

Sootfree Tehran – UNESCO + AQCC + VERT September 7<sup>th</sup> 2016

# The Potential of DPF Technology for the Elimination of Diesel Soot

A.Mayer - TTM, VERT



# Health Impact Worldwide → Priority for PN

newest numbers by WHO 2012, Max Planck and Harvard 2015

ALRI: acute lower respiratory illness

IHD: ischaemic heart disease

CEV: cerebrovascular disease

COPD: obstructive pulmonary disease

LC: : lung cancer

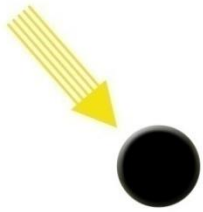
**10'000 killed per day - 20'000 by 2050 ( 30 per day in Tehran)**

WHO region	Year	Population (×10 <sup>6</sup> )	Mortality attributable to air pollution (deaths × 10 <sup>3</sup> )						
			PM <sub>2.5</sub>					O <sub>3</sub>	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	11	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

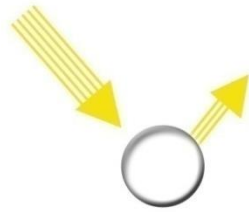
NO<sub>x</sub>

### Warming Effect of Black Carbon Aerosols



"Low albedo"

### Cooling Effect of Organic & Sulfate Aerosols



"High Albedo"

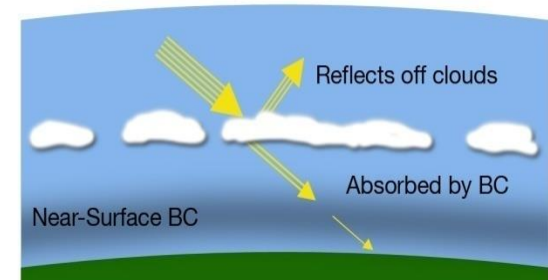
### Multiplying Effect When Mixed Together



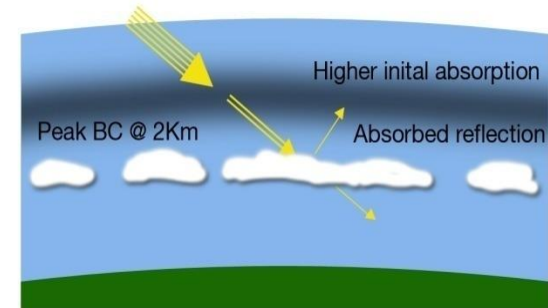
"Very Low Albedo"

## Higher in atmosphere

Traditional View: Peak Black Carbon Close to Surface

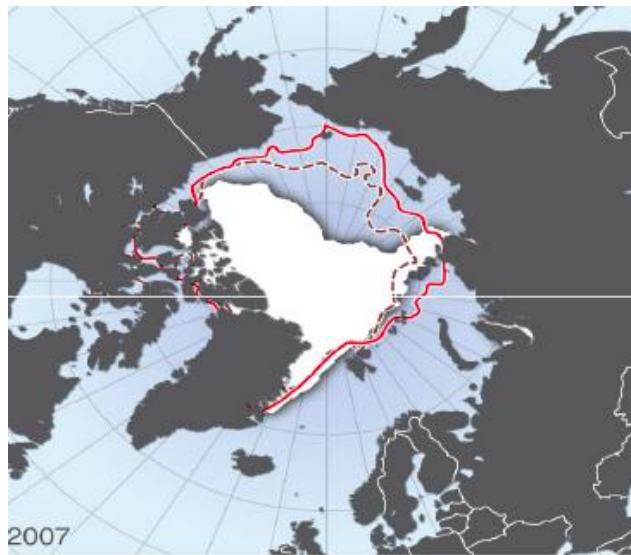


New Findings: Peak Black Carbon at 2Km



Science Daily, United Nations Environment Program Nov 2008

BC on snow  
decreases  
albedo,  
turning to  
water..  
further  
lowering  
albedo



Minimum extent  
of ice cover 2005

Median minimum extent  
of ice cover (1979-2000)

