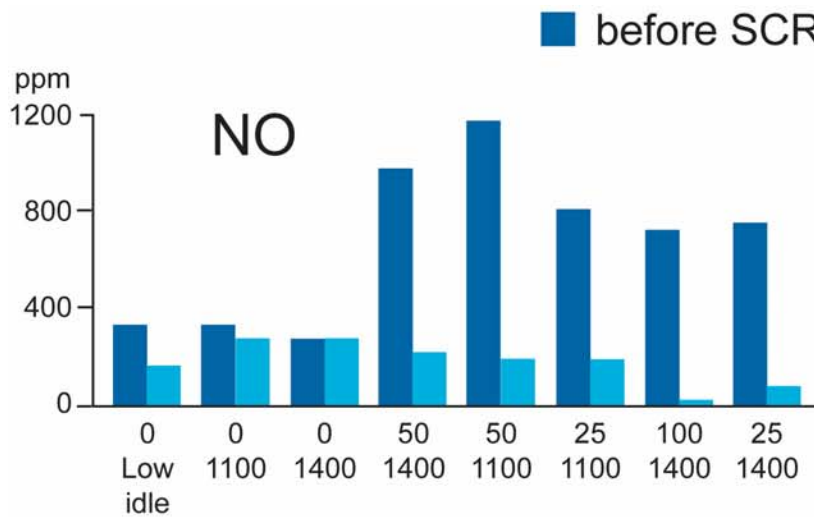
PN-Emissions at 1400 rpm, 25 % load



Influence of Adblue Injection on ultra-fine Particle Emission



Gas Emissions Euro 5 [ppm]



Secondary Emissions ?

**Mineral
Nano-Particles**

**Ammonia
 NH_3**

Nitric Acid HNO_3

**Cyanuric
acid
(HNCO)₃**

V_2O_5

**Nitrous oxide
 N_2O**

Nitrous acid HNO_2

**Ammonium-Sulfate
Particles**

Isocyanic acid HNCO

Dioxines with Cu-exchanged Zeolithes

**Ammonium
nitrate $\text{NH}_4 \text{NO}_3$**

Urea (NH_2)₂ CO

SCR-DeNOx + DPF (2)

