STRATEGIES TO MITIGATE AIR POLLUTION / SEDEMA + ITP + CAF
Mexico City 18 &19 January 2017

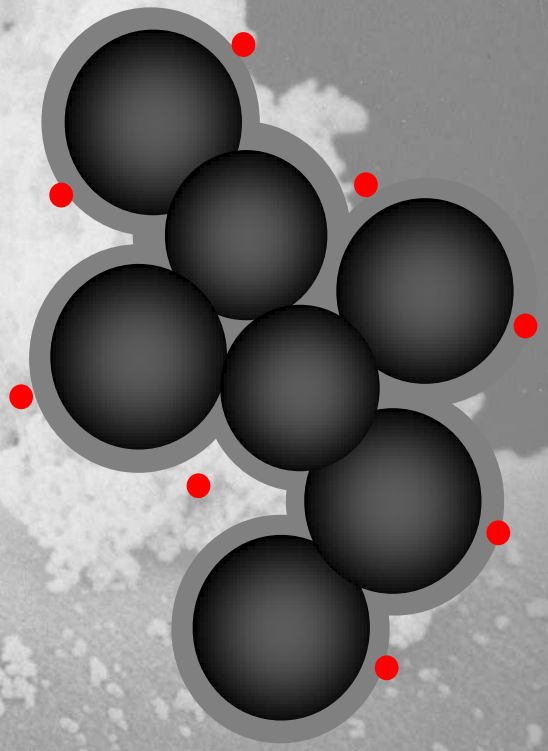
Experience with DPF and GPF to eliminate Ultrafine Particles

First Fit and Retrofit in Europe and in Megacities of Latin America and Asia

Andreas C.R..Mayer

Soot Particle

- black
- small
- anywhere
- unevitable
- cancinogenic
- Difficult to control
- Mass of one particle is
  0.000 000 000 001 mg = 1 fg
- up to 10 Mio particles in one cm^3
- 100 P en each alveoli at each breath



Particle Emission of ICE

Diesel

Sootpeak: 80 nm; 10^6

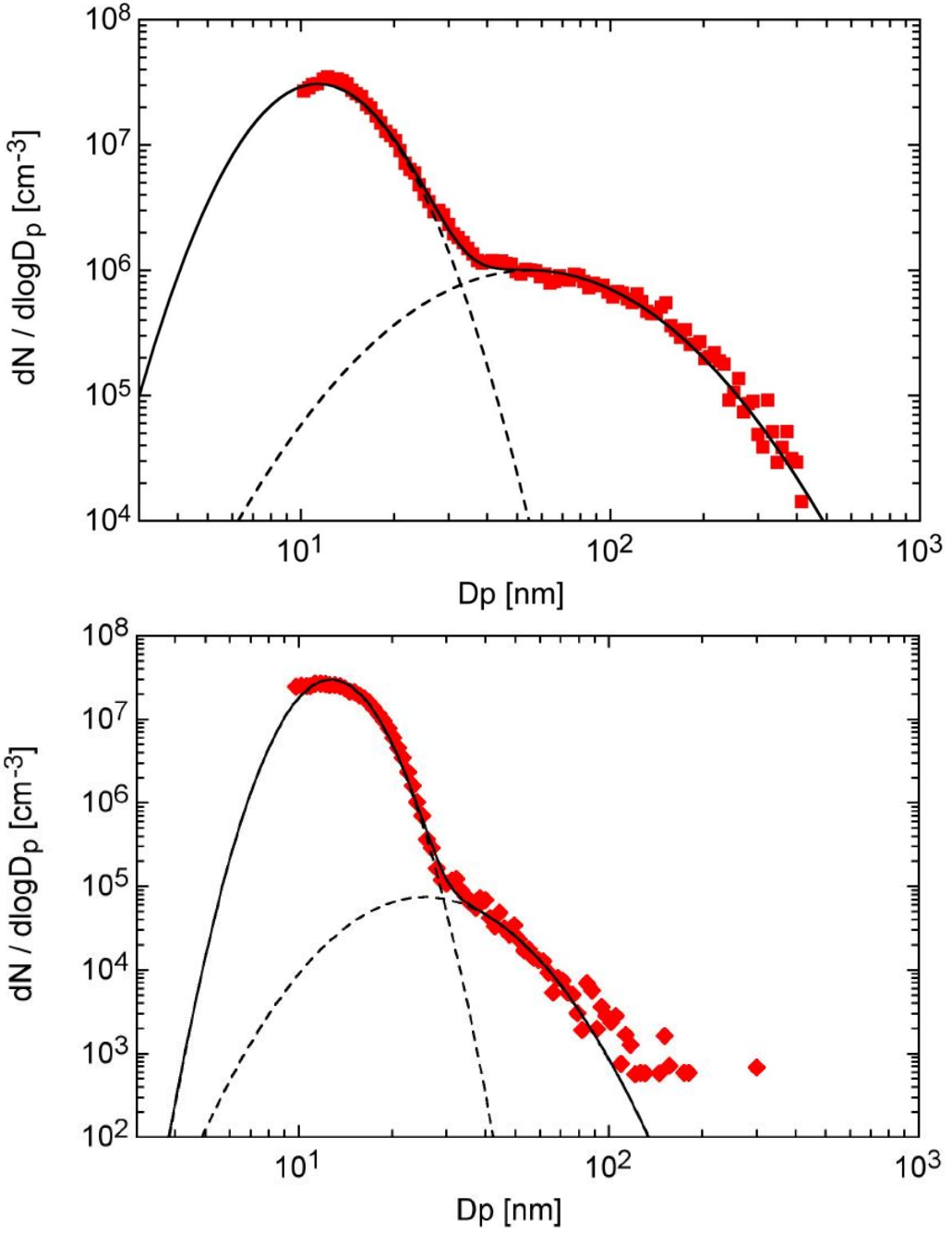
Ashpeak: 10 nm; 10^7

Petrol

Sootpeak: 40 nm; 10^5

Ashpeak: 10 nm; 10^7

Soot and Ash Peaks



DPF and GPF

reduce PM, PN

and if catalysed CO, HC, PAH

and with SCR-coating even NO2

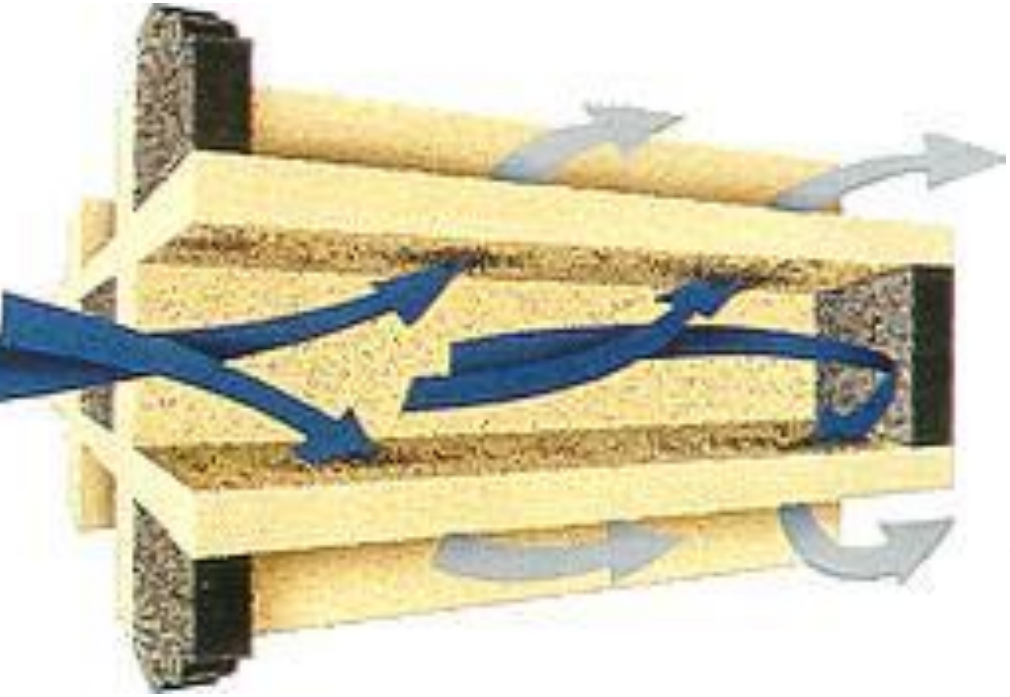
but can also be a Chemical Reactor ?

