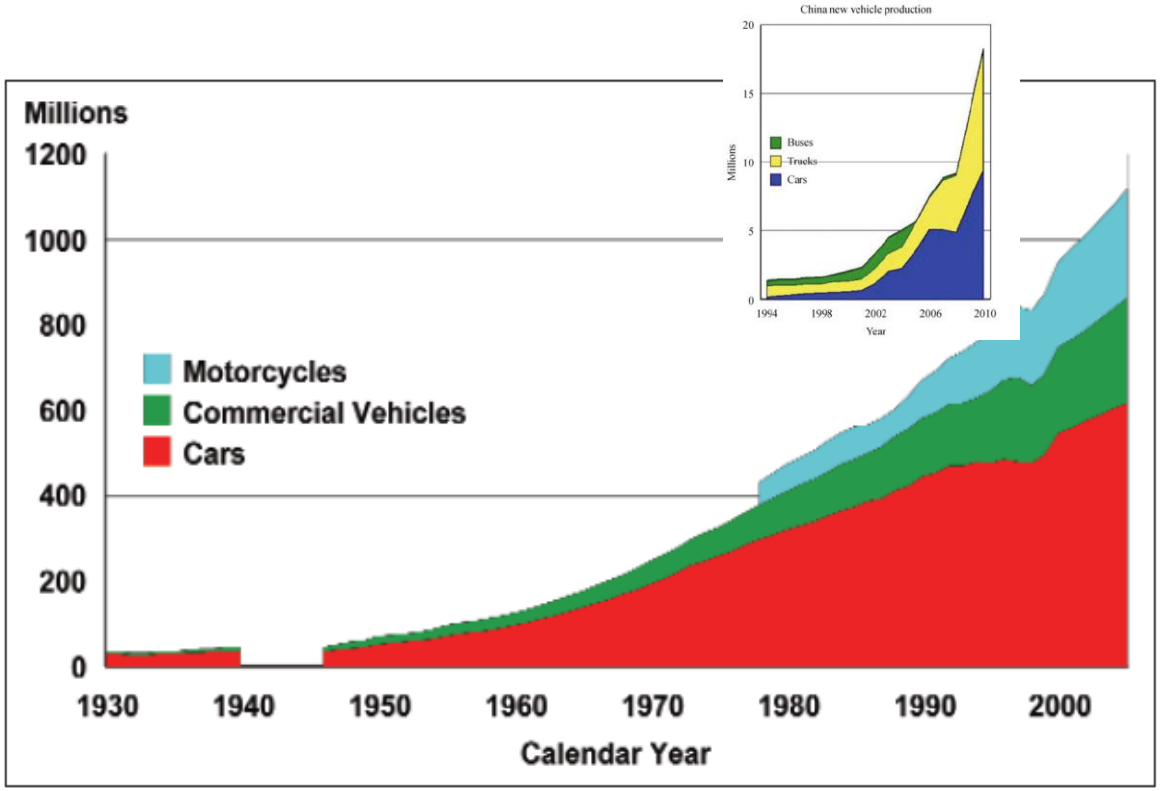
STRATEGIES TO MITIGATE AIR POLLUTION / SEDEMA + ITP + CAF
Mexico City 18 &19 January 2017

Policy Priorities to eliminate Toxic Emissions from Urban Traffic

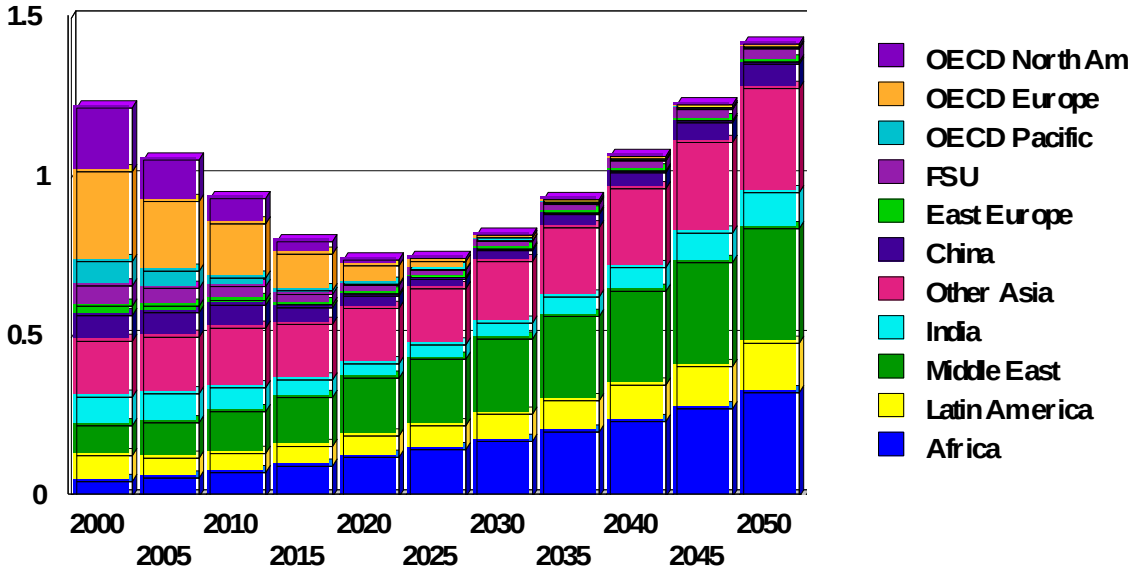
Andreas C.R. Mayer

Society
needs
Mobility



Mobility produces toxic air contaminants

source: ICCT



We must confess
Formation of Toxic Emissions in Diesel (and Petrol) Combustion not avoidable

Combustion time in ICE is only milliseconds

Mixture of air and fuel can never be perfect

Combustion is > 99% complete ! Efficiency very high

but this remaining 1 %

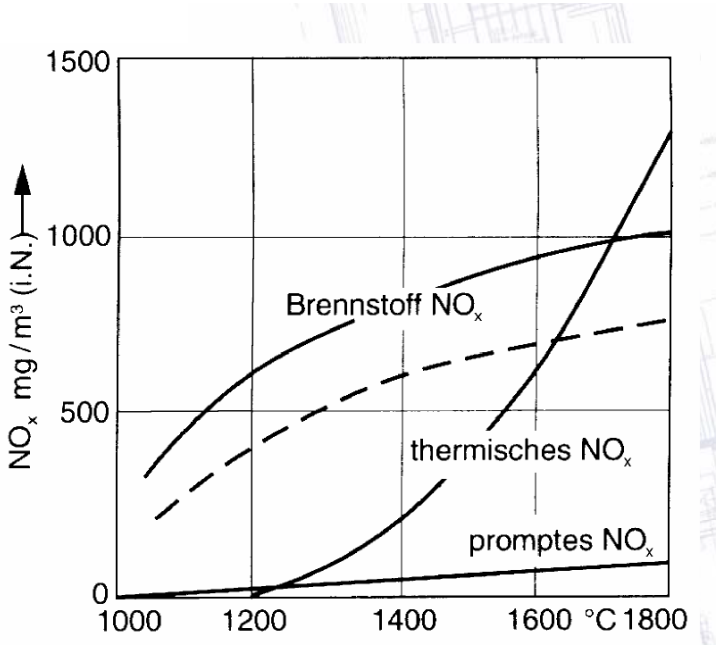
forms higly toxic, even carcinogenic substances

which are emitted in the center of the cities

and this is the dominant part of urban air pollution

Why is Formation of Nitric Oxides unavoidable

- Air contains 70% N_2
- Combustion of Fuel with Air produces much NO, some NO_2 and a little N_2O
- ***Zeldovich*** showed that this accellerates **> 1200°C**



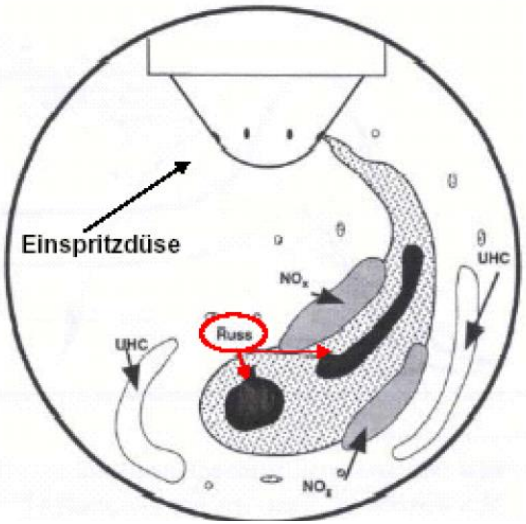
The Challenge

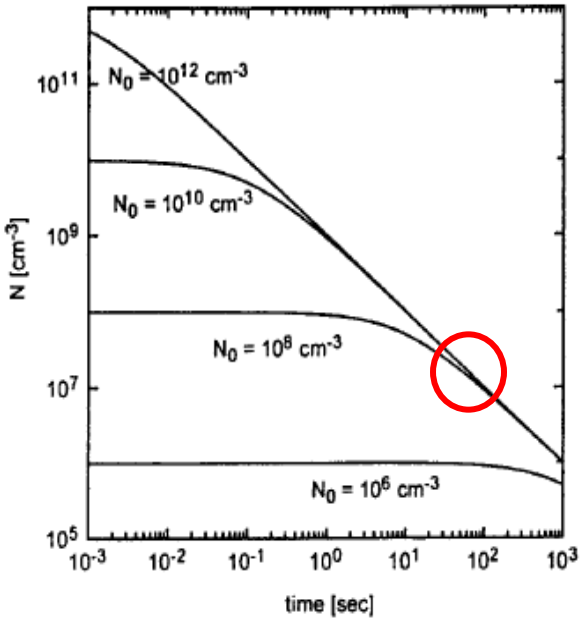
- *Improving combustion needs increased temperatures - Carnot*
- *Modern engines emit higher NOx than older ones*

→ de-coupling of combustion and emission control permits good combustion, low CO2 and eliminating emissions

Why is Formation of UFP unavoidable

- **Source one** is the fuel injection inhomogeneity forming soot
- **Source two** is lubrication oil metal compounds
- **Source three** is friction metals, vaporized and renucleated





Primary particles have a diameter of 20 nm they agglomerate very fast

We measure about 1-10 Mio P/cc with old and with new engines in the tail pipe

Formation of additional Toxics like PAH, Nitro-PAH, CO, SOx and trace substances is also unavoidable

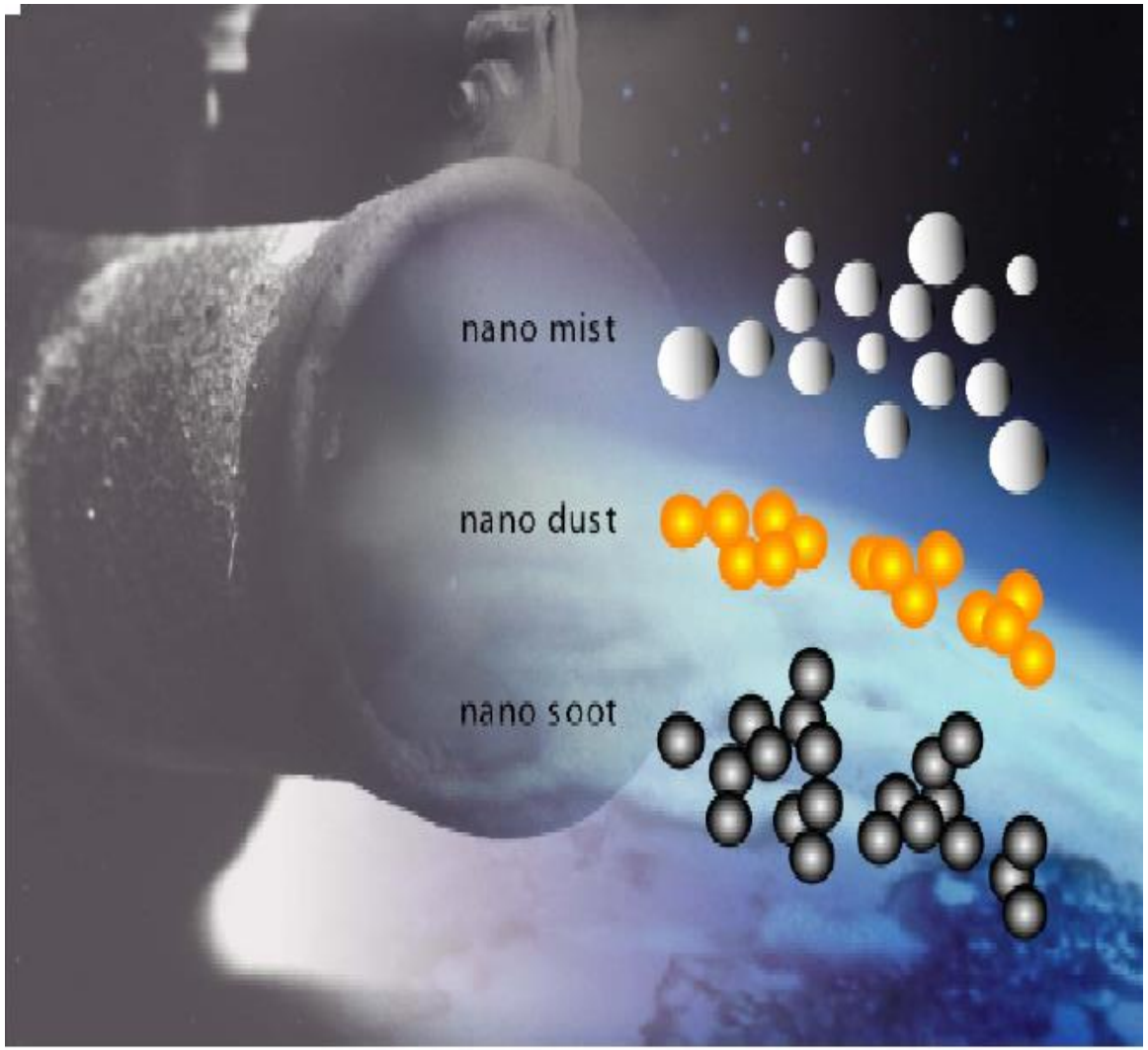
- Exhaust gas contains thousands of different chemical substances, provides high temperature, air excess and long residence time DPF and SCR so the exhaust system can produce «de novo» new toxic substances
- **we have to detect these toxic substances and provide technical solutions to eliminate them**