for stationary engines

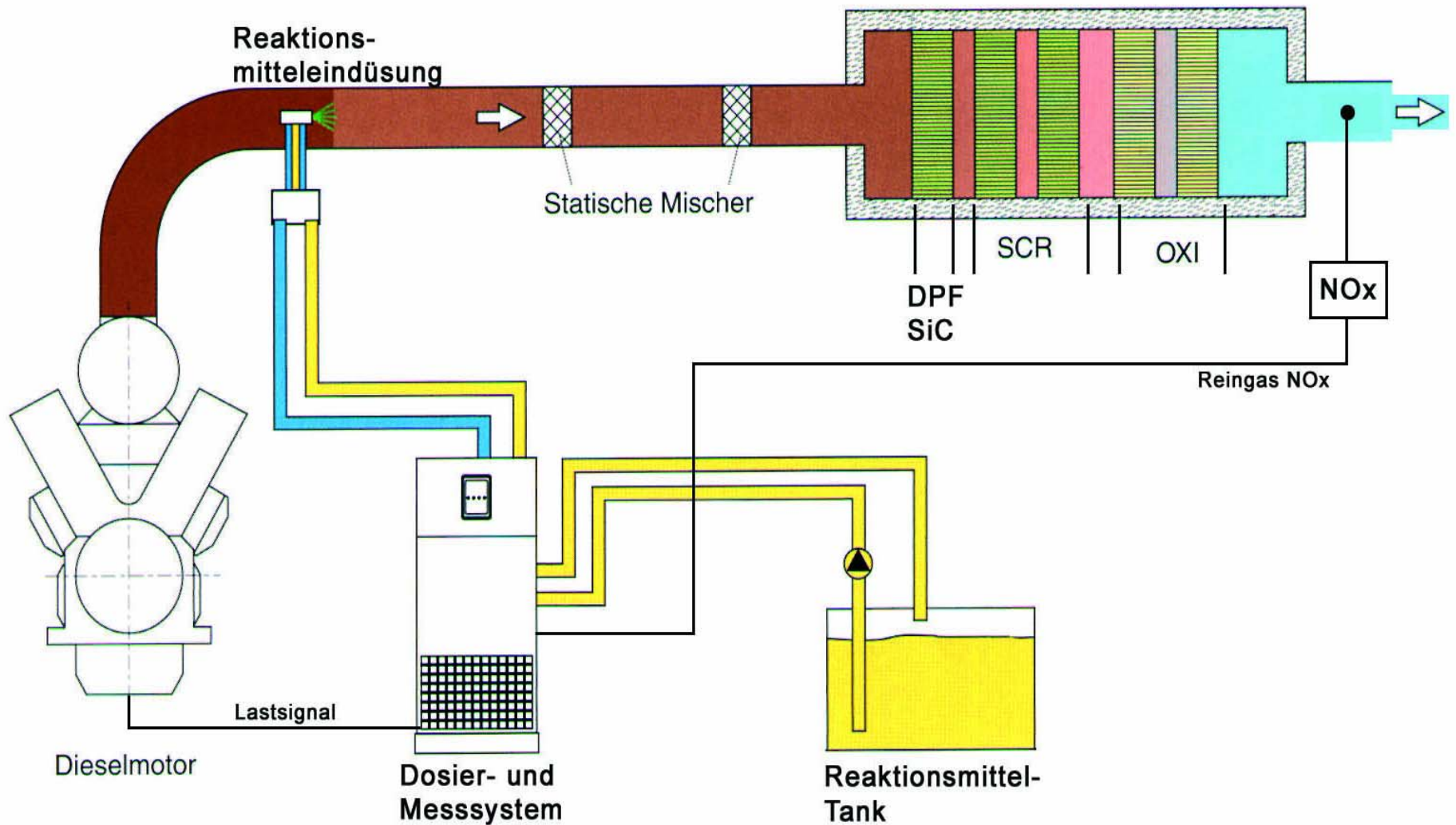
gensets, ships, locomotives

→HUG experience SCR 20 years

→now more than 10 manufacturers

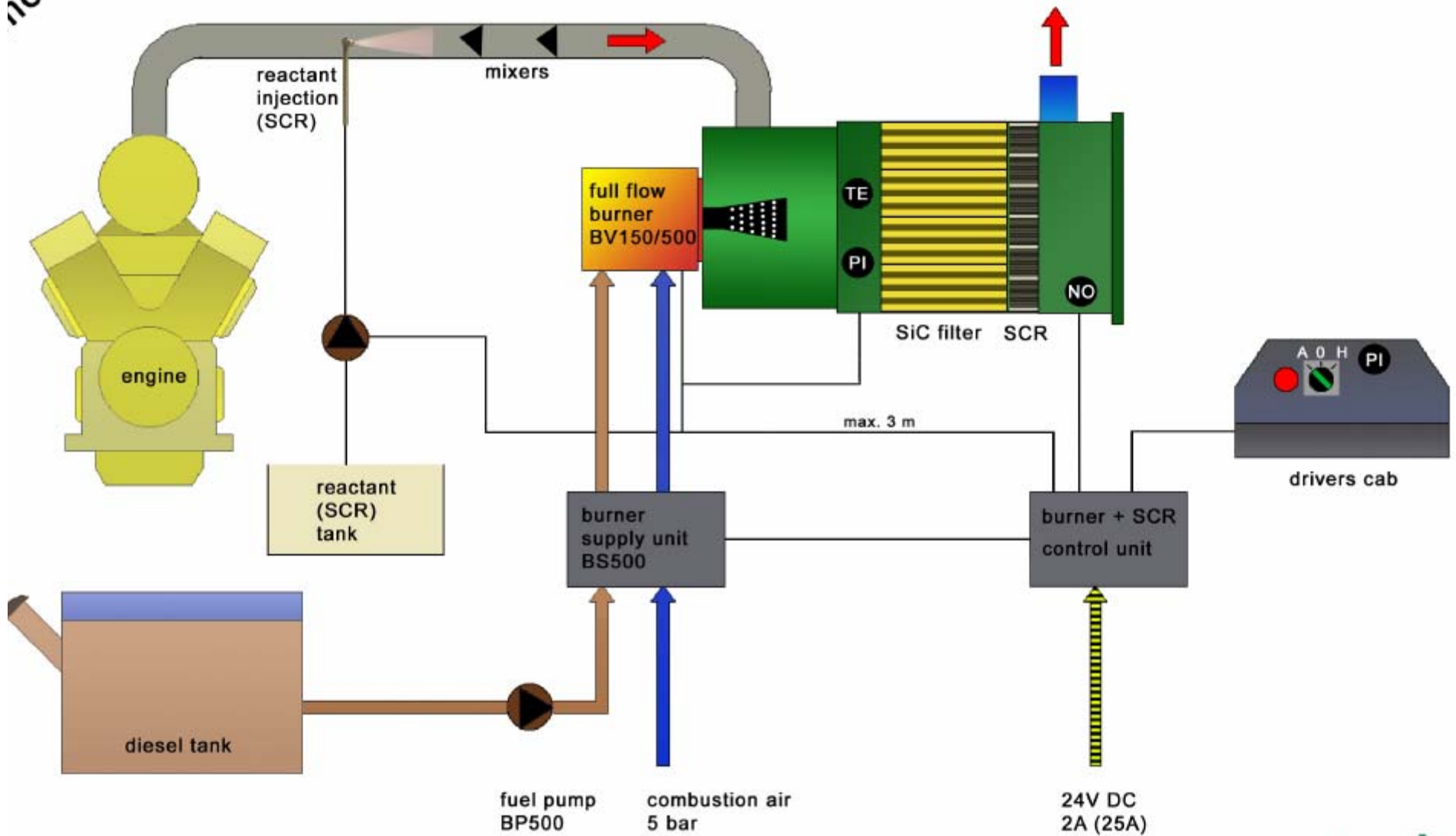
→HUG experience SCR+DPF 10 years

HUG stationary PFS + SCR-DeNOx



nobiclean

Mobiclean S2 ... S36 filter system for diesel particulates with full flow regeneration



Cost HUG exWorks for Engine Size 1000 kW (stationary)

| PFS passiv Base metal coating, no NO ₂ -Emission | PFS activ with fullflow burner | SCR-DeNOx Urea-dosing; Sensor-regulated |
|------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 25 US\$/kW | 30 US\$/kW | 30 US\$/kW |
| 95-99 % filtration > 20'000 op.hours > 10 years useful life ULDF not required Low SAPS recommend. No add. running cost | Online full flow burner 30–400 kW Energy consumption for regeneration < 1% of engine performance | 95-98 % NO _x -reduction NO ₂ elimination NH ₃ -slip < 10 ppm No secondary emissions Running cost prop. to NO _x -emission > 10 years useful life |

Operation Experience HUG „stationary“

- **1700 units SCR, 600 SCR+DPF in operation**
- Engine Performance 100 KW – 10'000 KW
- Largest Particle Filter System: 6 MW
- **Typical NOx-conversion 95 – 98 (best 99.8) %**
- Typical Filtration Rate for Nanoparticles > 98 %
- **Life for DeNOx: some units over 10 years**
- **Life for PFS: some units over 30'000 hours**
- Gensets, Emergency, Greenhouses, Ships, Locos
- Engines: Diesel, Gas, Light and Heavy Fuels
- Boilers: Light and Heavy Fuels

SCR / PFS-Combo mobile (3)