with extremely long residence time

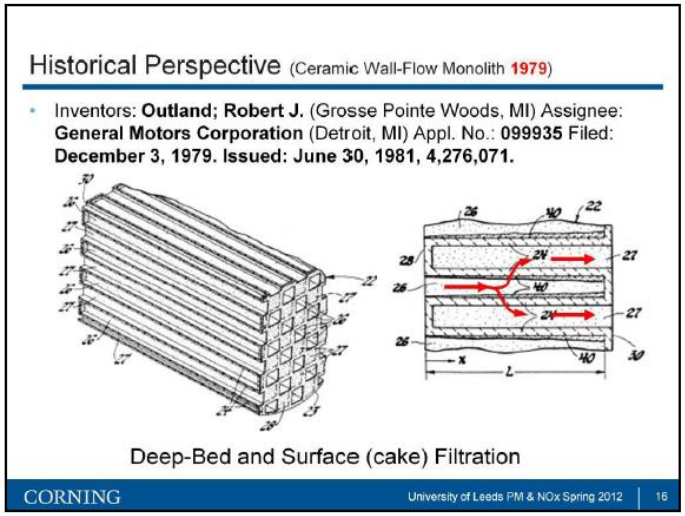
Filter for Diesel-Exhaust 1982

now over 100 Mio successful on the road

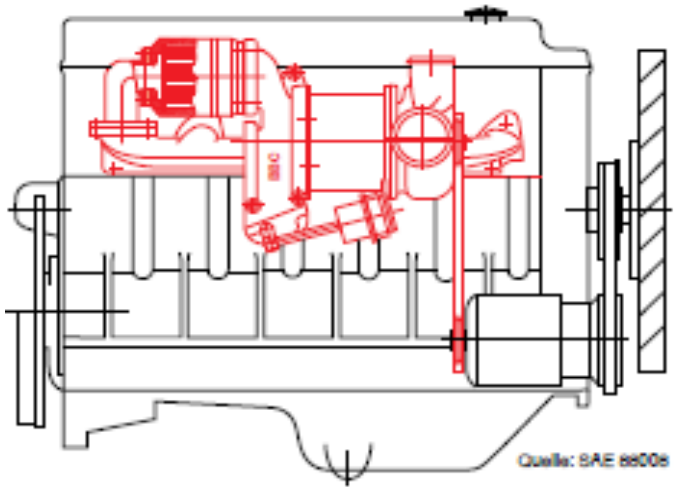
1982
Corning



1979
GM

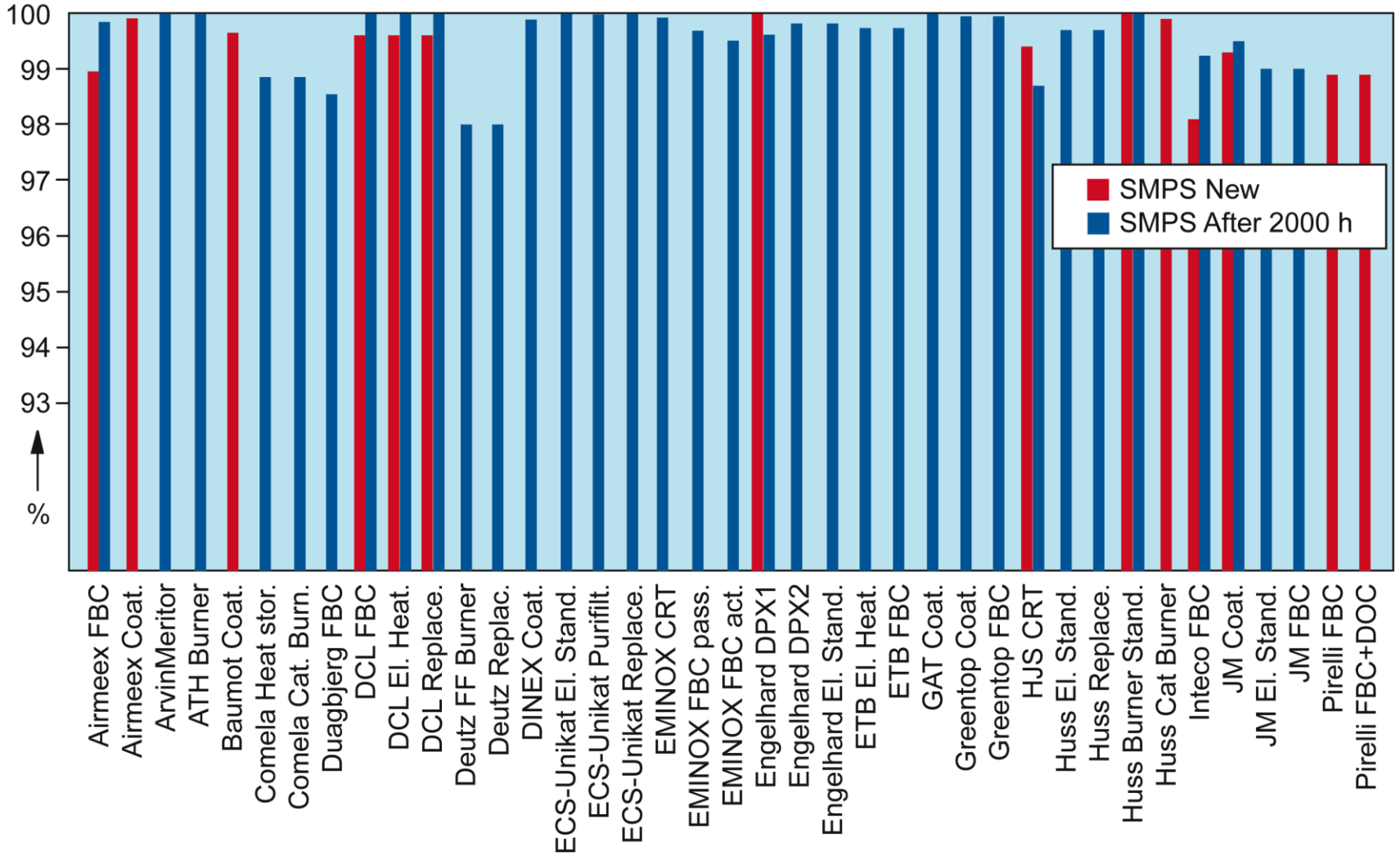


1985
BBC-DB
A.Mayer

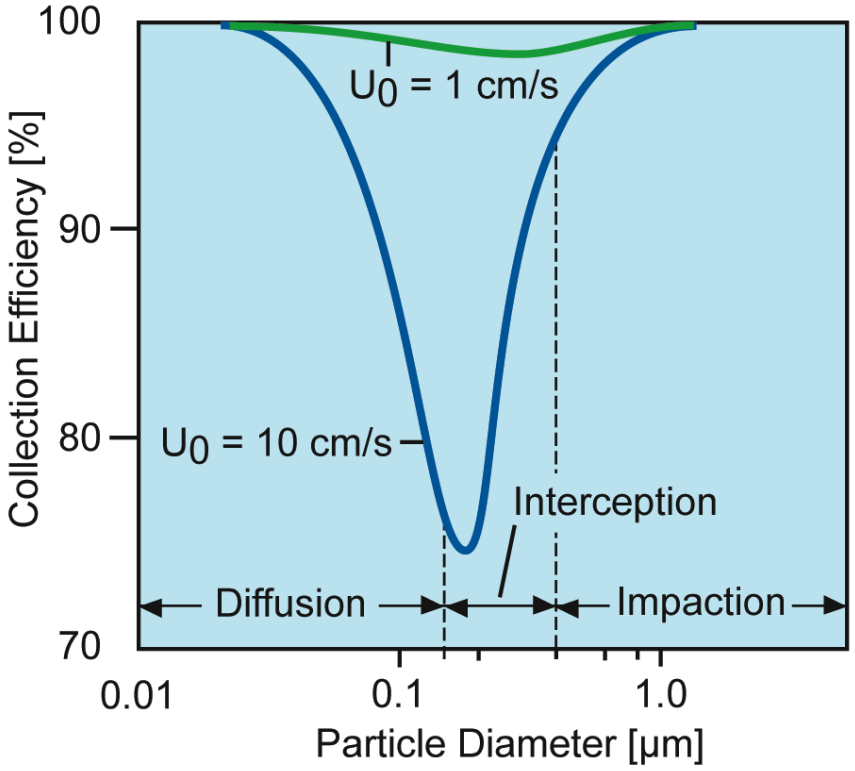


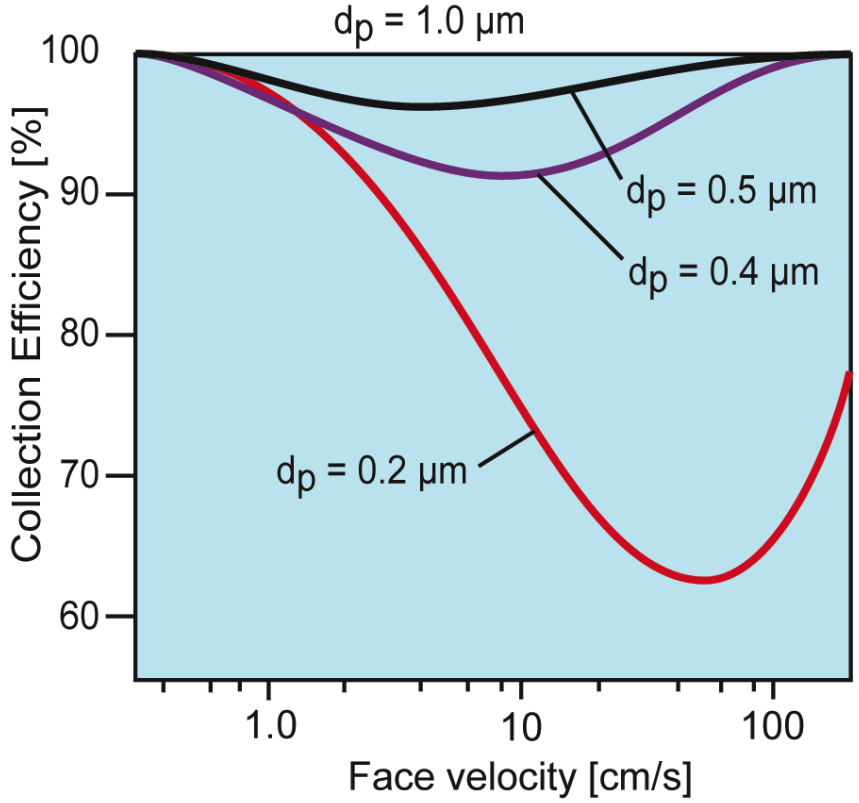
Selection by Certification
65 DPF VERT-tested

average 98.4 %; 25 % > 99.8 %



Many Filters are not perfect





→ Careful Filter Verification is required

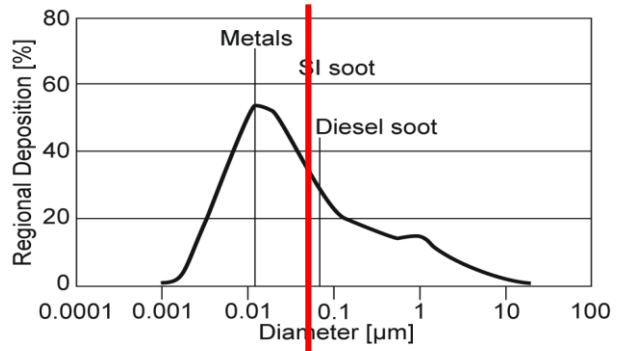
→ VERT-Standard based on PN

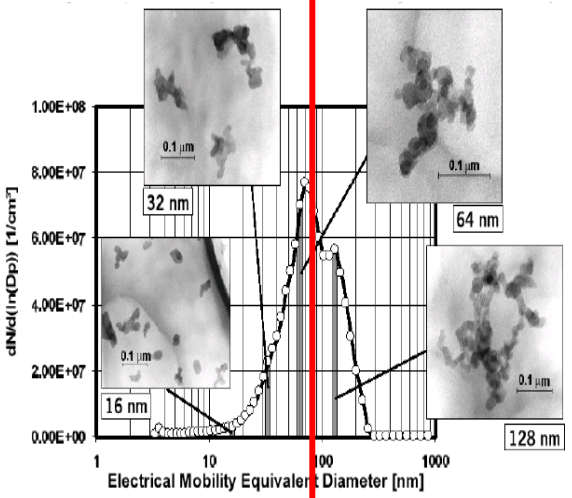
→ SN 277206

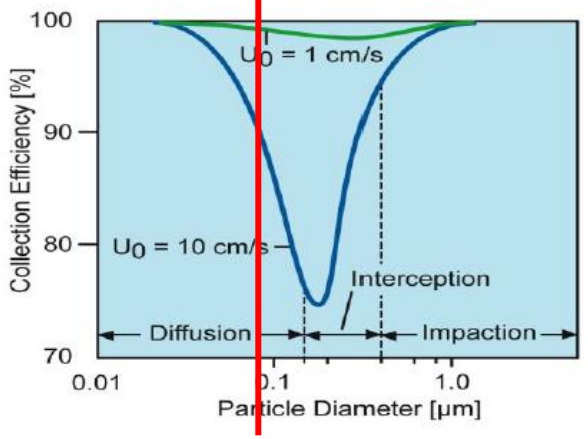
Strange Coincidence

The most sensitive size range of the lungs
is the most intensive emission range of the engines
and the weakest size range of filtration

The lung is an open door for engine emitted ultrafine particles in this size range

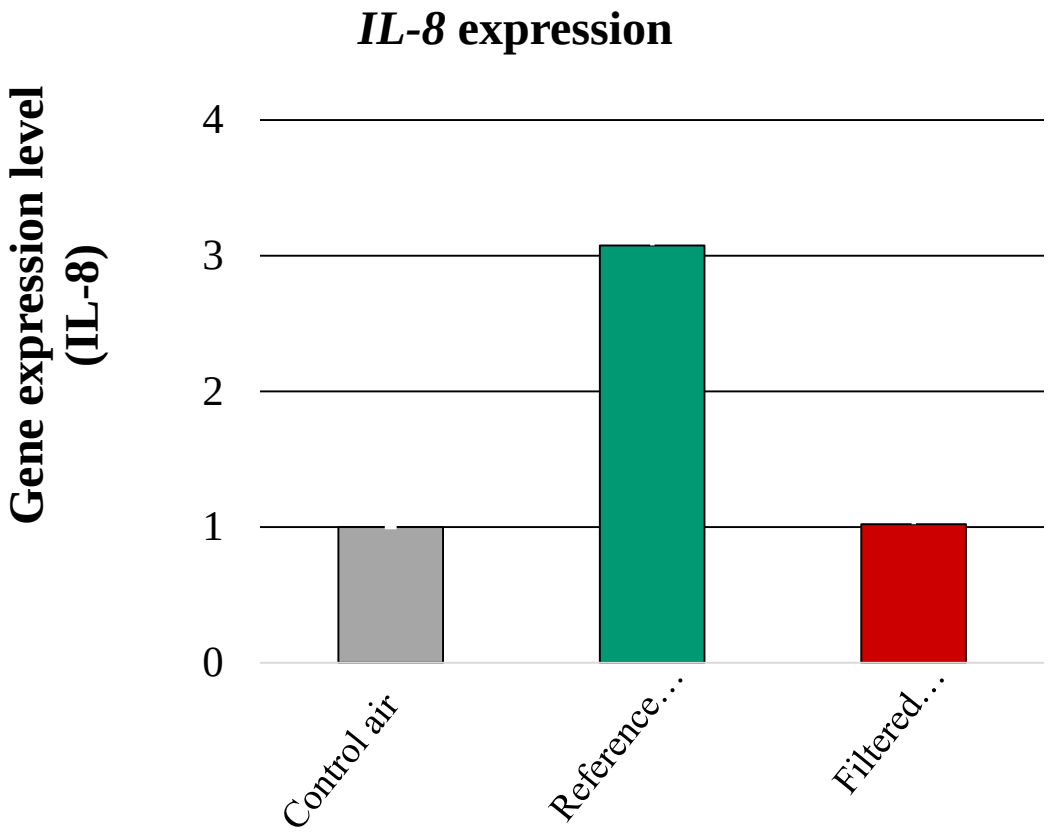






Inflammation

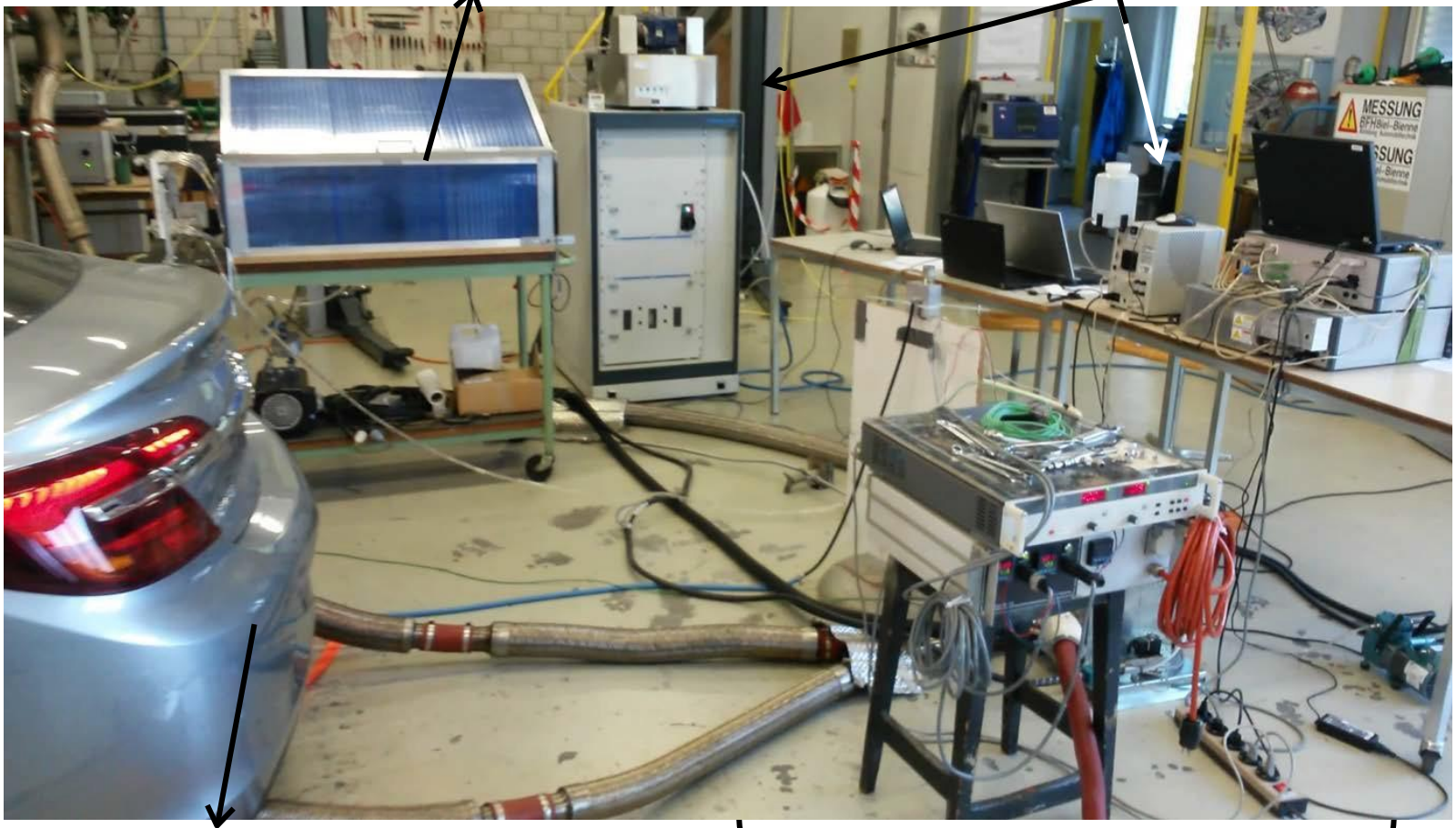
Proof of Health Effects by Aerosol Exposure to human lung cells → Filtration is needed



To learn more requires biologic testing in the engine lab: exposure of cell cultures to exhaust aerosol