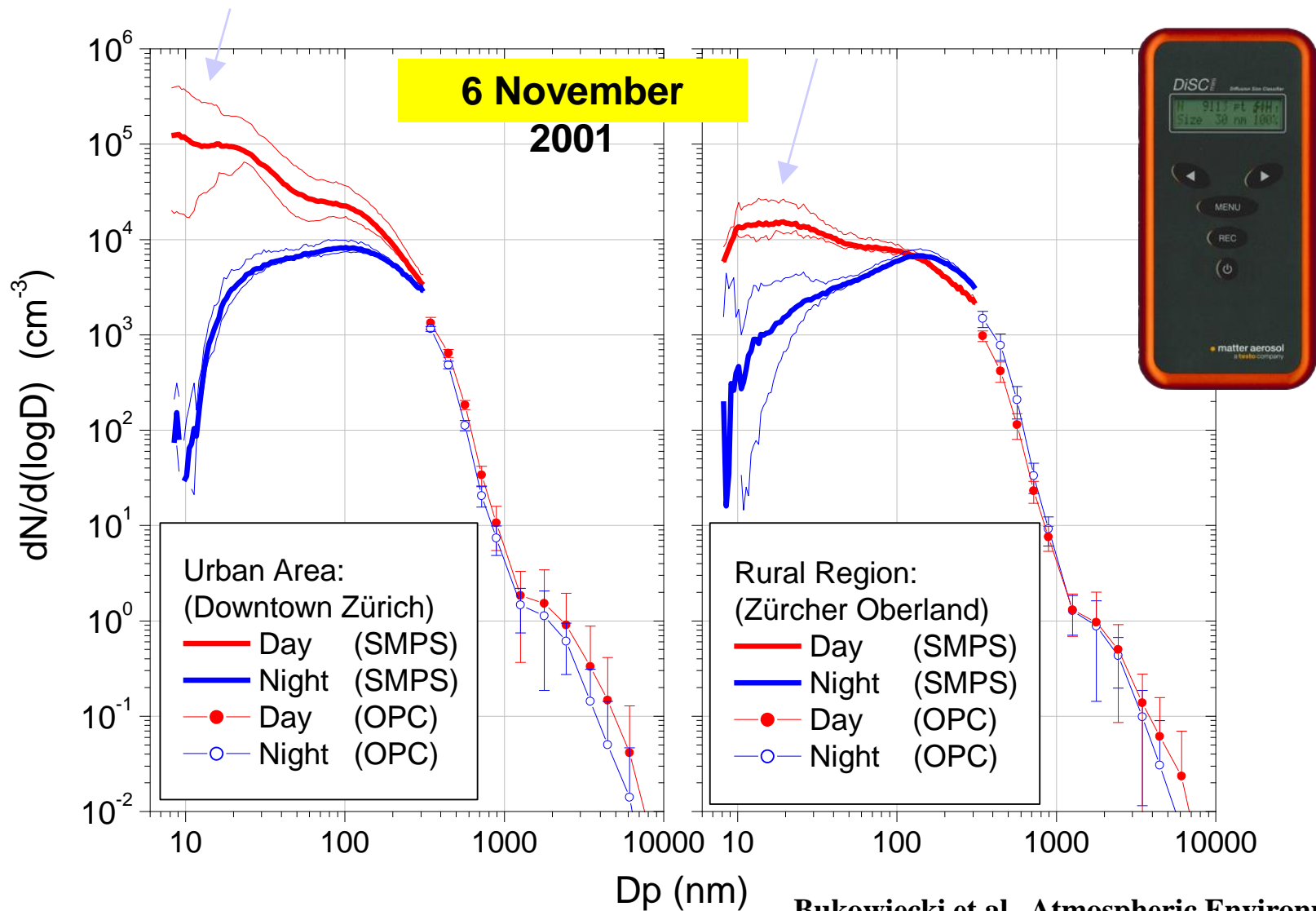
Source: UNEP/GRID Arendal & EPA

Journal of Geophysics Res.2007

# Global Warming by BC-Particles

# Ambient Aerosol Number/Size – Distribution

## City (Zürich) and Coutry (Zürcher Oberland)

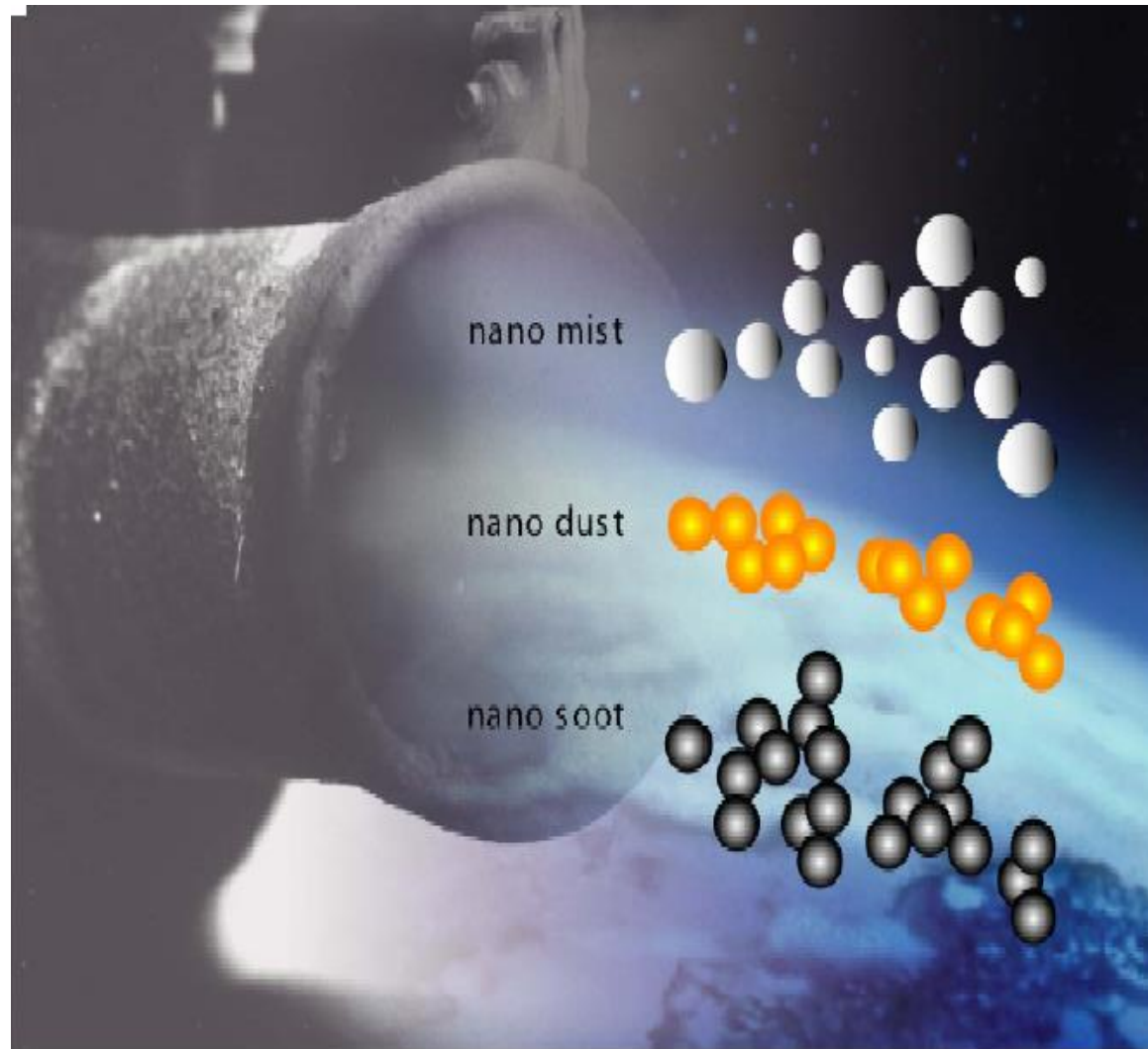


# Engine Emissions not avoidable

**Soot Particles**  
**Ash Particles**  
**Liquid Droplets**

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

**and many trace substances**

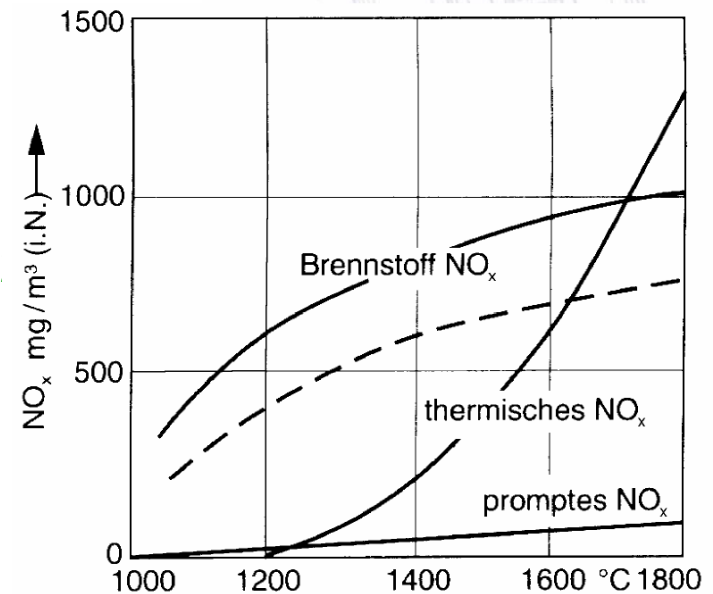


# Why is formation of Nitric Oxides unavoidable

- Air contains 70%  $N_2$
- Combustion of Fuel with Air produces much  $NO$ , some  $NO$  and a little  $N_2O$
- **Zeldovich** showed that this accelerates  $> 1200^\circ C$

## The Challenge

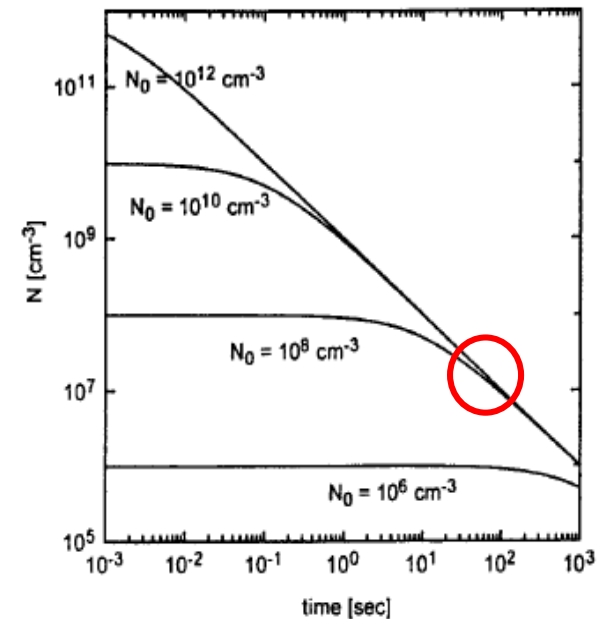
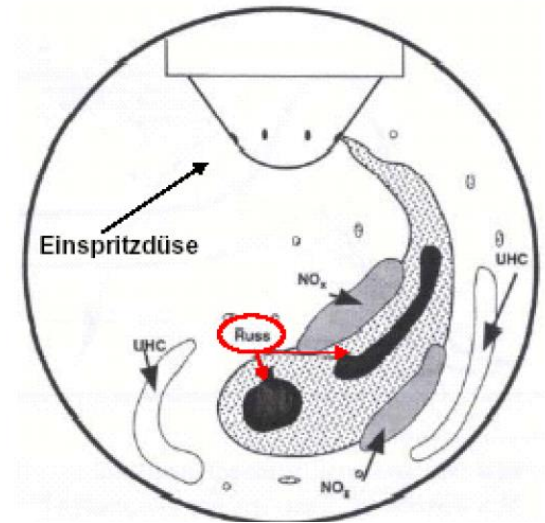
- *Improving combustion increases temperatures - Carnot*
- *Modern engines emit higher  $NO_x$  than older ones*



# Why is Formation of UFP unavoidable

- Source 1 is the fuel injection inhomogeneity forming soot
- Source 2 is lubrication oil metal compounds
- Source 3 is friction metals, vaporized and renucleated

Primary particles have a diameter of 20 nm – they agglomerate very fast and 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 so the exhaust system can produce many substance
- **And we have to find the toxic substances and technical solutions to eliminate them**

# Daimler Benz Euro V – EEV (SCR, no DPF)

**1.**  
Bis heute haben sich über 200 Schweizer Kunden für mehr als 480 Actros der Euro5-Generation entschieden.

Wir betreiben eine der meisten Flotten für den Transport in unser Land. Und deshalb kann, dass die mit Mercedes-Benz Technologie gezeigten Lkw die besten und besten Transporter sind.

**2.**  
Alle Lkw-Hersteller werden SCR-Technologie wählen müssen, um die Euro5-Norm zu erfüllen.

Alle internationalen Transporte über Europa werden werden, aber damit Euro5 zu sein Euro 5 von 7 Herstellern können kein Ziel sein. Nur mit SCR (Selective Catalytic Reduction) können die weiteren Anforderungen erfüllt werden. Und die meisten großen Unternehmen, welche die globalen Märkte bedienen.

**3.**  
Nur Euro5 bietet einen langfristigen Investitionsschutz bei Neufahrzeugen.

Wenn die dieselmotoren in den nächsten Jahren über 5 Jahre lang, das ist nicht, aber die im Jahr 2005 in den meisten Euro5-Flotten gezeigten Lkw sind. Und das ist ein langfristiger Investitionsschutz. Und das ist ein langfristiger Investitionsschutz. Und das ist ein langfristiger Investitionsschutz.

**4.**  
SCR-Technologie spart mindestens 3% Treibstoff.

Zusätzlich zur SCR-Technologie weniger Schadstoffe und Rußpartikel bei mindestens 3% geringeren Treibstoffverbrauch. Bei der SCR-Technologie sind die Abgasnachbehandlungsoptimalisierungen. Der Motor produziert Stickoxide (NOx), welche mit SCR-Katalysator reduziert.



**5.**  
Die AdBlue-Versorgung in der ganzen Schweiz ist heute sichergestellt.

Es gibt heute drei verschiedene AdBlue-Versorgungssysteme. Und das ist ein langfristiger Investitionsschutz. Und das ist ein langfristiger Investitionsschutz. Und das ist ein langfristiger Investitionsschutz.

**6.**  
Nur bei einem SCR-Lkw bleiben die Wartungsintervalle gleich hoch.

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**8.**  
Bei Mercedes-Benz bleibt die Nutzlast trotz SCR-Technologie gleich hoch.

Die Nutzlast bleibt bei einem SCR-Lkw gleich hoch. Und das ist ein langfristiger Investitionsschutz. Und das ist ein langfristiger Investitionsschutz. Und das ist ein langfristiger Investitionsschutz.

**9.**  
Mit SCR können alle Diesel- und Ölqualitäten verwendet werden.

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**10.**  
Nur Mercedes-Benz kann heute schon Euro5-Lkw mit bis zu 600 PS liefern.

