26th ETH Nanoparticle Conference 21.6.2023

Particle Filters for Combustion Engines to Mitigate Global Warming

Andreas C.R.Mayer

Global warming a new phenomenon ? not for the science

1824 Joseph Fourier 1824 predicted global warming by mixing gases into the atmosphere

1856 Eunice Newton Foote, an amateur scientist; she took several glass cylinders, filled with gases including CO2, placed the cylinders in the sun to heat up, then in the shaddow to cool down and observed that the cylinder with CO2 and water vapor became hotter than regular air (11° F). “An atmosphere of that gas would give to our earth a high temperature.” she noted.

1895 Svante Arrhenius calculated: 5-6°C increase by doubling CO2 content in the atmosphere; based on experimental data of Tyndall he calculated an atmospheric model by hand during several months.

The colour-play of airborne particles

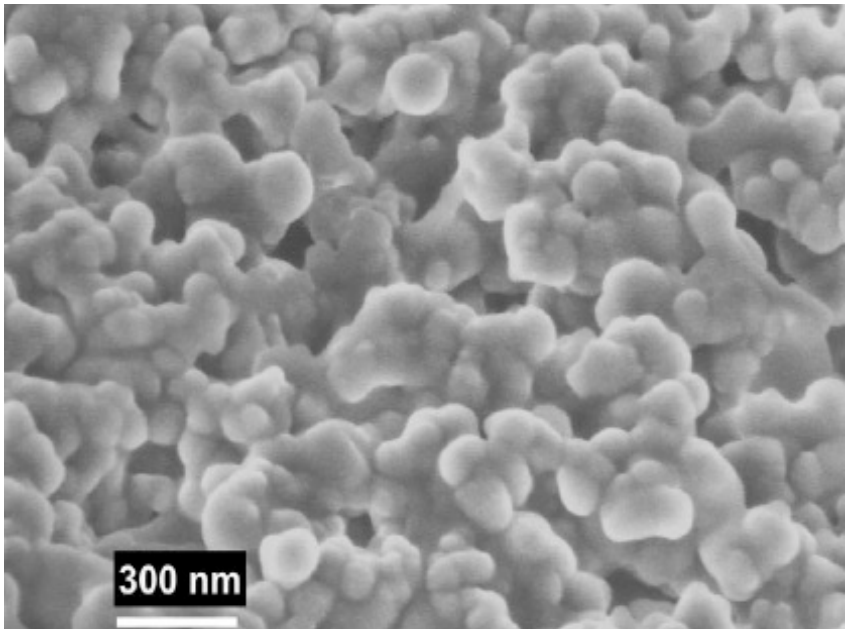
Shindell, Faluvegi - April 2009

Black Carbon responsible for 50% or nearly 1.0° C of the 1.9° C temperature increase in the Arctic from 1890 to 2007

Skyline von New York City am 7. Juni 2023 Foto: Lokman Vural Elibol / Anadolu Agency / picture alliance

Marsianisch orange leuchtete der Himmel über der Skyline von Manhattan diese Woche. Der Rauch von weit über 100 Waldbränden im Osten Kanadas war nach Süden gezogen. