

# **Milestones and Keys**

*from 10 DPF pioneering prototypes  
to 300 million DPF/GPF vehicles  
in operation*

A.Mayer - TTM, VERT



# VERT was there before 1993 *and may stay after 2018*

- 1984 BBC/ETH-DPF with DB tested successful in USA
  - Corning-Degussa-DPF disaster, 2000 engines failed in USA
- 1993 DPF the only solution for building NEAT
  - 1994 Filtertest at AFHB following the PN-standard
  - 1997 First ETH-Nanoparticle Conference
  - 1998 First VERT-Filterlist
  - 1999 Nanomet «the golden instrument» at Hannover fair
  - 2000 DPF mandatory in Swiss tunneling
  - PSA FAP roll out
- 2002 DPF mandatory in Swiss construction
- 2011 DPF mandatory for Euro 6 only possible due to PN-standard
- 2020 DPF offroad and GPF for DI-Petrol
- 2029 EV produce all PM10, ICE eliminate all PN < 500 nm
- 2038 Sun-Fuel CO2 neutral for ICE - EV becomes a niche application

## MEILENSTEINE DER PARTIKELFILTEREINFÜHRUNG

- 1775 Percival Pott beweist die Korrelation von Russ und Krebs bei Kaminfegern – erster Epidemiologe. → *Er wird geädelt, sonst interessiert das niemand*
- 1910 Englische Arbeitsmediziner vermuten neben Staublunge und Silikose schwere Lungenschädigungen durch viel kleinere, unsichtbare Partikel, beginnen die Grösse zu klassieren und Partikel zu zählen. → *Konimeter*
- 1928 Lawther weist eine Korrelation zwischen Lungenkrebs und Anstieg des Verkehrs in London und Wales nach.
- 1936 Die erste Ausgabe der Arbeitsschutzzeitschrift „Staub“ vermutet schwere Erkrankungen via Lunge durch Partikel im Grössenbereich von  $< 1 \mu\text{m}$  und fordert die Verbesserung der Messtechnik.
- 1936 Asbest als karzinogen erkannt, US-Versicherungen nehmen keine Arbeiter aus Asbest verarbeitenden Industrien mehr auf. Massnahmen werden erst ab 1990 in der Schweiz eingeführt: Das Kriterium ist die Anzahl der Faserbruchstücke, weil eine Wägung (Masse) nicht möglich ist. *Niemand nimmt diesen wichtigen, physikalisch absolut evidenten Paradigmenwechsel für partikuläre Schadstoffe richtig ernst.*
- 1951 Die Johannesburger Konferenz der Arbeitsmediziner bestätigt 1952 den frühen Verdacht der englischen Minenärzte, klassiert Partikel in thorakale, broncheale und alveolare Fraktion  $< 1 \mu\text{m}$  und fordert Massnahmen – grossartige Proceedings, ein Jahr später publiziert. *Umweltmediziner sprechen nicht mit den Arbeitsmedizinern, damals nicht und heute nicht.*
- 1976 TSI entwickelt Anzahlmessgeräte im Nanopartikelbereich für die Wissenschaft und Siegmann/ETH misst an Motoren; stellt fest, dass neue Daimler-Benz-Motoren mehr Nanopartikel emittieren als ältere; das Problem solid/volatile ist noch nicht erkannt.

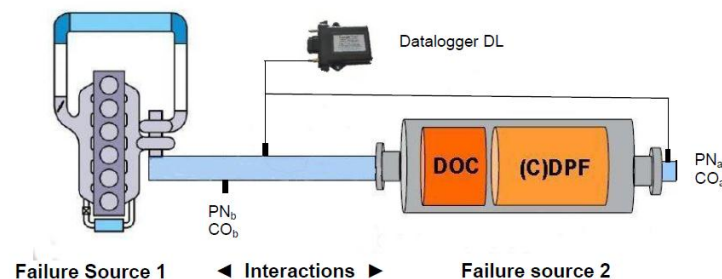
## DPF TROUBLESHOOTING DIAGNOSIS AND REMEDY

### Technical requirements to prevent malfunctions

- Select a certified DPF
- Install the DPF correctly
- Select or adapt the regeneration method to operation profile
- Use the correct fuel
- Maintain the engine to prevent excessive lubricant consumption
- Respond immediately to alarms
- Maintain the DPF system well – see manufacturer operation manuals

### Diagnosis tools and instruments:

- Filter monitoring system (→ datalogger analysis, DLA)
- PN counter ( $\text{PN}_b$  /  $\text{PN}_a$ : measurements before/after filter)
- Opacitymeter ( $\text{OM}_b$ ) – see VERT TA
- Gaseous emission measuring device ( $\text{CO}$ ,  $\text{HC}$ ,  $\text{NO}_x$ ,  $\text{O}_2$ )



- CRT-System
- Metall-Sinterfilter (SHW) mit Additiv-Regeneration



# VERT-Conformity Criteria 1998

## VERT-Pflichtenheft für Partikelfiltersysteme bei Baumaschinen

Stand 15.4.98

### Abscheidegrad (am Referenzmotor Liebherr 914 T)

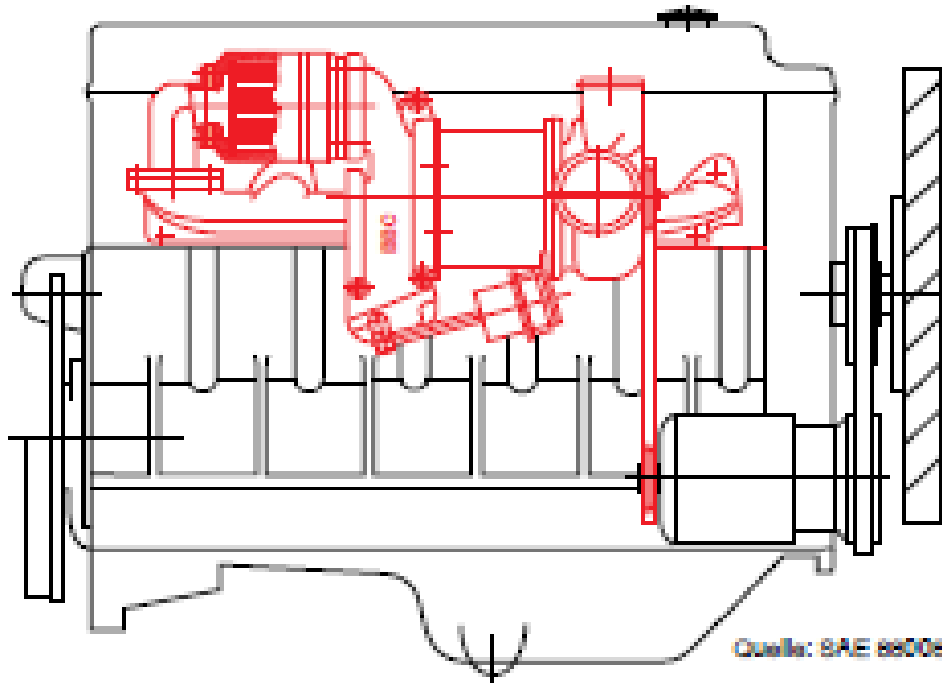
- Gesamtpartikel, gravimetrisch (ISO 8178 C1, 4 Testpunkte) > 90%
- Elementarer Kohlenstoff, coulometrisch > 95%
- Russstoss bei freier Beschleunigung: Opazität < 10%
- Penetration von Feststoff-Feinpartikeln im Grössenbereich 10-500 nm < 5% (Anzahlkonzentration)

### Zusatzanforderungen Emissionen

Es ist keine messtechnisch eindeutig nachweisbare und relevante Erhöhung folgender Emissionen gegenüber dem Ausgangszustand des Motors zulässig, insbesondere:

- Sulfatbildung, Schwefelsäure-Aerosole
- Sekundäremissionen durch Brennstoff-Additive
- Sekundäremissionen durch Dioxinbildung
- Erhöhung der Grundemission CO, HC, NO<sub>2</sub> (Summe Zyklus)
- Mineralfaser-Emission

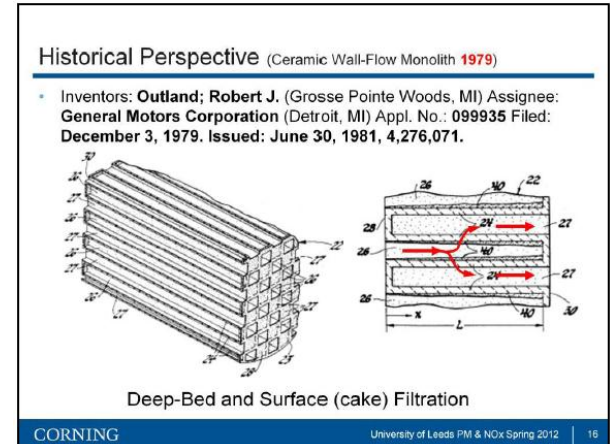
# Filter for Diesel-Exhaust since 1982



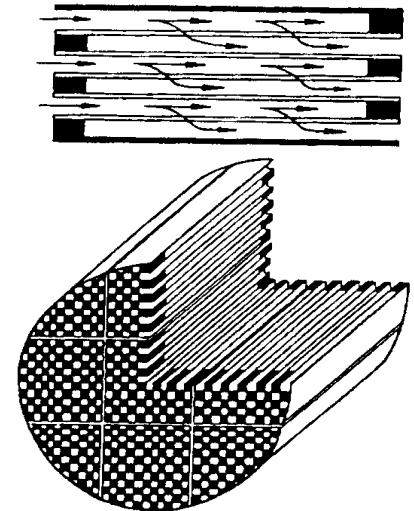
1984  
BBC-Daimler

Our first innovative depollution sytem

1979  
GM



1982  
Corning



# 1993 the NEAT-Tunnel – big step

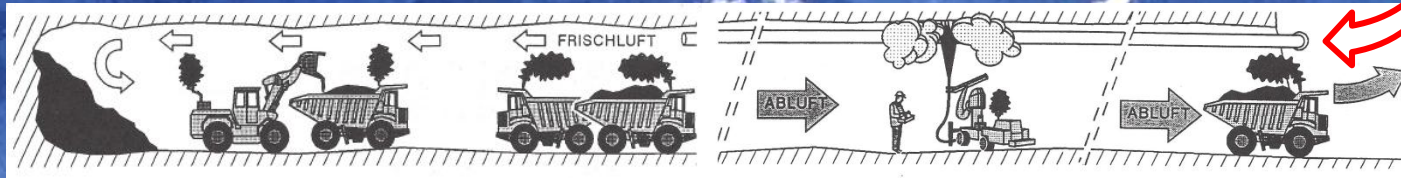
## Occupational Hygiene Requirement

«Reduction of solid submicron particles to  $< 100 \mu\text{g}/\text{m}^3$  within three years» by 97 % - **by dilution ?**