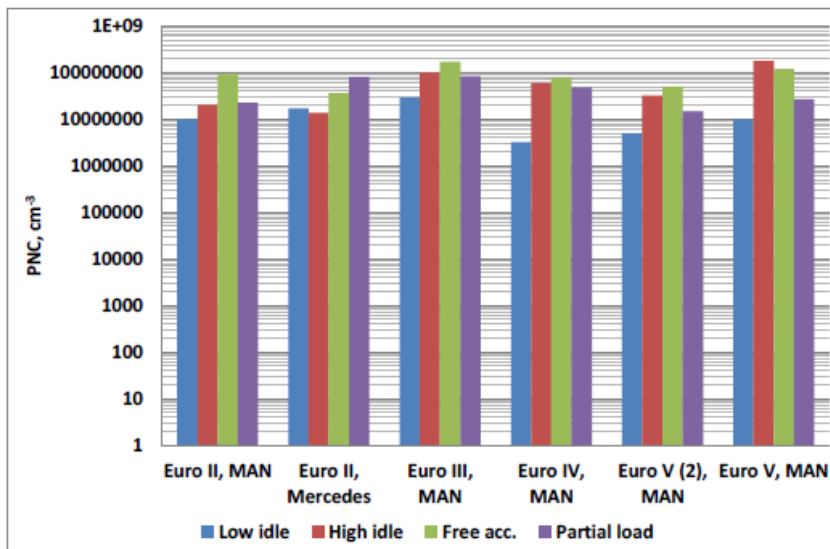
Bei Mercedes-Benz ist es möglich, Lkw mit bis zu 600 PS zu liefern. Und das ist ein langfristiger Investitionsschutz. Und das ist ein langfristiger Investitionsschutz. Und das ist ein langfristiger Investitionsschutz.

**7.**  
OBD I (On-Board-Diagnose) bei Mercedes-Benz Lkw schon jetzt an Bord.

Die OBD I (On-Board-Diagnose) ist bei Mercedes-Benz Lkw schon jetzt an Bord. Und das ist ein langfristiger Investitionsschutz. Und das ist ein langfristiger Investitionsschutz. Und das ist ein langfristiger Investitionsschutz.

Noch mehr Infos zu SCR-Technologie und Euro4/5 auf [www.mercedes-benz.ch](http://www.mercedes-benz.ch)

# 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

NO<sub>x</sub> has been reduced  
but NO<sub>2</sub> increased

→ more toxicity

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

- DOC Diesel Oxidation Catalyst
- SCR Selective Catalytic Reaction
- LNT Lean NOx Trap
- DPF Diesel Particle Filter

They shall be discussed now with respect to our priority target to **eliminate solid ultrafine particles** under the local application conditions of Tehran

# DOC

*Reduction CO, HC*

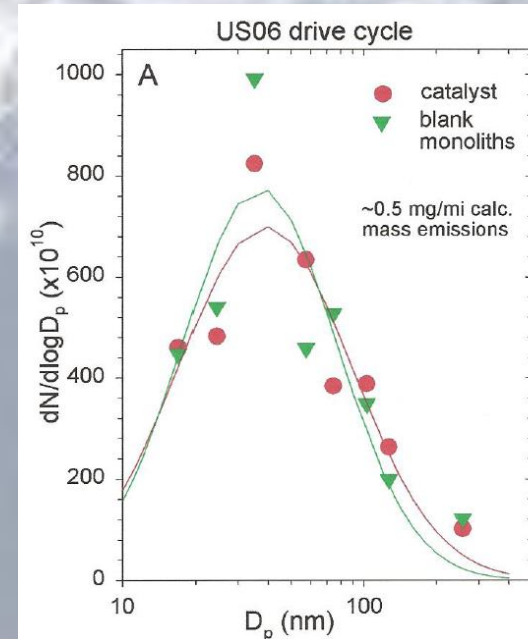
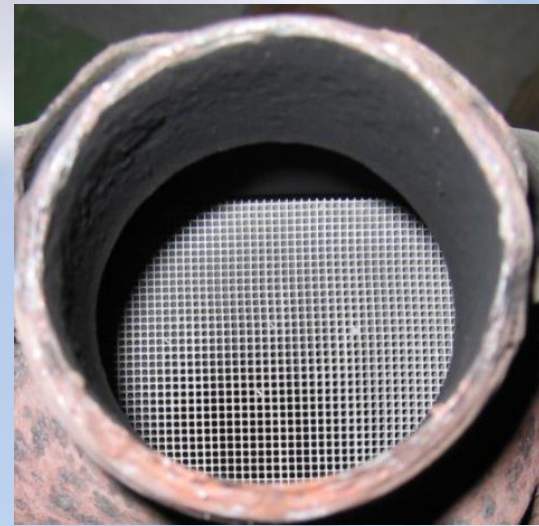
*Production*

*NO → NO<sub>2</sub>*

*SO<sub>2</sub> → O<sub>3</sub>*

**No Effect on Particles**

(M.Maricq)



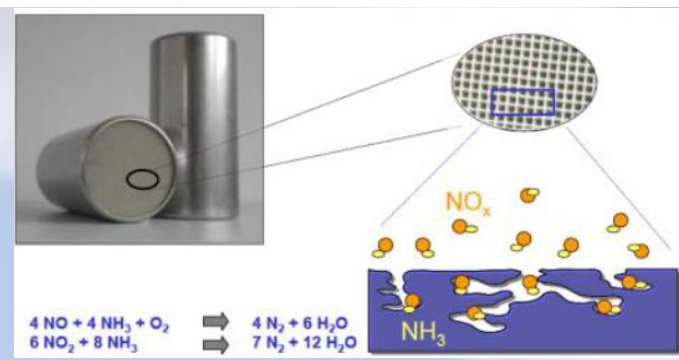
# SCR

*reduces NO and NO<sub>2</sub>*

*but no effect on particles*

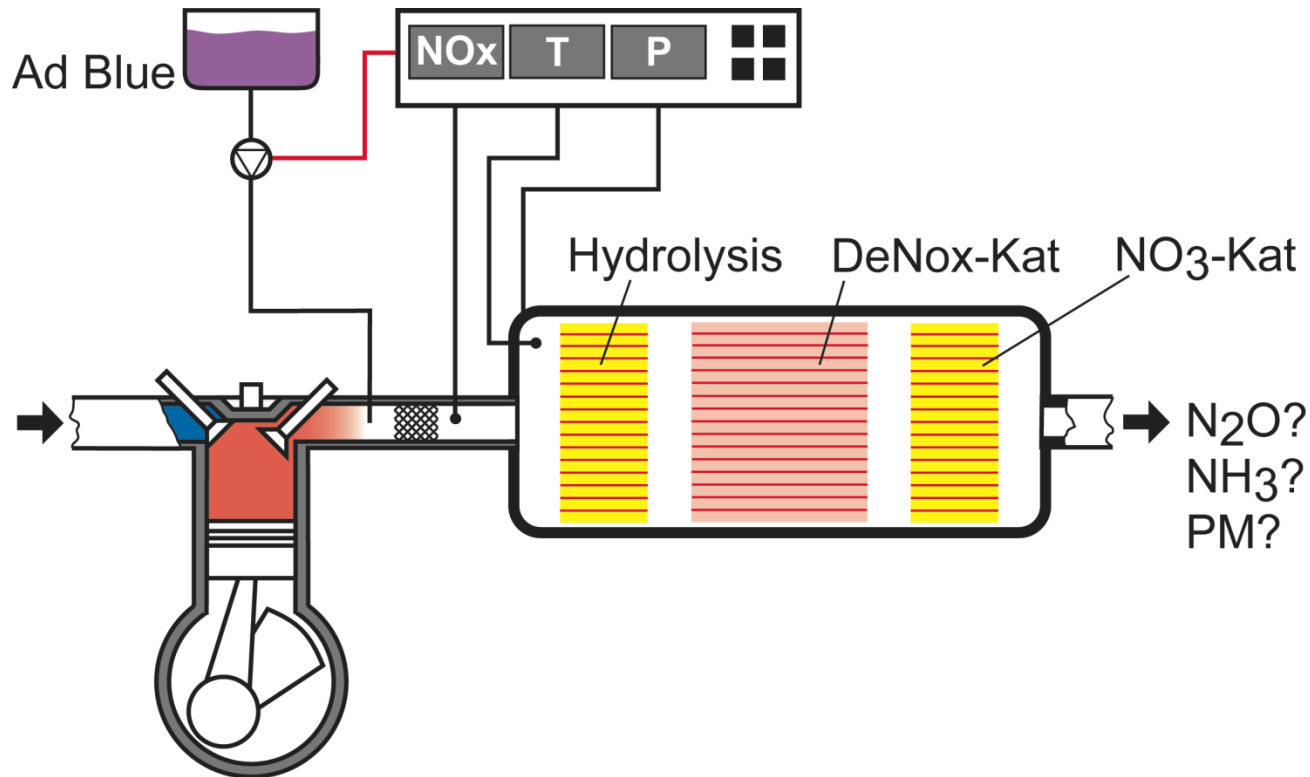
*nor CO, HC, PAH*

*and needs elevated exhaust  
temperature*

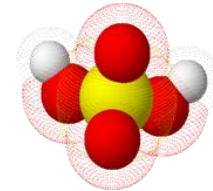
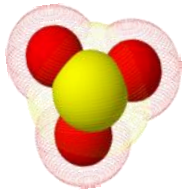
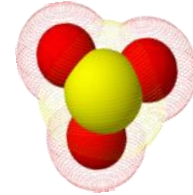
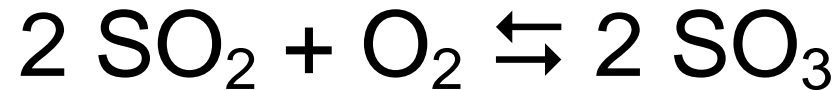