Engine Exhaust Gas contains

Soot Particles
Ash Particles
Liquid Droplets

Gases:
CO, HC, NOx
PAH, Nitro-PAH

and many trace substances

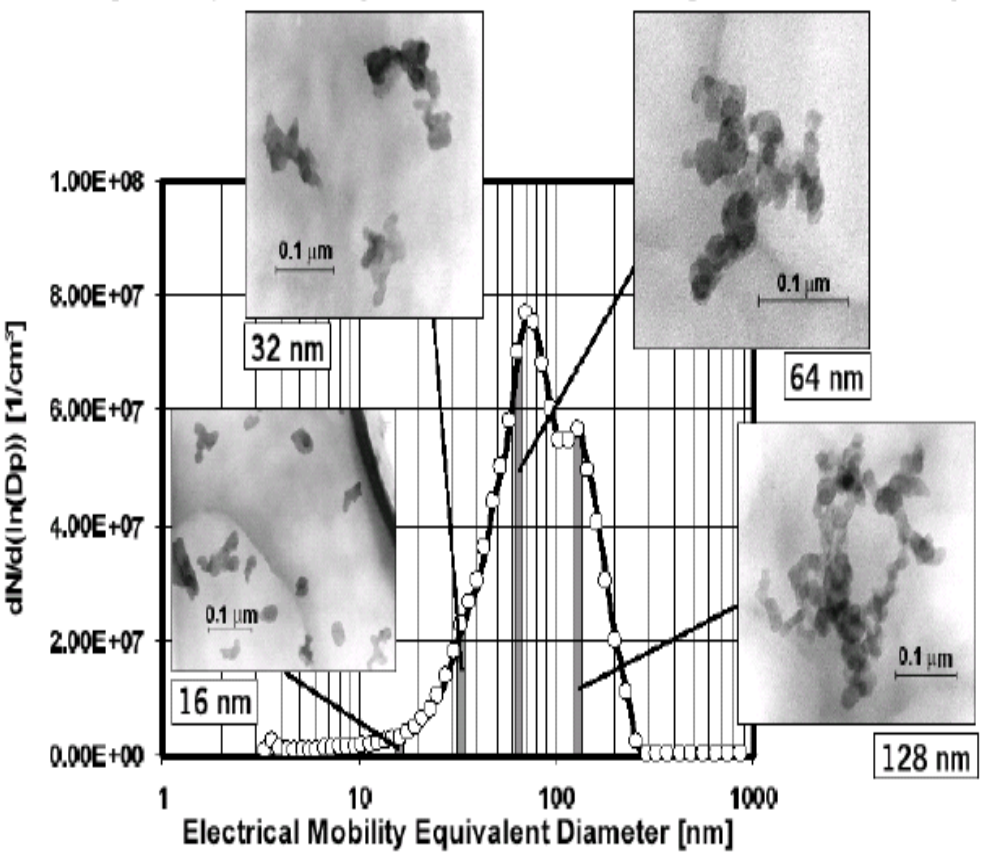


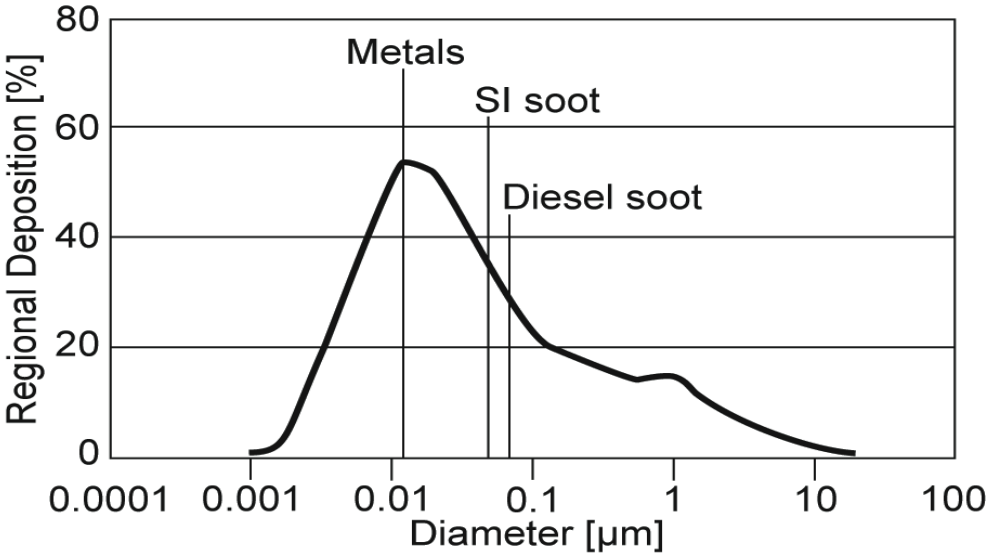
To conclude on Priority

1. We must define the most important **Toxic Air Contaminant TOC** for the area in Question
2. We must have a very effective mitigation strategy for this TOC, which can be **applied to the whole fleet onroad and nonroad**
3. We must immediately start with **a very broad implementation** for new and in-use vehicles
4. We must adapt the monitoring metrics and methods
5. We must not forget to prepare implementation for Priorities 2 and 3

The weakest size range
of the Lungs
is the strongest emission
range of the Engines
and the weakest size
range of Filters

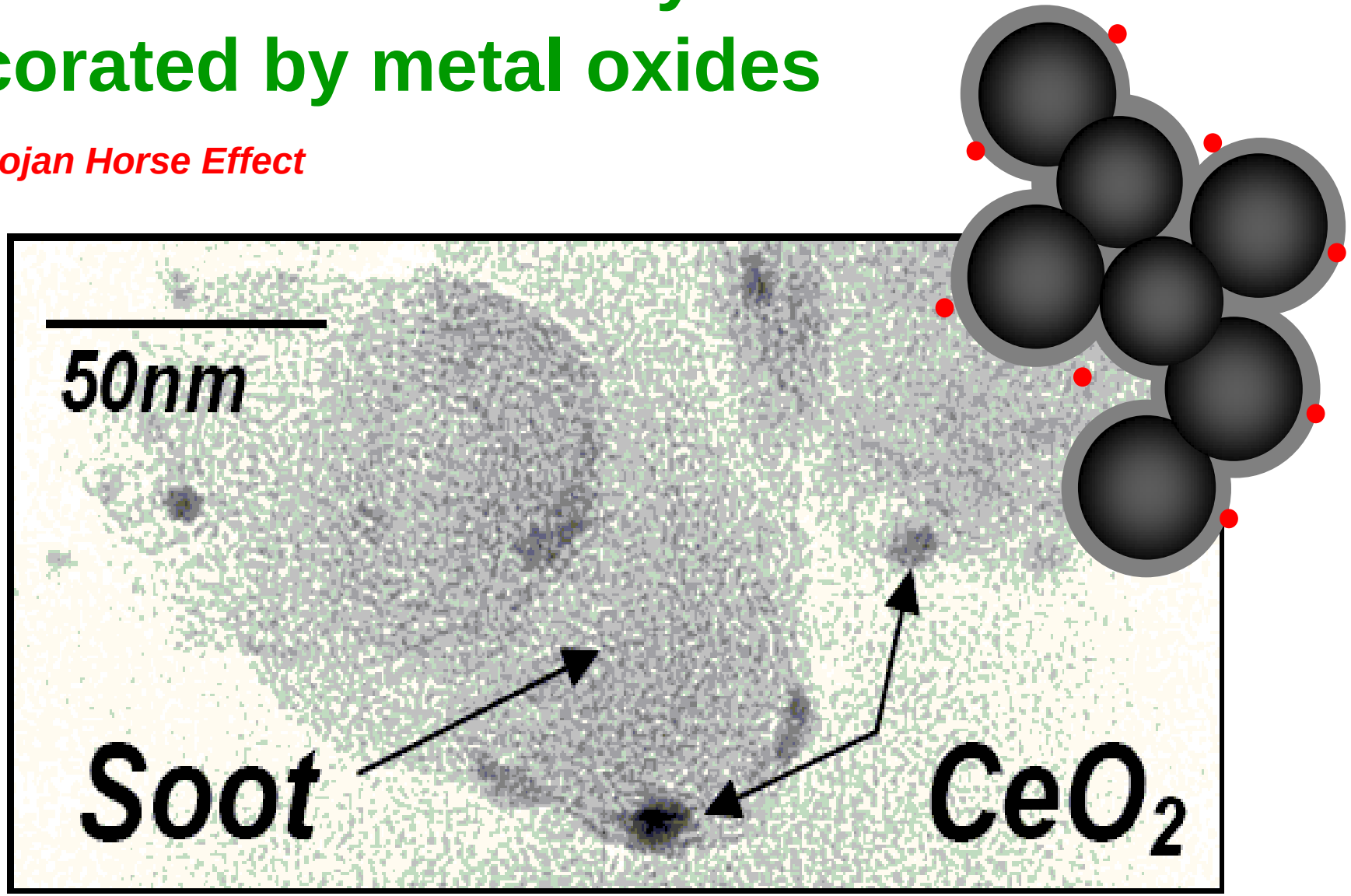
The Lung is an open door for engine emitted particles