Biological test system
Triple-cell model, killer cells

On-line exhaust characterization

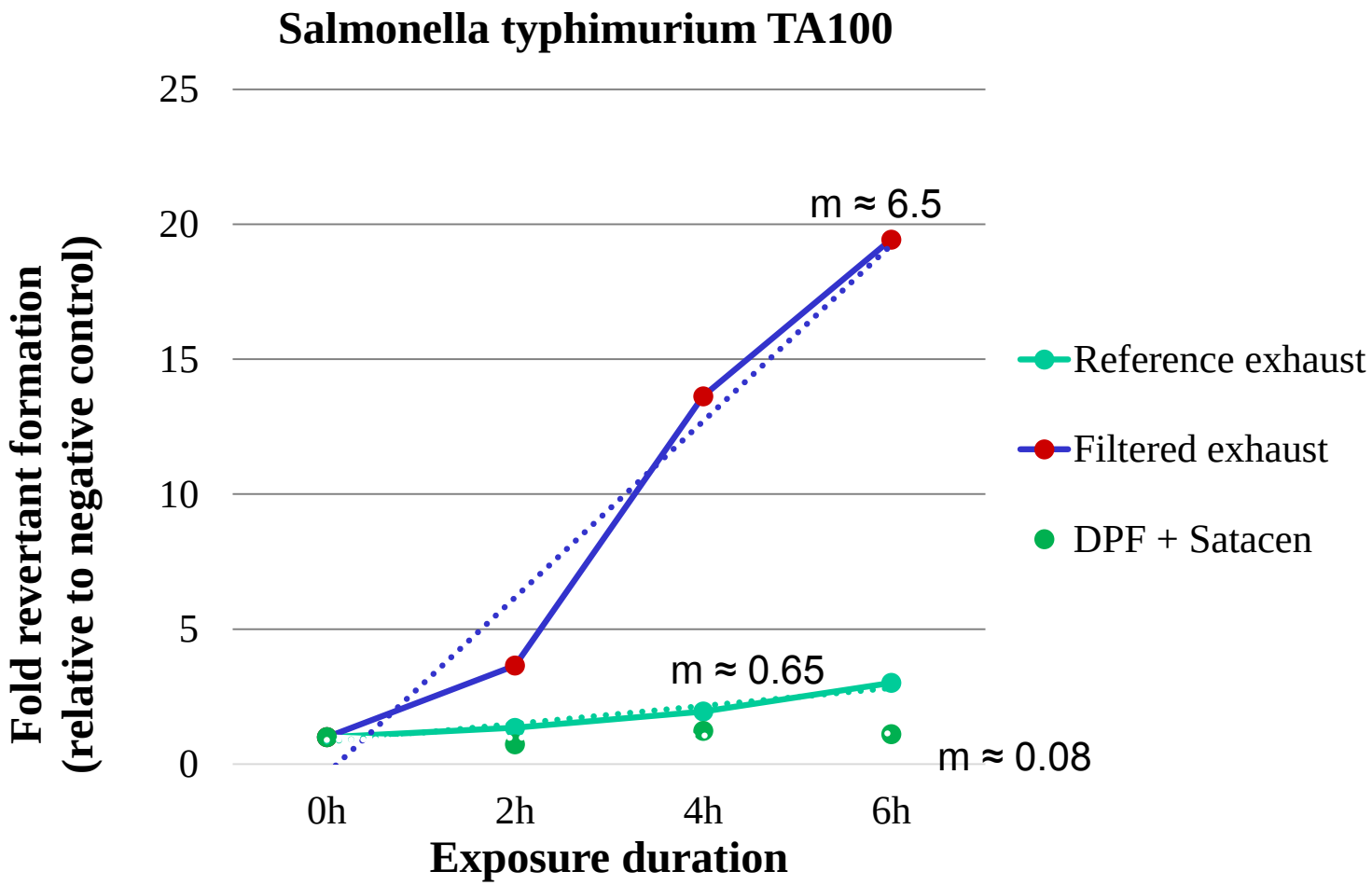


Test vehicle

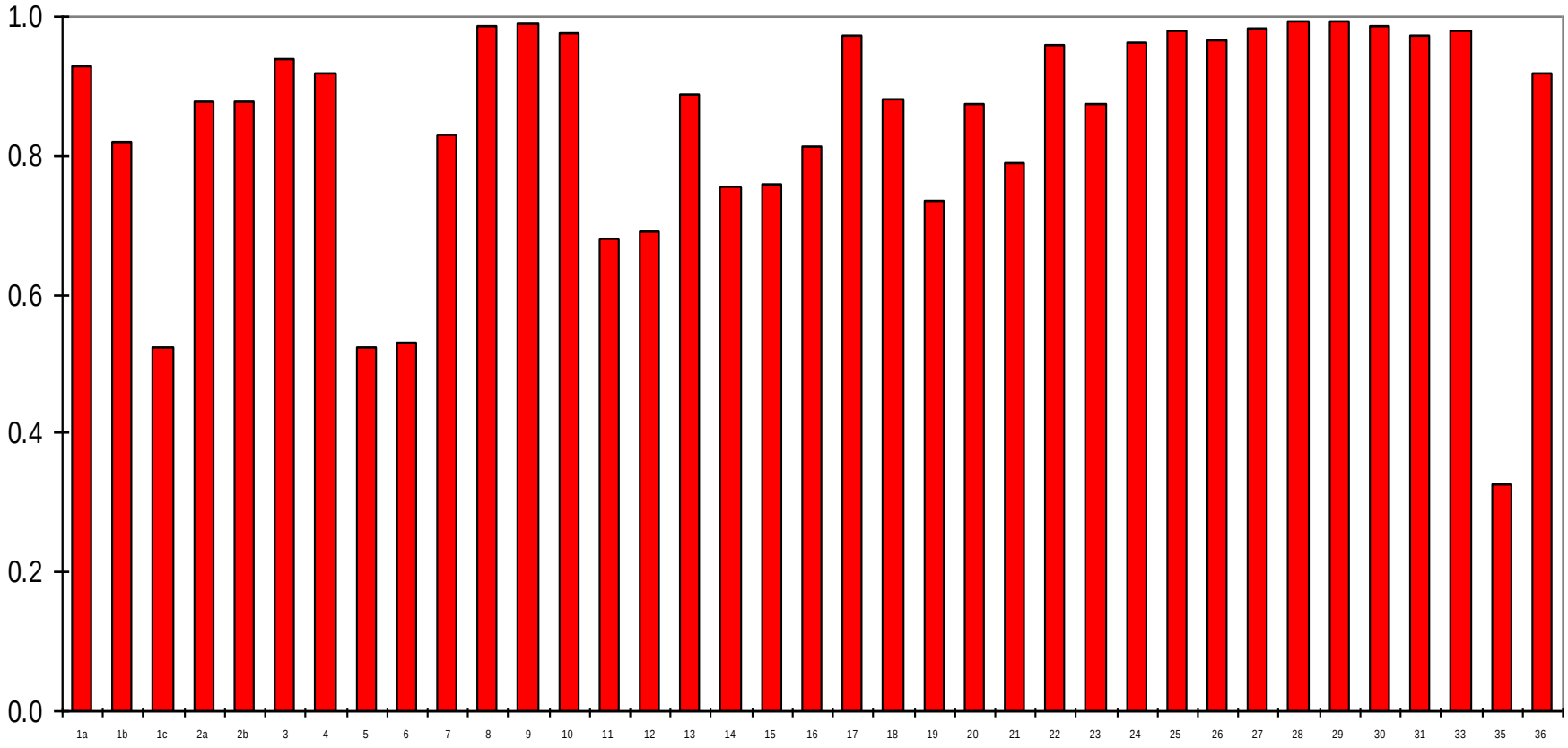
Exhaust sampling

Mutation – DNA-attack (Ames-Test)

Proof of Health Effects by Aerosol Exposure to human lung cells → Catalysis is needed



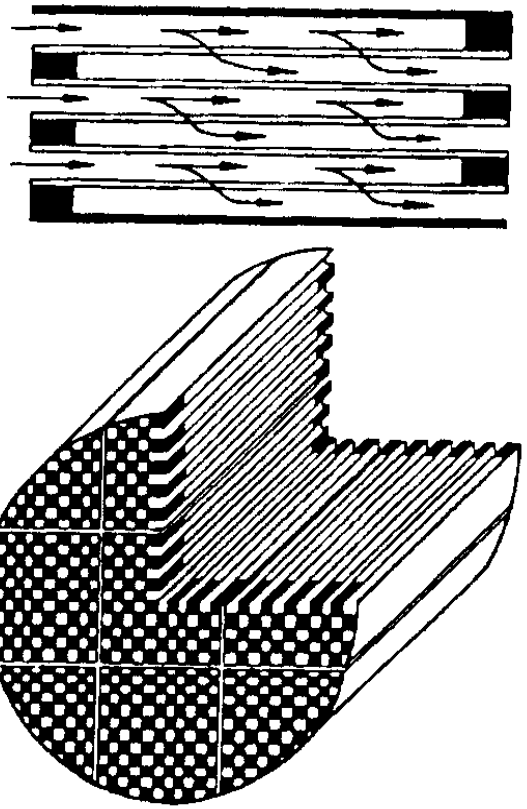
PAH Emission Reducion with BAT- VERT-DPF



Soot Storage is limited

- Storage Limit is < 10g/L Filtervolume

- If Emission is 1g/kWh this Limit is reached after 6 hrs → Regeneration twice every Day
- If Emission is 0.1 g/kWh this Limit is reached after 60 hrs → Regeneration once every Week



Regeneration is controlled O_2 and T

$$\frac{dM}{dt} = k_o \cdot M^m \cdot p_{O_2}^n \cdot e^{\frac{-E}{RT}}$$

M = relative Russmasse
p_{O2} = Partialdruck des Sauerstoffs
R = Gaskonstante
T = absolute Temperatur
E = Aktivierungsenergie

- plenty of **Oxygen** is available in Diesel Engine Exhaust Gas at light load - but altitude can be a problem
- **Temperature** is sometimes to low to support regeneration at light load conditions → active filters

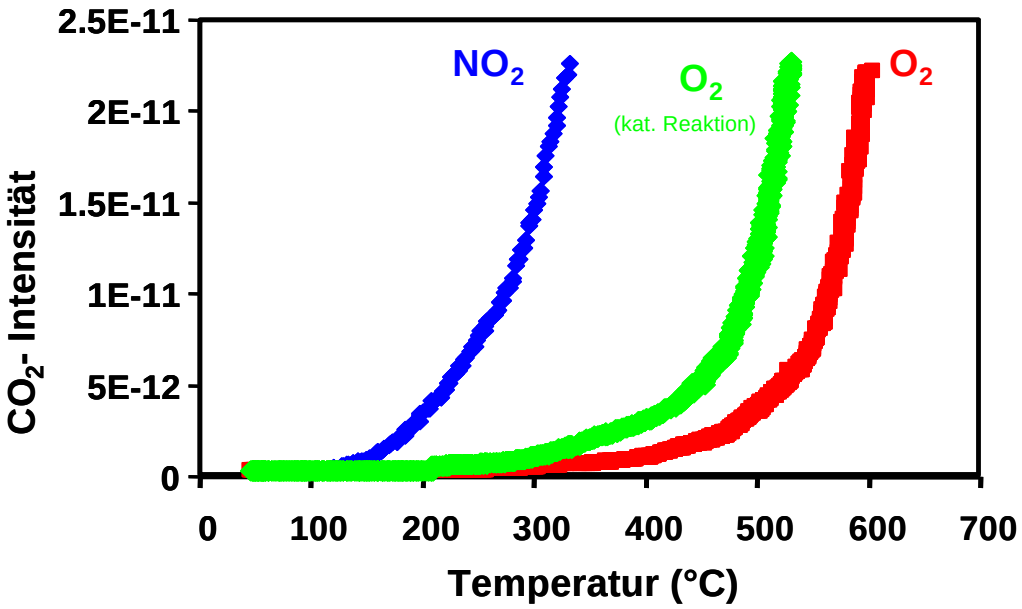
Soot-Reactions with O_2 und NO_2

- $C+O_2 = CO_2$

and the CRT-Process (JM)

- $C+2\ NO_2 = CO_2+2\ NO$

this CRT-process needs NO_2 which is not available in engine exhaust but can be provided by catalysis

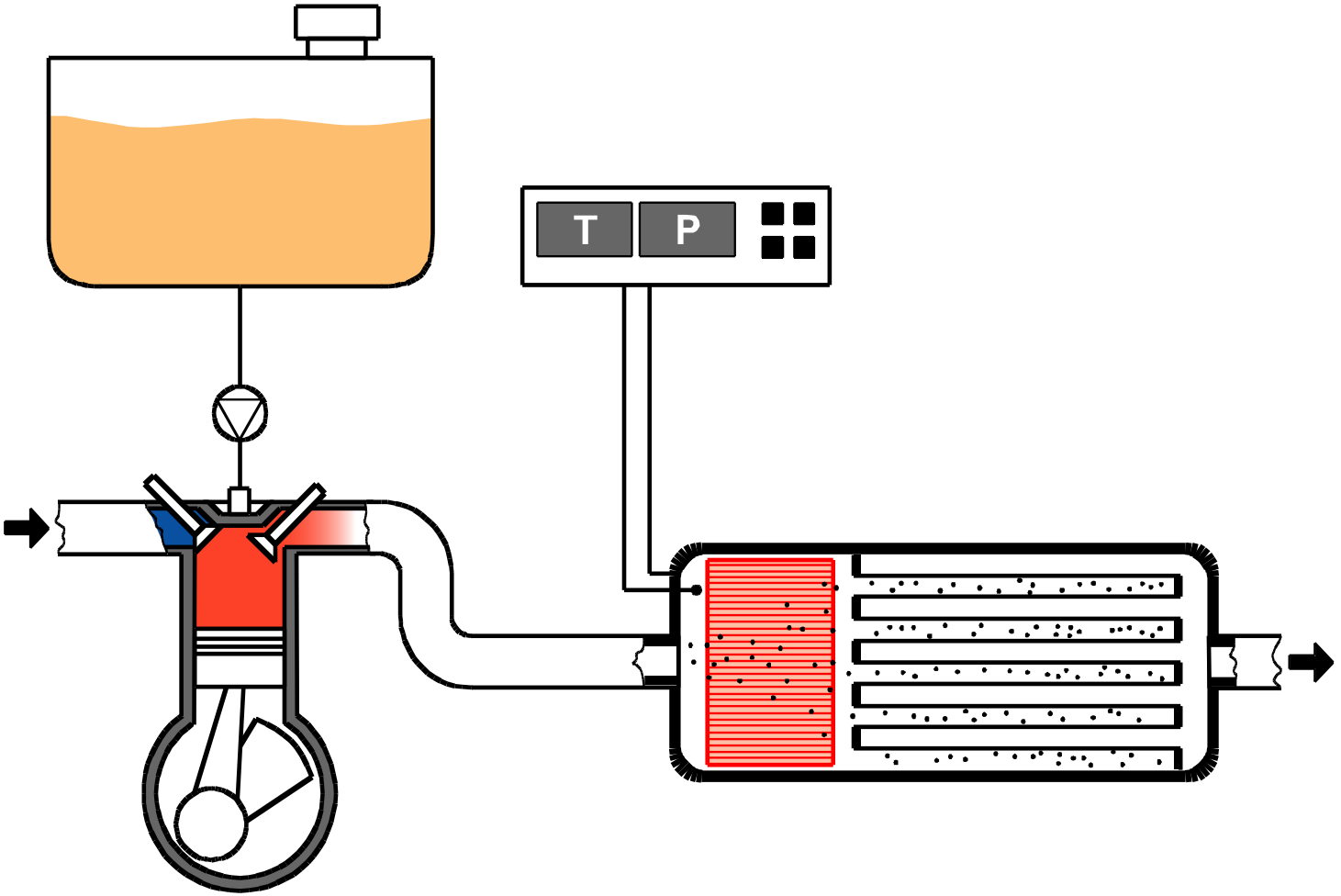


NO2-Rection is very attractive because of low temperatur

→ but NO2-slip must be contolled

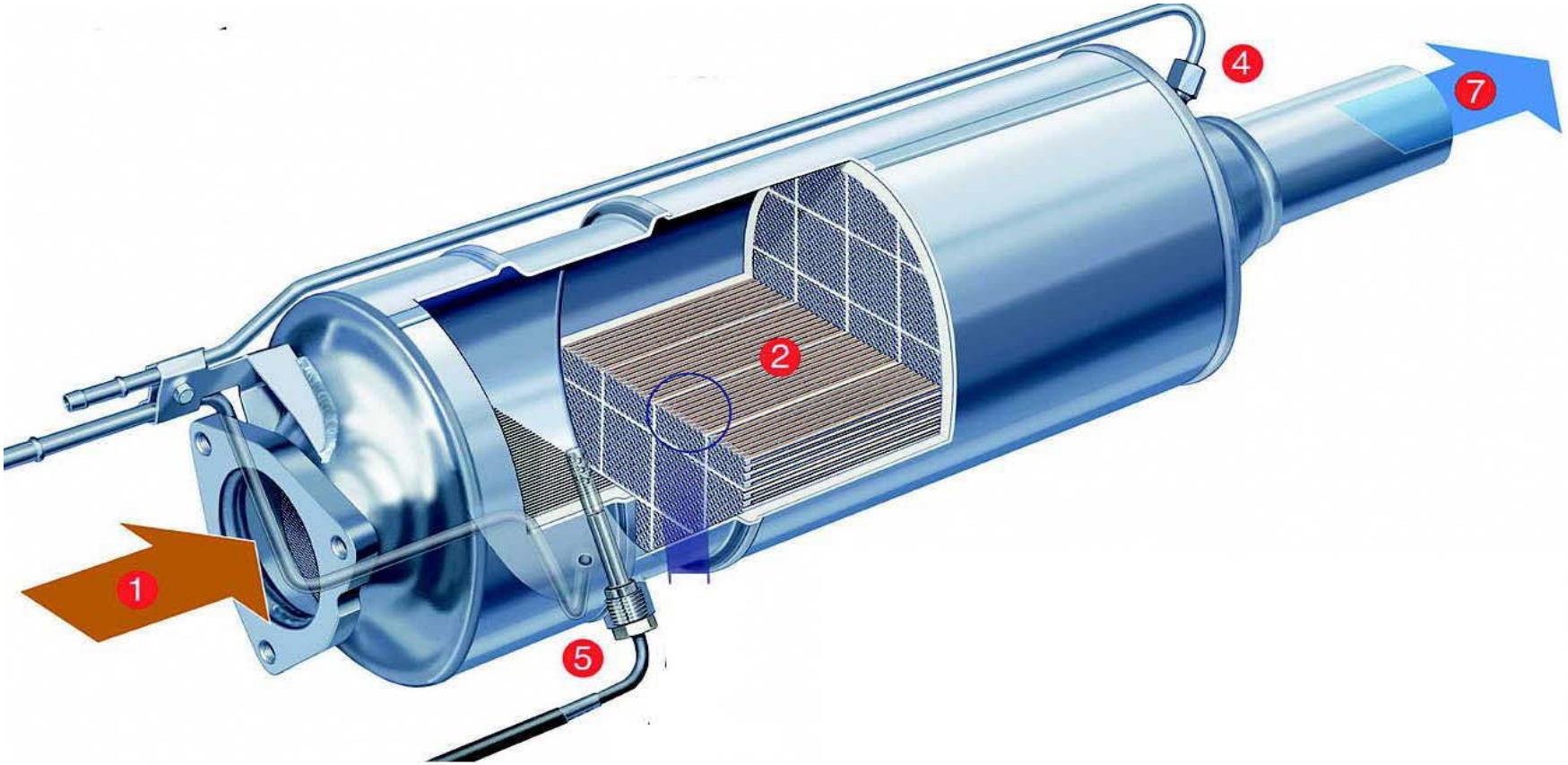
CRT: Passive Regeneration with Pt-Catalysis to generate NO_2 > 230 °C