4 Manufacturers onroad

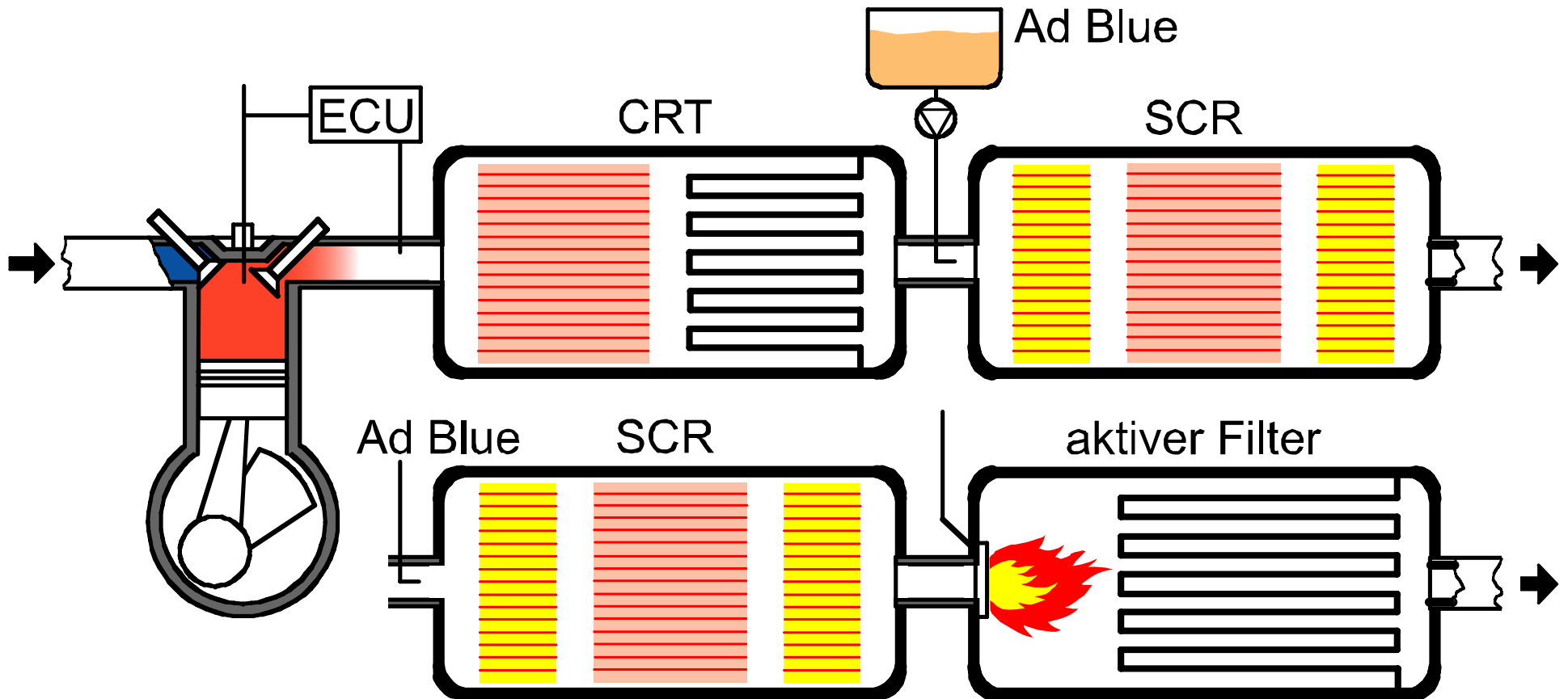
on Swiss customers demand
IVECO, MERCEDES, MAN, VOLVO

9 Manufacturers offroad

HUG, UMTEC, DINEX, AIRMEEX, DES, GREENTOP,
HUSS, JOHNSON MATTHEY, EMINOX

with VERT-Filter- certification
but no DeNOx-certification yet

Combinations of SCR und Particle Filter



Application Examples

3 Manufacturers supplying offroad retrofit DPF+SCR

- HUG
- UMTEC
- DINEX

with VERT-Filter- certification

but no DeNOx-certification yet

PFS and DeNOx- Systems HUG



Tm III (300kW)



Am 843 (1500kW)