Particles are coated by PAH and decorated by metal oxides

The Trojan Horse Effect



Particle Emission of ICE

Diesel

Sootpeak: 80 nm; 10^6

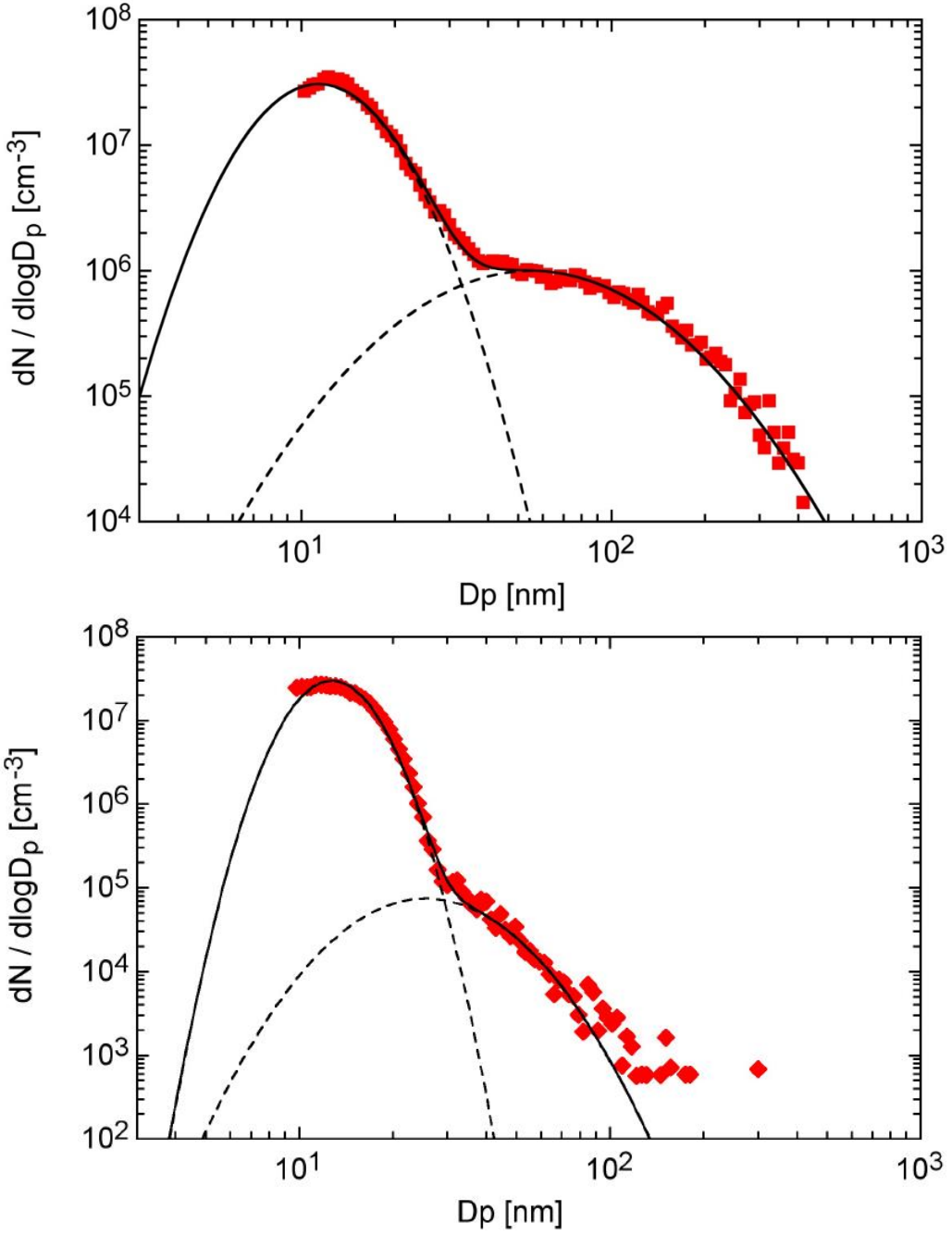
Ashpeak: 10 nm; 10^7

Petrol

Sootpeak: 40 nm; 10^5

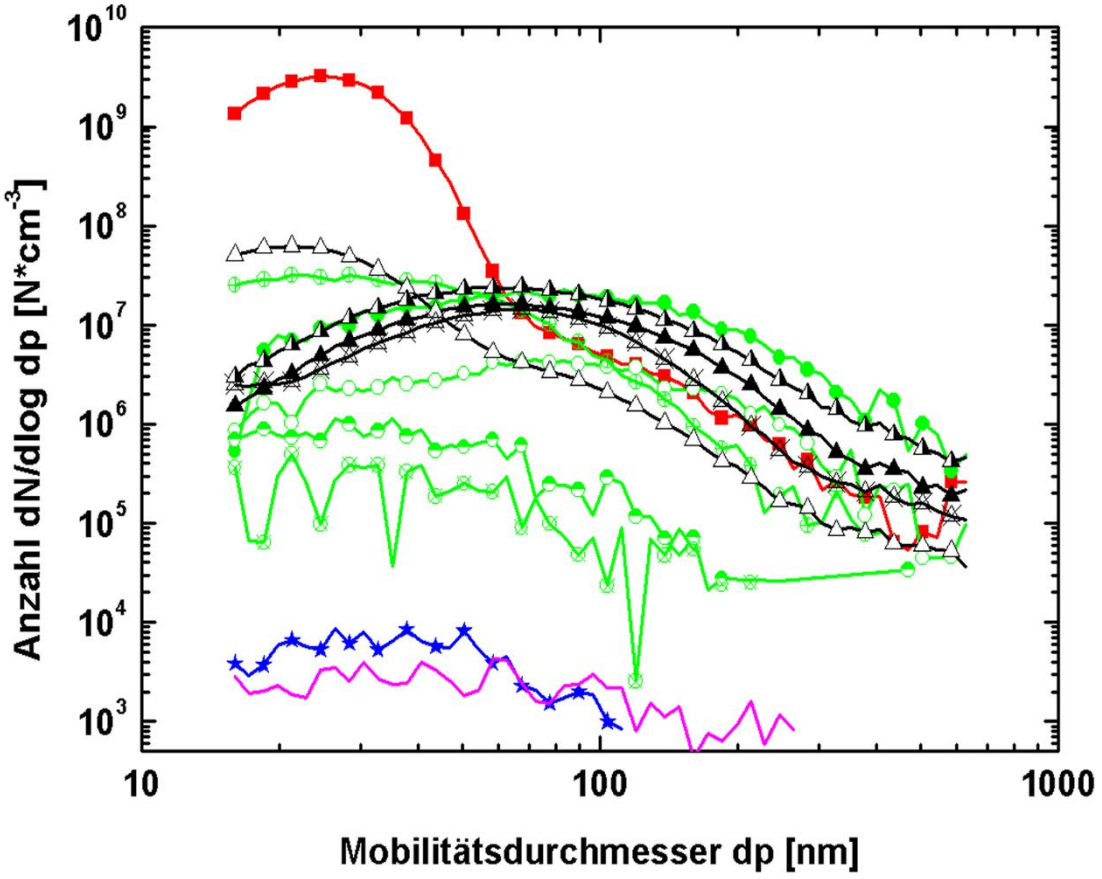
Ashpeak: 10 nm; 10^7

Soot and Ash Peaks



First Tests 1999-2002 ETH-VERT

Comparison Diesel/Petrol; LD/HD/Marine



(A) 2-Takt-Schiffsmotor 25% Last,105 U/min

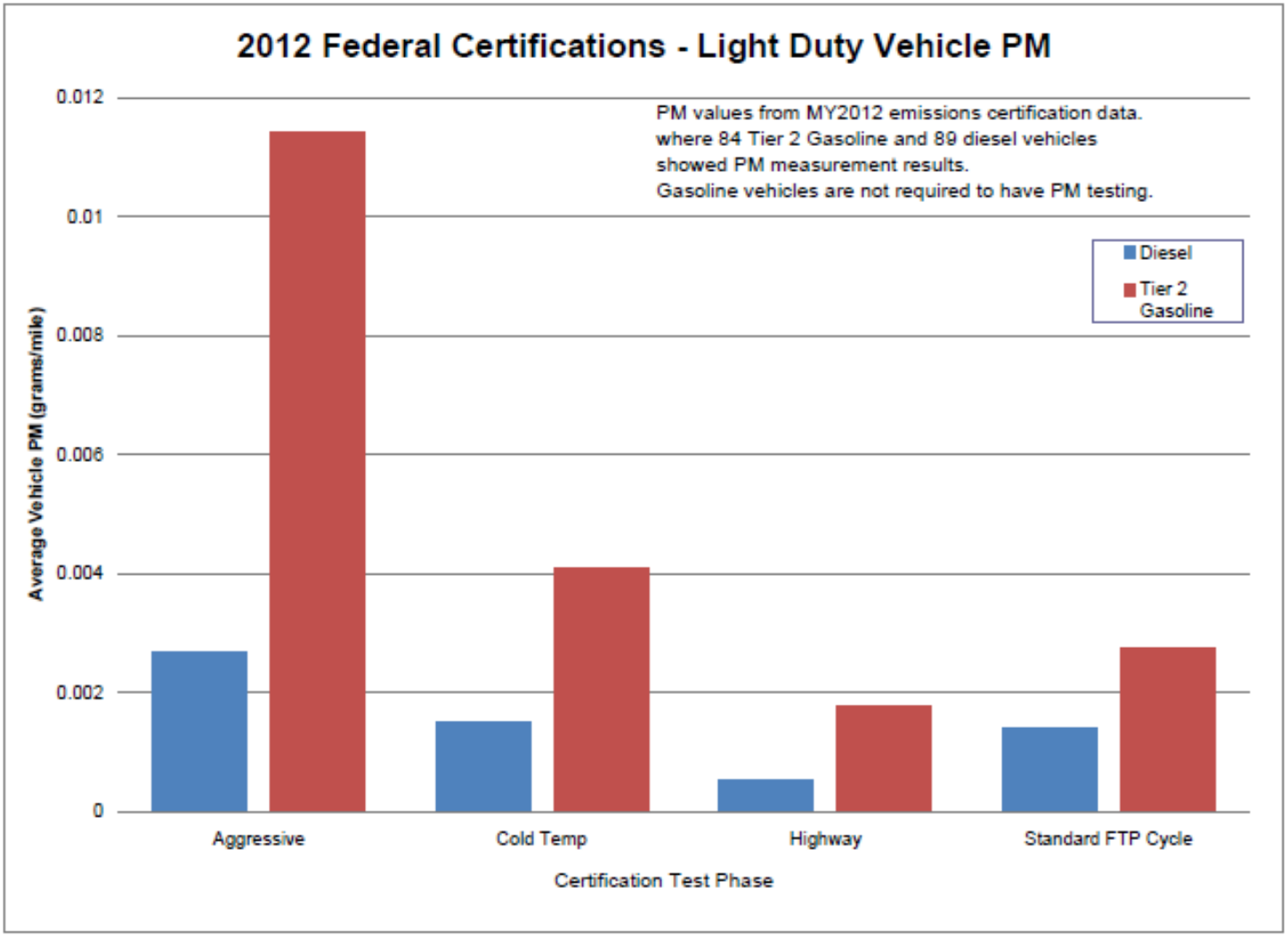
(B) Dieselmotor 25% Last, 500 bar, 1180 U/min, tB 6°vOTP
(C) Dieselmotor 25% Last, 1200 bar, 1180 U/min, tB 12°vOT
(D) Dieselmotor 25% Last, 1200 bar, 1180 U/min, tB 12°vOT
(E) Dieselmotor 75% Last, 900 bar, 1740 U/min, tB 5°vOTP

(F) Ottomotor Schichtladung DI, 25% Last, 2000 U/min
(G) Ottomotor Homogenbetrieb DI, 50% Last, 2000 U/min, λ
(H) Ottomotor Homogenbetrieb SR, 50% Last, 2000 U/min,
(I) Ottomotor Homogenbetrieb SR, 50% Last, 2000 U/min, λ
(K) Ottomotor Homogenbetrieb SR, 50% Last, 2000 U/min,

(L) Stationärmotor Gasbetrieb, 50% Last, 1500 U/min

(M) Umgebungsluft

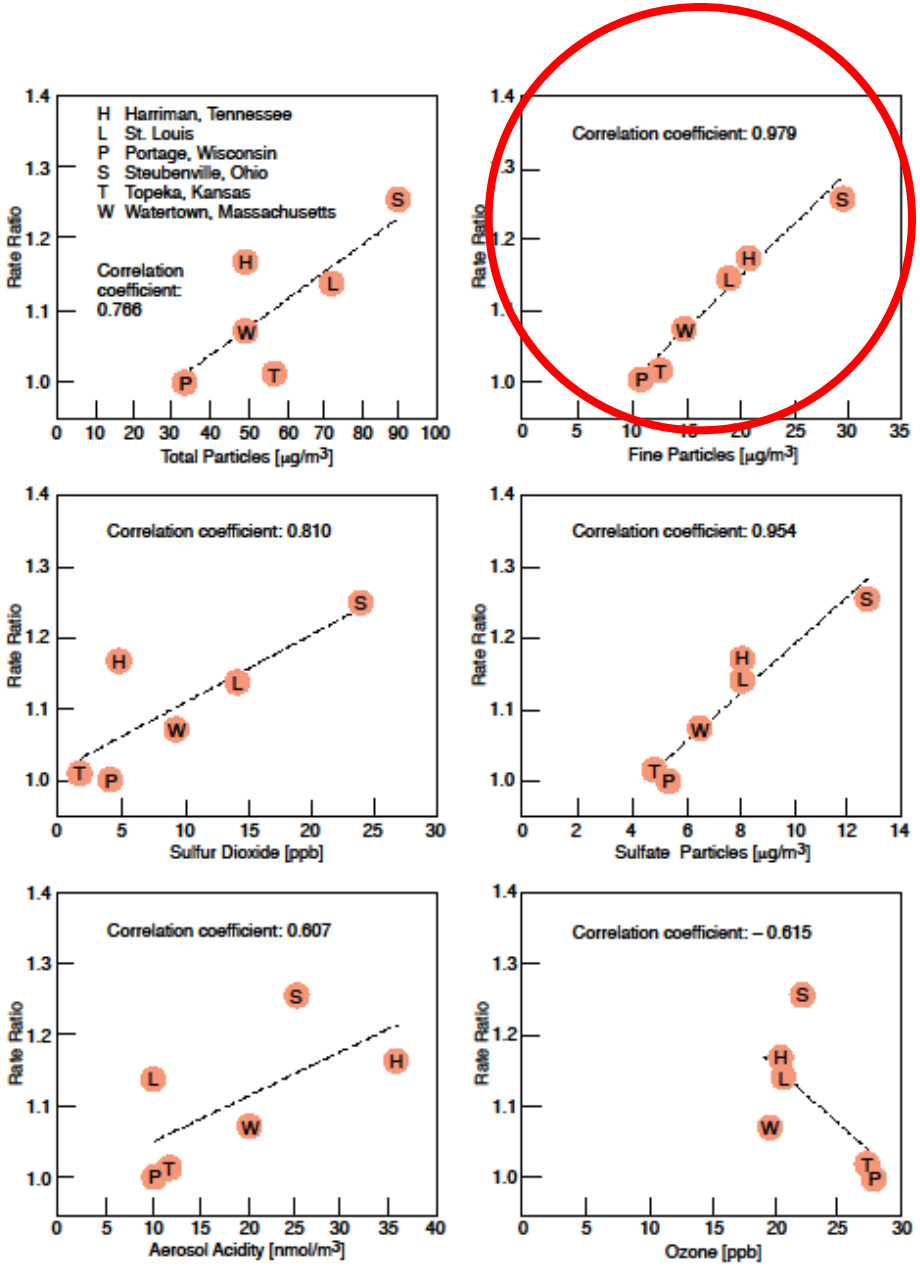
New Jersey Fleet Statistics MY 2012



Which Substance correlates to Mortality ?