# Two conditions for operating SCR

- Ultralow Sulfur Fuel < 10 ppm
- Exhaust Temperature > 250 °C



# Sulfur - Reactions due to Pt-Catalysis



**with Catalyst**

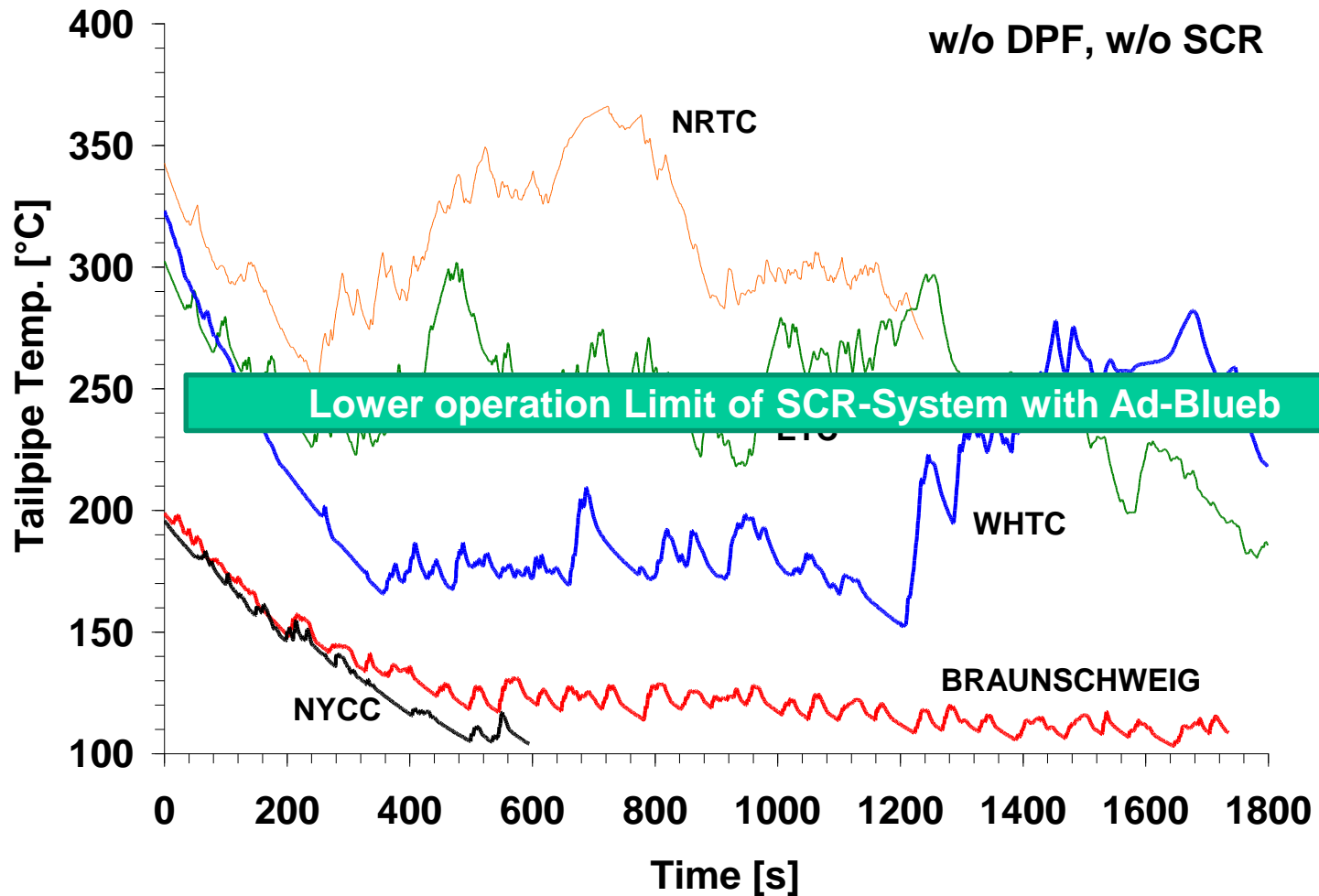
**Sulfuric Acid is generated**

**→ a terrible problem for the environment**

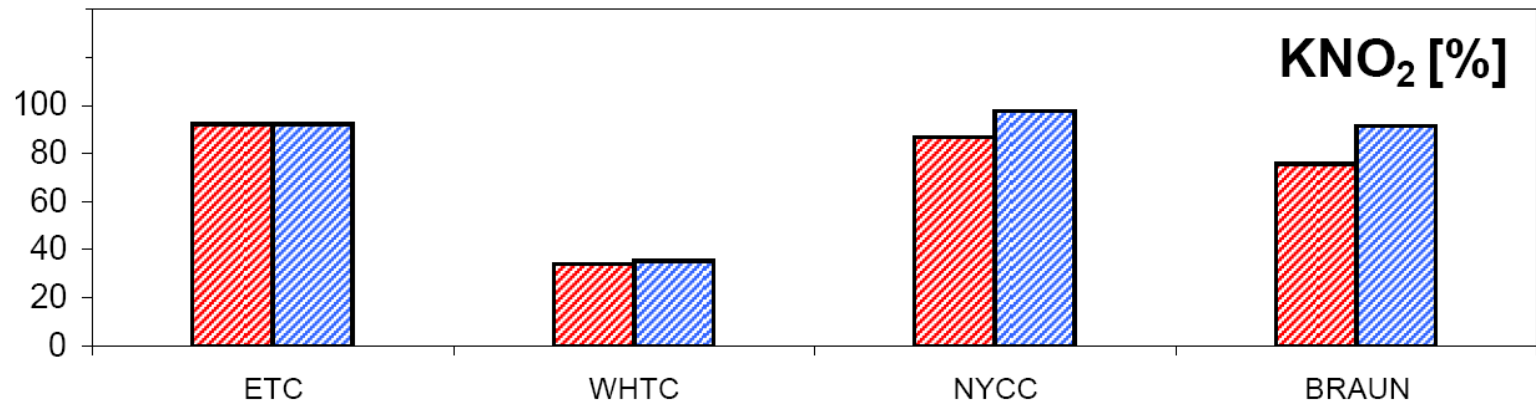
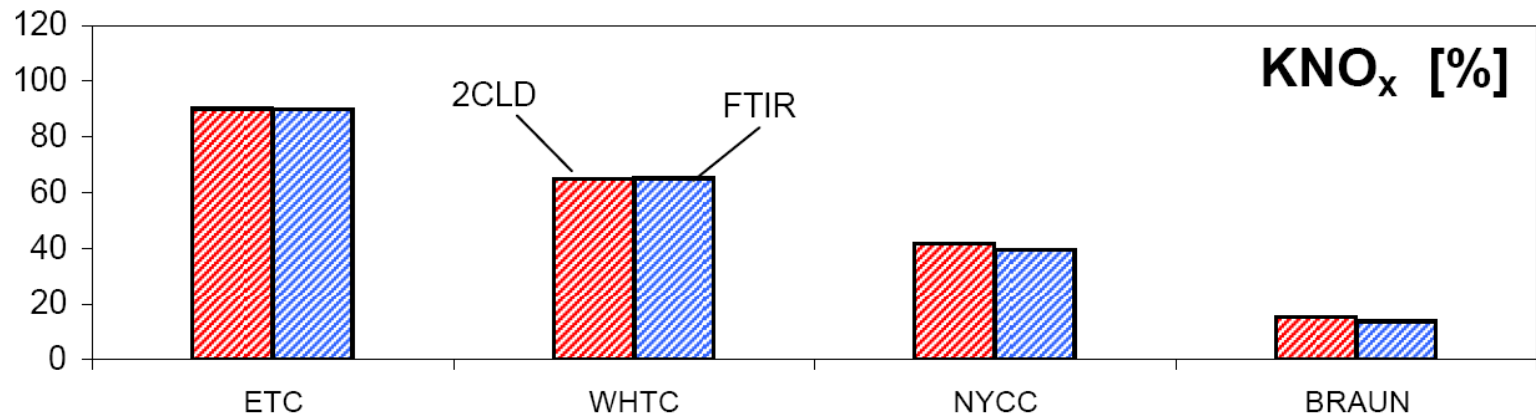
**→ and for the engine as well**