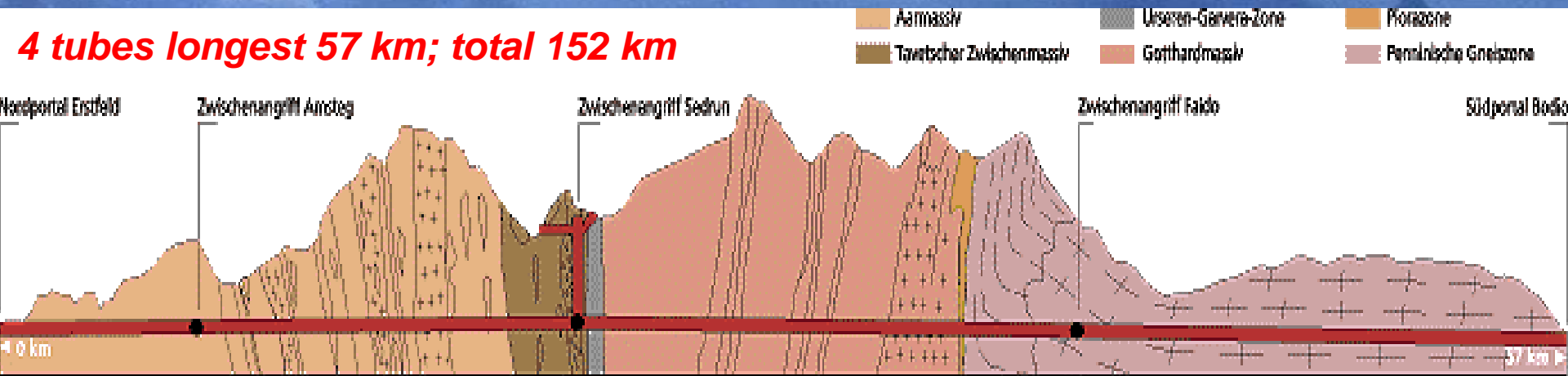
Dicke Luft  
im Tunnel?

VERT

Die SUVA entwickelt im  
Projekt VERT Lösungen  
zur Abgasreinigung von  
Baumaschinenmotoren



**4 tubes longest 57 km; total 152 km**

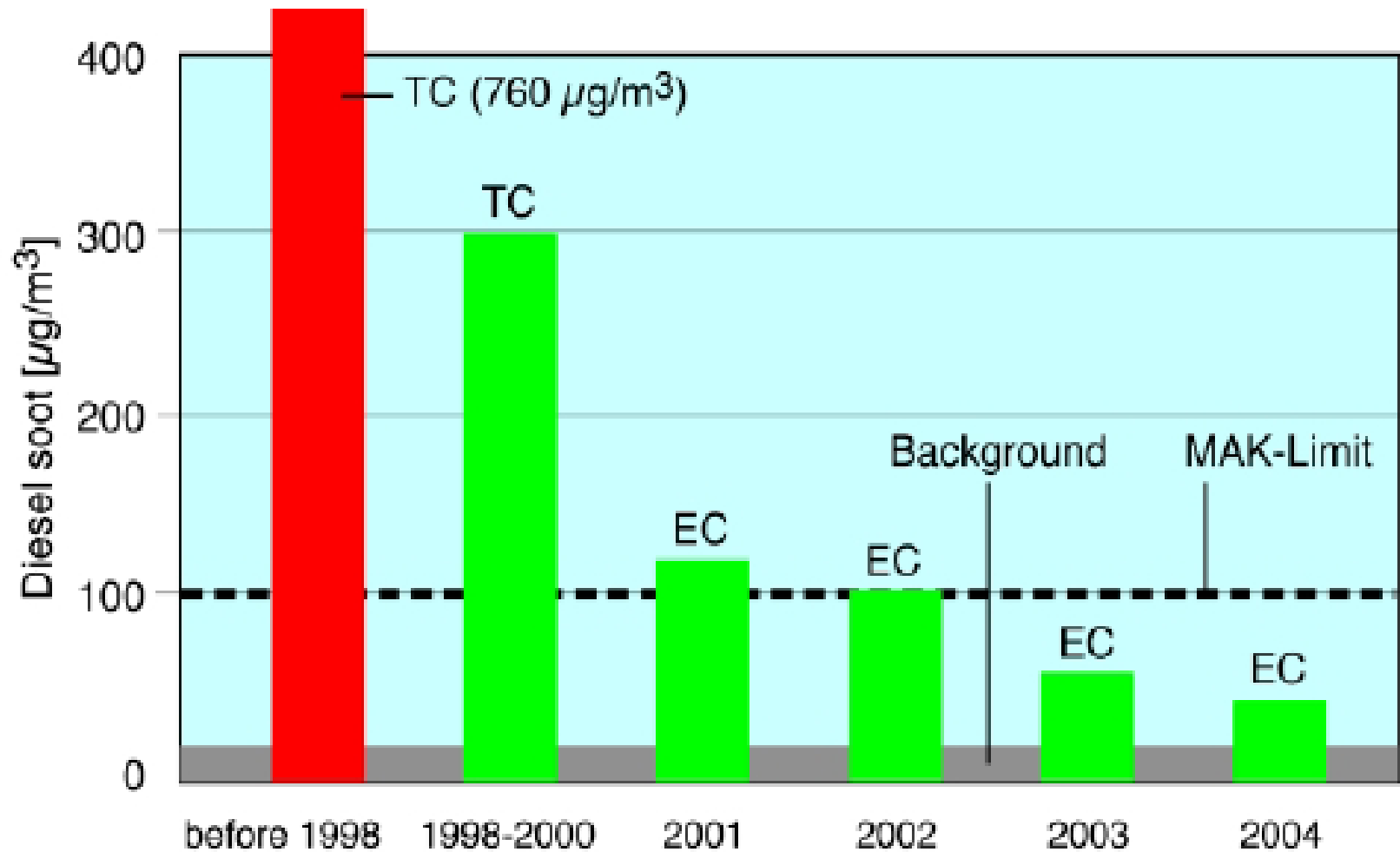


# Switzerland startet with Tunneling 1993

*„VERT-Filter for each Diesel“*







## Improvement of Air Quality in Swiss Tunneling

*“no Diesel without filter” since 1997*

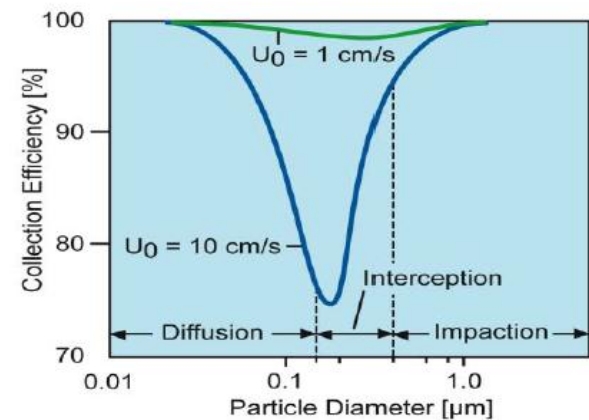
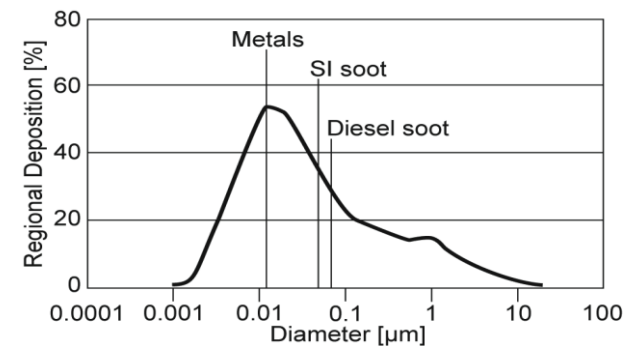
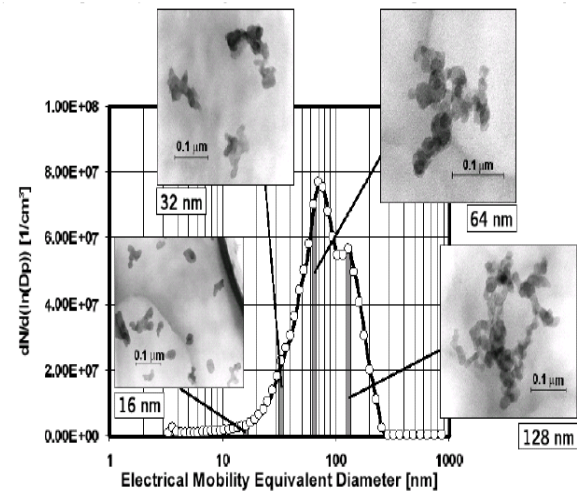
# Aerosol Research

## 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*

Filter quality depends on particle size  
and space velocity and not on engine  
properties.