JOHNSON MATTHEY / HJS-DES / EMINOX

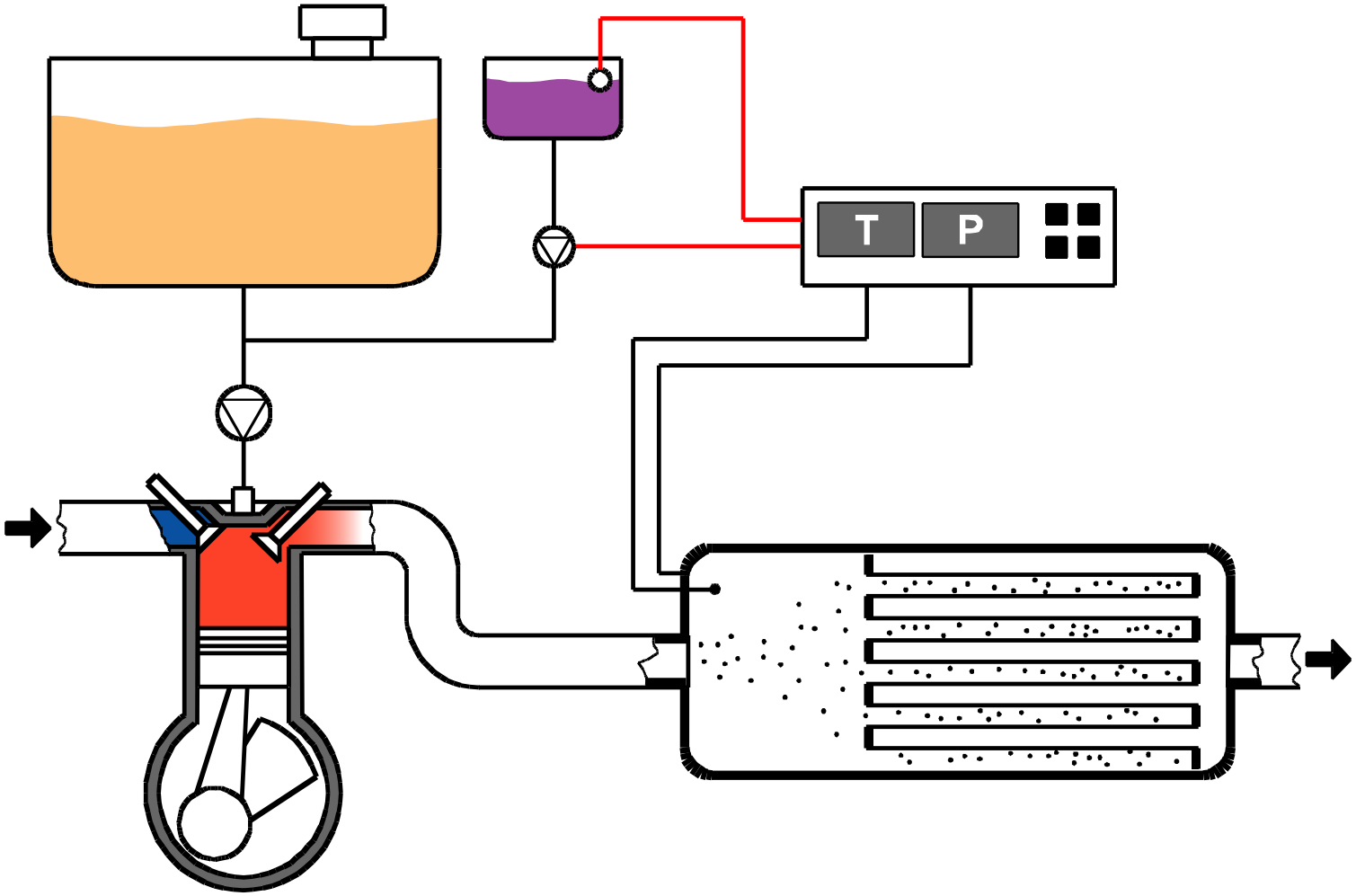


CRT-Filter System

Johnson Matthey Patent 1988

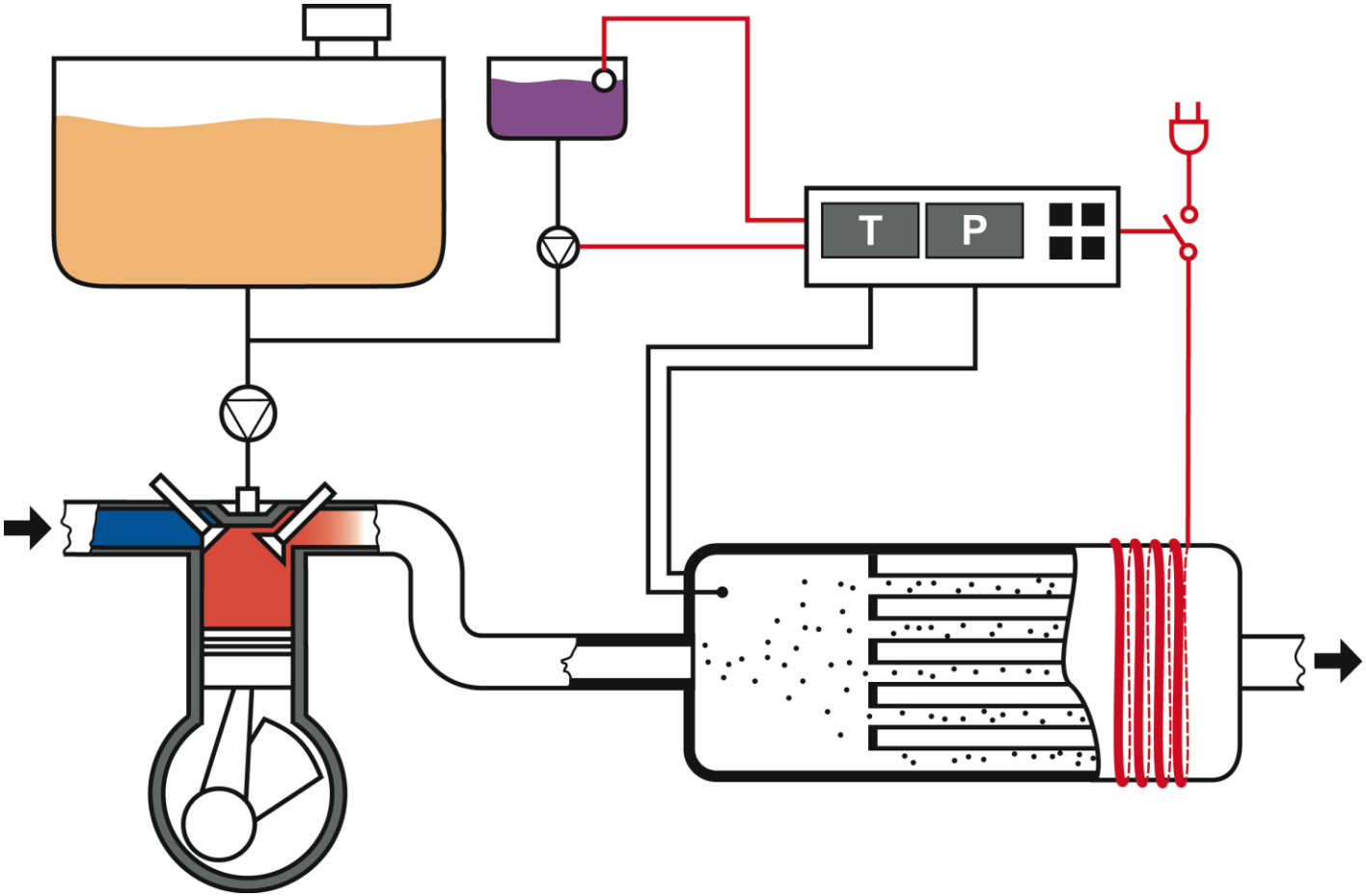


Passive Regeneration with FBC > 340 °C



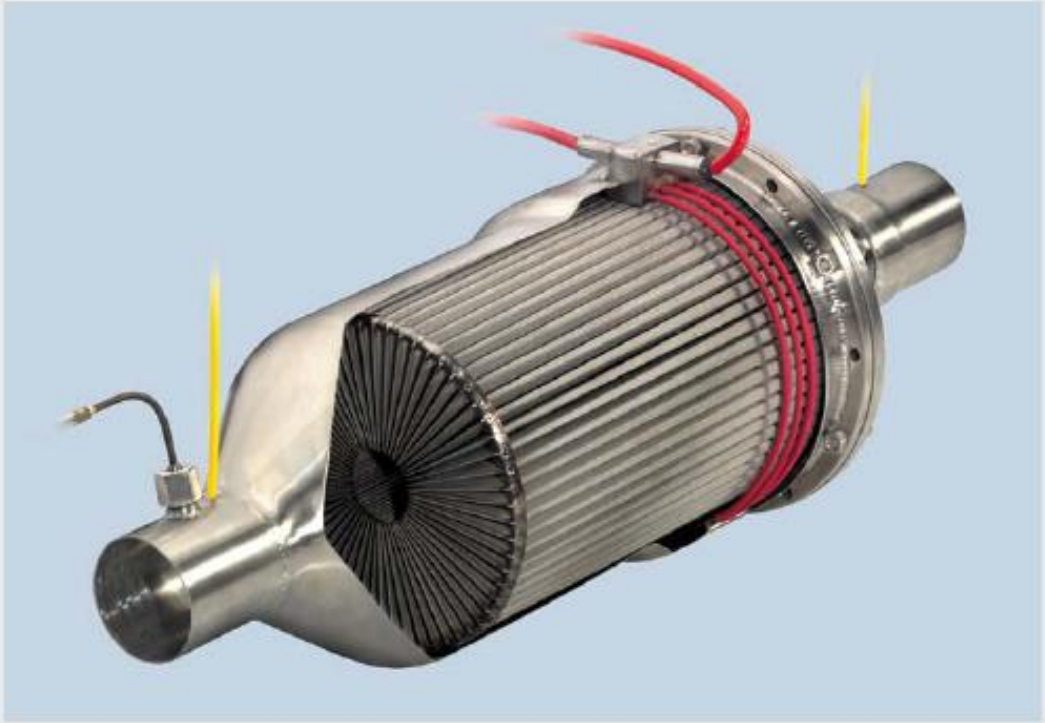
Active Regeneration with FBC

triggered by electric heat

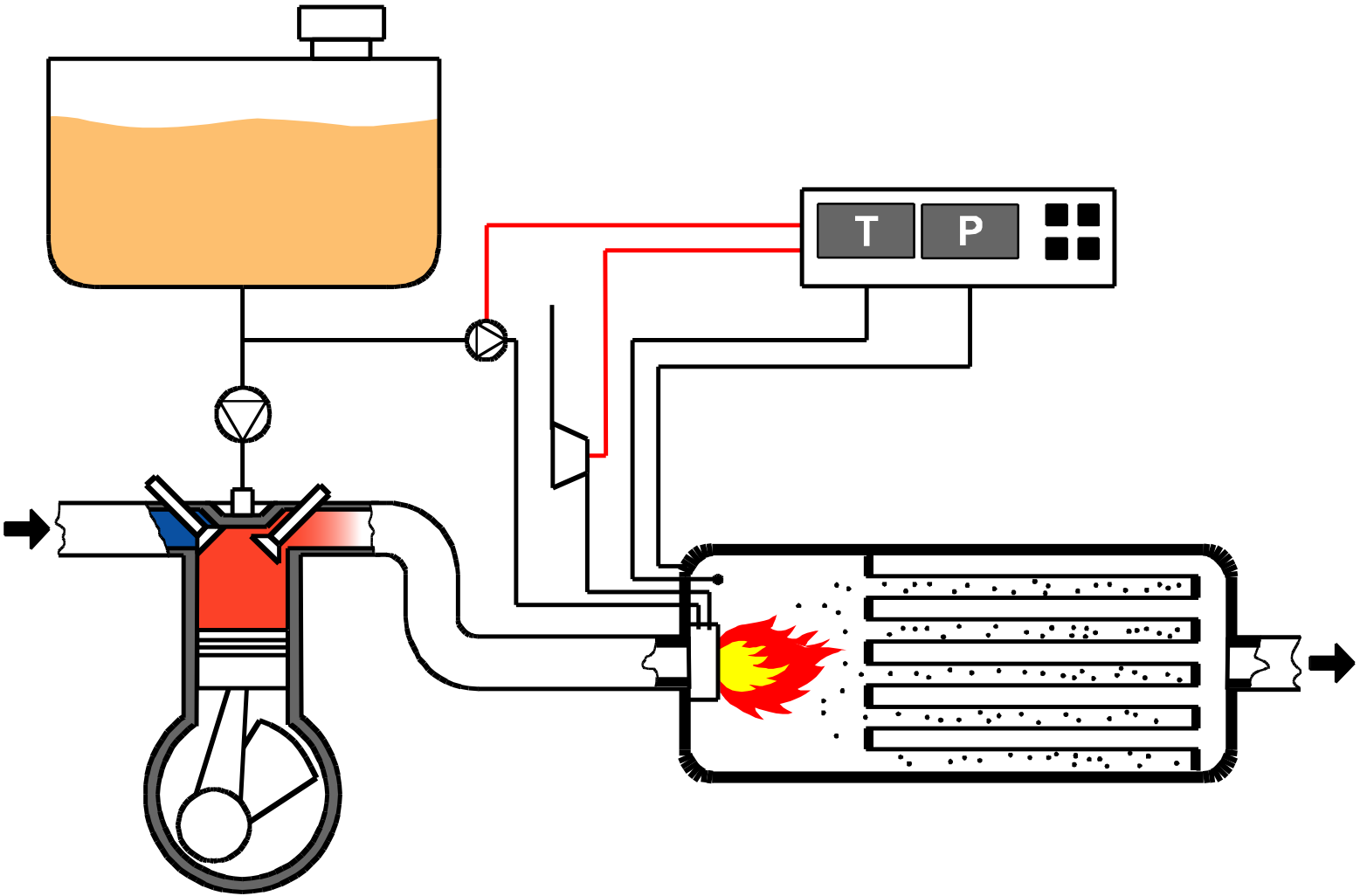


Regeneration triggered by electric Heating
combined with FBC-Catalysis

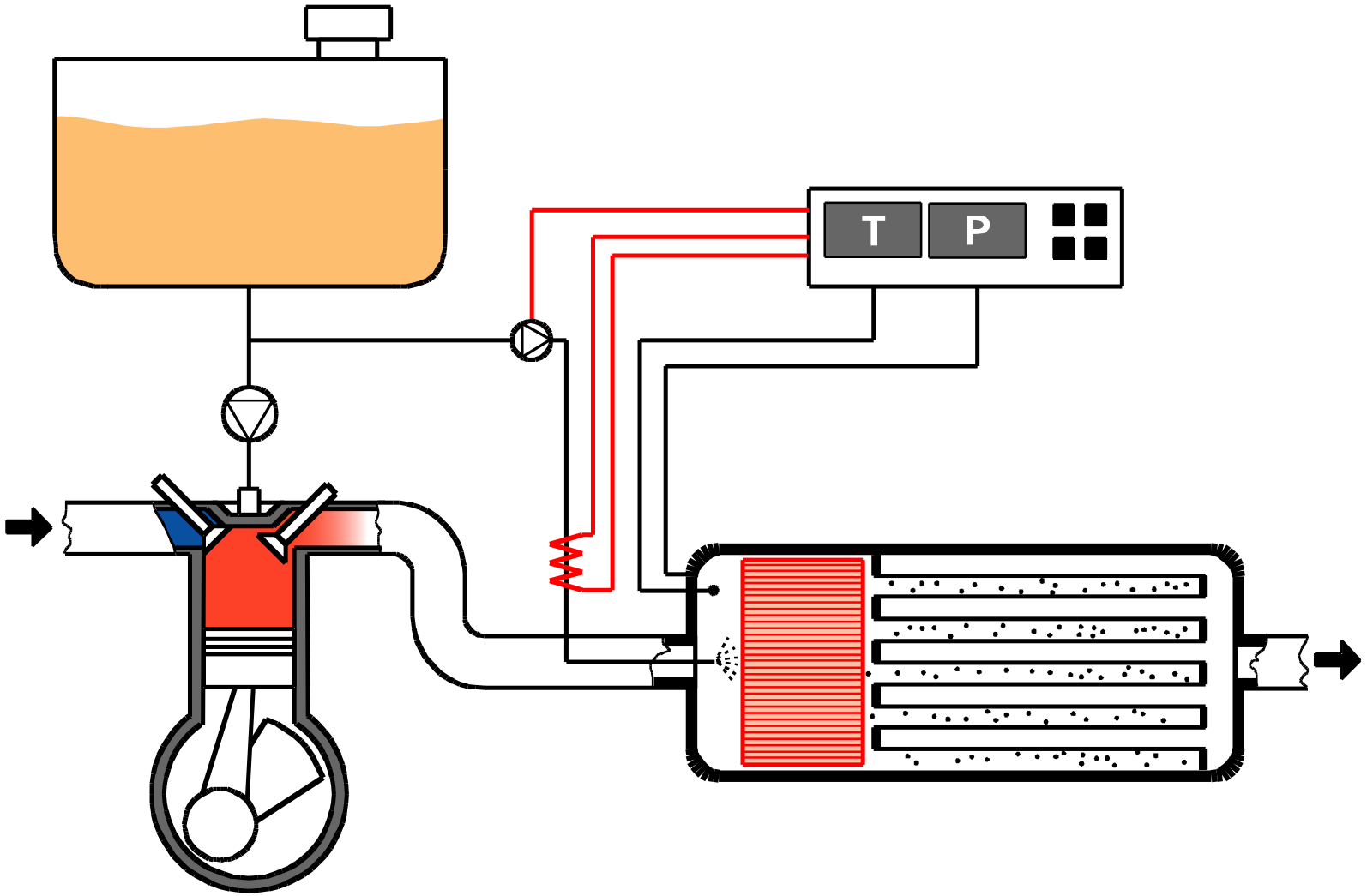
HJS SMF® – System mit autarker Regeneration