# Exhaust Temp.in different Test Cycles

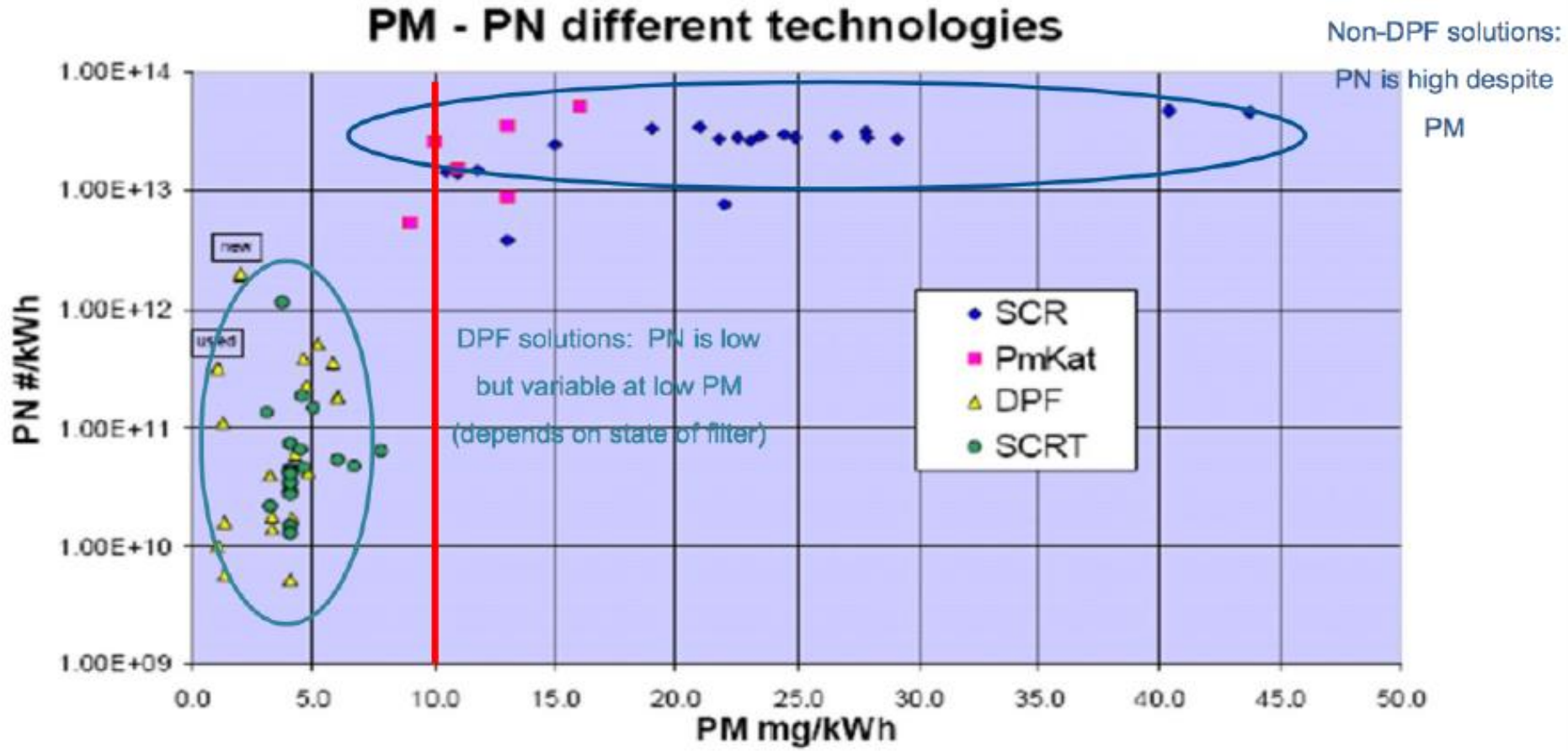


# Comparison of Reduction Efficiencies in Dynamic Cycles



# Conclusion Daimler

→ SCR is not reducing PN

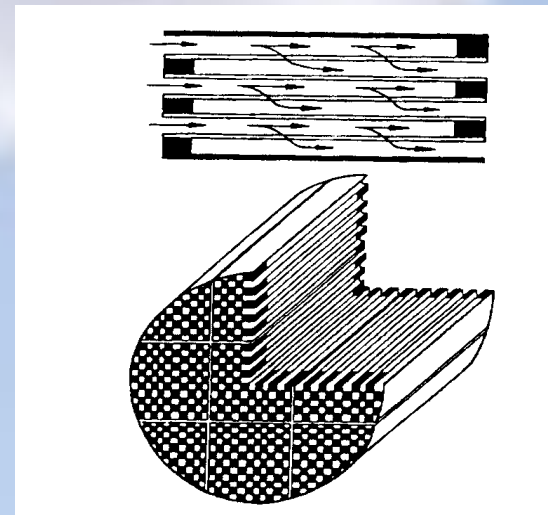


# ***DPF***

***reduces PM, PN***

***and if catalysed CO, HC, PAH  
and with SCR-coating even NO<sub>2</sub>***

***but can be a Chemical Reactor  
with long residence time***



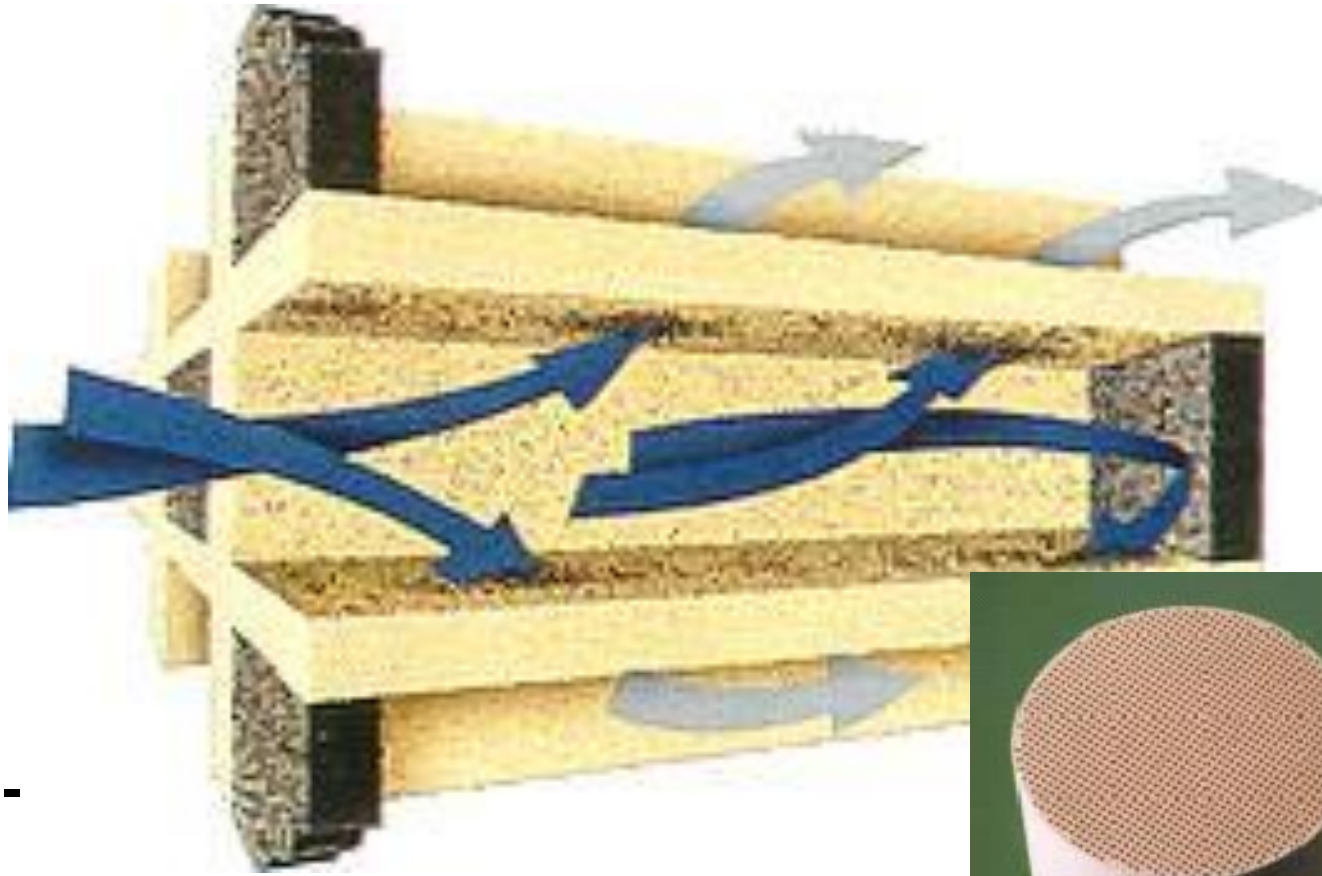
# Conclusion on European Level

## 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.

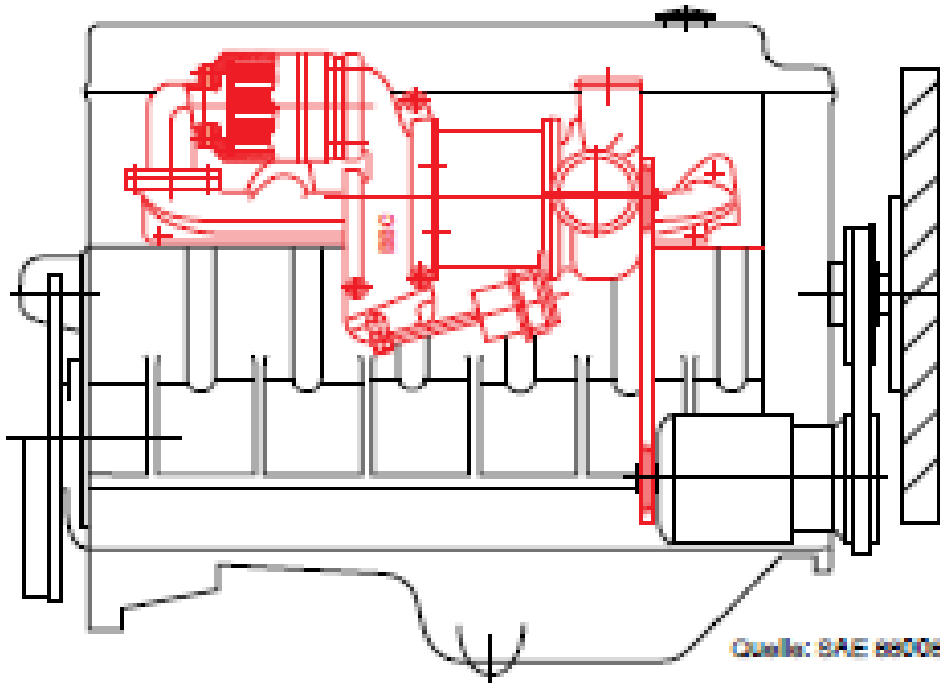
→ **Iran follows EU and adopts the same philosophy in 2014**

# Classic Wall Flow Filter (since 1982)



# Filter for Diesel-Exhaust since 1982

now over 90 Mio DPF successful on the road



1984  
BBC-Daimler

1979  
GM

Historical Perspective (Ceramic Wall-Flow Monolith 1979)

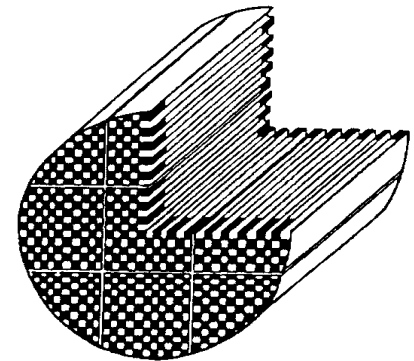
• Inventors: **Outland; Robert J.** (Grosse Pointe Woods, MI) Assignee: **General Motors Corporation** (Detroit, MI) Appl. No.: 099935 Filed: December 3, 1979. Issued: June 30, 1981, 4,276,071.