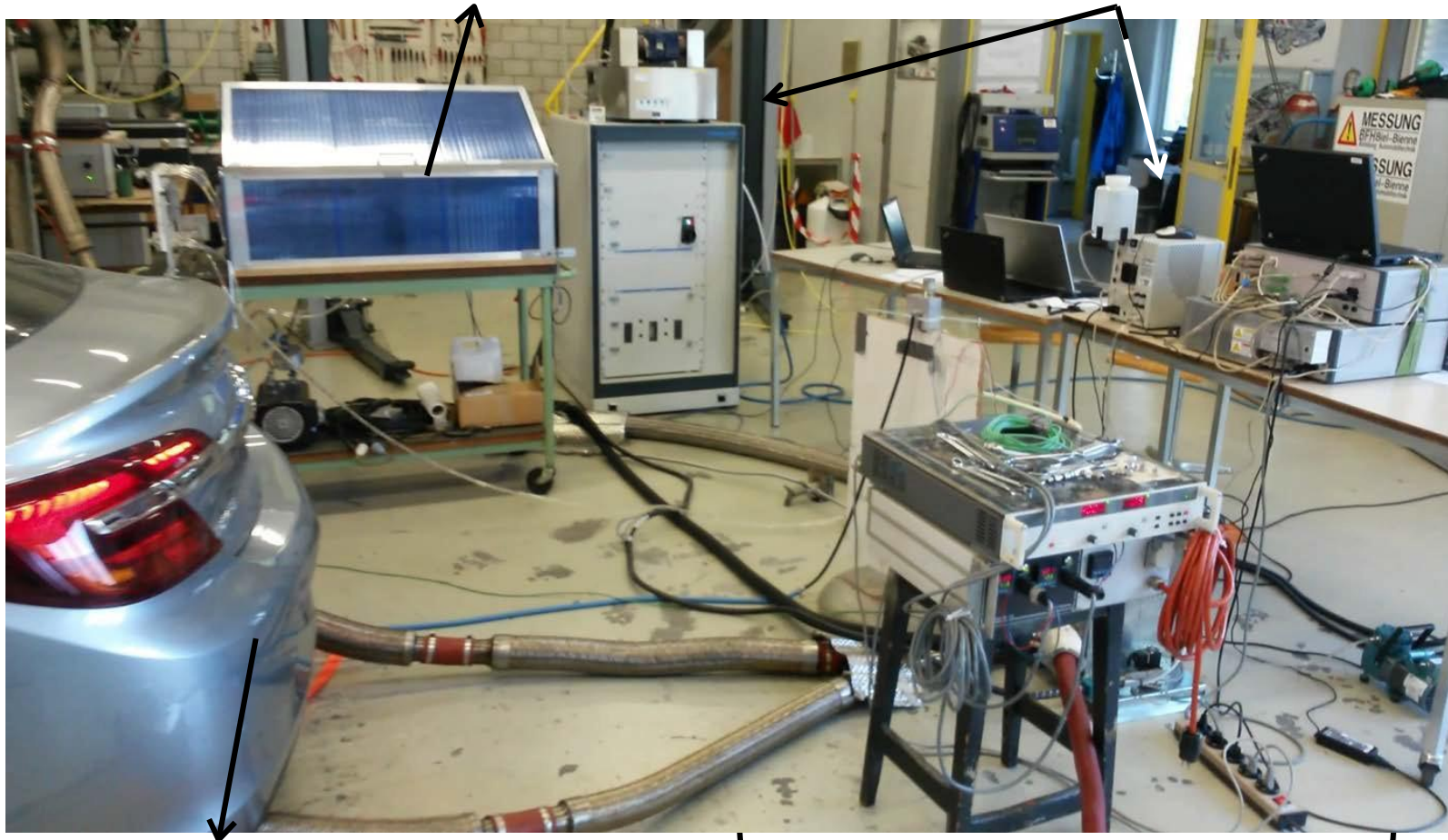
Testing on mass-filtration is useless  
Testing on one representative engine  
is sufficient → but scrutinize for  
Chemistry