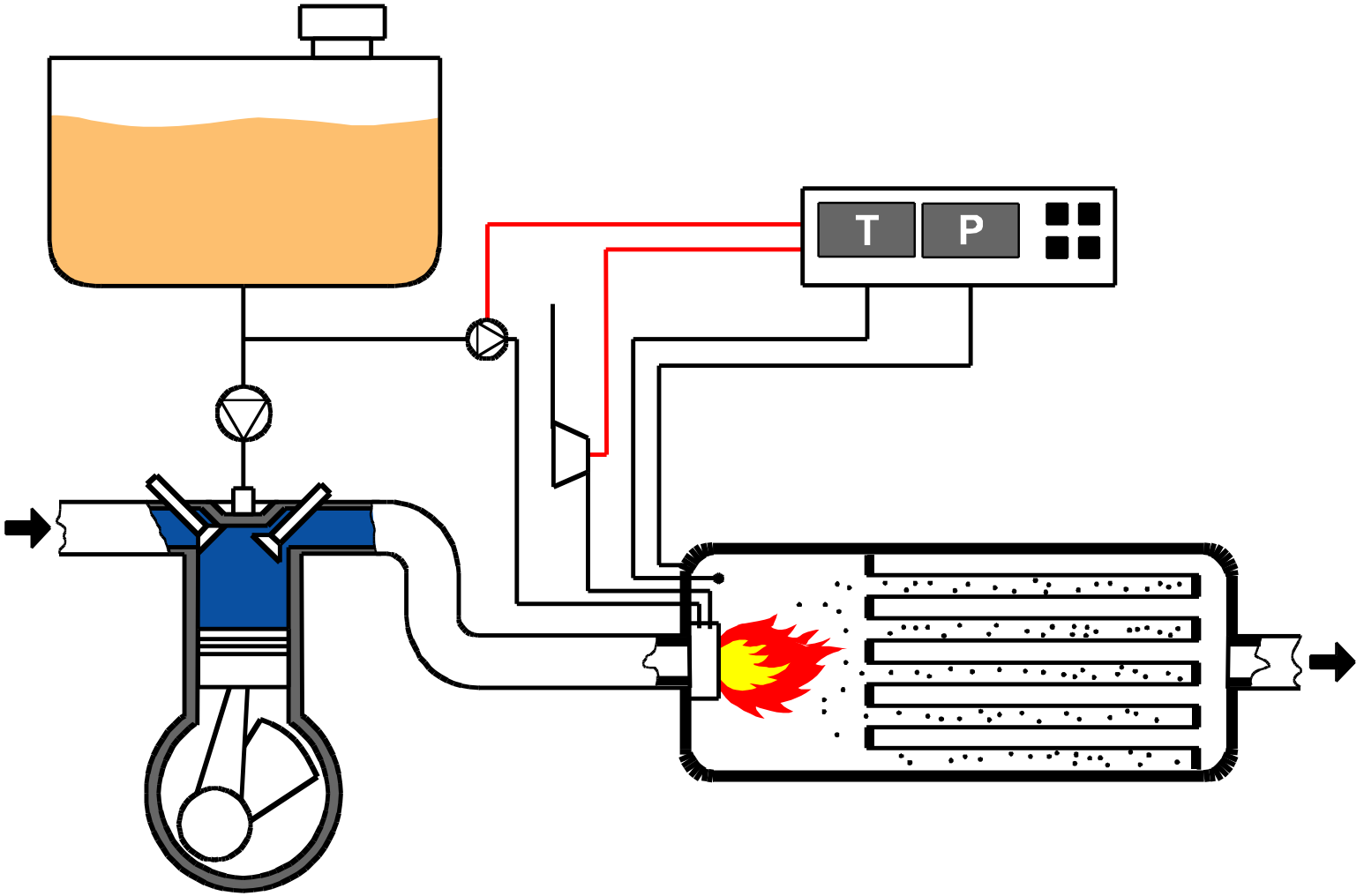
Full Flow – Diesel-Burner



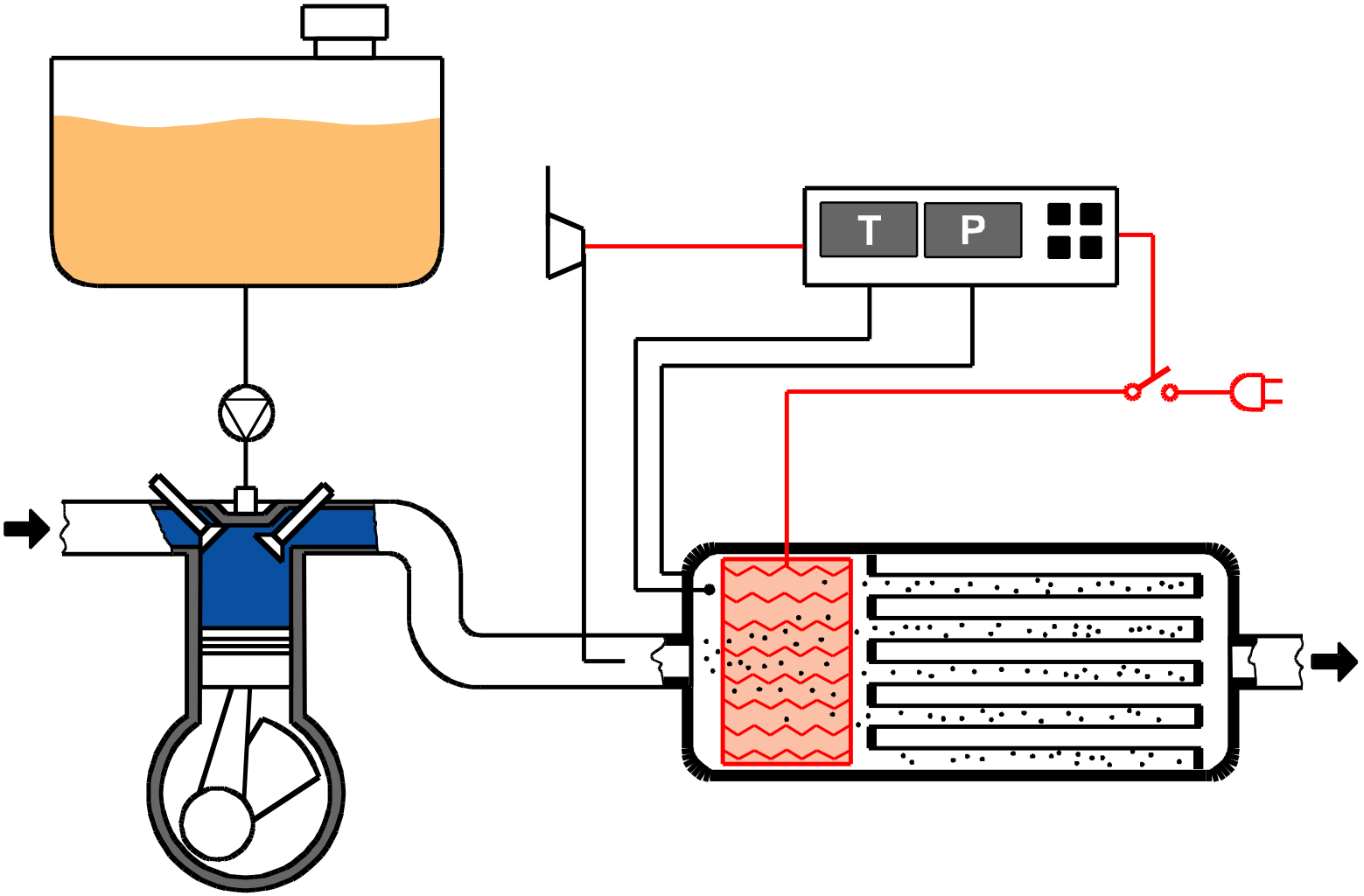
Active Catalytic Combustion



Diesel-Burner at Standstill

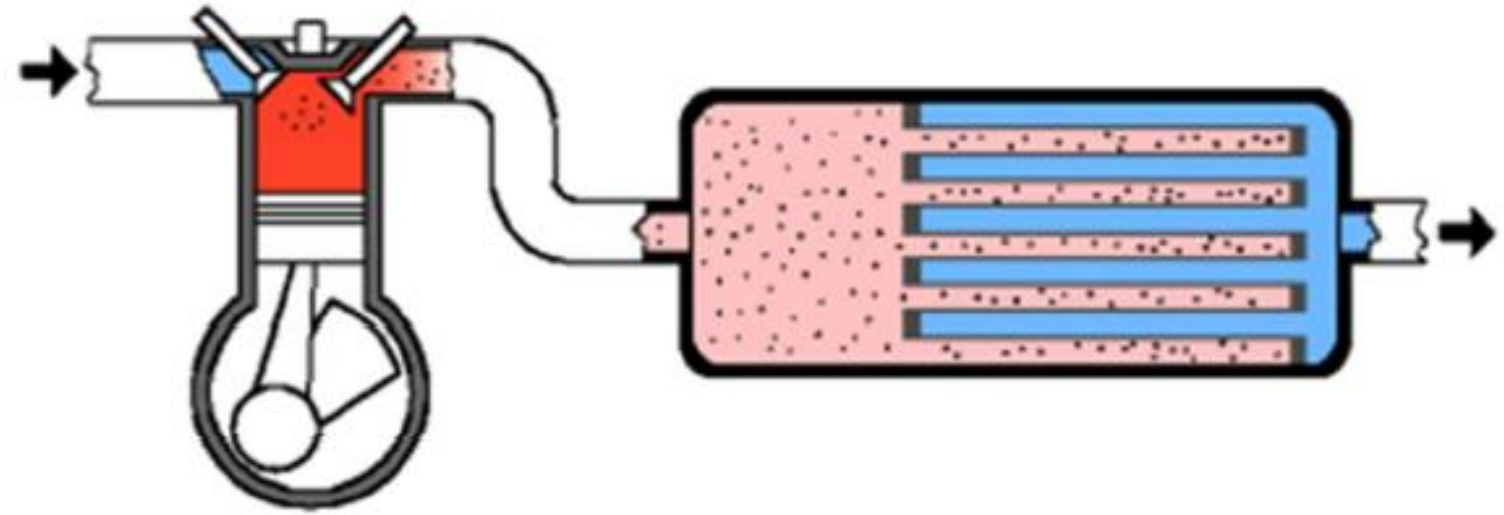


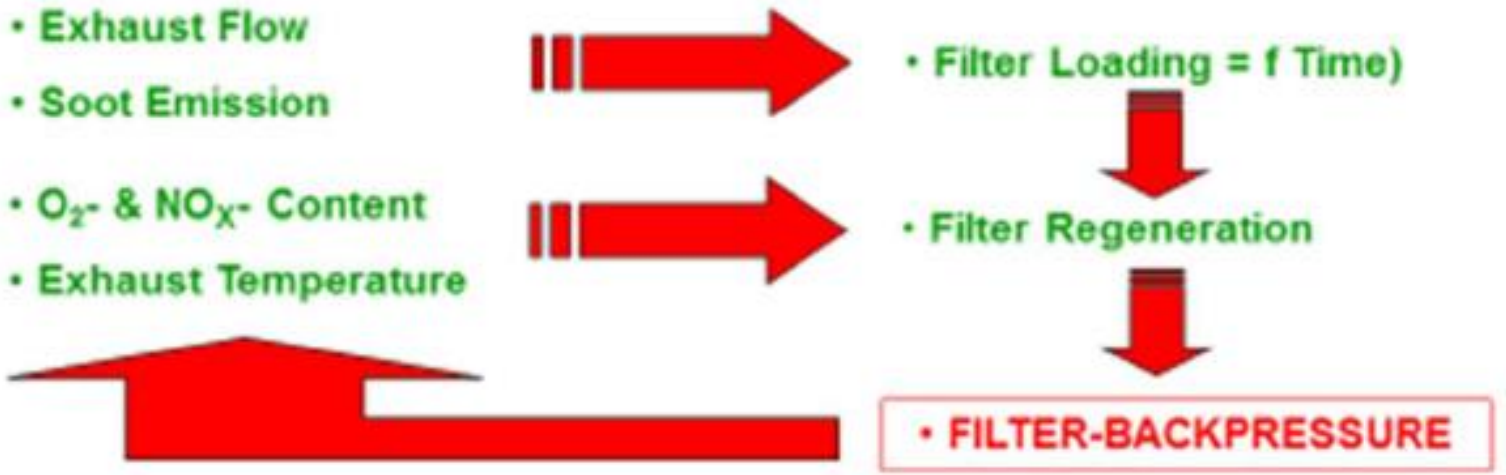
Electric Heating at Standstill



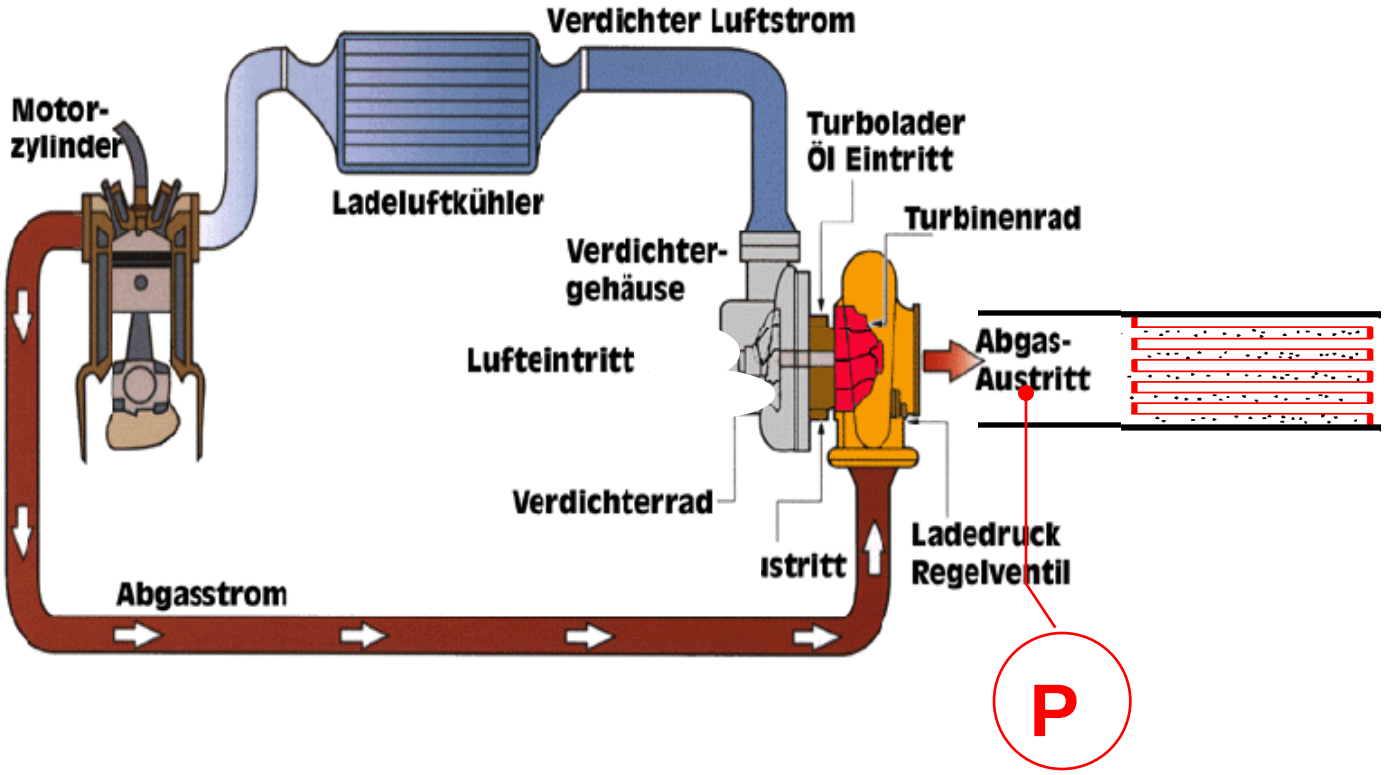
The vicious circle

above 400 mbar the engine may reacts non-linear





Turbocharged Engines are more sensitive



If Backpressure increases ↑

Charging Pressure Air Excess and Performance Decrease ↓

Soot Generation Increases ↑

Backpressure must be under Control

Electronic Datalogging

Sensors for Backpressure and Temperatures

Anzeige von Messwerten der ECU, z. B.

- Gegendruck
- Temperaturen
- Betriebsspannung
- Drehzahl
- Kraftstofftankinhalt
- Additivtankentnahmemenge

Auslesemöglichkeit aktive Fehlerliste