The diagram illustrates a ceramic wall-flow monolith. On the left, a perspective view shows a stack of parallel channels. On the right, a cross-sectional view shows the internal structure of the channels. Red arrows indicate the flow of exhaust gas through the channels. The diagram is labeled 'Deep-Bed and Surface (cake) Filtration'.

CORNING University of Leeds PM & NOx Spring 2012 16



1982  
Corning



# 1993 the NEAT-Tunnel – big step

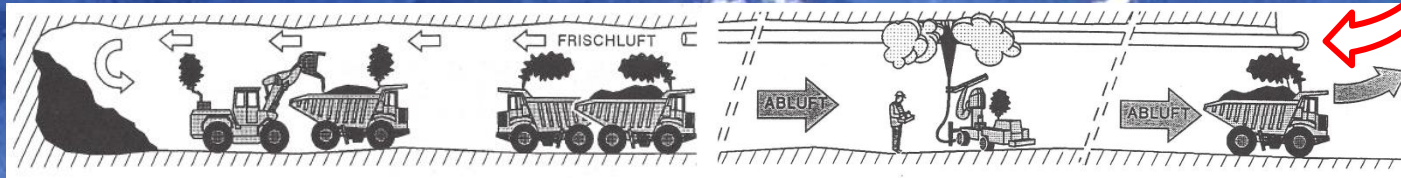
Occupational Hygiene Requirement

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

Dicke Luft im Tunnel?

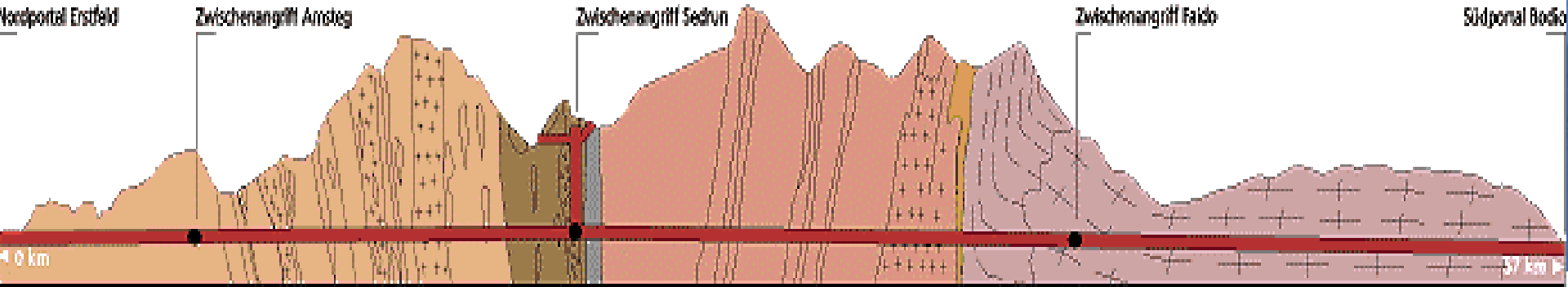
VERT

Die SUVA entwickelt im Projekt VERT Lösungen zur Abgasreinigung von Baumaschinenmotoren

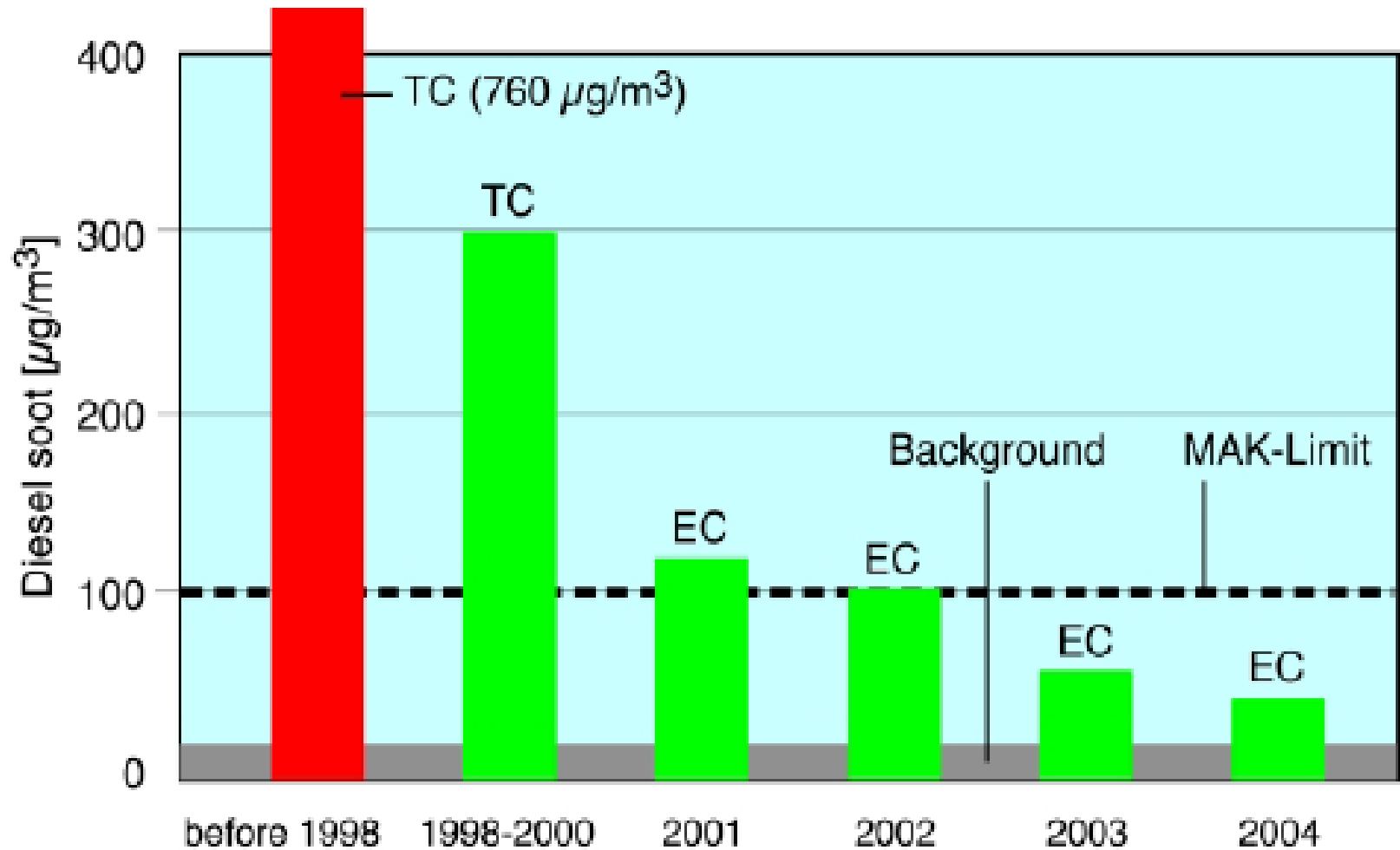


4 tubes longest 57 km; total 152 km

Almassiv      Urseren-Garvera-Zone      Plorazone  
Tavetscher Zwischenmassiv      Gotthardmassiv      Penninische Gneiszone