# Health Research .

Biological test system  
Triple-cell model, killer cells

On-line exhaust  
characterization

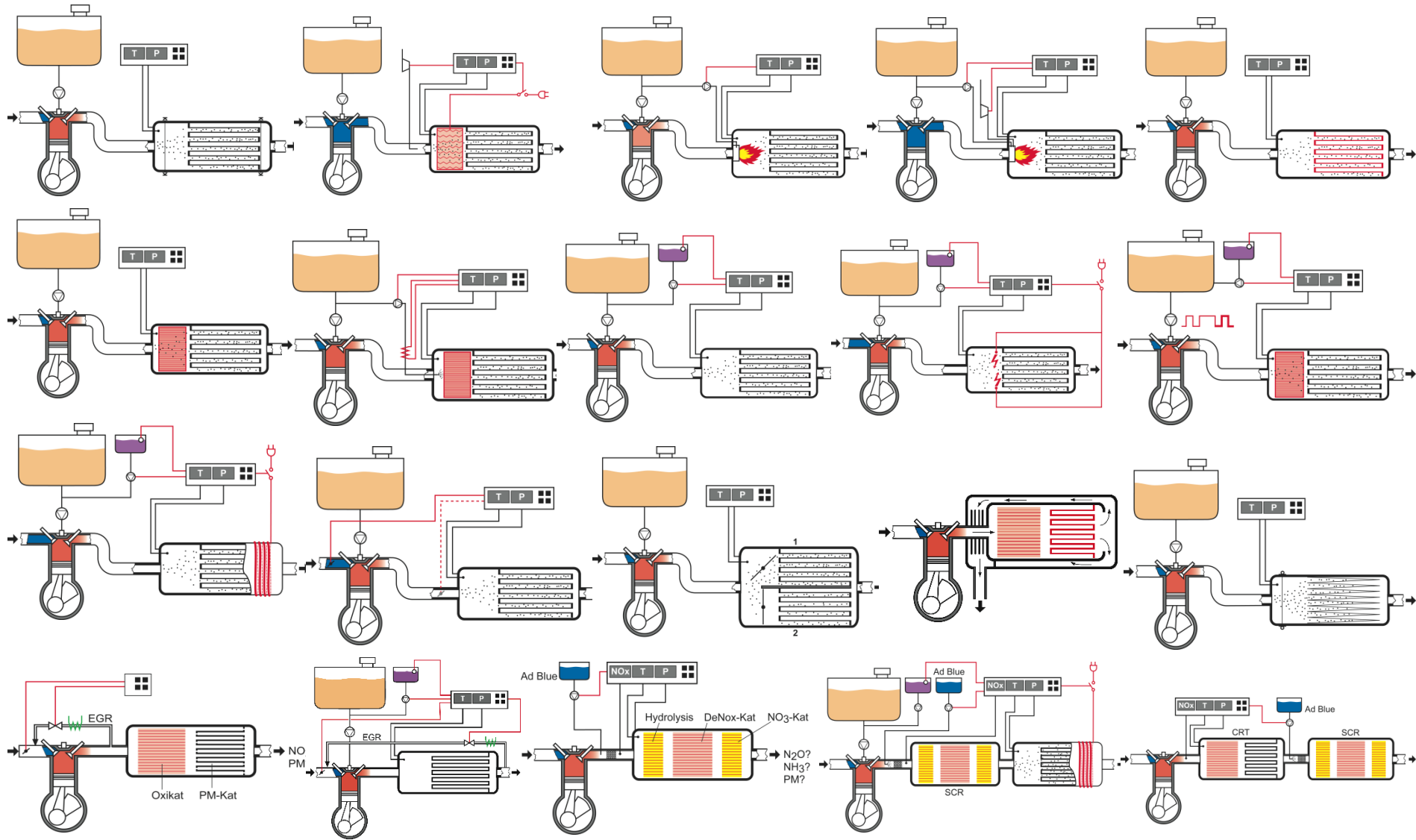


Test vehicle

Exhaust sampling

# VERT-certified DPF Systems

## for different targets and applications

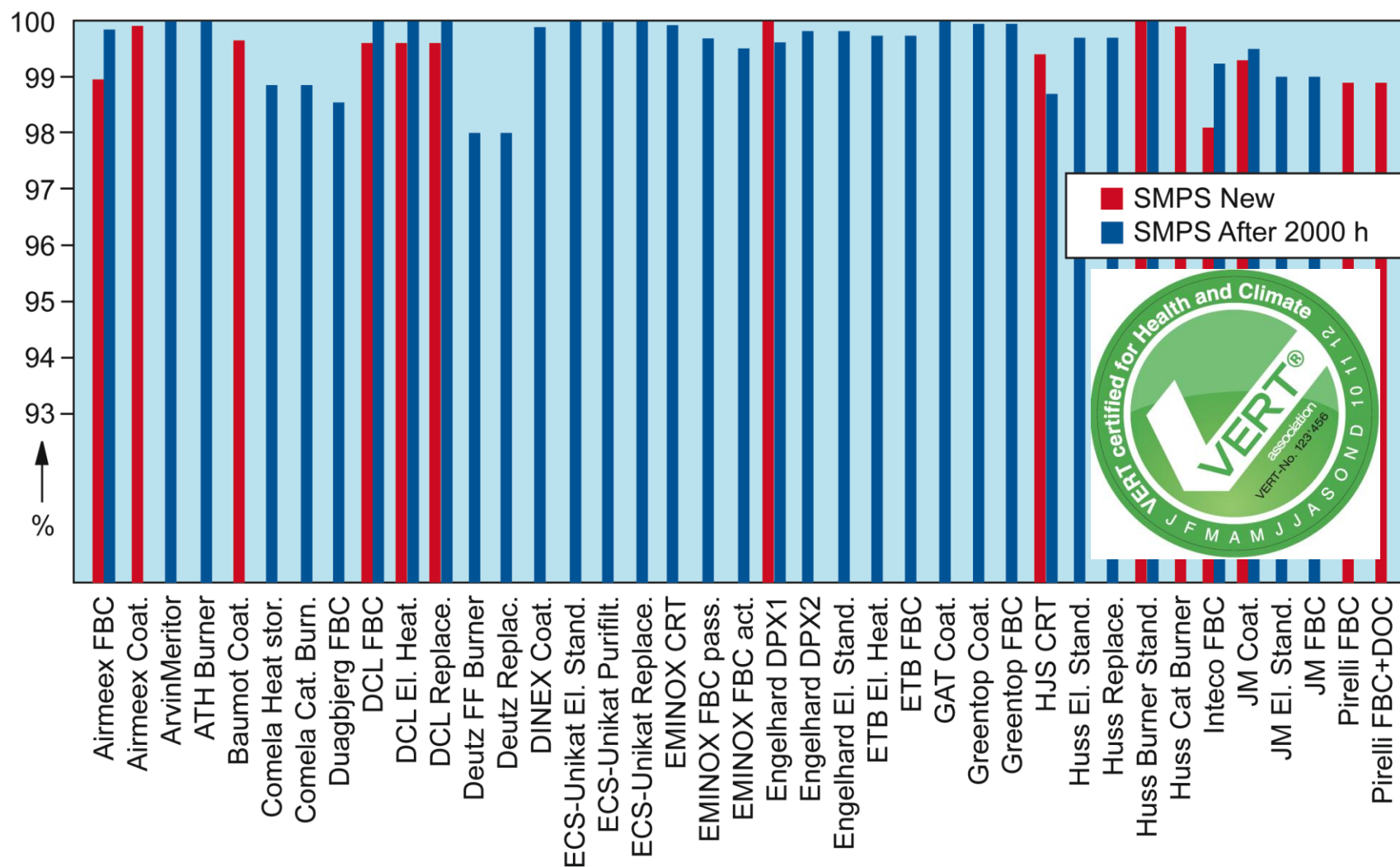




# Control by Step: Certification of Filtration

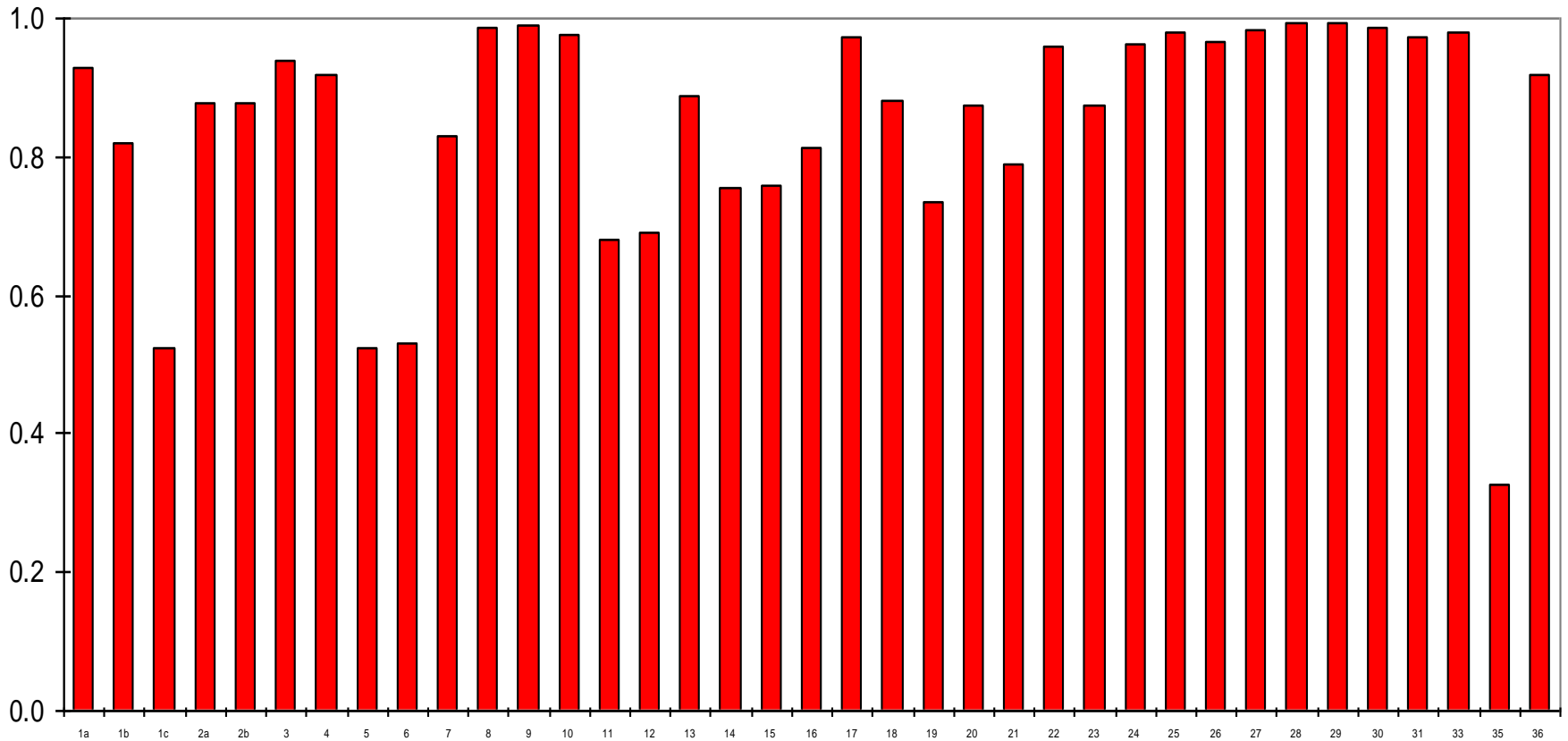
Filtration - 74 DPF Systems VERT tested

25 % > 99.8 % within size range 20-300 nm



# Improvement by De-Toxification

PAH are very effectively reduced in most filter systems

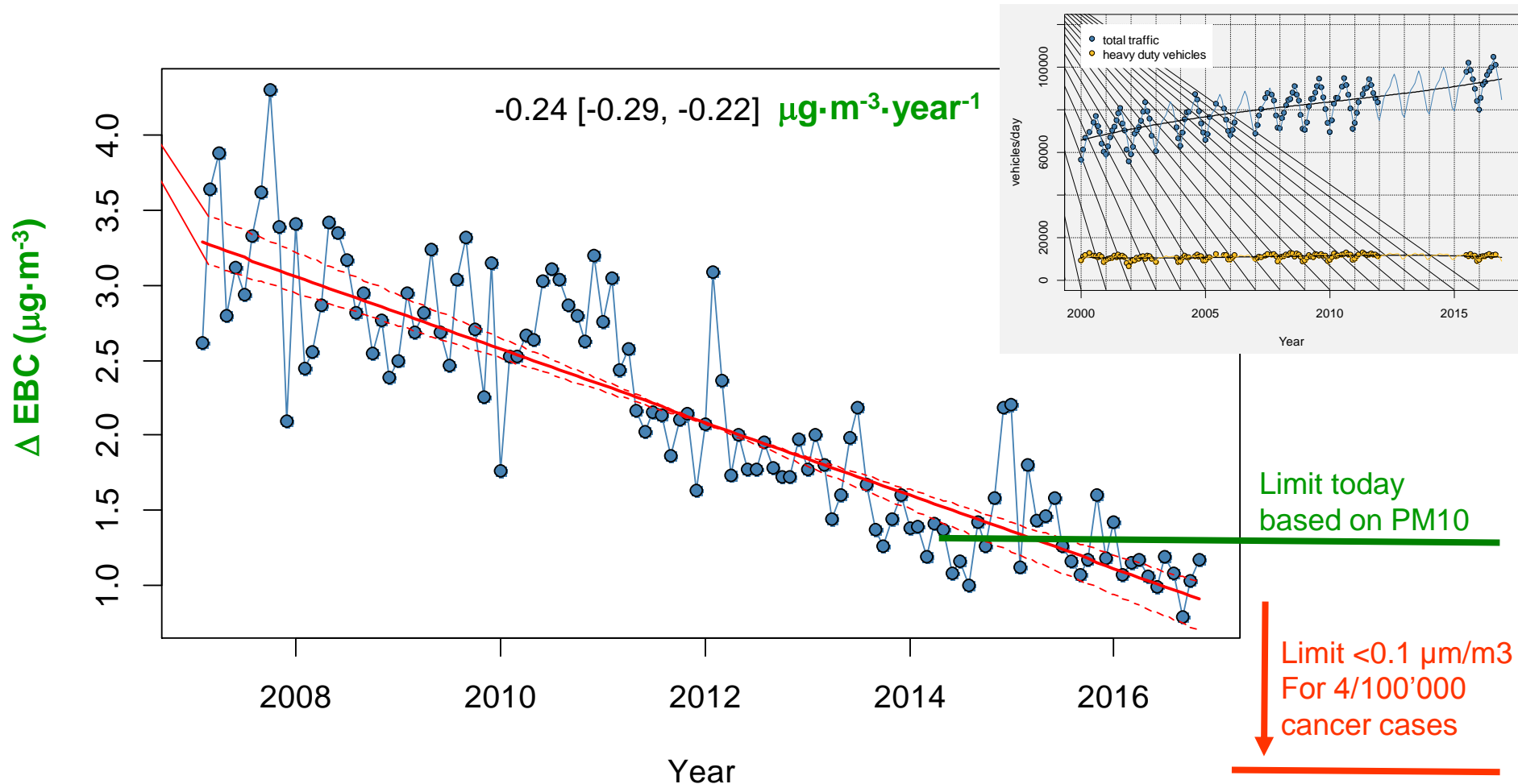


# Retrofit of Construction and Public Transport in Switzerland until 1994-2016 and OE First Fit of HDV and LDV 90% in 2000-2017