Warnung des Fahrers bei

- Zu hohem Gegendruck (VERT)
- Additivreserve …

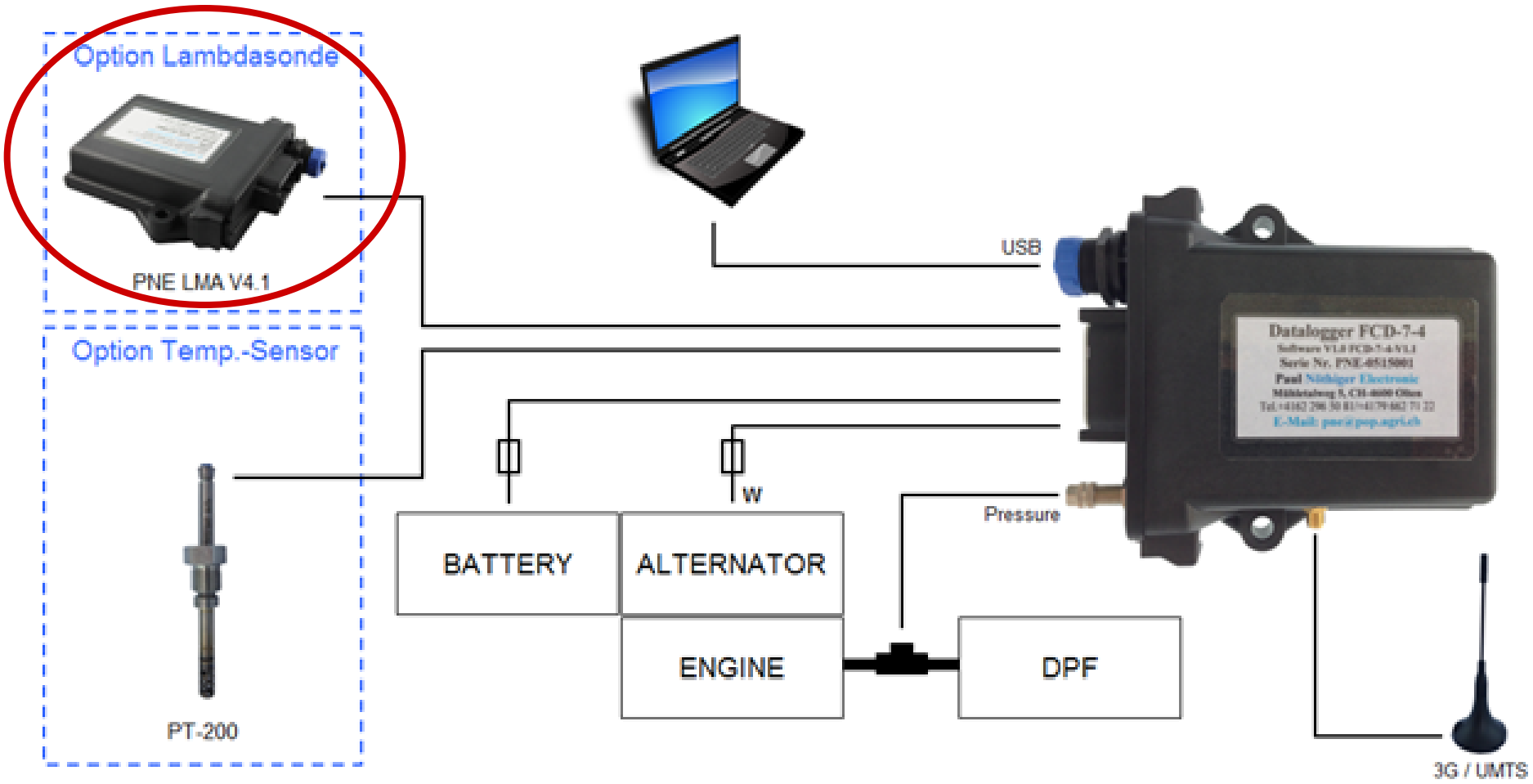
Alarm Indicator at the Drivers Seat

or remotely controlled

Data Analysis (Diagnosis)

Filter Monitoring System: Elements

High Altitude Mexico



Source: Paul Nöthiger Electronic

Maintenance and Emission Inspection

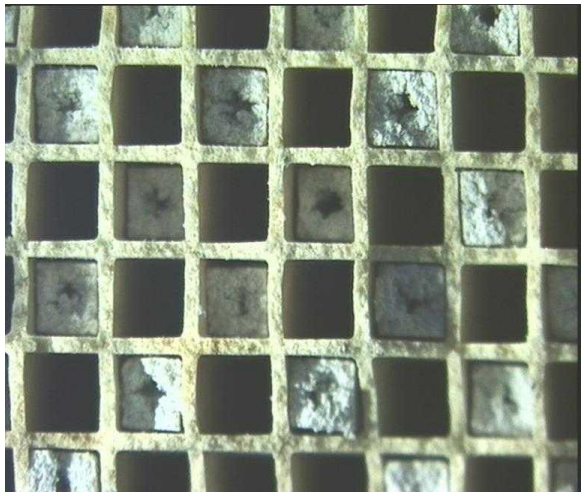
- ***Ash Cleaning***
- ***Emission Stability***
- ***Trouble Shooting***

Maintenance must be Part of Legislation

Quality of Retrofit must be documented

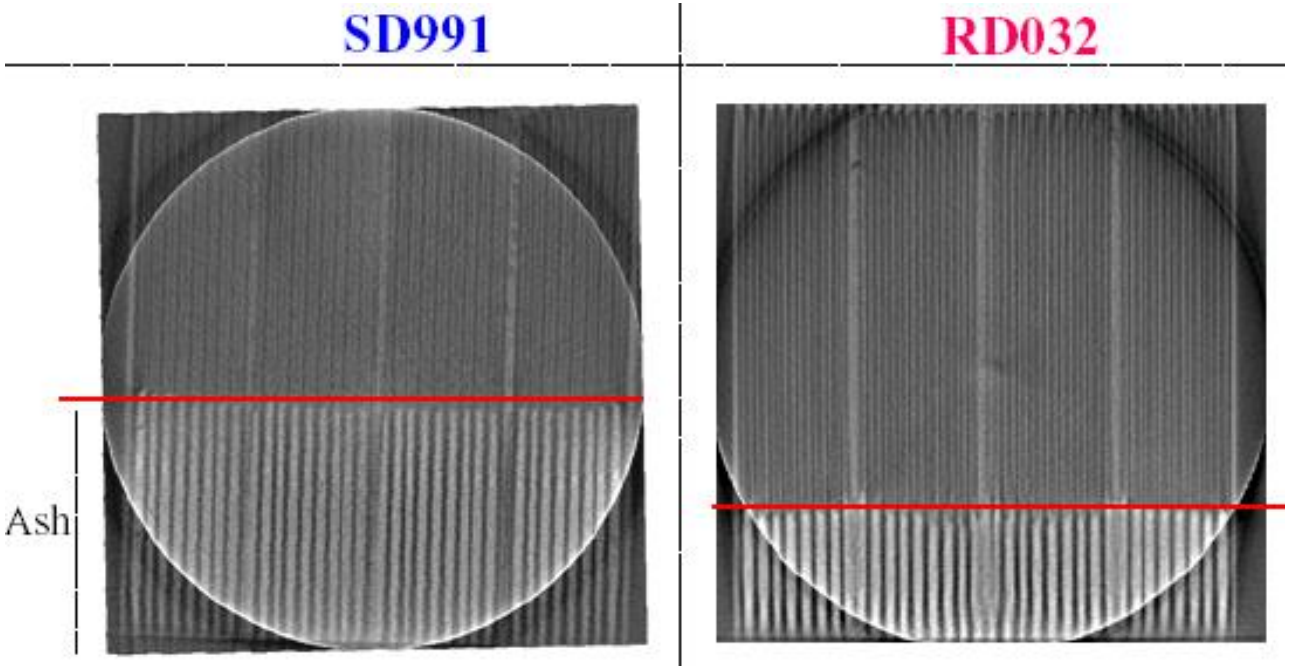
Periodic Quality Control must be documented

Periodic Emission Control must be visible by Stickers

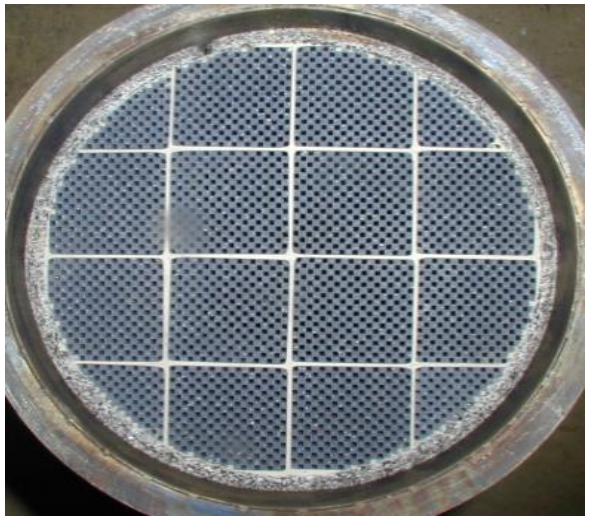


Ash Deposits

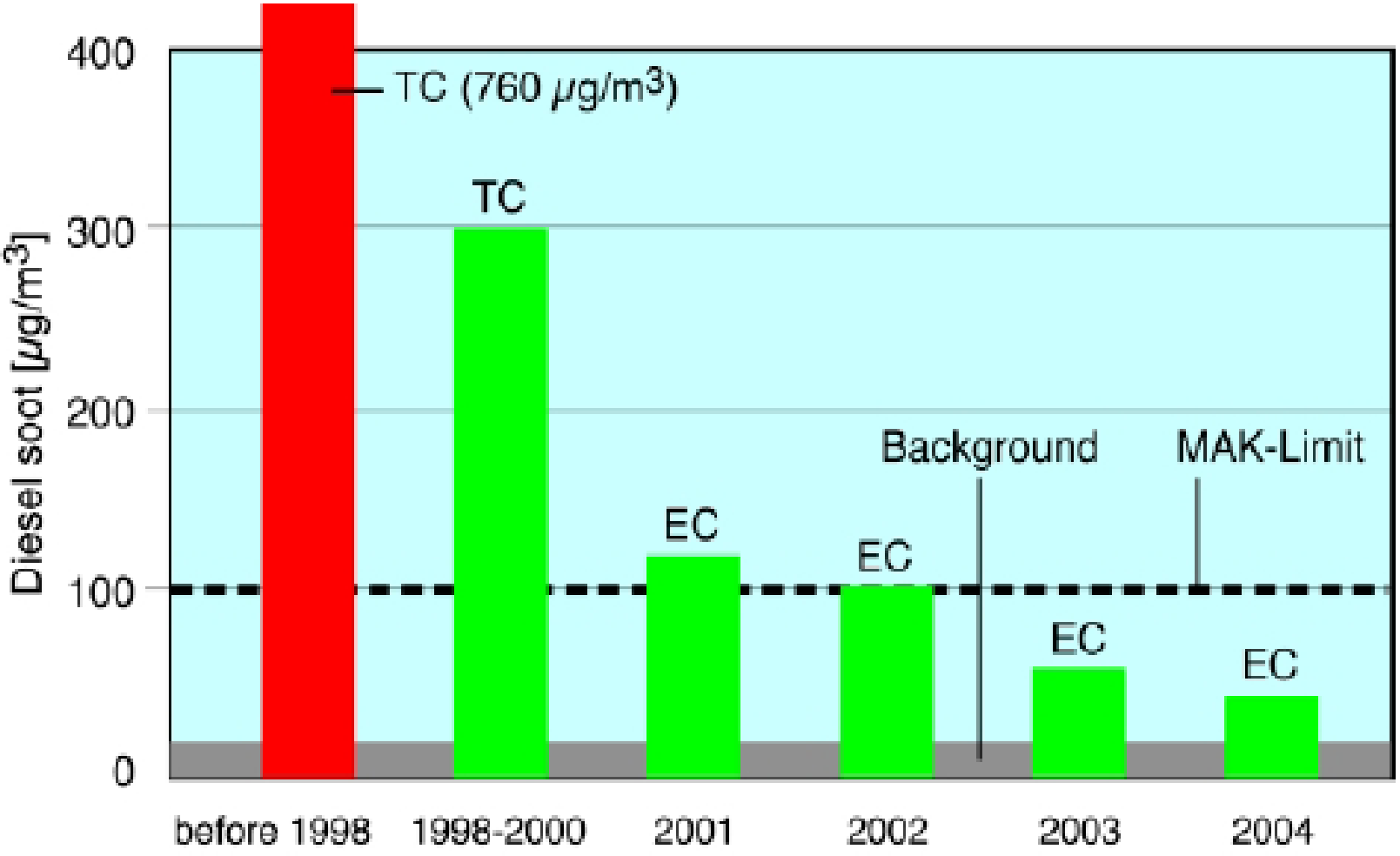
filters must be cleaned professionally 1-2 times per year