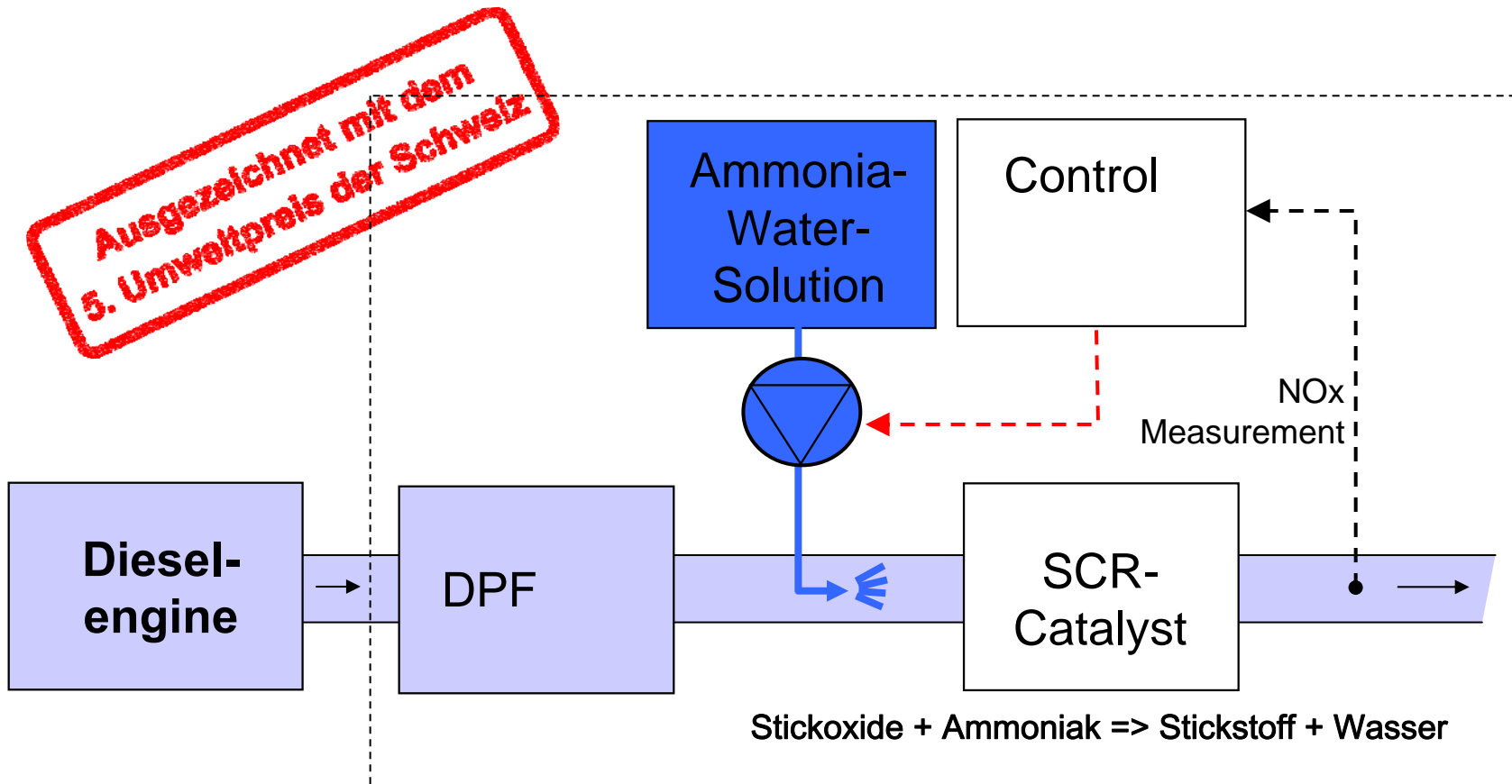


Tm234 (450kW)



Am 841 (1000kW)