# And the Result: Cleaning the Air by DPF in Switzerland

Monitoring BC at the motorway crossing Härkingen





# Learning Curve in Switzerland

*Success need a Vision and Persistence*

*Inspiration & Transpiration*

Year	Fuel Sulfur ppm	Retrofit total	Retro- Fitters	Failures % p.a.	VERT Certified
1988	2'000	100	2	>10	-
1992	2'000	350	2	>10	-
1995	500	500	3	>10	5
1998	500	900	8	10	16
2000	350	2'500	12	8	23
2002	50	4'900	7	3	8
2003	50	6'500	11	2	22
2005	10	11'500	21	2	30
2007	10	17'500	26	2	50
2010	10	25'000	30	<2	71
2012	10	35'000	30	<2	75
2015	10	46'000	32	<2	80
2020	10	55'000	35	<1	85

**Y 2000: failure rate too high, 15 manufacturer deverified,  
2000 hrs endurance introduced**

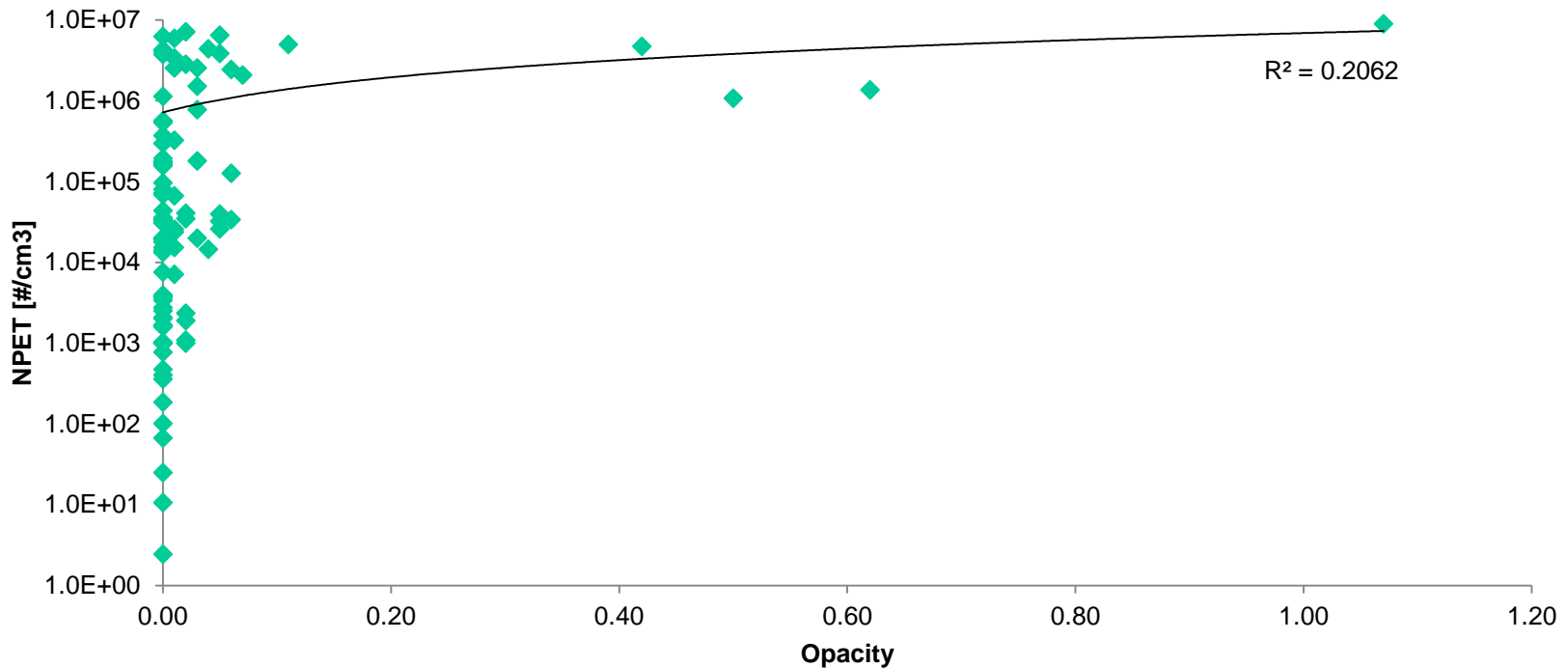
# Followers worldwide

- **EUROPE: 540'000 (2001-2015)**
- **USA : 120'000**
- **ASIA : 545'000 mainly Korea and Japan**

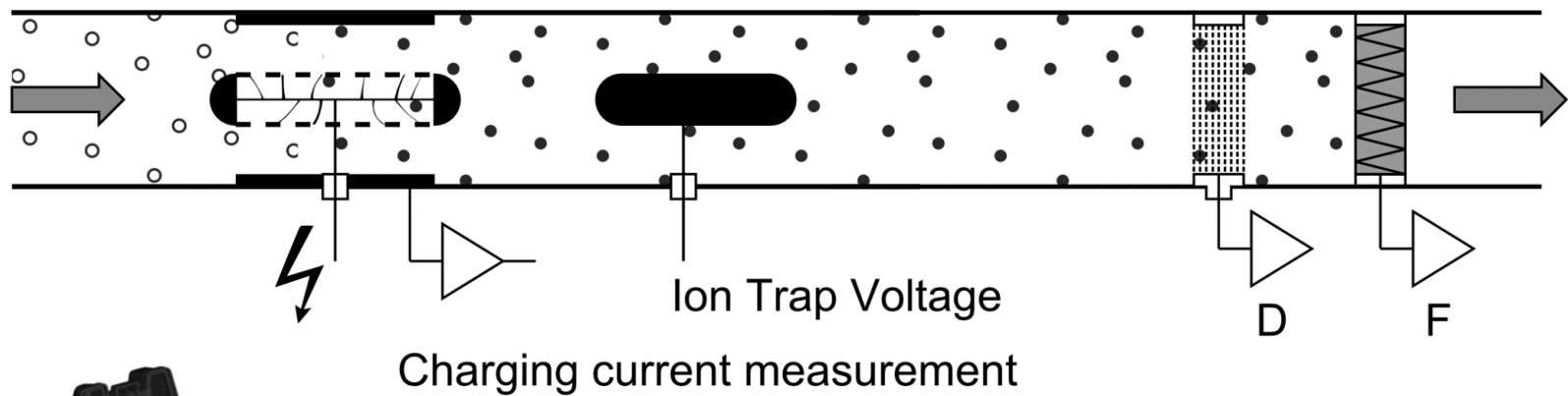
	Y2001-Y2005			Y2006-Y2010			Y2011-Y2015			Y2016-Y2020			Total
	Bus	Truck	NR	Bus	Truck	NR	Bus	Truck	NR	Bus	Truck	NR	x 1000
Switzerland	3	1	7	2	1	11	3	2	16	-	1	8	55
Germany	20			25	50		5	50				40	190
Italy	10			20			15						45
France	7			3			2					10	22
G.Britian	9	11			12			10	1			5	48
EU-Rest	15			15			15						45
EU Indoor			50			75			75			50	250
USA	20	10		12	22	2	20	28	7	10	20	10	161
Latin Amer.				3			1			10	40	10	64
Iran										8	35	2	45
Israel										4	5	2	11
Korea	10	20		20	130		20	80		20	70		370
Japan	30	30		30	30		30	30		-	-		180?
China				4	4		15	10	1	50	30	50	164?
Asia-Rest	15			15			15			25			70
Sum	139	72	57	149	249	88	141	210	100	127	201	187	
Total	268			486			451			515			
Total	1'205 (Europe: 541)												1'720

Table 2: Retrofits worldwide (x 1000)

# Correlation Opacity / Particle Number ?



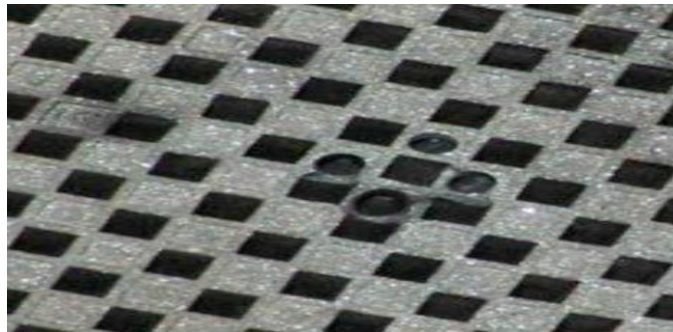
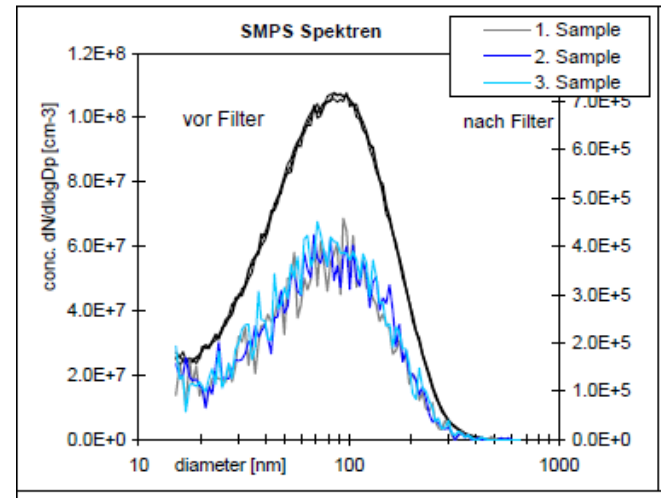
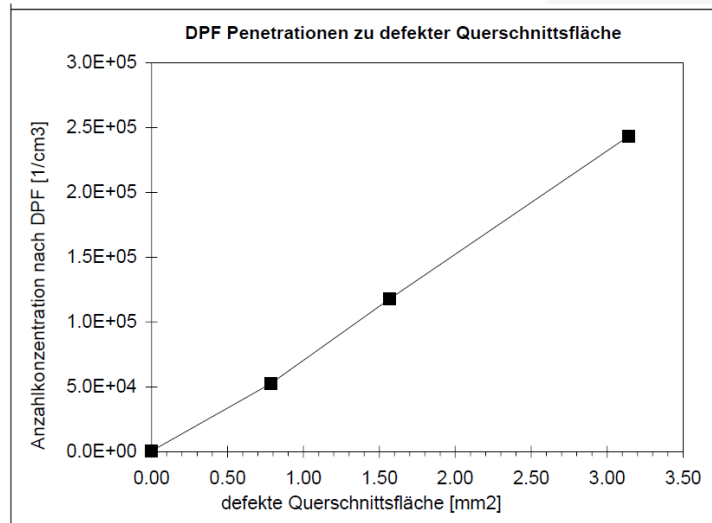
# Portable Particle Counting instruments are available