6-Cities-Study
USA 1978-93
15‘000 cases

Correlation
with fine particles only:
soot + sulfate + metal oxides



Source: Dockery NEJM 1993

Health Impact Worldwide → Priority for PN

newest numbers by WHO 2012, Max Planck and Harvard 2015

ALRI: acute lower respiratory illness
IHD: ischaemic heart desease
CEV: cerebrovascular desease
COPD: obstructive pulmonary desease
LC: : lung cancer

10'000 killed per day - 20'000 by 2050 **(> 50 per day in Mexico City);**

WHO region	Year	Population ($\times 10^6$)	Mortality attributable to air pollution (deaths $\times 10^3$)						
			$PM_{2.5}$					O_3	Total
			ALRI < 5 yr	IHD ≥ 30 yr	CEV ≥ 30 yr	COPD ≥ 30 yr	LC ≥ 30 yr	COPD ≥ 30 yr	
Africa	2010	809	90	55	77	11	2	2	237
	2050	1,807	158	185	262	38	5	12	660
Americas	2010	930	0	44	8	4	7	5	68
	2050	1,191	0	75	15	7	11	11	119
Eastern Mediterranean	2010	602	56	115	86	12	5	12	286
	2050	1,021	66	321	246	37	13	40	723
Europe	2010	867	1	239	95	13	27	6	381
	2050	886	1	307	156	18	37	11	530
Southeast Asia	2010	1,762	64	327	250	124	15	82	862
	2050	2,332	104	865	807	419	48	227	2,470
Western Pacific	2010	1,812	19	299	794	209	107	35	1,463
	2050	1,861	16	413	1,120	309	155	57	2,070
World	2010	6,783	230	1,079	1,311	374	161	142	3,297
	2050	9,098	346	2,166	2,604	828	270	358	6,572

PN

NOx

WHO 12.Juni 2012

„*Diesel Exhaust Carcinogen Class 1*“

237 y

International Agency for Research on Cancer

World Health Organization

PRESS RELEASE
N° 213

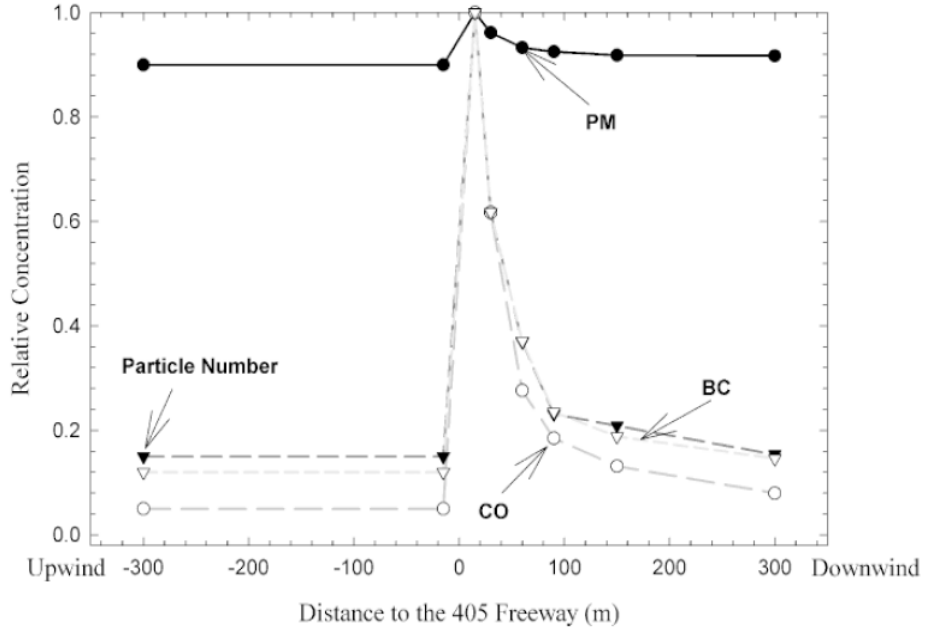
12 June 2012

IARC: DIESEL ENGINE EXHAUST CARCINOGENIC

Lyon, France, June 12, 2012 -- After a week-long meeting of international experts, the International Agency for Research on Cancer (IARC), which is part of the World Health Organization (WHO), today classified diesel engine exhaust as **carcinogenic to humans (Group 1)**, based on sufficient evidence that exposure is associated with an increased risk for lung cancer.

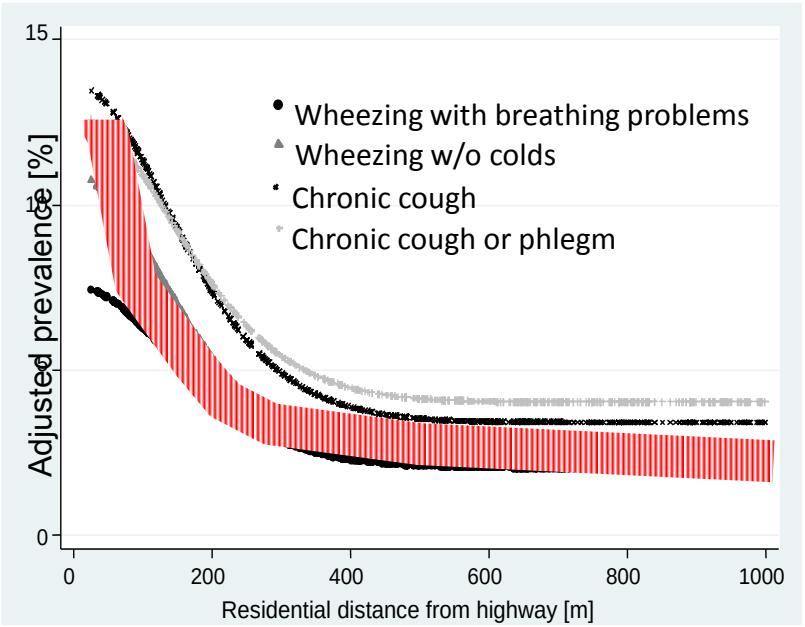
UFP-Concentration and Health Impact
depend strongly on distance to high traffic roads

Particle Number Distribution near Roads



Hinds, Zhu et al, University of California, L.A.
Size distribution of UFP neas Los Angeles 405
Air & waste management Sept. 2002

Respiratory Health Impact near Roads



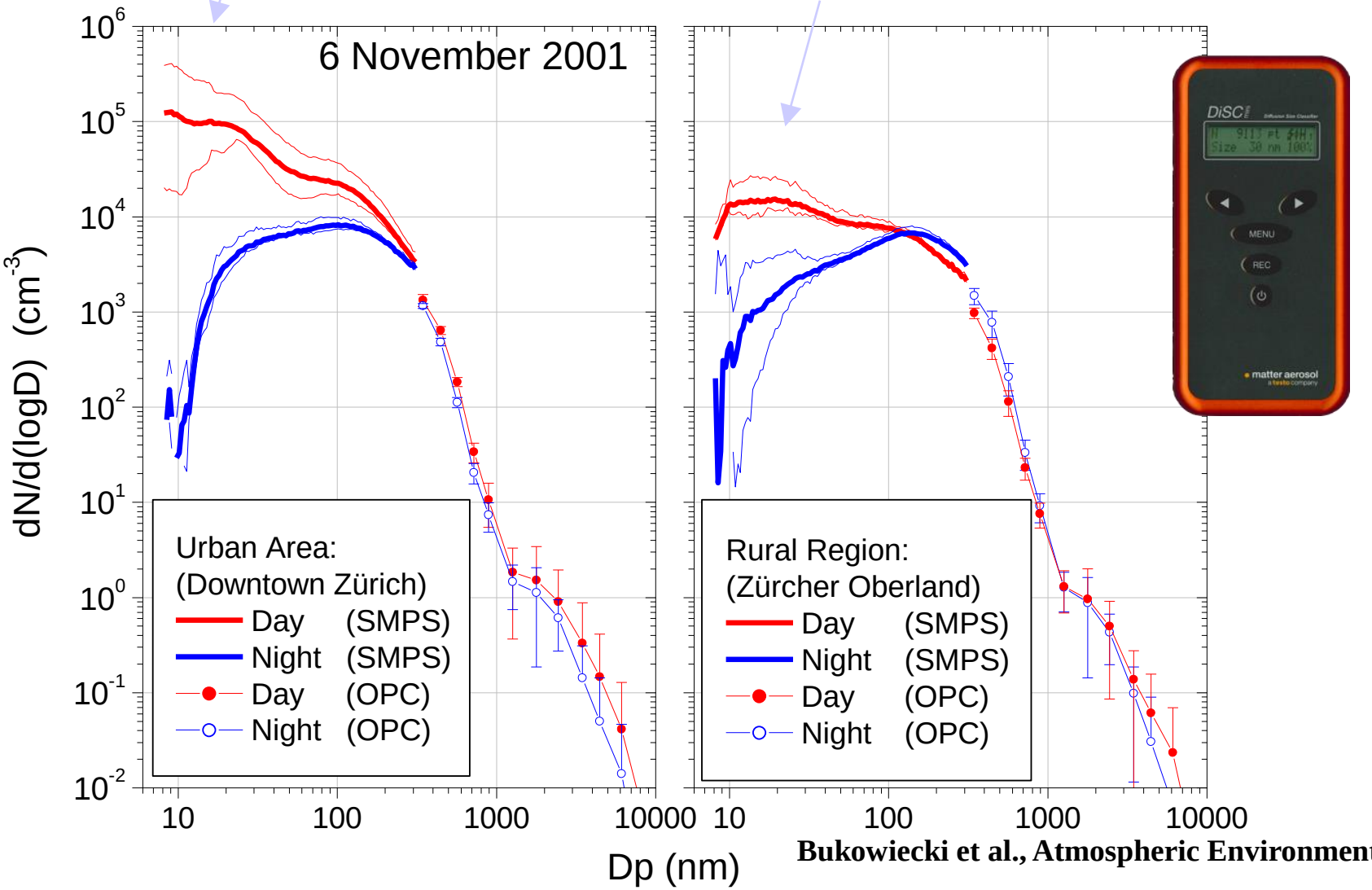
Hazenkamp, Künzli et al Swiss Tropical and Public Health Institute, TPH Impact of highway traffic on repiratory health in adults Environmental Health 10/2011

Living near major roads and the incidence of dementia, Parkinson's disease, and multiple sclerosis: a population-based cohort study in Toronto – Lanzet January 2017 – see comments of Lilian Calderón, Mexico

Ambient Aerosol Number/Size – Distribution

City (Zürich) and Coutry (Zürcher Oberland)

but they are not part of the AQ-Monitoring



Bukowiecki et al., Atmospheric Environment, 2002

Toxicity of solid Nanoparticles UFP

- UPF is a carcinogen,
- has no no-effect level
- penetrates alveoli and reaches brain and placenta fast
- causes Alzheimer and probably Parkinson – *L.Calderón*

→ Eliminate – highest Priority

Limits

- 10 µg/m^3 - WHO defined as PM 2.5
- 12 µg/m^3 - EPA defined as PM 2.5 – annual mean
- 20 µg/m^3 - EU defined as PM 2.5
- 20 µg/m^3 - Switzerland defined as PM 10
- 5 µg/m^3 - CARB defined as BC (?)
- 10^4 P/cc – proposal Switzerland – corresponds to 10 µg/m^3

Toxicity NO_2

NO_2 is not a carcinogen, but a «normal» toxic substance with a no-effect level defined by the max.exposure level

but a precursor of Ozon and of photochemical smog

US-EPA NAAQS 27.Sept.2016 for 1 hr-averaged exposure

- 200 ppb (390 µg/m^3) first airways responsiveness for asthmatics
- 100 ppb remains national 1 hr ambient air limit value
- 53 ppb for primary+secondary

Switzerland

- 52 ppb for ½ hr-average of one year

EU

- 104 ppb for 1 hr-average of one year

EU-working place

- MAK = 500 ppb (8hrs); lowest resposiveness level 1000 ppb

In contrast to the ever repeated statements of engine industry the emission reduction potential of IC engines is very limited

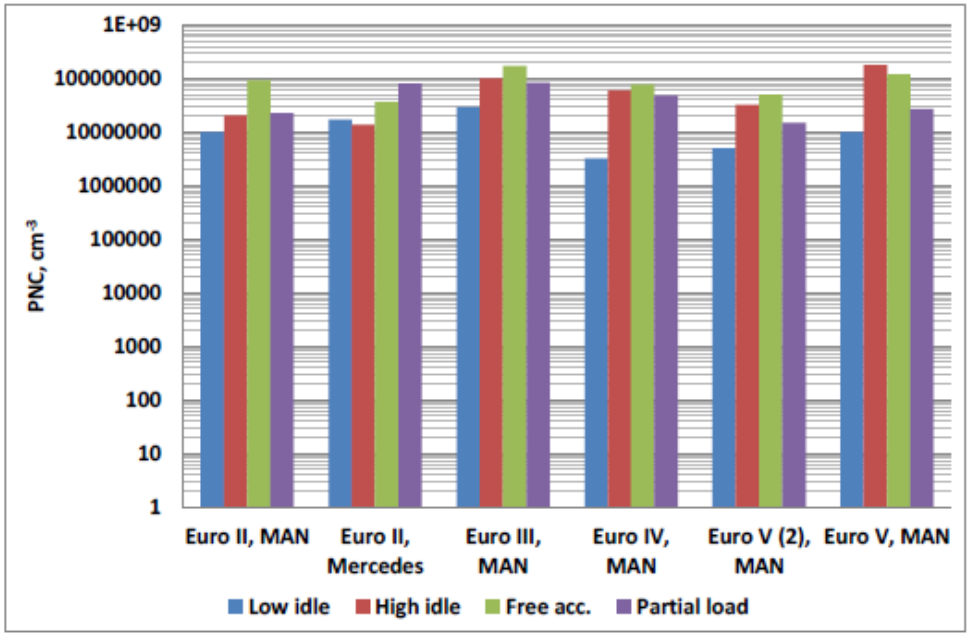
Petrol engines are high emitters and were only cleaned by the 3WC aftertreatment – John J.Mooney 1970 – still they emit high PN and the 3WC let PN pass – GPF is needed

Diesel engines need DPF to «eliminate» PM/PN-emissions from fuel, lubrication oil and wear.