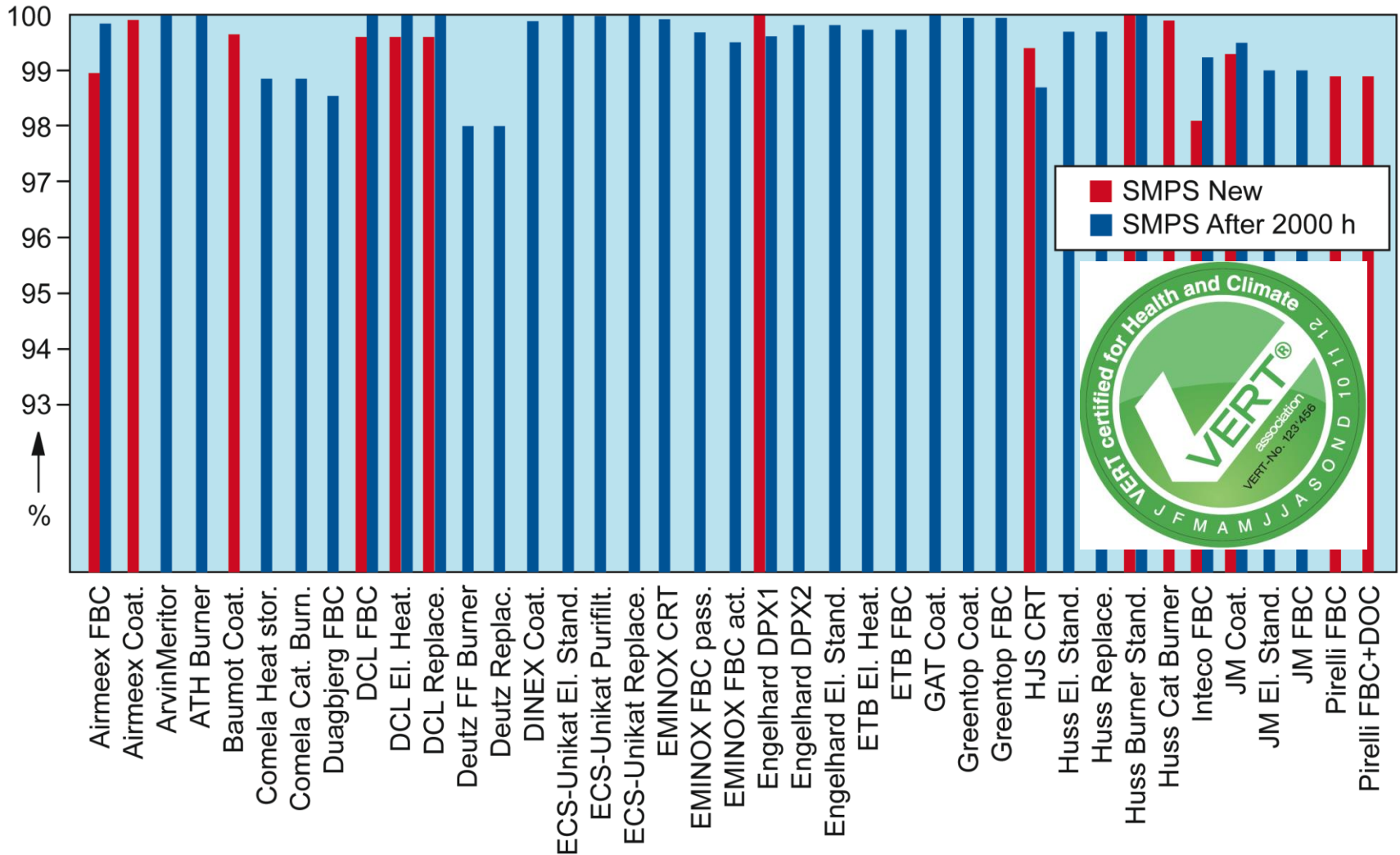




Improvement of Air Quality in Swiss Tunneling

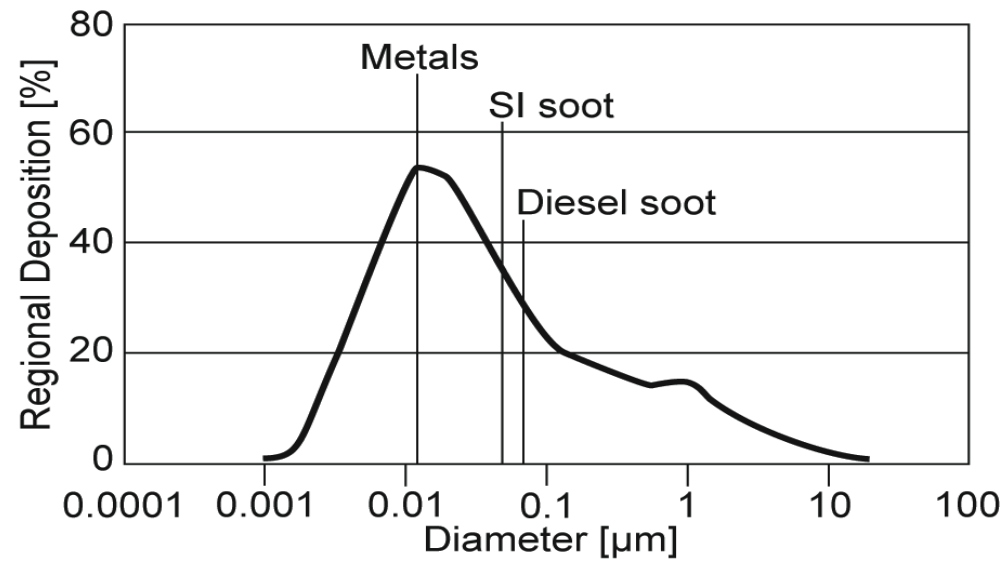
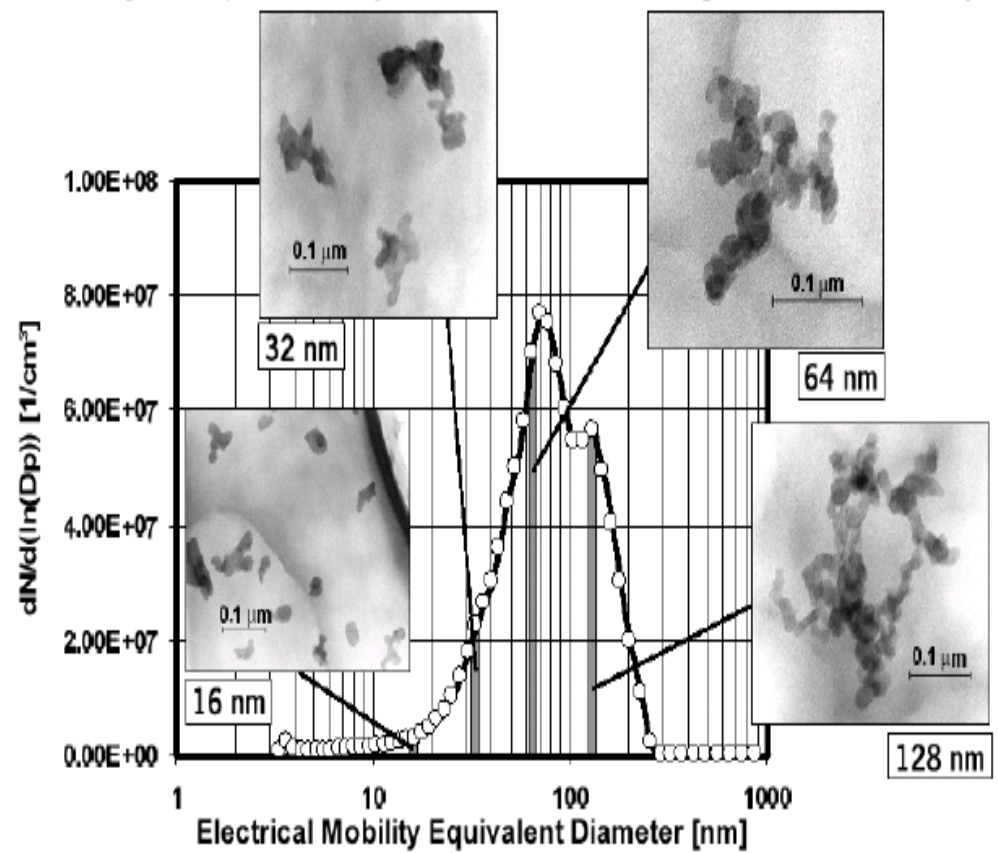
# Filtration - 65 DPF VERT tested

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



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

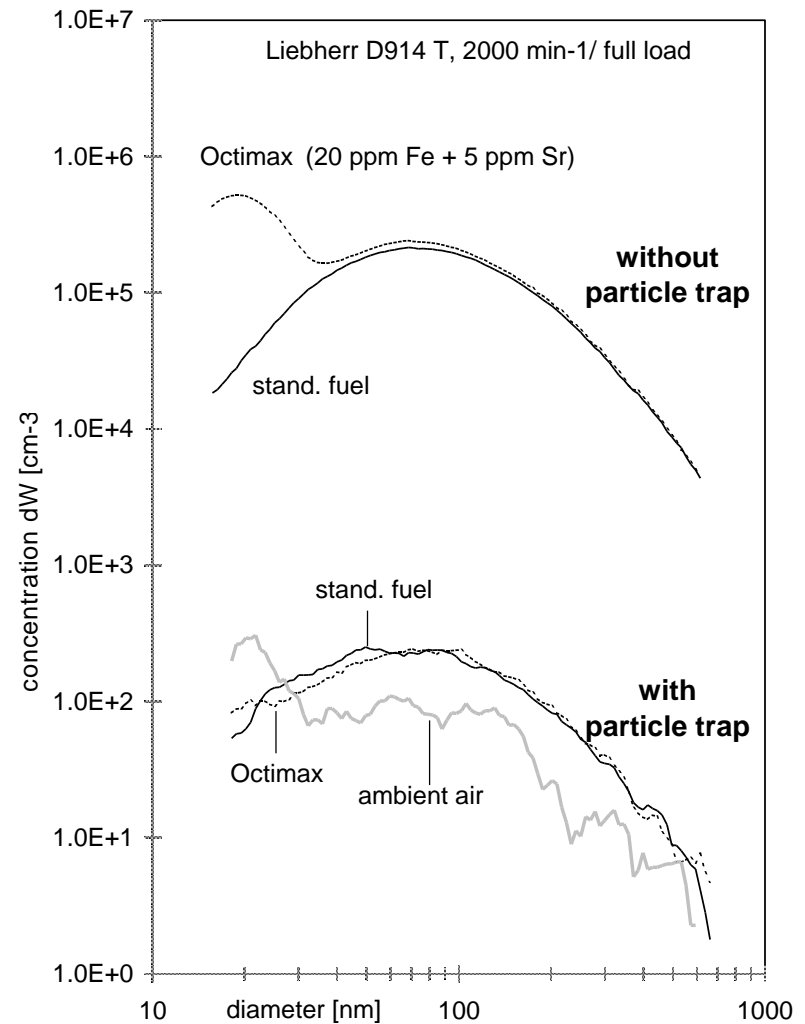
*The Lung is an open  
door for engine emitted  
particles*