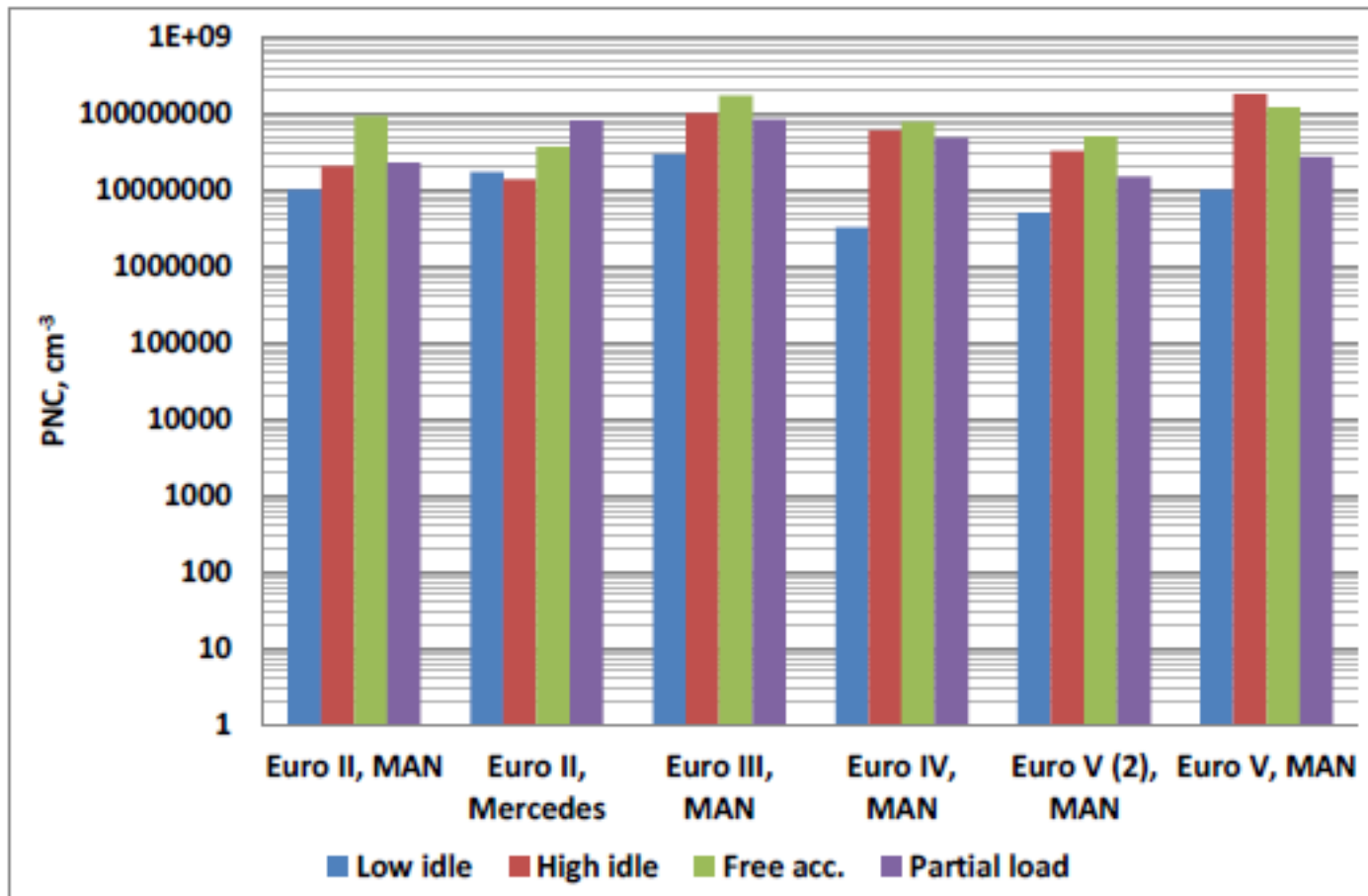
# Detect Small Failures by Number Counting

(M.Kasper ETH-NPC 2008)



# What happened in Europe and in the USA?

## PM reduction – PN stagnation



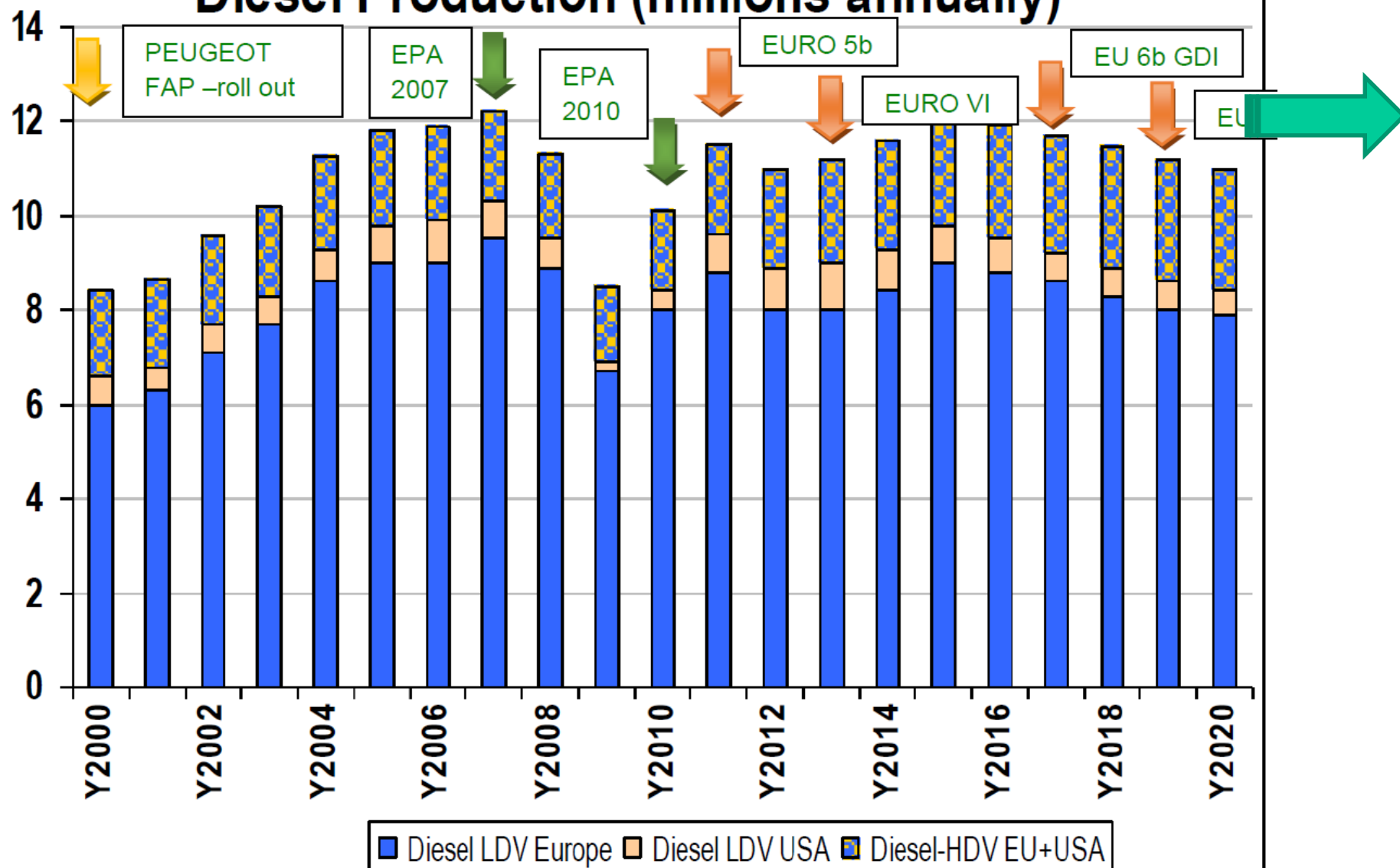
# EU adopts VERT Criteria in 2006

EU Co-Decision (Art.12, Rec.15 )

- *In order to achieve these environmental objectives it is appropriate to indicate that **particle number limits** are likely to reflect the **highest level of performance** with **particle filters** using **best available technology***
- *.. the commission shall introduce **particle number based limit values** at a level appropriate to the technologies actually being used.*