Diesel Engines also need oxidation catalysis DOC to eliminate PAH, Nitro PAH and other highly toxic substances

Diesel engines need DeNOx to reduce NO2 and NO → SCR

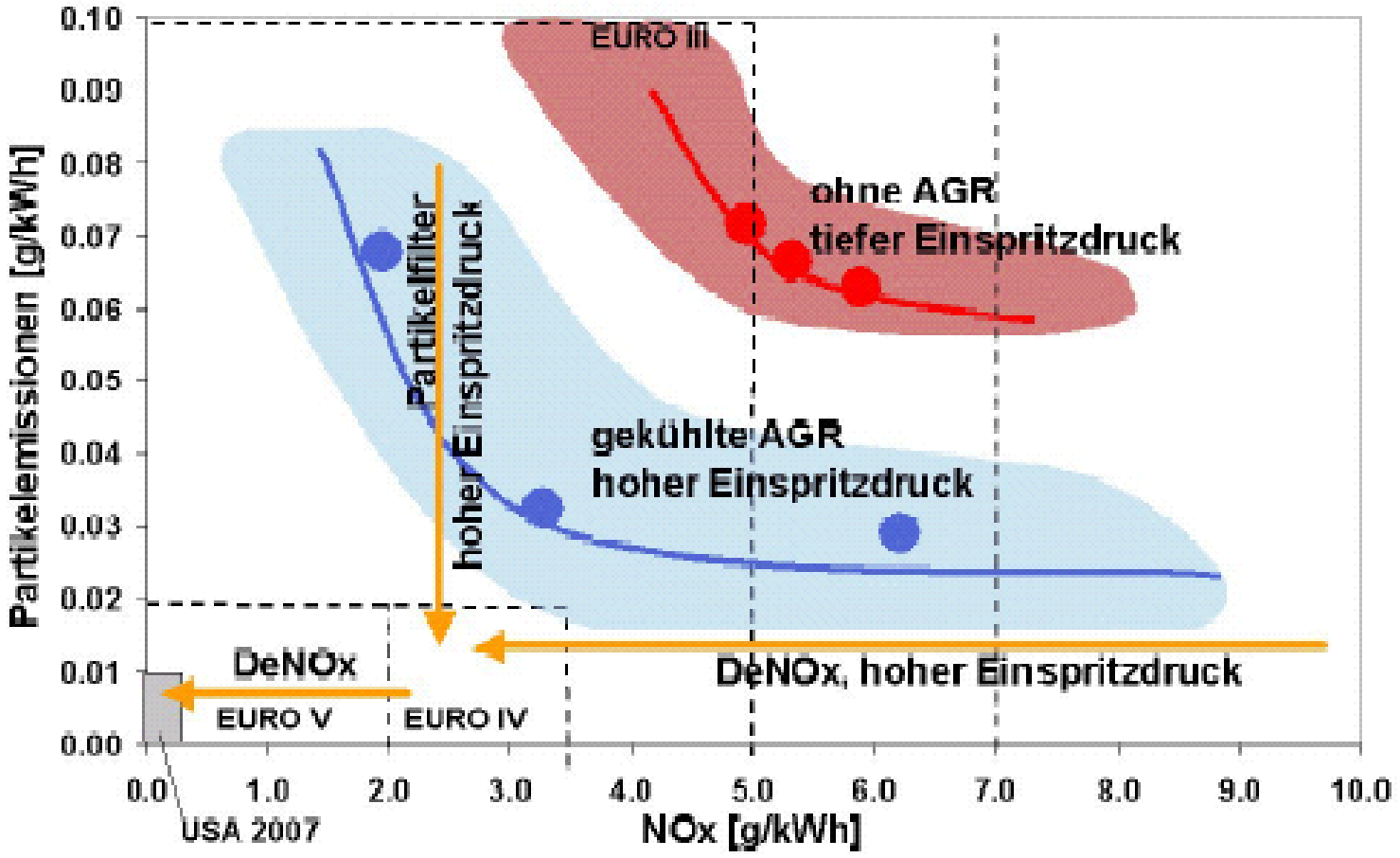
Engine Combustion Development was so far not able to eliminate Particle Emissions



PM has been reduced
but PN was not changed,
particles are smaller
→ **more toxicity**

NOx has been reduced
but NO_2 increased
→ **more toxicity**

Internal Engine Measures unsufficient
→ Aftertreatment is required



Conclusion on European Level

EU CO-Decision (Art.12, Rec.15 - 2008)

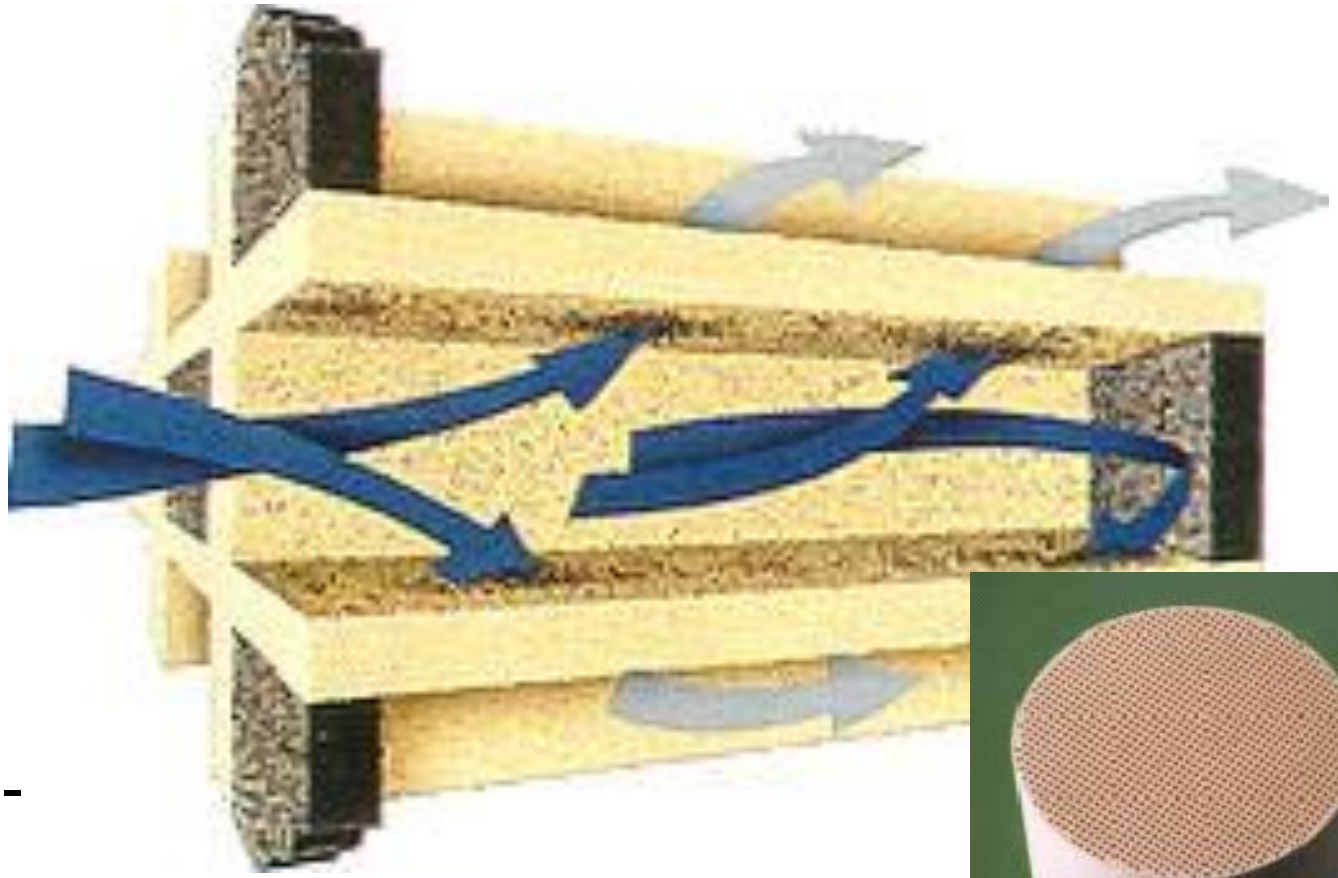
- In order to achieve these environmental objectives it is appropriate to indicate that particle number limits are likely to reflect the highest level of performance with **Particle filters** using best available technology
- .. the commission shall introduce particle number based limit values at a level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

→ Iran follows EU and adopted the same philosophy in 2014

The good News: we have a Toolbox of very efficient Exhaust Gas Cleaning Devices by Aftertreatment

- DOC Diesel Oxidation Catalyst
- SCR Selective Catalytic Reaction
- EGR from downstream DPF for light load DeNox
- LNT Lean NOx Trap
- DPF Diesel Particle Filter

Classic Wall Flow Filter
(since 1982)



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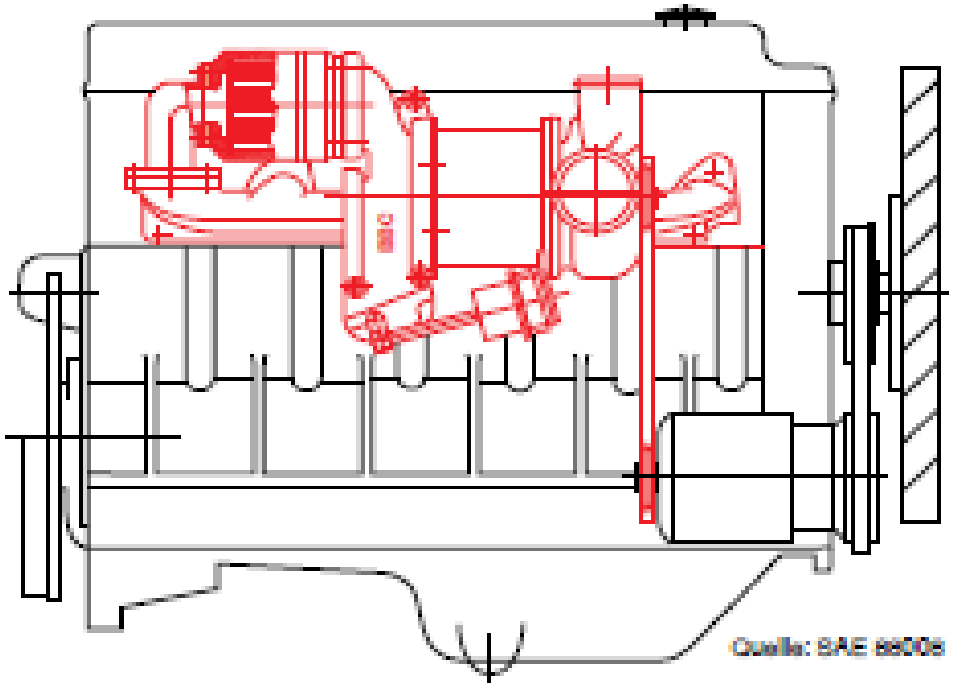
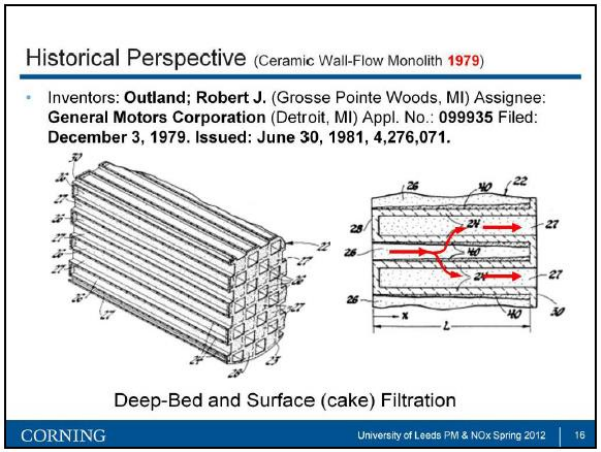
Filter for Diesel-Exhaust since 1982