NOxOFF - System UMTEC



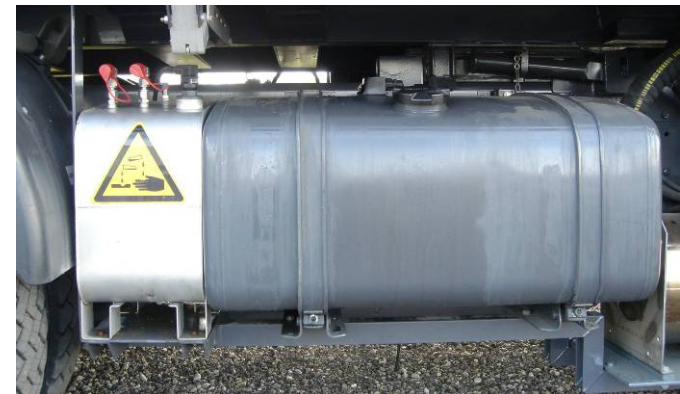
Installation-Space required = 2 x DPF +



SCR-Katalysator und Partikelfilter

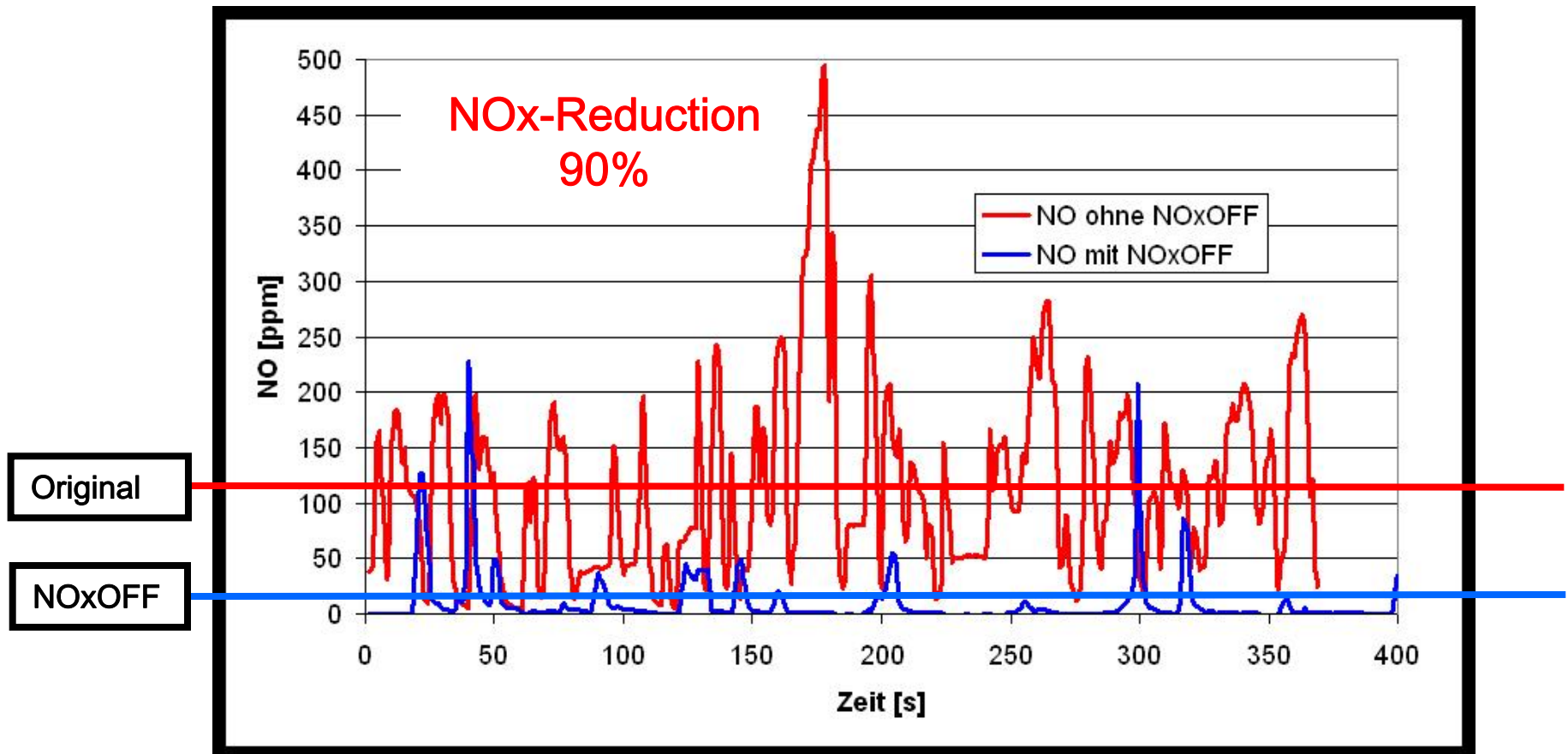


Regelung



**Reduktionsmittel- und
Dieseltank**

NOxOFF on a Bus

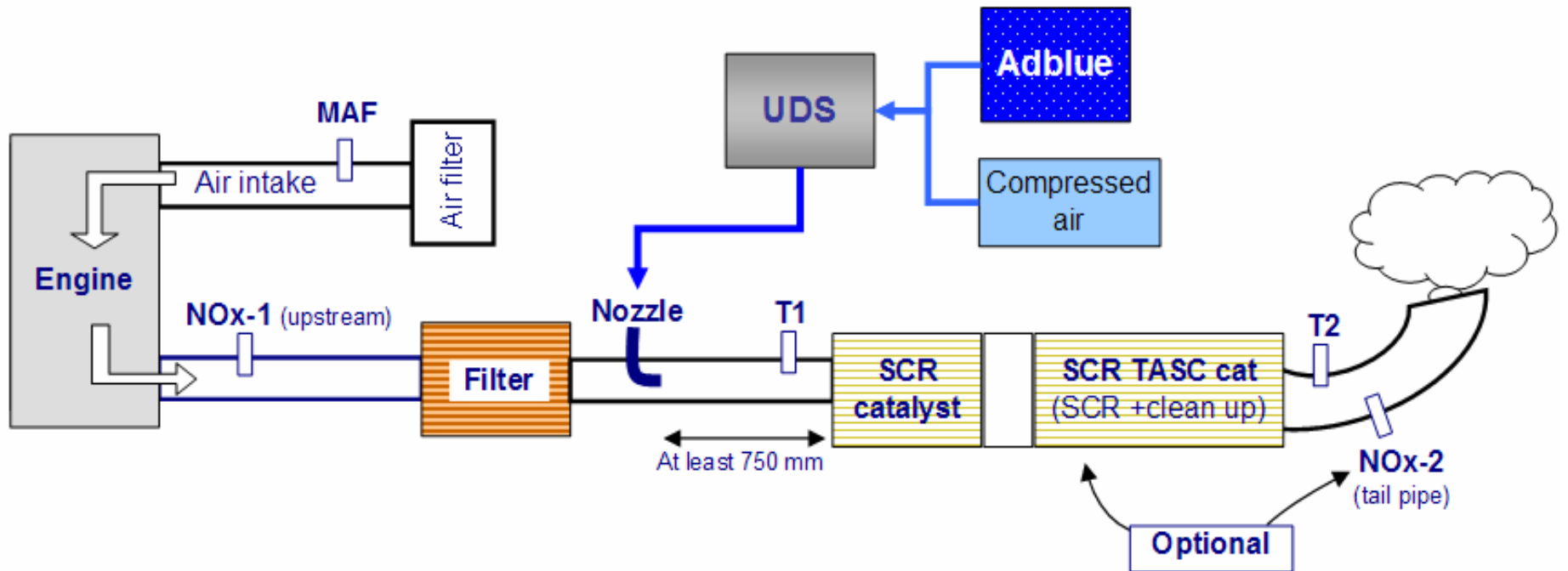