**but introduces DPF only with Euro 6/VI 2011**

# Diesel Production (millions annually)

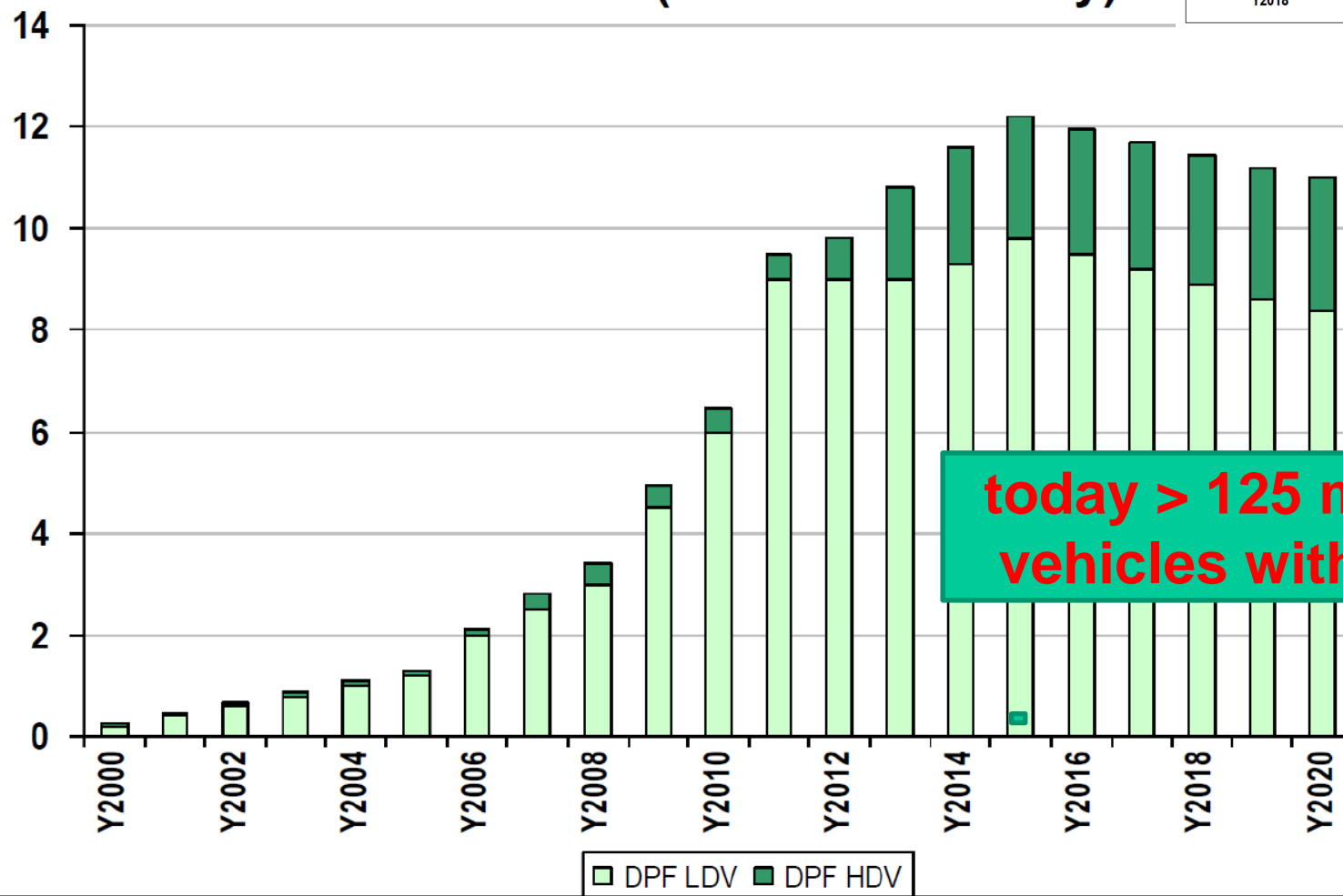




# DPF-Installations in Europe

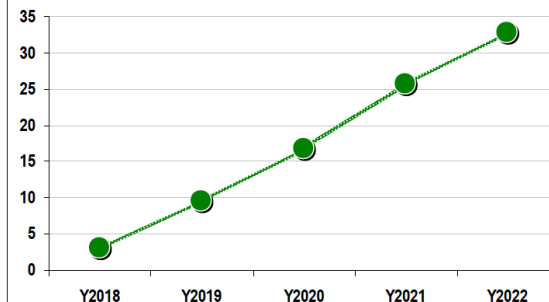
## and GPF to come

DPF Production (millions annually)



today > 125 million  
vehicles with DPF

Gasoline Filters Forecast (million units annually)

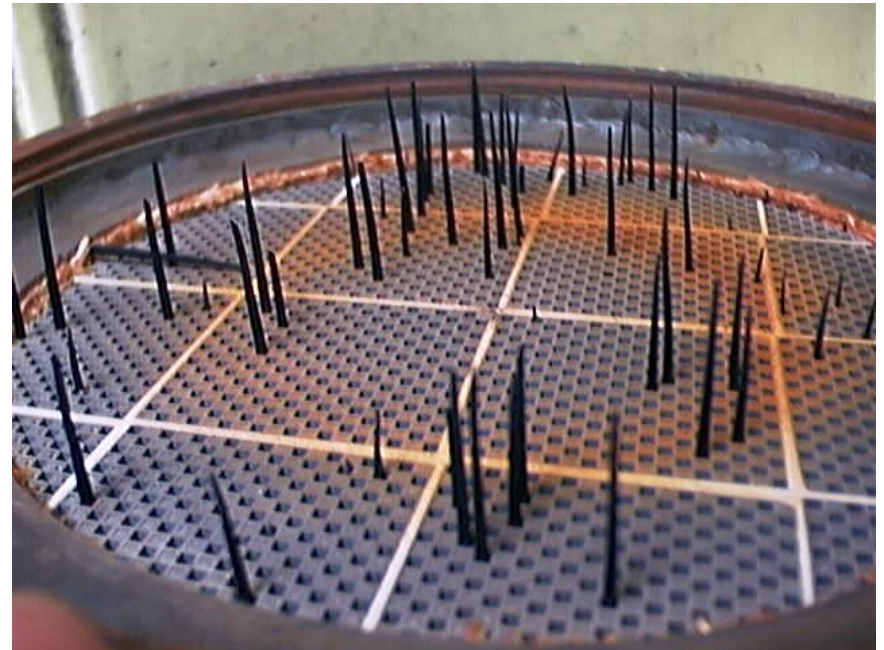


	Regeneration chart	Cross Section	Outlet Surface
10 g/L			
20 g/L			
30 g/L			

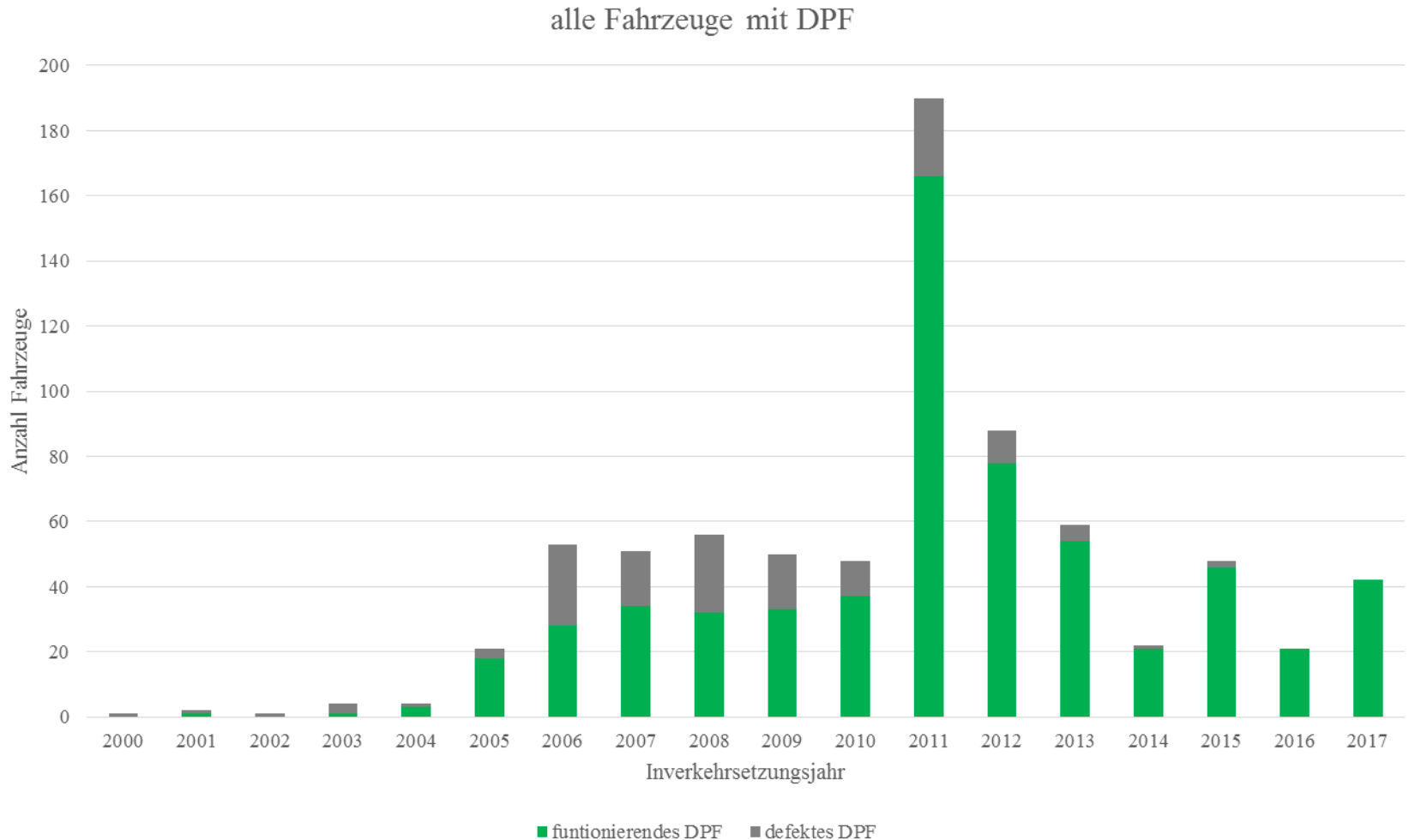
Learning by trouble  
shooting and failure  
analysis

# Regeneration interrupted

- Pyrolysis, Soot Densification, Gaphitisation
- Soot Combustion Temperature climbs up