# Best Available Technology BAT is only provided by Filtration

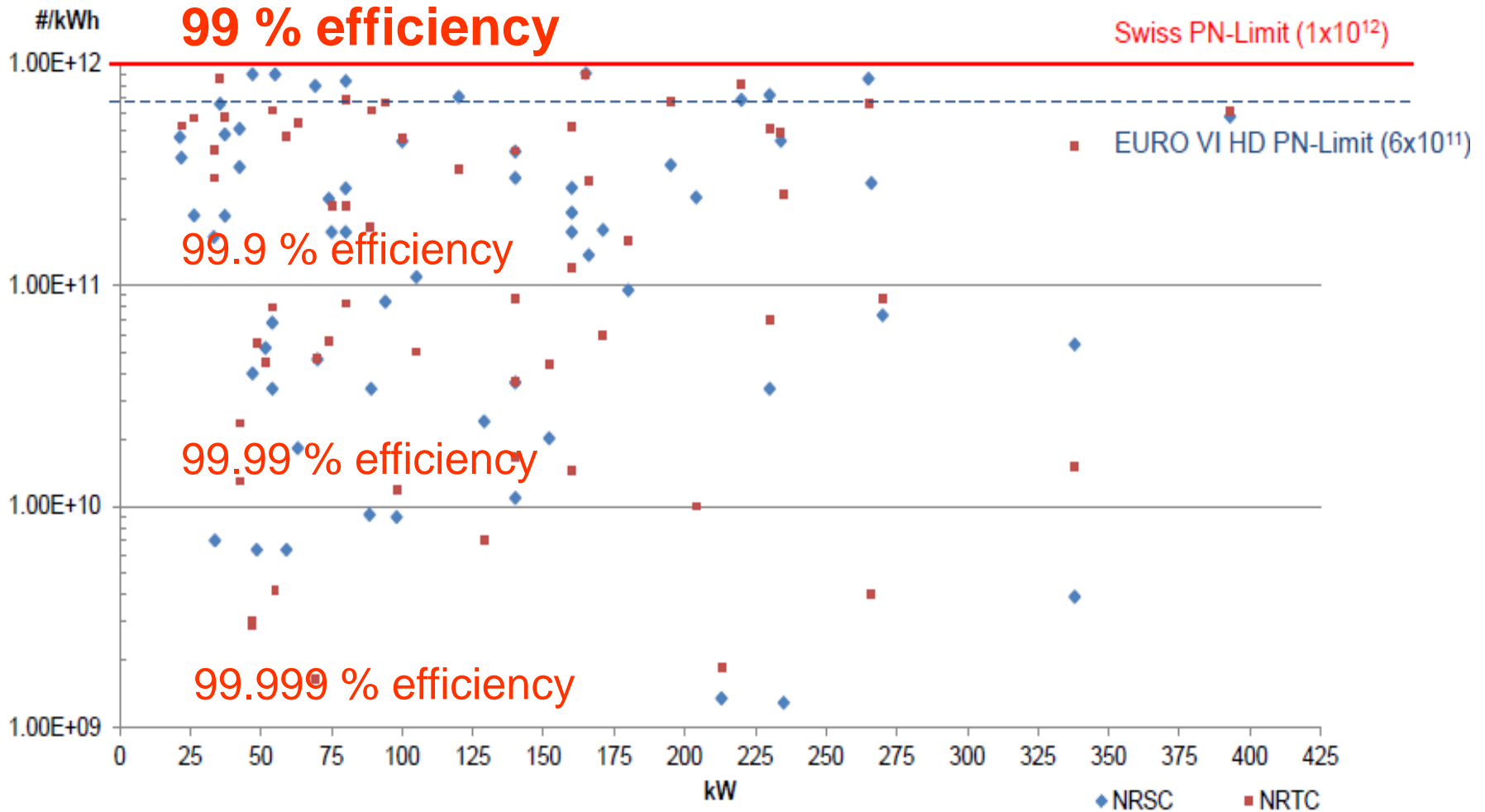
Filtration achieves 99.99 %  
on every engine within  
certification conditions

99.99 % means  
0,001 mg/kWh



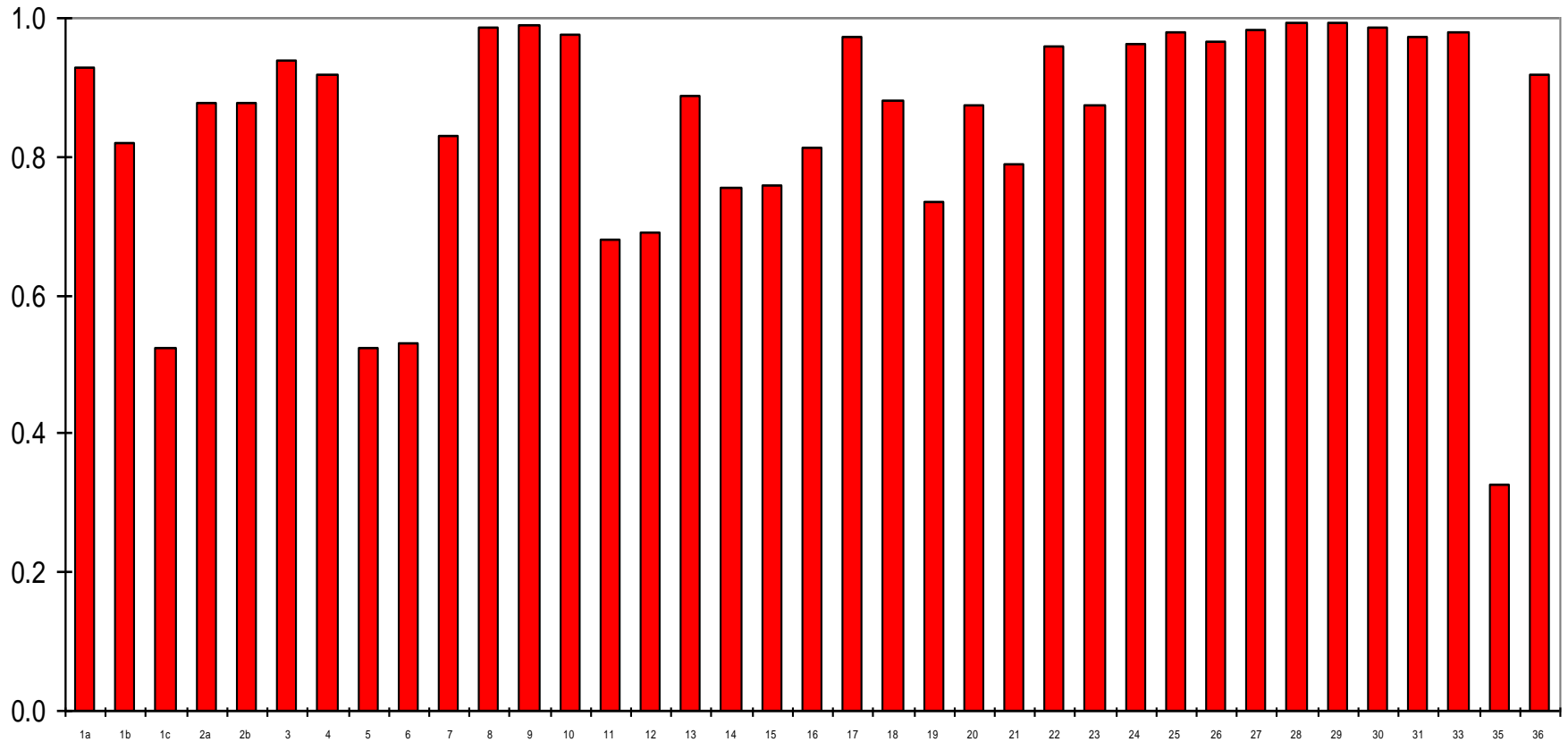


# PN-Test results



Swiss Statistics for imported construction machines with DPF

# PAH are also very effectively reduced in most filter systems



# Monetary Health Benefit

## DPF-Application on a Heavy Duty Truck

	HDV+FFF	
<b>PM-Emission (Euro III / 3)</b>	0.1 g/kWh	
<b>Mileage</b>	1000 hrs/yr	
<b>Average Performance [kW]</b>	100	
<b>PM Emission [kg/year]</b>	10	
<b>Overall vehicle life [year]</b>	15	
<b>Emission [kg/vehicle life]</b>	150	
<b>Filter type</b>	wall flow	
<b>Filter efficiency [%]</b>	99.9	
<b>Health Cost [€/kg PM10]</b>	460	
<b>Total prevented soot [kg/life]</b>	150	
<b>Health Benefit [€]</b>	69'000	

**Cost / Benefit = 10**  
 $69'000 / 7000 = 10$

# Experience

**20 years**

- > 50'000 Retrofits in Switzerland**
- > 500'000 Retrofits worldwide**
- > 50 million DPF OE first fit**



# Conclusions

- The Potential of Particle Emission Control by DPF Aftertreatment is a revolution, several orders of magnitude reduction – a must for public health
- Introduction is possible for OEM and also by retrofit with vehicles of the existing dirty fleet
- Fuel quality in Iran is no hindrance for introducing BAT-DPF immediately
- SCR-deNO<sub>x</sub> has lower priority and will be introduced as soon as low sulfur Diesel will be available
- Introduction of these technologies requires a new concept of inspection & maintenance