Test-Vehicles UMTEC

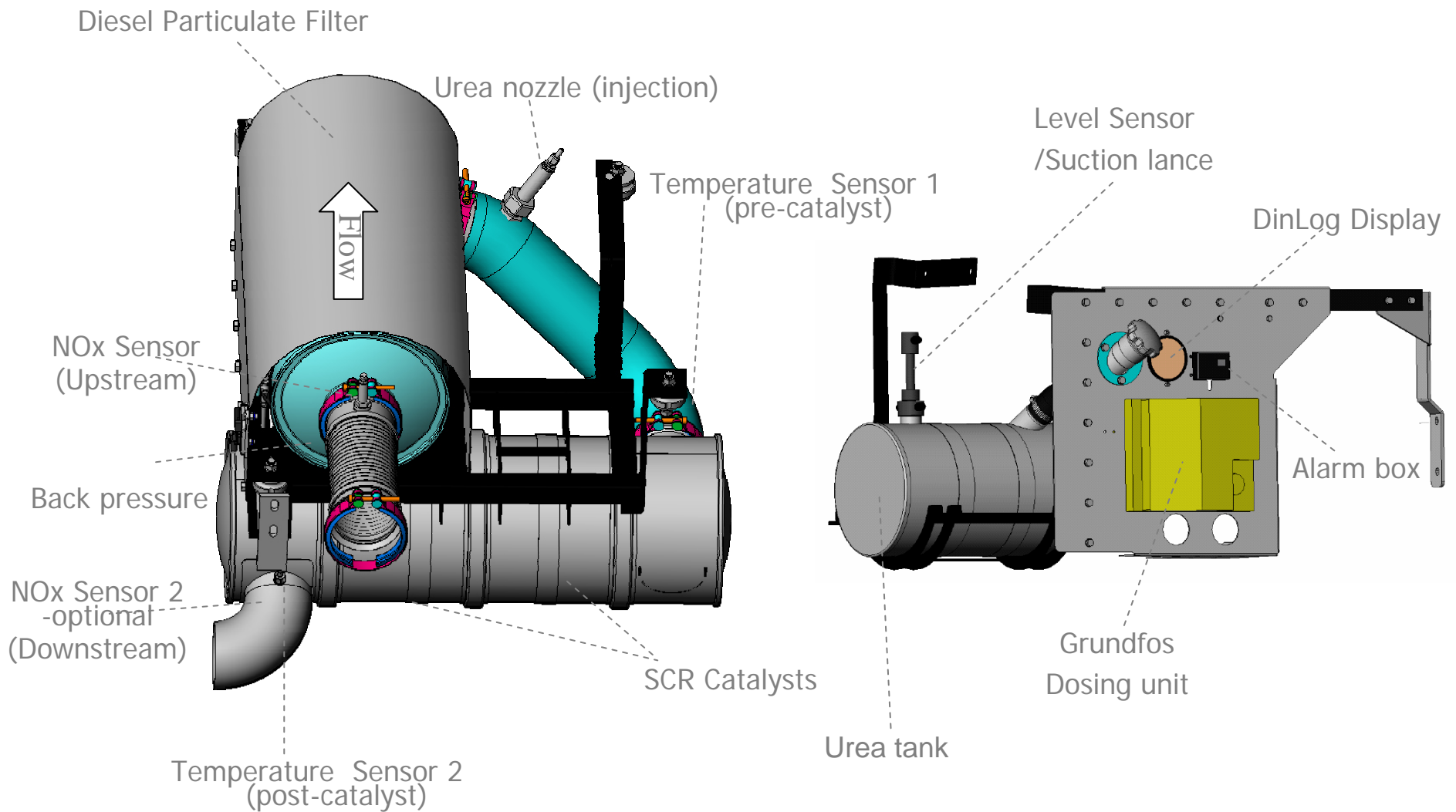


DiNOx - System overview - DINEX

Schematic of SCR + Filter system



DiNOx - System overview- DINEX



SCR Sensors - DINEX

**Mass Air Flow
MAF sensor**



OBD DINEX

- SCR → UDS & alarm box
 - Pump, sensors, nozzle, urea level, etc.