now over 100 Mio DPF successful on the road

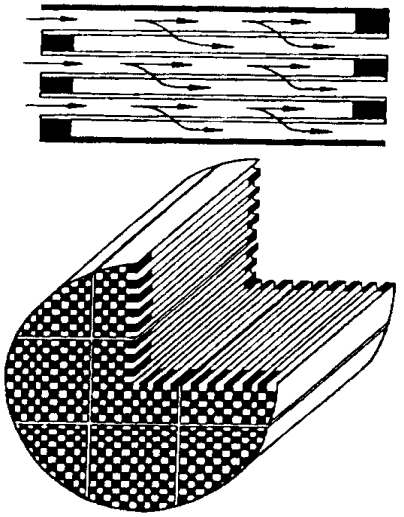


1984
BBC-Daimler

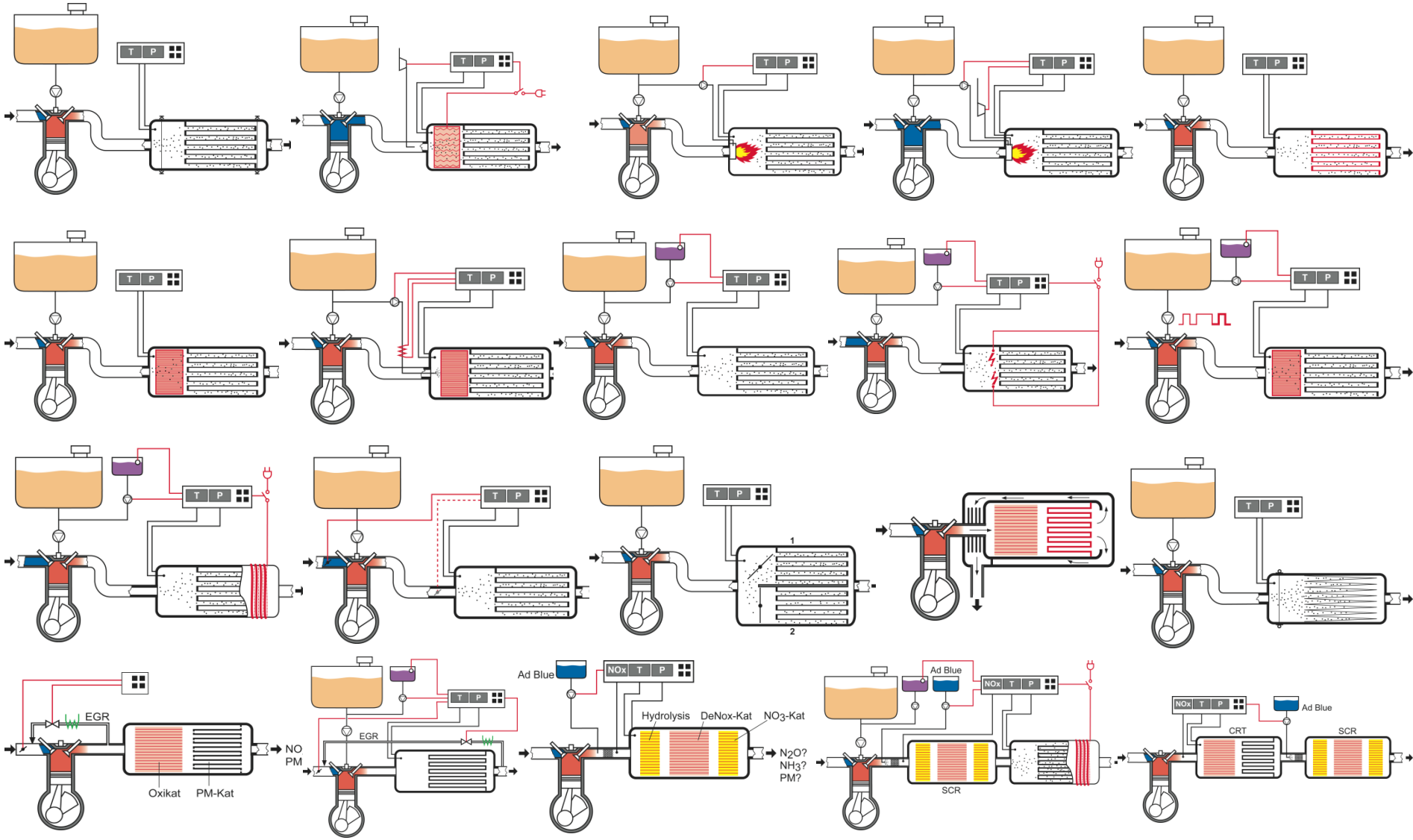
1979
GM



1982
Corning

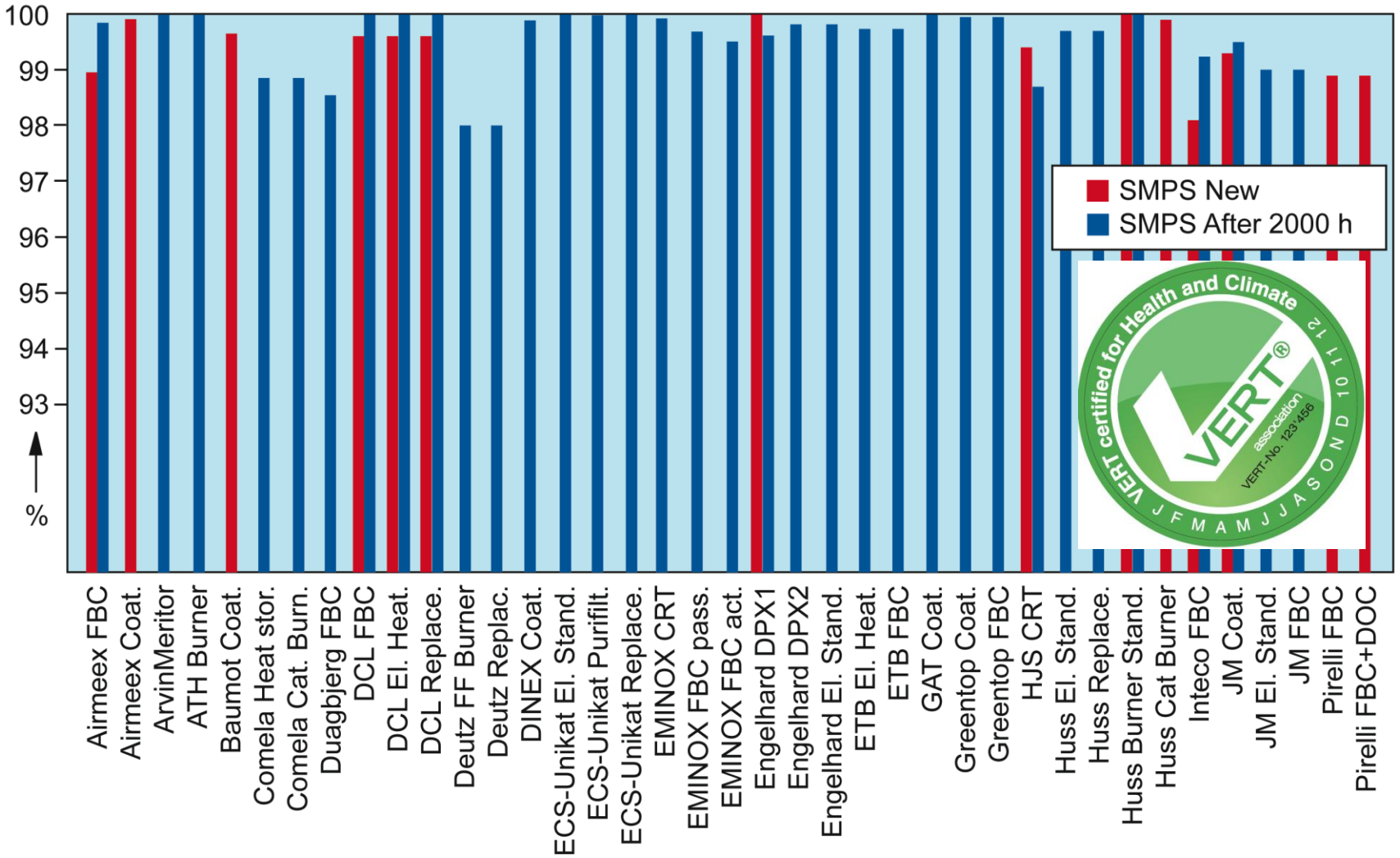


Many Filter System Designs are needed to cover all engine applications

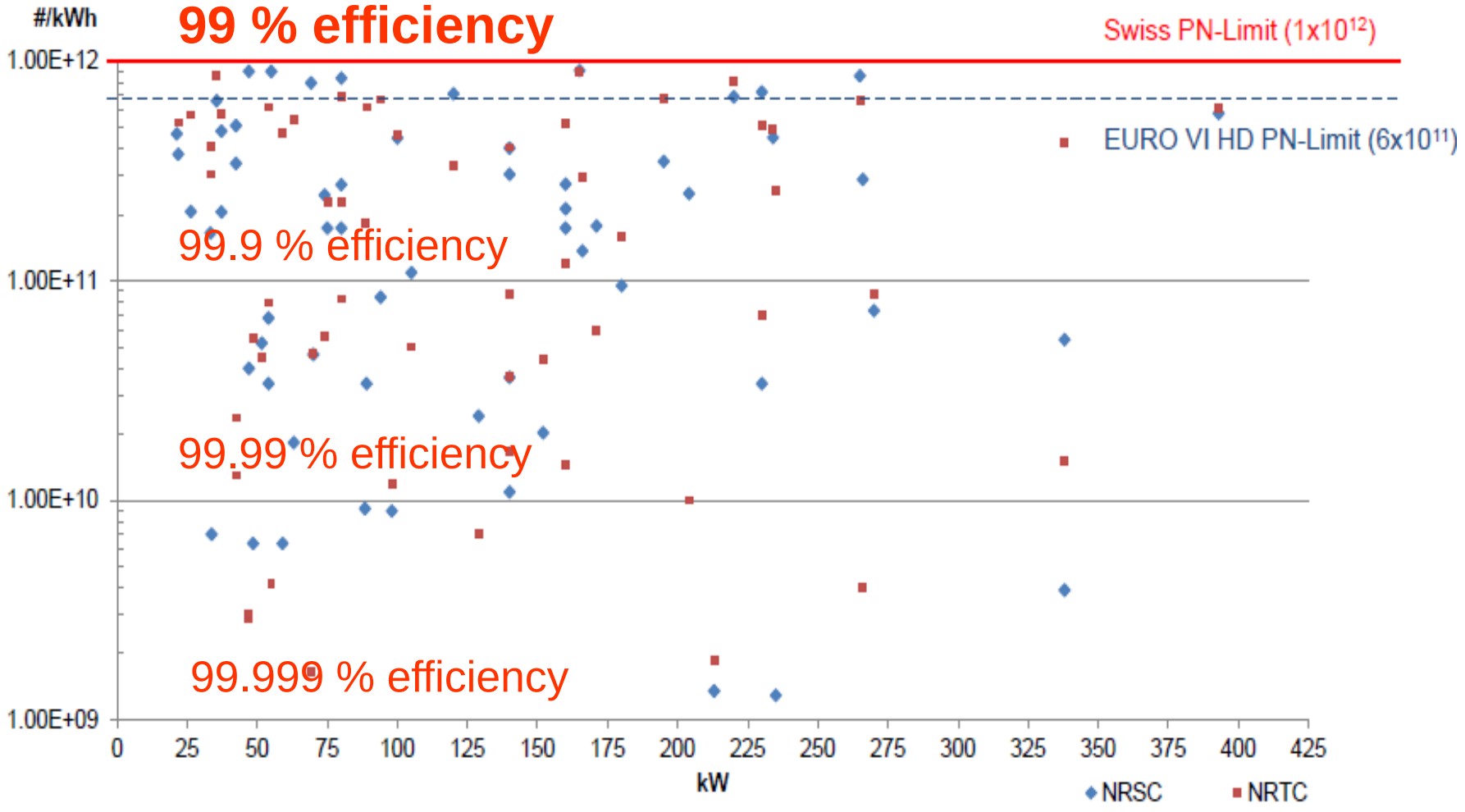


Filtration - 65 DPF VERT tested

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

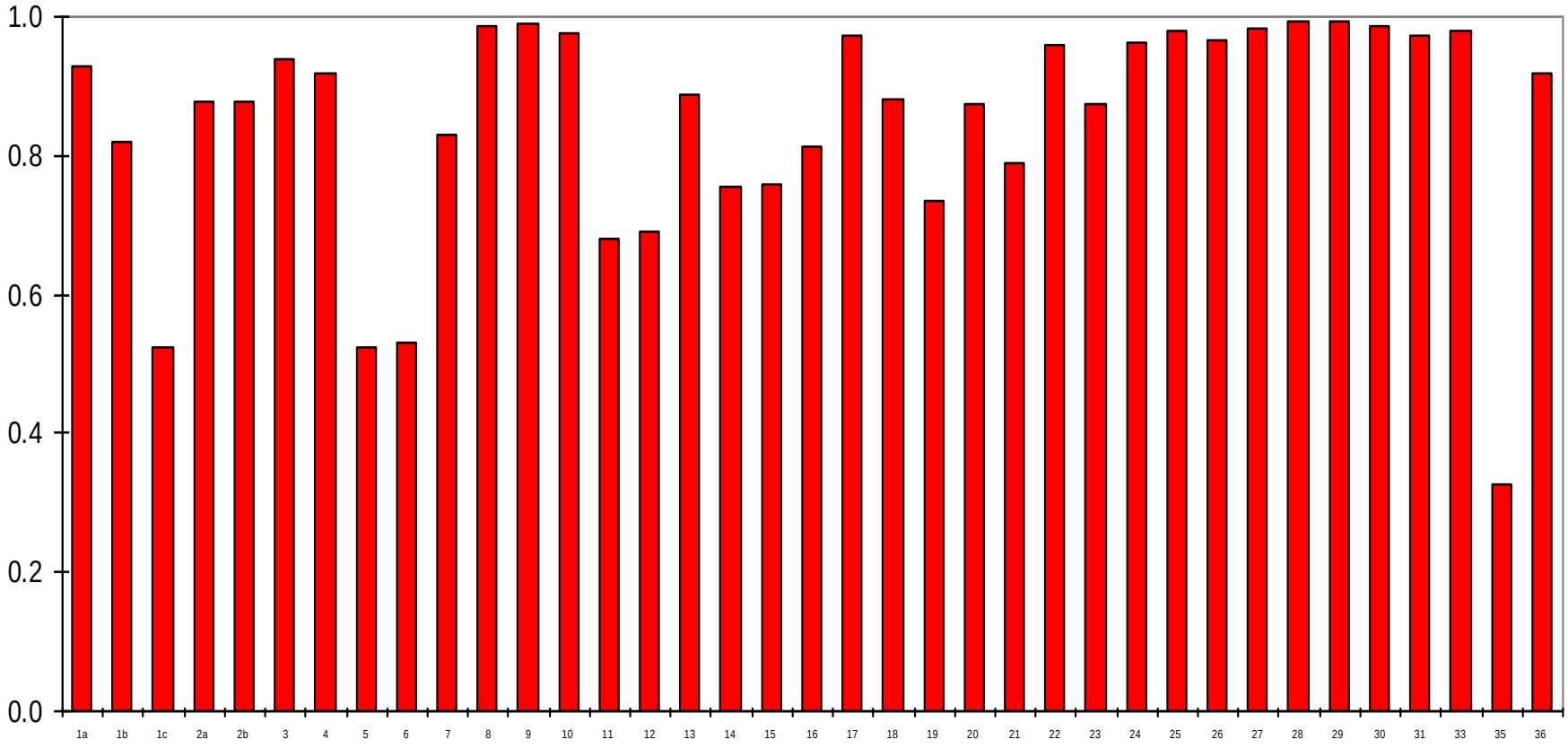


PN-Test results



Swiss Statistics for imported construction machines with DPF

PAH are also very effectively reduced in most filter systems

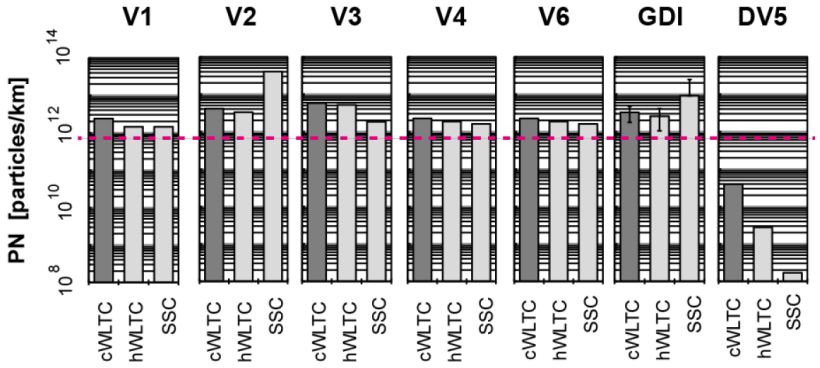


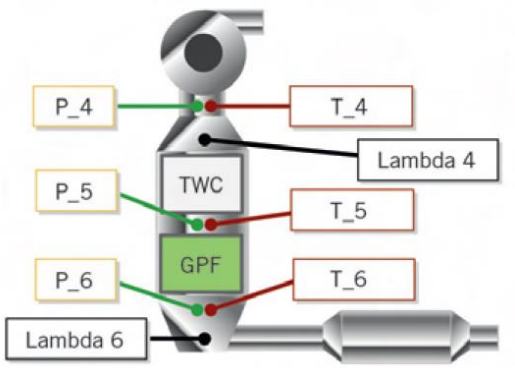
Particle Filtration of Petrol Engines