Repair Small Failures by Ceramic Cement



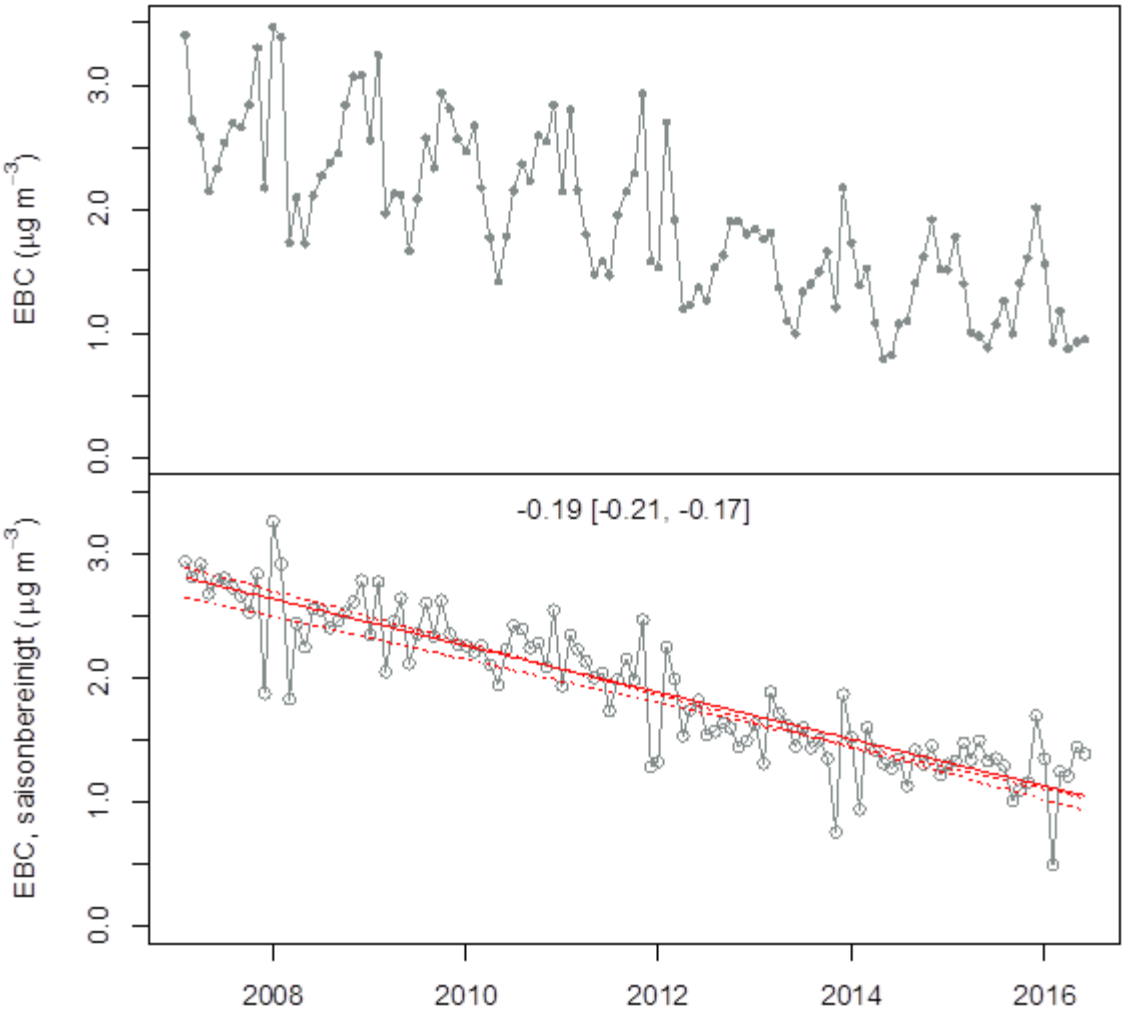
This Phase ended 2000 with the compulsory Requirement „No Diesel without Filter“



Improvement of Air Quality in Swiss Tunneling

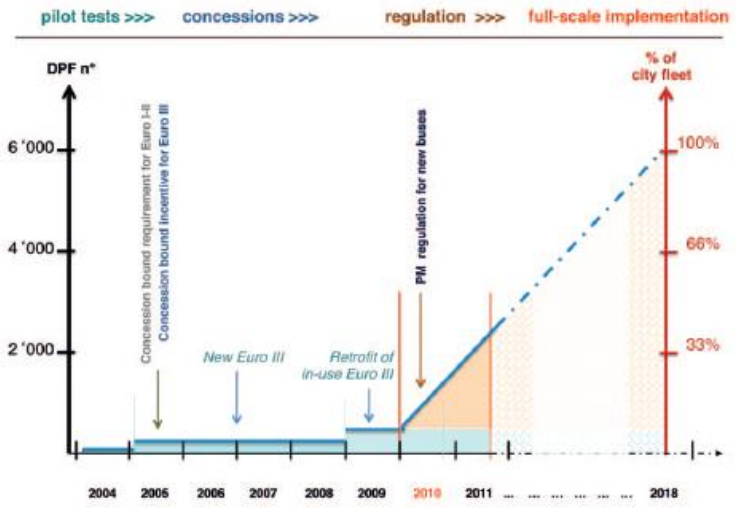
The Swiss Success Story

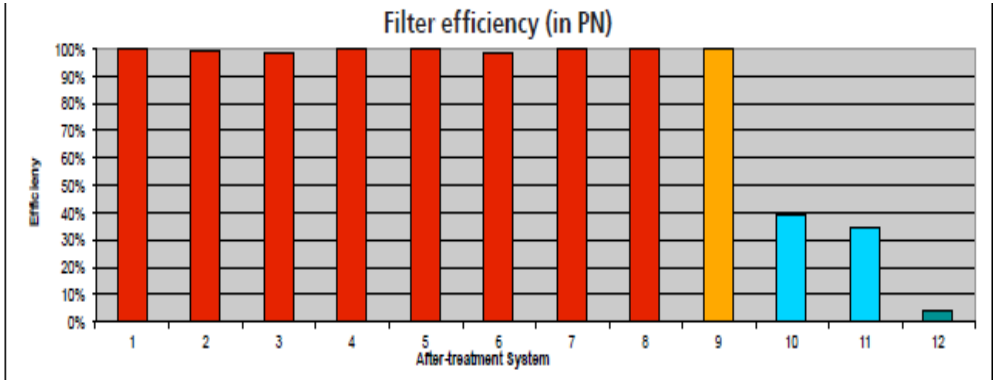
BC monitoring at a very busy motorway crossing



First Project Santiago de Chile 2005-2008:

now 3‘500 buses with DPF retrofitted





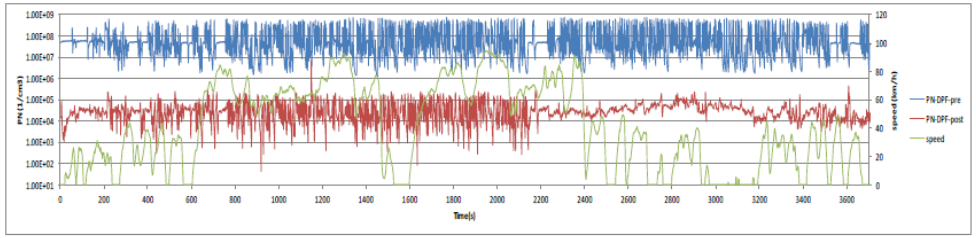
China DPF-Retrofit mit VERT in 3 Cities
with old vehicles at high Sulfur content 350 ppm

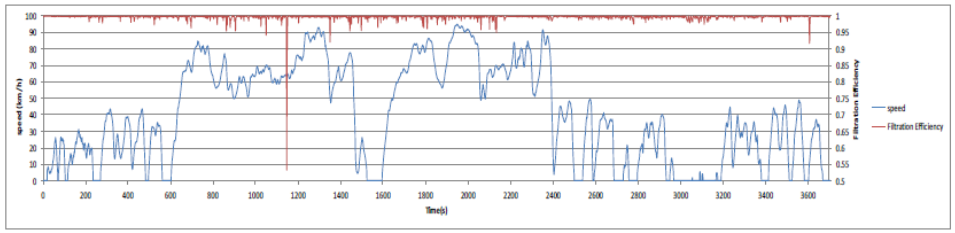
Beijing 20.12.2012 9:00
day before predicted apocalypse

DiSCmini: 90'000 P/cm^3
(60 nm → 20 µg/m^3 BC)

PM2.5 official: 182 µg/m^3

PM2.5 US: 320 µg/m^3
(24h-mean value)





Average Particulate Number Concentration before DPF: 1.18E+08/cm^3

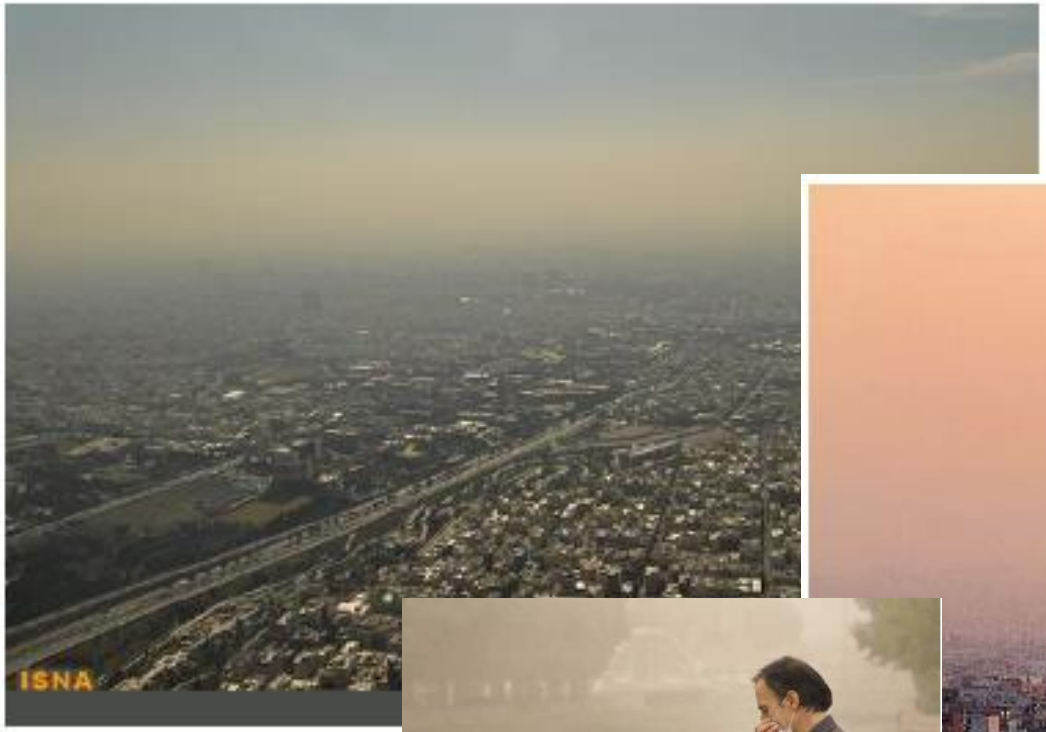
Average Particulate Number Concentration after DPF: 4.41E+04/cm^3

Average Filtration Efficiency of DPF: 99.96%

Tehran started with VERT 2014

first tender for 600 city bus retrofit published Oct.2014

New HDV must have VERT-BAT-DPF from 3/2016

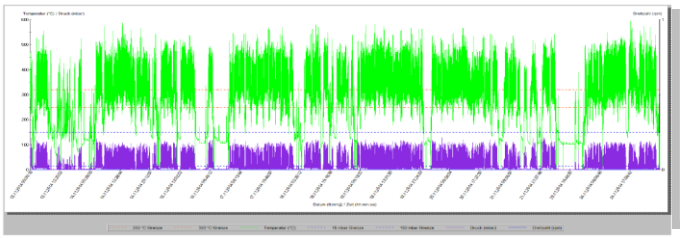


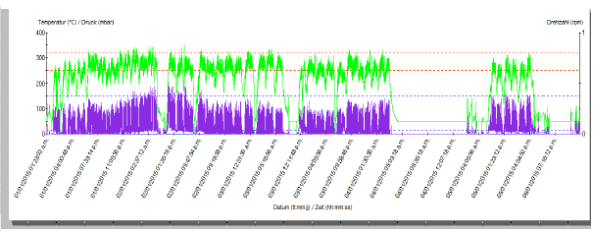
Bogotá 2014 – 2600 m above See Level

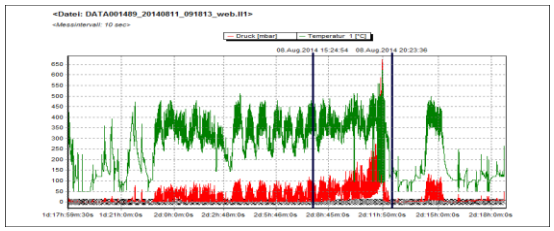
DPF-Retrofit Technology Transfer VERT

Foto tomada el 20 de abril de 2006 a las 8:30 a.m. (smog fotoquímico)

Foto tomada el 3 de mayo de 2006 (segundo día para de transporte). 8:30 a.m.