- Filter → Dyntest
 - Back pressure
 - Temperature

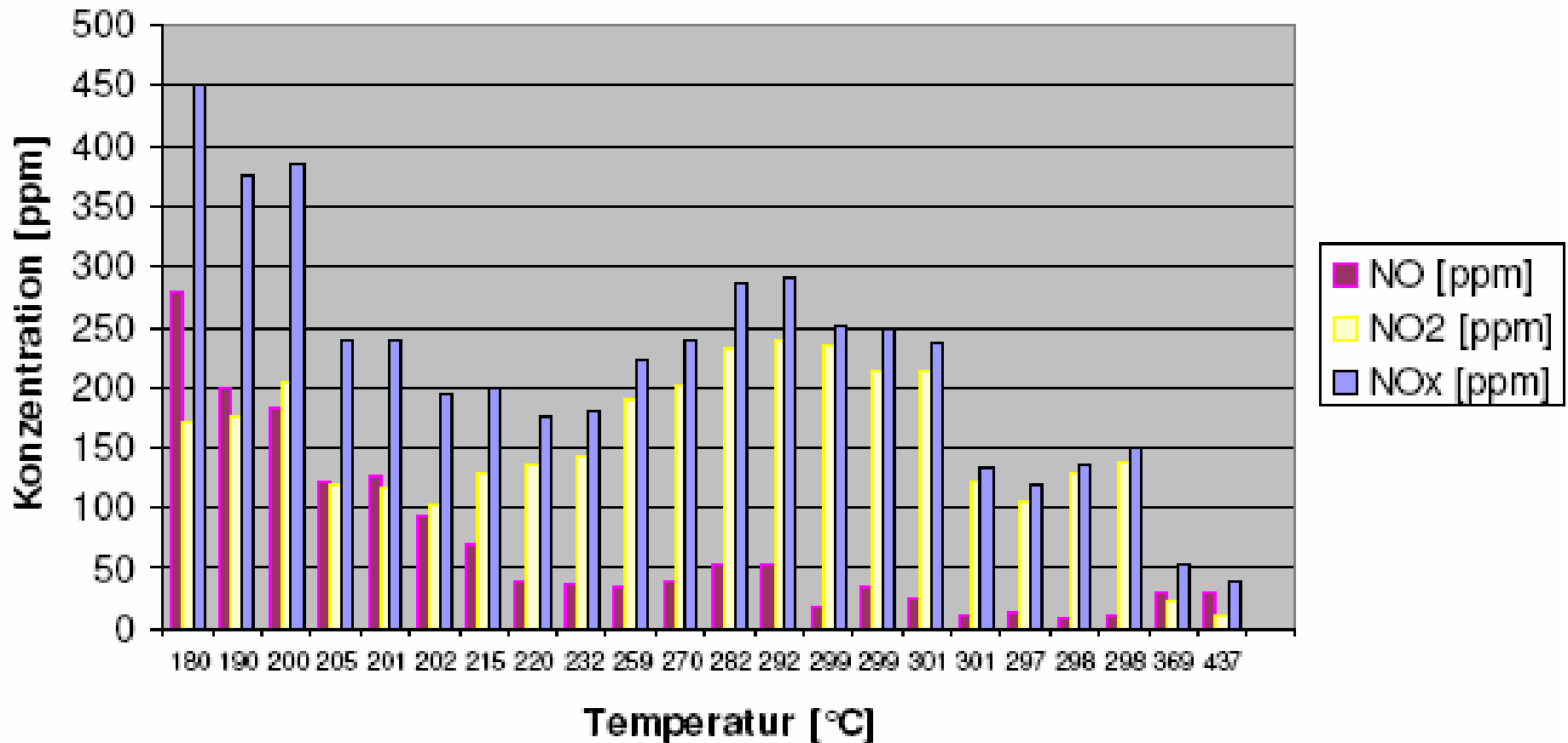




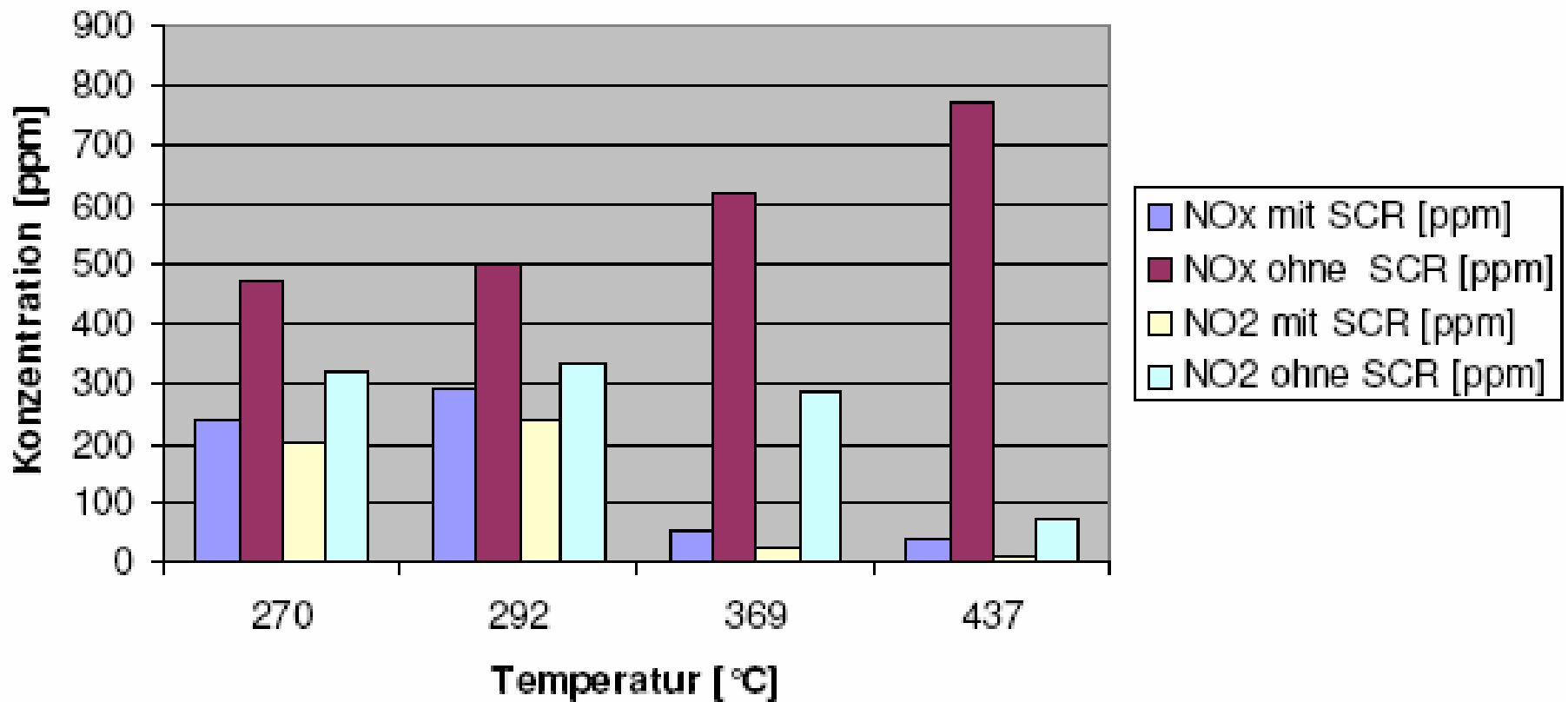
NO and NO₂ downstream CRT + SCR

SCR-reaction depends **strongly** on NO₂/NO_x

- with NO only → standard reaction, rate = 1
- with NO₂+NO → fast reaction, rate = 10
- if NO₂ > NO → slow reaction rate = 0.1