The Law in Europe from 2017

Why not replace 3 WC by 4 WC with GPF used as substrates?

Gasoline DI w/o GPF compared to Diesel w.DPF

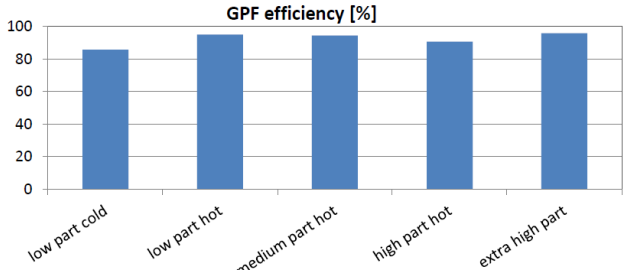


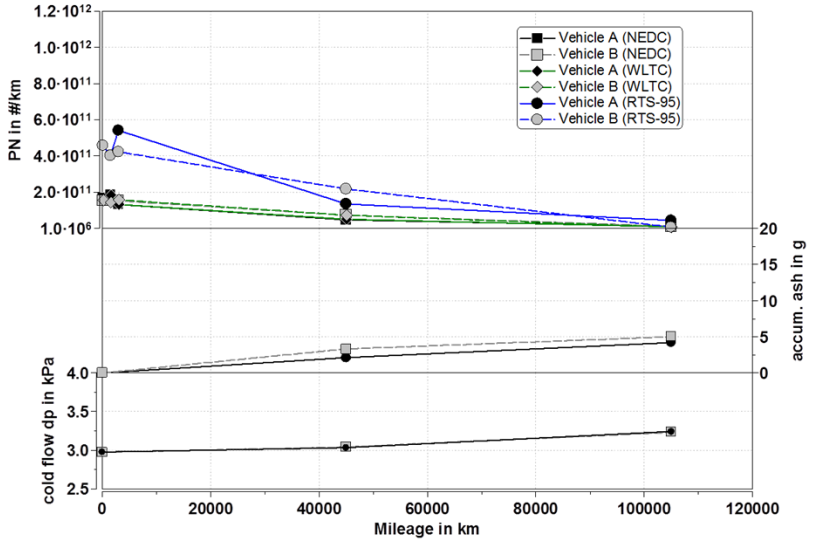


Mean of GPF efficiency during the WLTC driving cycle over 4 days.

Volvo V60 T4F; 3-way catalyst & non coated GPF; fuel: gasoline

04. - 07.08.2015

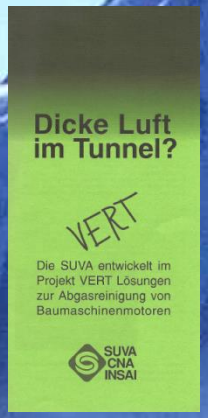


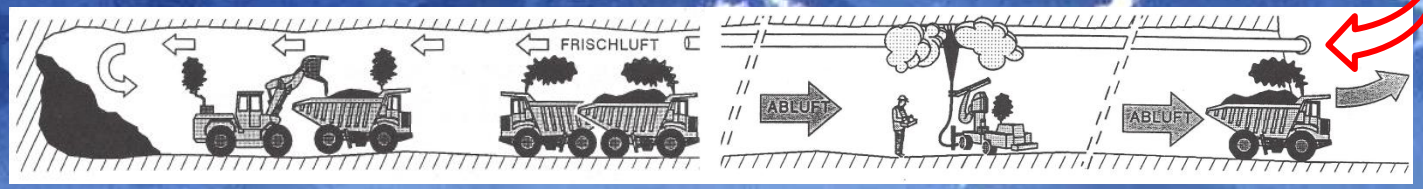


1993 the NEAT-Tunnel – big step

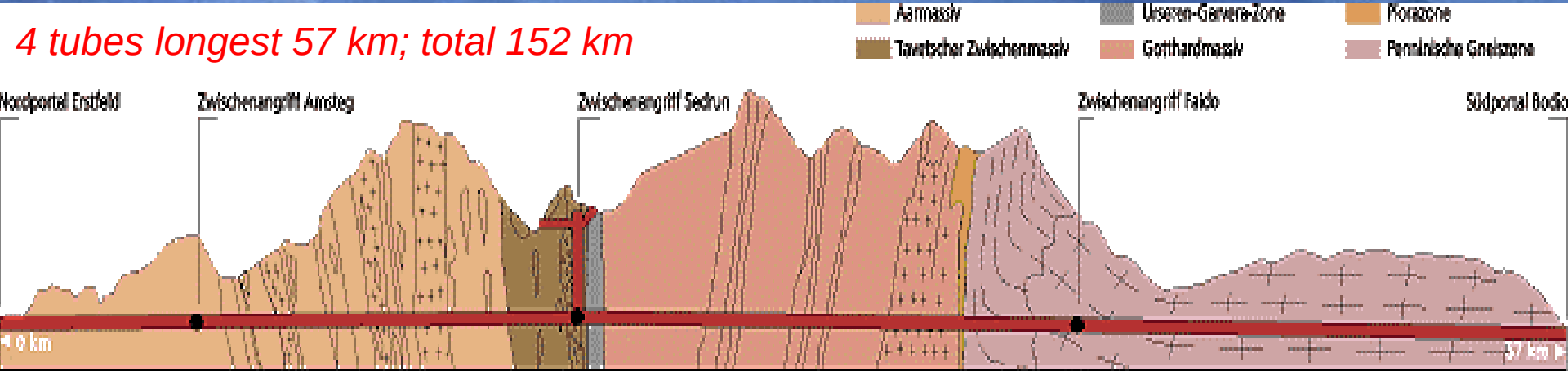
Occupational Hygiene Requirement

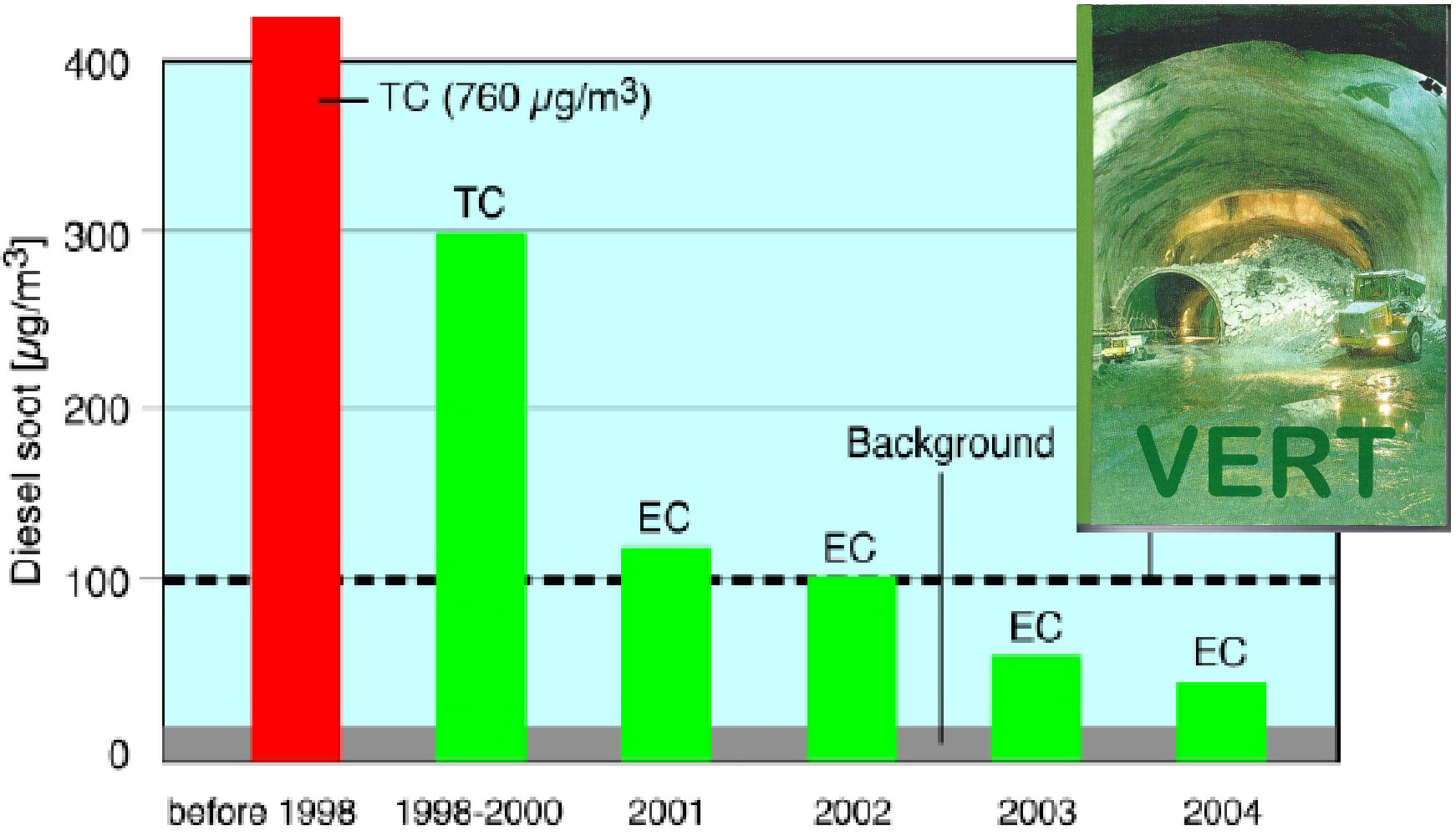
«Reduction of solid submicron particles to < 100 µg/m³ within three years» by 97 % - ***by dilution ?***