Retrofitting In-Use Engines

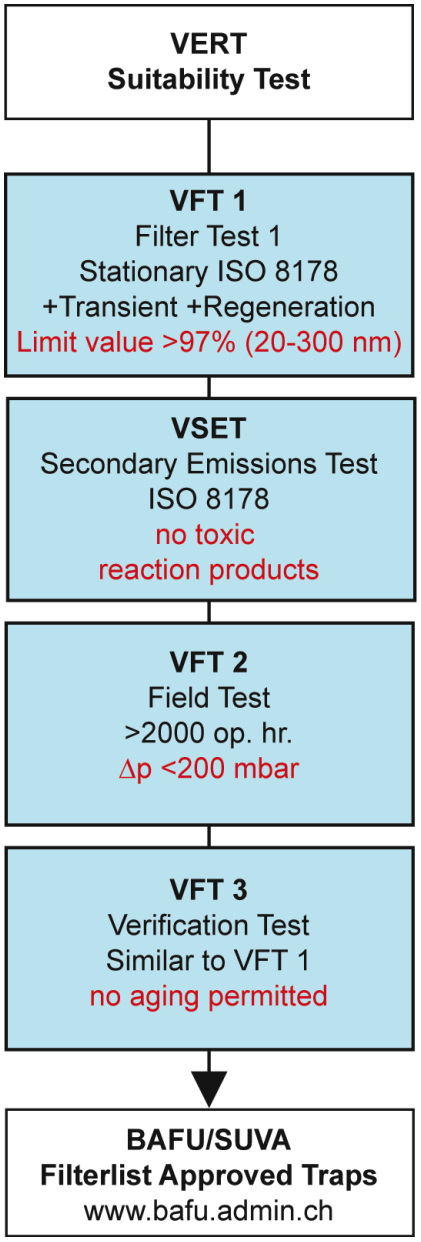
is not a «fit and forget» task

Pilote Tests are required to find the right solution

- DPF Retrofit is not cheap – but 10 times cheaper than health cost
- DPF evaluation requires a careful selection based on monitoring vehicle operation and pilot testing
- DPF require a continuous electronic on-board control
- DPF require a careful engine and filter maintenance
- Failure rate is below 2 % worldwide in professionally managed vehicle fleets (see Berlin and Santiago)

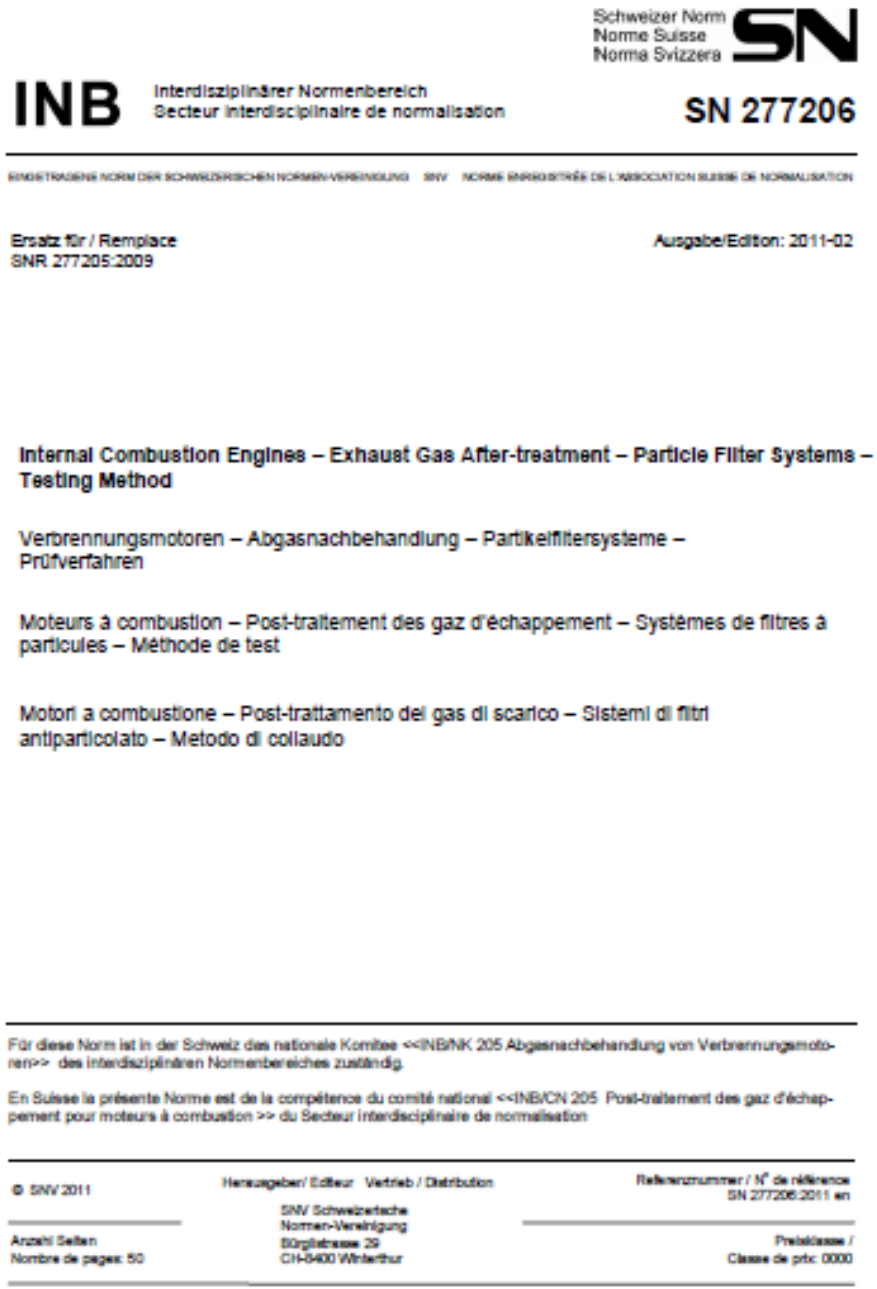

Exclusive use of
VERT certified Filters

VERT
Type Approval



Swiss Standard (Techn.Norm)

How to measure and characterize Nanoparticle Filtration systems for Combustion Engines



Schweizer Norm
Norme Suisse
Norma Svizzera
SN

INB Interdisziplinärer Normenbereich
Secteur interdisciplinaire de normalisation

SN 277206

EINGETRAGENE NORM DER SCHWEIZERISCHEN NORMEN-VEREINIGUNG SNV NORME ENREGISTRÉE DE L'ASSOCIATION SUISSE DE NORMALISATION

Ersatz für / Remplace
SNR 277205:2009

Ausgabe/Edition: 2011-02

Internal Combustion Engines – Exhaust Gas After-treatment – Particle Filter Systems – Testing Method

Verbrennungsmotoren – Abgasnachbehandlung – Partikelfiltersysteme – Prüfverfahren

Moteurs à combustion – Post-traitement des gaz d'échappement – Systèmes de filtres à particules – Méthode de test

Motori a combustione – Post-trattamento dei gas di scarico – Sistemi di filtri antiparticolato – Metodo di collaudo

Für diese Norm ist in der Schweiz das nationale Komitee <<INB/NK 205 Abgasnachbehandlung von Verbrennungsmotoren>> des interdisziplinären Normenbereiches zuständig.

En Suisse la présente Norme est de la compétence du comité national <<INB/CN 205 Post-traitement des gaz d'échappement pour moteurs à combustion >> du Secteur interdisciplinaire de normalisation

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The International VERT-Filterlist

- 65 Certifications
- First Publication 1998
- Published on VERT-homepage
- www.VERT-certified.eu
- Update whenever modified
- Language: English only
- Responsible: VERT-Scientific Committee

VERT is recognized worldwide by

- BAFU, SUVA, ASTRA, BAV - Switzerland
- AUVA, Wien, Tirol - Austria
- BG Bau, UBA, TRGS 554 –Germany
- CARB, MSHA, NY City – USA
- VROM – Netherlands
- Alto Adige – Italy
- Santiago de Chile
- DEEP – Canada
- London LEZ – UK
- Bogotá Colombia
- Denmark LEZ
- Tel Aviv Israel
- Beijing China
- Teheran Iran

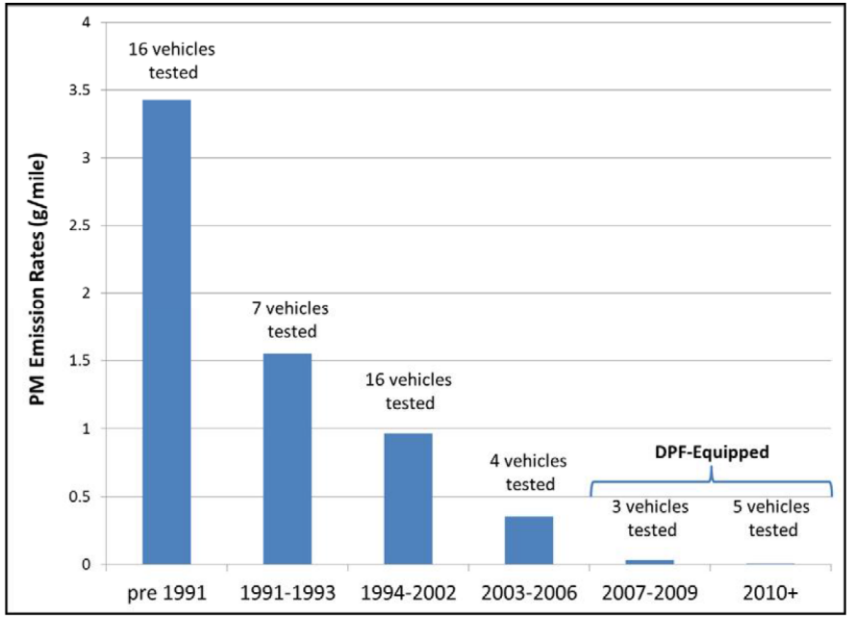
History of PFS-Retrofit in Switzerland

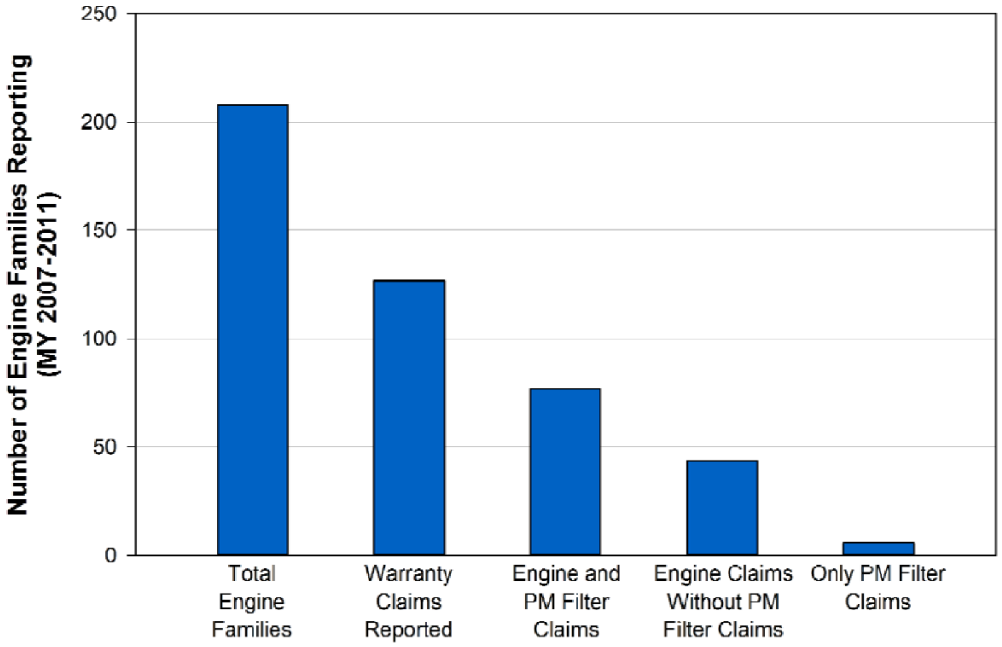
Year	Retrofit per year	Retrofits until year	Retrofit Companies	Failures % p.a.	PFS on Filterlist	Events
1995		453	3	15	-	VERT Field Test
1998		835	8	10	16	VERT concluded
2000	971	2'425	12	8	23	SUVA Tunnel Regulation
2002	1'418	4'900	7	3	8	2000 h Endurance Tests and OBC
2003	1'567	6'497	11	2	22	Construction Regulation > 37 kW
2005	2'473	11'365	21	<2	30	Construction Regulation 18-37 kW
2007	3'172	17'342	26	<2	50	Efficiency > 97 %

CARB investigated 587 trucks (OE and Retrofit) for engine and DPF problems (report May 2015)

As discussed in Section 3, staff conducted 621 roadside truck inspections, 587 of which were trucks equipped with PM filters. The resulting sample of paired truck inspections and operator surveys was representative of the California fleet. Appendix V provides a table showing the number of trucks inspected by body type relative to statistical sample targets.

Based on responses from truck operators, about 2 percent (11 of 587 trucks) reported a past problem with the PM filter on their truck that required service to resolve the





How to avoid Failures

- **Use only VERT-certified filters –VERT-Filterlist**
- **Evaluate vehicle operation → VERT Guide**
- **Select filter acc.VERT and prefer active regeneration**
- **Design installation carefully → VERT-Guide**
- **Install datalogger and alarms – remote download**
- **Set alarms to max 150 mbar; for EGR lower**
- **Training for mechanics, drivers and management**
- **Acceptance test of each retrofit → VERT-Guide+Label**
- **Control emission once a Year → VERT-Guide**
- ***Be proud cleaning the air of your environment***

Bus Fleet of Berlin (1200 vehicles) respecting these rules
has 1-2 failures per year – 0.1 %

>100 Million DPF on European Roads

- Retrofit in Switzerland since 1990 – now > 50’000 on buses, construction machines, Ships and Locomotives
- All european cities retrofit public transprt buses since 1995
- First passenger car by Peugeot in May 2000 – other manufacturers follow step by step
- Since 2010 all new Diesel passenger cars have DPF
- Since 2013 all buses and trucks have DPF
- From 2017 GTI Gasoline cars must have GPF
- From 2018 most Nonroad Mobile Maschines have DPF

What counts is clean exhaust gas much cleaner than intake air

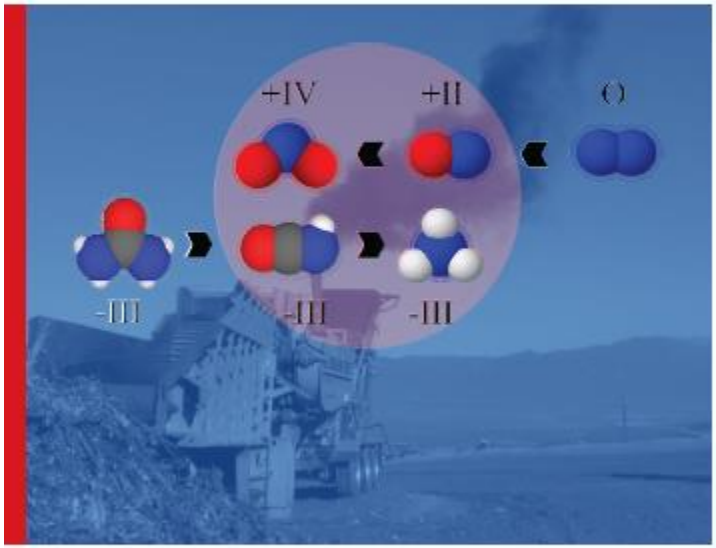
City Bus Exhaust
after 85’000 km

Picture A.Mayer 2006

8th VERT FORUM

Combined particle filter and deNOx-technologies

Will blue technology be
green enough in the future?



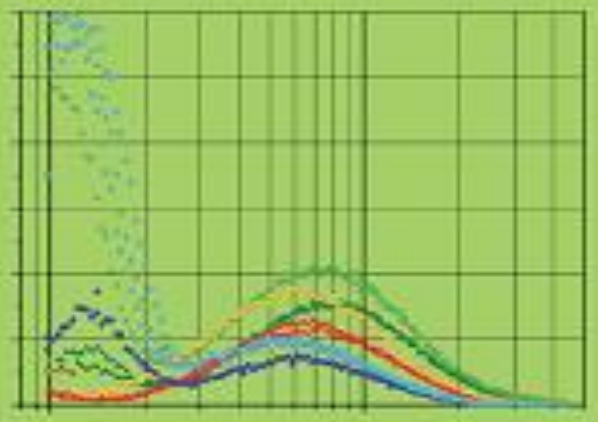
Empa, Dübendorf, Überlandstrasse 129
Friday, March 17, 2017, from 9:00 to 17:00

Registration by e-mail: *ttm.a.mayer@bluewin.ch*

Invitation and call for papers to the

21st ETH-Conference on Combustion Generated Nanoparticles

Focus Event:
Will Diesel Technology Survive?



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