NOx and NO₂ with DPF (CRT) upstream and downstream SCR



Applications DINEX

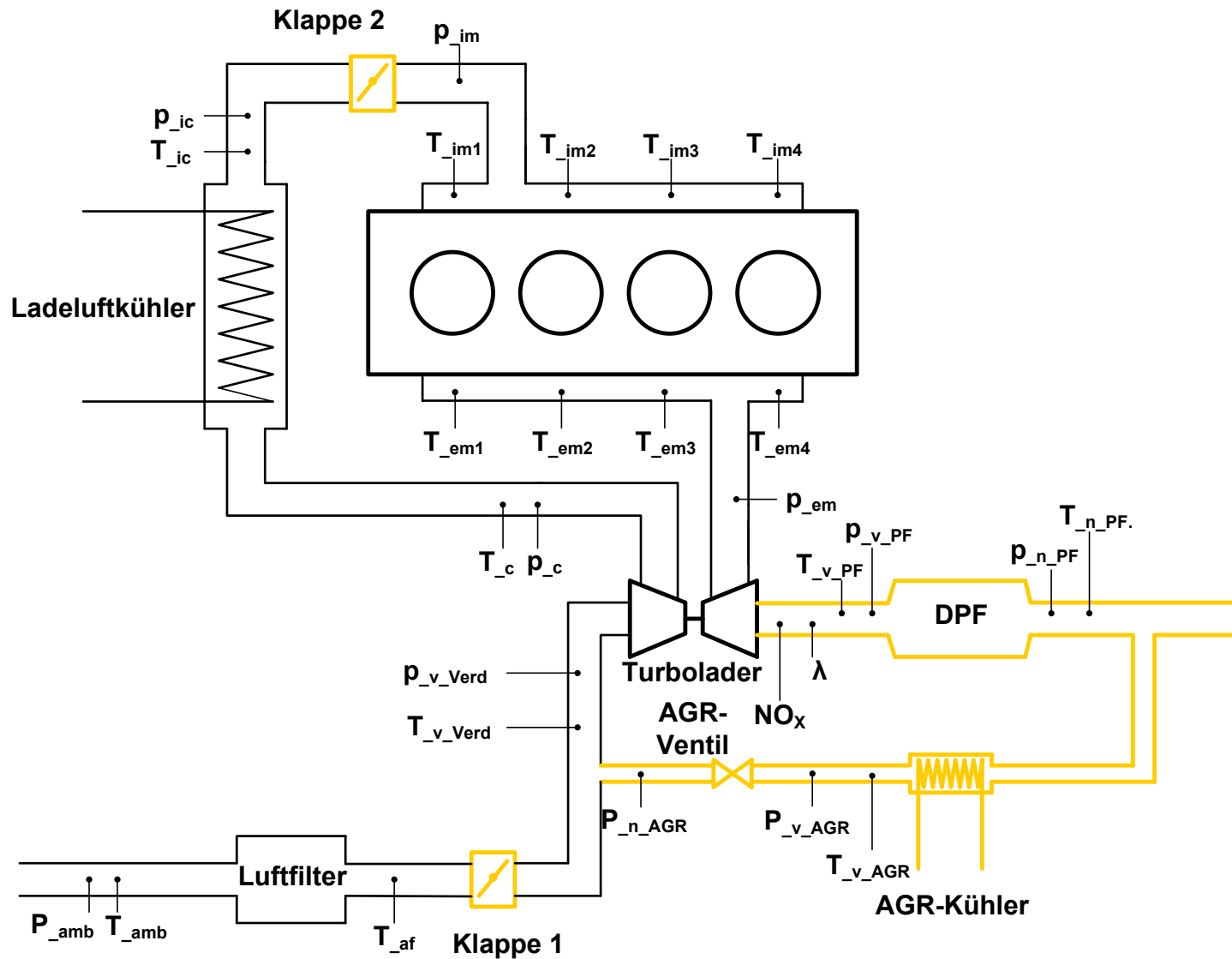


Alternatives ?

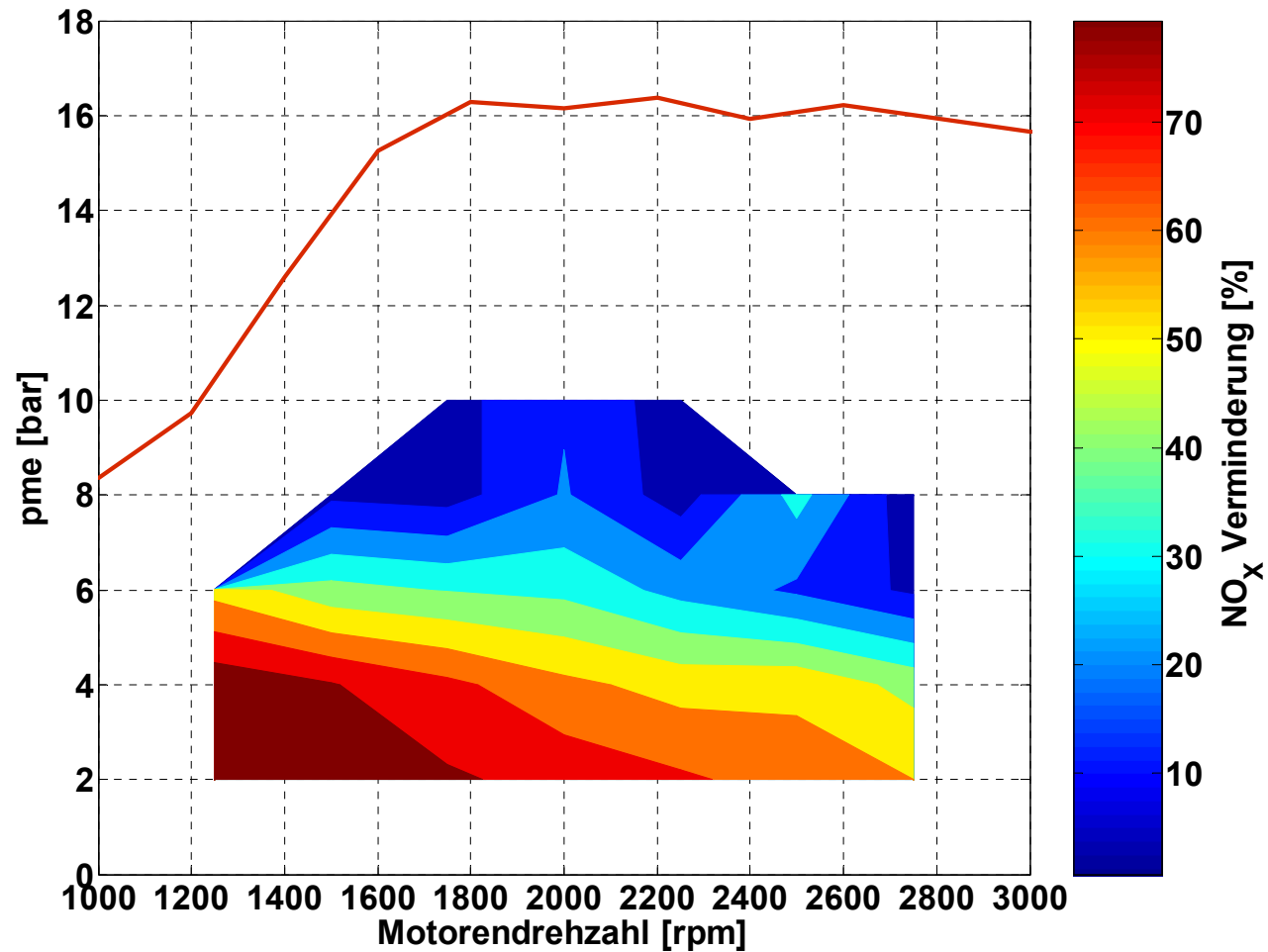
**Particle Filter + Clean Cooled EGR
with closed loop Lambda control
and intake throttle regeneration**

- **50 % NO_x-Reduction at city driving**
- **less bulky compared to SCR+DPF**
- **no additional infrastructure needed**
- **no additional running cost (no Adblue)**
- **easy to retrofit**

Particle Filter + clean cooled EGR



NO_x-Reduction focussed on light load





Conclusions

- Retrofit of **DPF** is highly efficient, technically feasible for all Diesels and cost-effective
 - **DPF retrofit must be enforced with high priority**
 - DPF with active regeneration without NO₂-emission
- Retrofit of **DPF+SCR** limited by installation space and cost and many questions are still open
 - **DPF+SCR function should be combined in one unit**
 - specifications and verification protocol needed
(VERT-DePN-project started November 2006)
 - investigate SCR-effectiveness in city driving
 - **EGR should also be considered for retrofit with DPF**
 - Fuel/water-emulsions, water injection, TC/IC ultracooling ??