# DPF-Failures Switzerland for different immatriculation years





# Particle Emission by all combustion engines

## Diesel

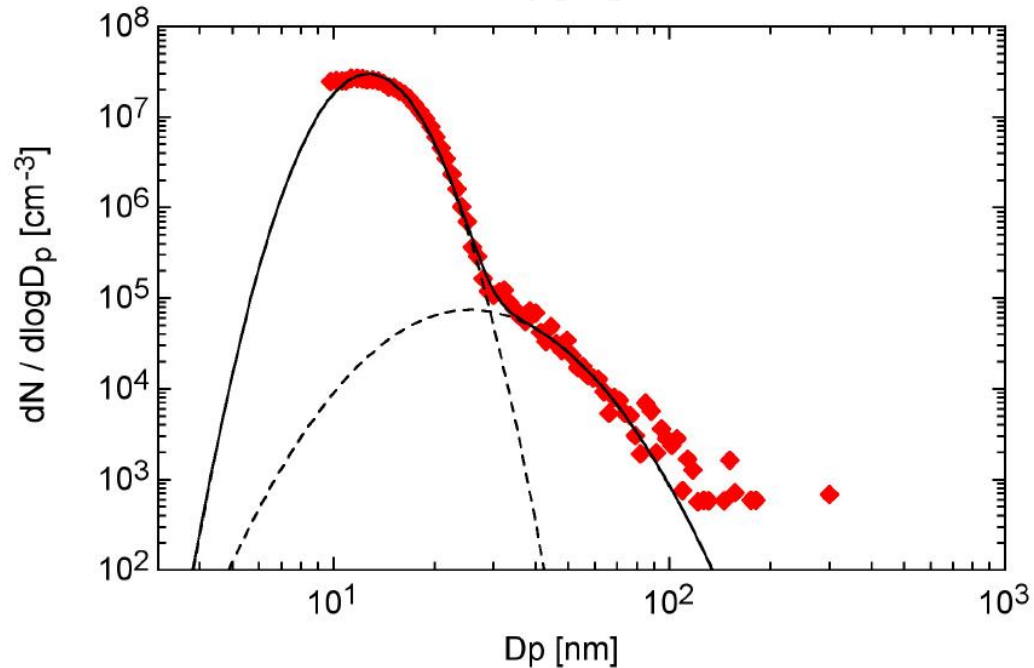
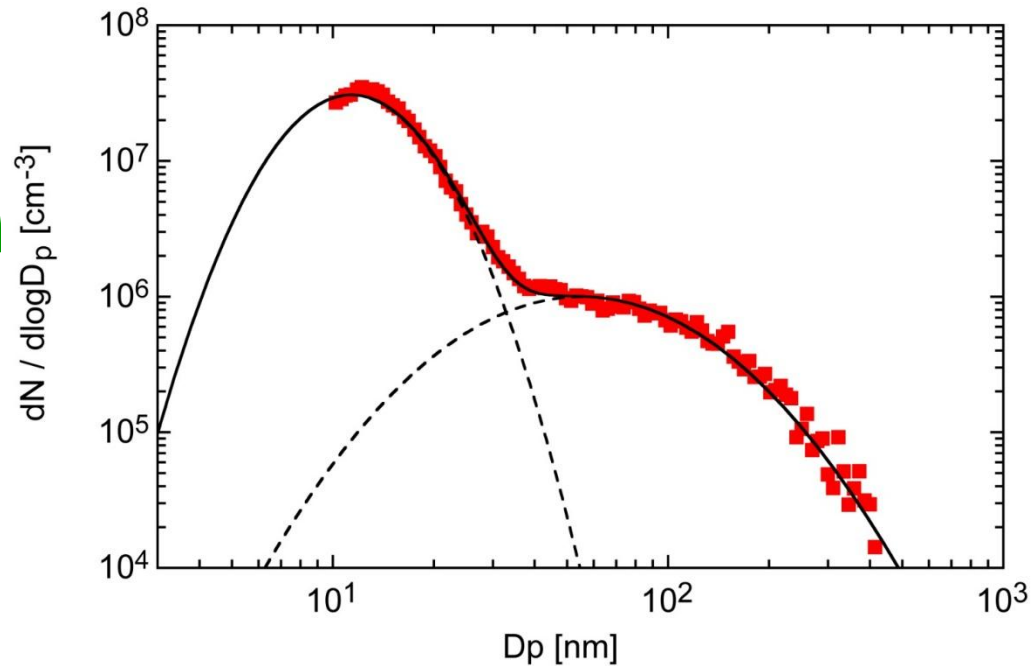
Sootpeak: 80 nm;  $10^6$

Ashpeak: 10 nm;  $10^7$

## Petrol

Sootpeak: 40 nm;  $10^5$

Ashpeak: 10 nm;  $10^7$





Teheran



Bogotá



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

Beijing



Systems for all Diesel Engines /  
Tips for Selection, Installation and Operation

All Megacities have the same  
pollution problem due to size  
and traffic and VERT is active  
to transfer technology

VERT

BEST AVAILABLE TECHNOLOGY  
IN EMISSION REDUCTION

[www.VERTCertification.eu](http://www.VERTCertification.eu)

### Die saubere Lösung

- ## Particulate filters for diesel engines used underground

# The Challenge

## Combustion engines emit toxic air contaminants:

**PN:** solid ultrafine particles coated with **PAH** and **metal** oxides

→ < 500 nm penetrates alveoli, brain and placenta

→ heart attacks, strokes, **cancer**, Alzheimer, Parkinson

→ >4000 premature death in Switzerland

→ health cost > 1000 CHF per kg emitted PN

**NOx:** toxic but **no mortality** at today's traffic concentration

**CO:** toxic but **no mortality** at today's traffic concentration

**HC:** toxic but **no mortality** at today's traffic concentration

→ **focus on elimination of PN**  
**and lower limit values by factor 10**



# Conclusion

***Diesel with VERT DPF are the cleanest cars  
- best available technology –  
and they clean the breathing air in cities  
from particles emitted by petrol engines***

	Emission NOx	Emission PN<500 nm Auspuff	Emission PM gesamt	Emission CO2	GWP Emission + BC + CH4	Reich Weite km	Masse	Verbrauch Energie	Ökologie Lifecycle Herst.- Betrieb -Ents.	Ausfall Rate	Kosten Inv.Betr.- Infrastr.			
Diesel + SDPF	1	1	1	1	1	1000	1	1	1	1	1	1	1	
Otto +TWC ohne GPF	0.8	100	1.1	1.2	1.25	700	0.95	1.2	1	1.2	1	1.1	0.9	1
CNG + TWC ohne GPF	0.8	100	1.2	0.6	1.2	400	1.2	1.2	1.2	0.8	1	1.2	1.2	5
Hibrid-Diesel ohne SDPF	1	1000	1.1	0.6	0.6	1000	1.1	0.6	1.2	0.6	1.2	1.3	1.3	1
Hibrid-Otto ohne GPF	0.8	100	1.1	0.7	0.7	700	1.1	0.7	1.2	0.7	1.2	1.3	1.3	1
E-Mobil bis 100'000 km	0	0	1.2	1	0	300	1.20	?	2	1	2	3	2	20

# VERT-Team *power on demand*



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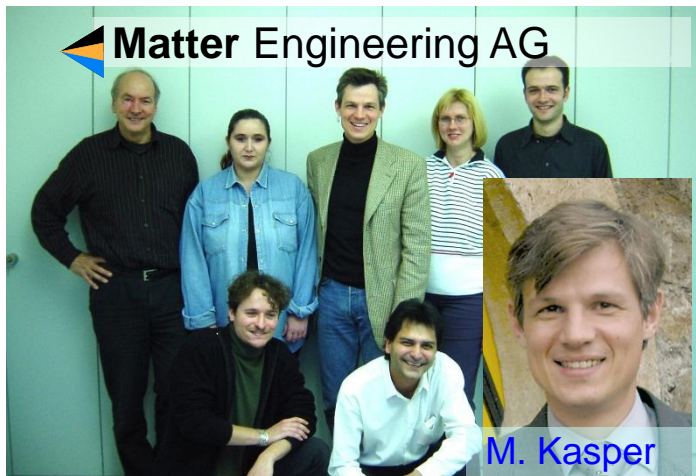
 **AKPF**




 **krebsliga schweiz**

**ETH** H.C. Siegmann  
Eidgenössische Technische Hochschule Zürich  
Swiss Federal Institute of Technology Zurich

**DieselNet**



 **Matter Engineering AG**

M. Kasper  
& sein Team

**u<sup>b</sup>**

**UNIVERSITÄT  
BERN**

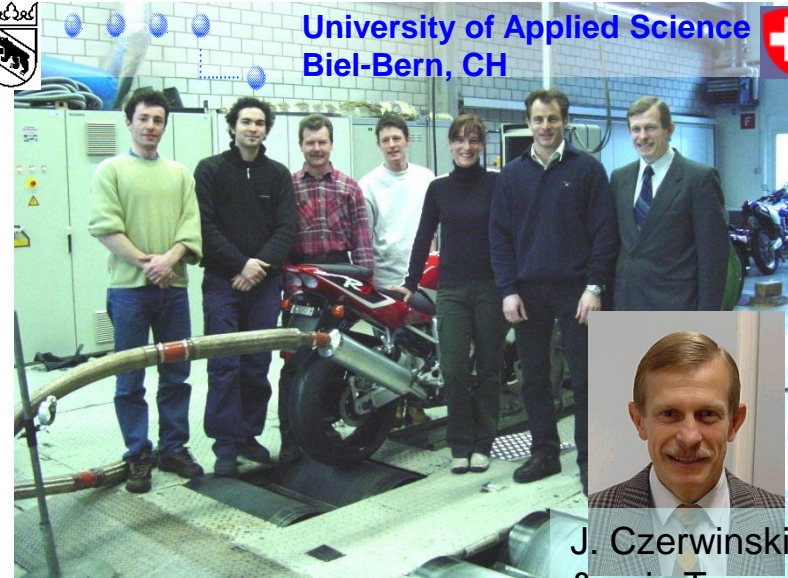


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& sein Team



**Es kommt drauf an, was hinten  
rauskommt**

**Helmut Kohl**

***Thanks for your  
Attention***



**any**

**Questions ?**

**dont hesitate  
to ask**

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