4 tubes longest 57 km; total 152 km





How we cleaned Swiss tunneling sites

And now: there are well experienced solutions for all construction machines

Public Transport in Switzerland

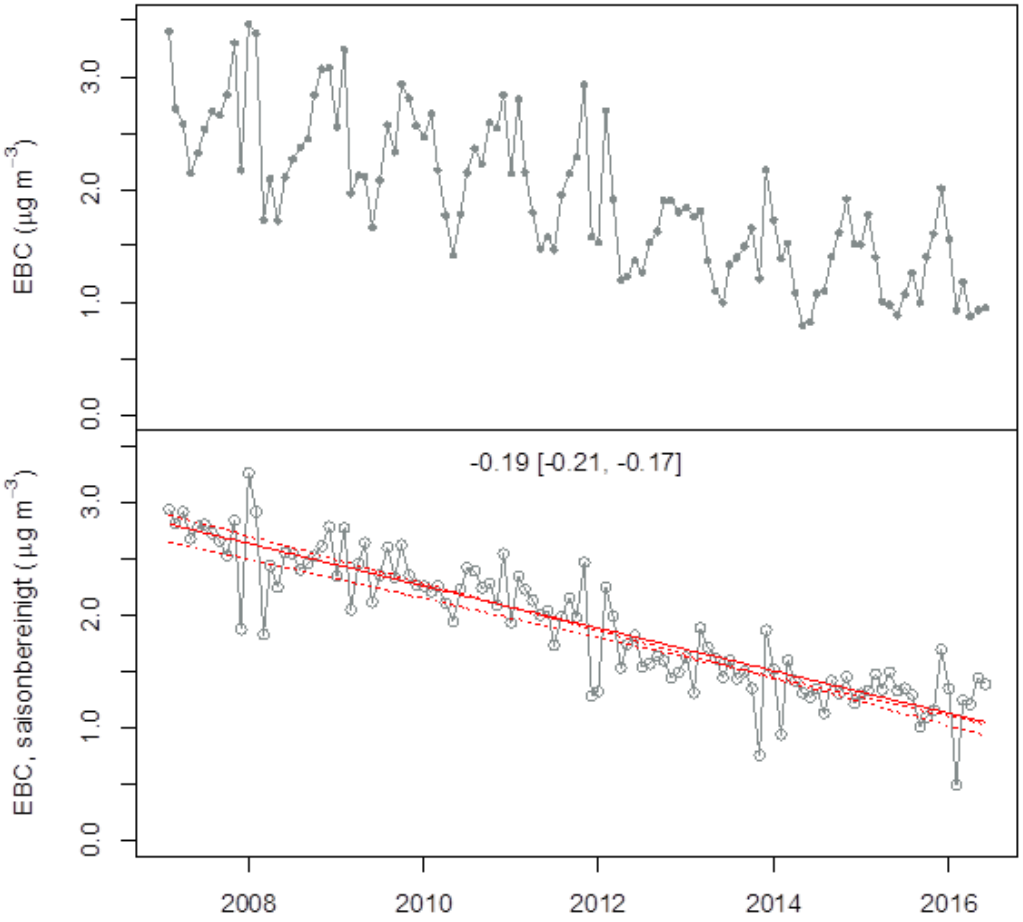
> 90 % BAT-DPF

Locomotives and Ships in Switzerland

> 60 % BAT-DPF

The Success Story:
Cleaning the Air by DPF in Switzerland

Monitoring BC at the motorway crossing Härkingen



Experience

20 years

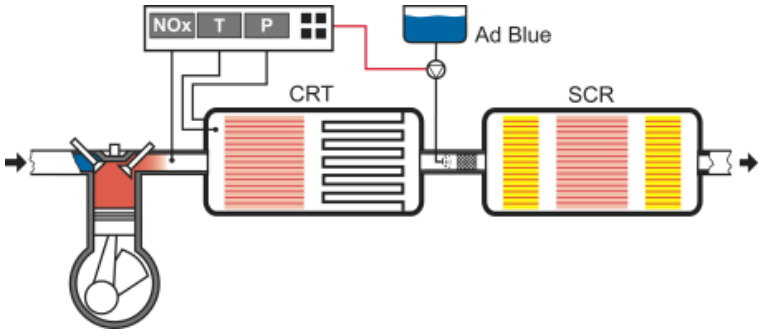
> 50’000 Retrofits in Switzerland

> 500’000 Retrofits worldwide

> 100 million DPF OE first fit

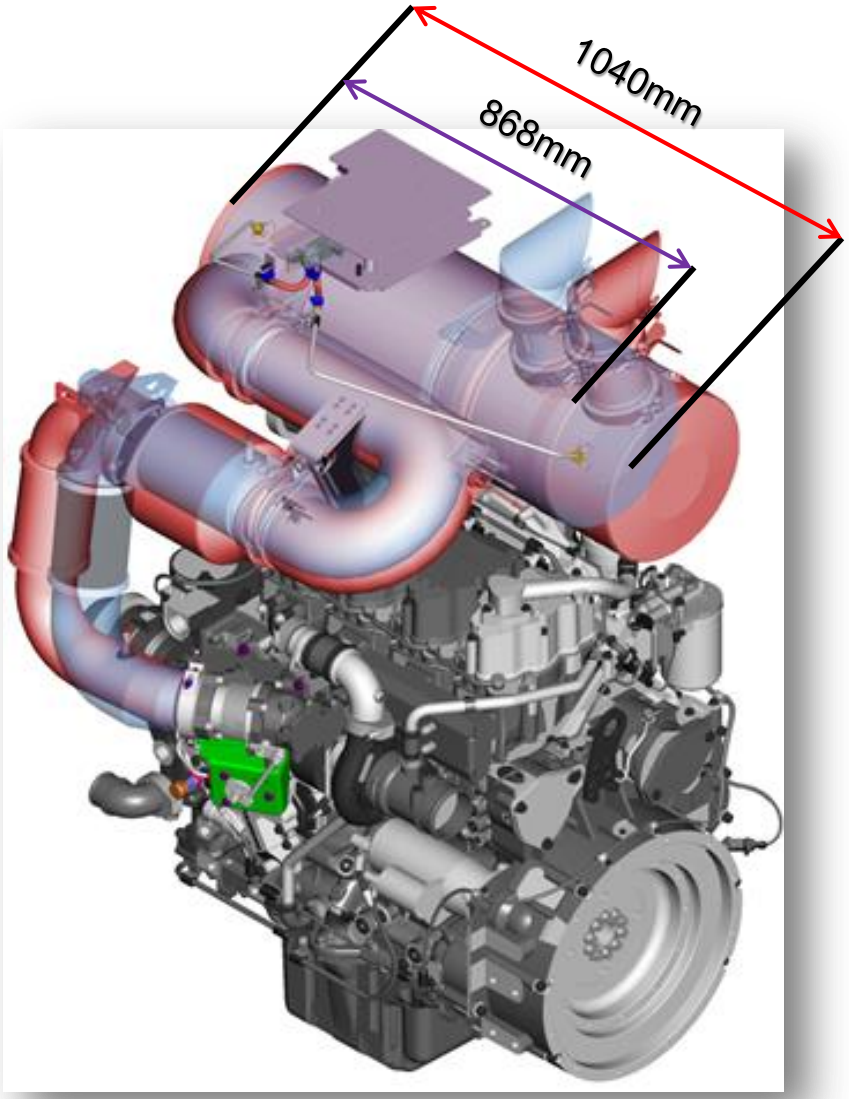
SCR + DPF

expensive and bulky



but coming

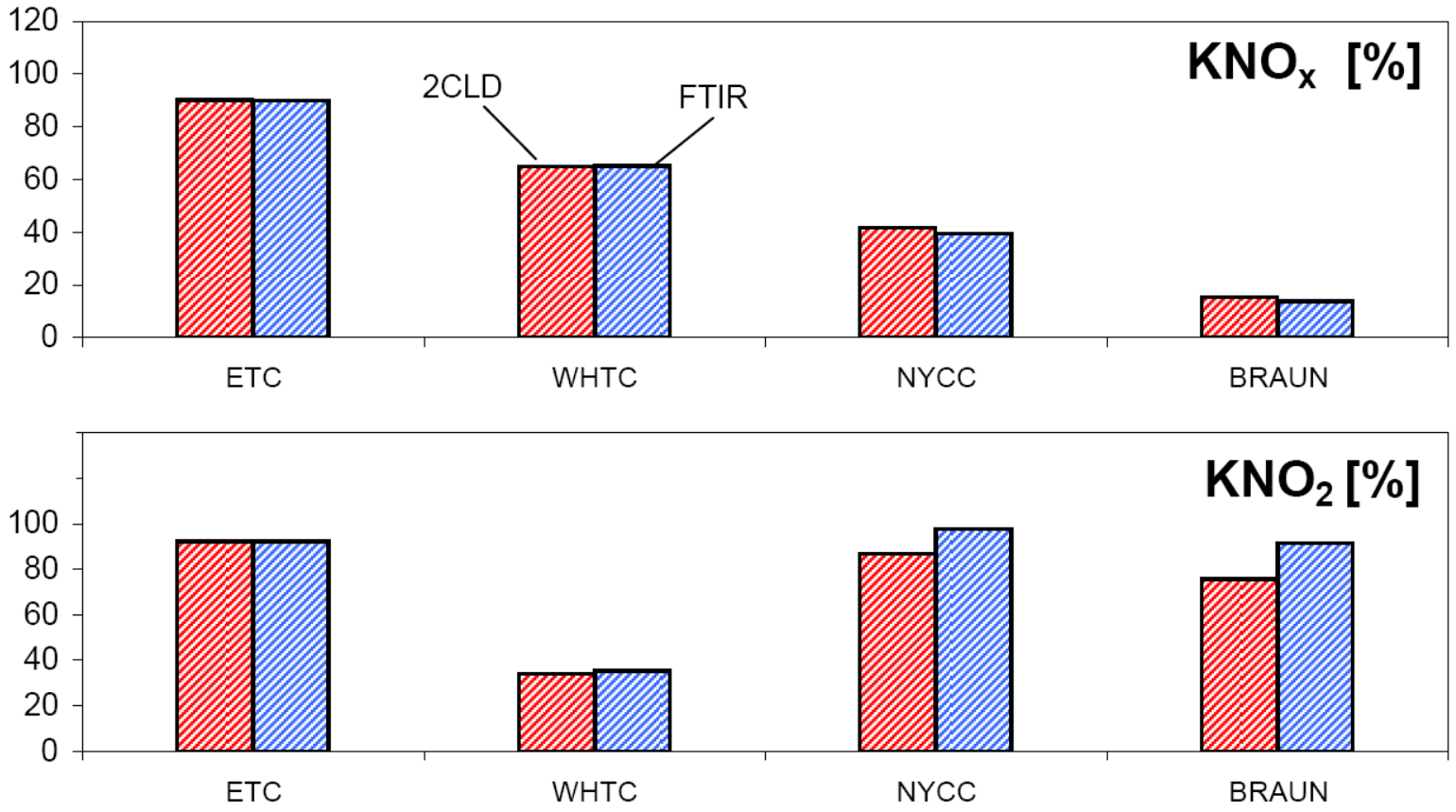
SCR on DPF → →



Red → SCRoF (1040mm)
Purple → SCR-only (868mm)

Source: LIEBHERR Dr Regis VONARB

NOx Reduction Efficiencies in Dynamic Cycles



Comparing DePN and DeNOx

DePN by DPF has highest Priority

- Because of the extremely high Toxicity of Nanoparticles
- Because of the outstanding high efficiency of DPF and GPF
- Because of the easy fealibility of Retrofit
- Because of the high Benefit/Cost of > 10 (OE even > 30)

DeNOx has lower Priority for Retrofit

- Because of lower toxicity and lower efficiency
- Because of higher cost unless combined with DPF
- But should be implemented with new vehicles

Conclusions

- The Potential of Particle Emission Control by DPF aftertreatment is a revolution – reduction by 99.9 % - and can be combined with catalysis for PAH reduction → a must for public health; with Benefit/Cost > 10

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- Introduction is required for new vehicles as well as for the existing dirty fleet for Diesel and Petrol engines
- NOx-Reduction by SCR and EGR can be combined with DPF and reduce Diesel-NOx by 90%
- Introduction of these technologies requires a new concept of inspection & maintenance → see presentation A.Reinoso
- **Replacing Diesel by Petrol** acc. to C40 mayors reduces NOx but increases breathing air toxicity by increasing UFP concentration dramatically, increases Global Warming and Fuel Consumption

como dice Miguel de Cervantes
con Don Quijote

“ .. basta que no se salga un punto
de la verdad ”

con esto
les agradezco
por su atención

y estoy listo para responder
a sus consultas

A.Mayer - TTM

Independent Consultant
on Emission Reduction of IC-Engines

- **VERT®**
  Verification of Particle Filter Systems
- **Quality Control of DPF, DOC and SCR**

- Research and Development in International Projects since 1983
- Implementation of Emission Reduction Measures
  (EU, Poland, Italy, California, Canada, Chile, China, Iran, Israel, Columbia ..),
- Organization of Seminars and Conferences .
- 5 books co-published 2004/5 on “Elimination of CGP” and > 100-papers
- ETH-Nanoparticle Conference organizator since 1997
- Society of Automotive Engineers SAE-fellowship 2004
- Award of Swiss Cancer Ligue 2006
- Dr.med.h.c. of Uni Berne for the introduction of nanoparticle criteria 2010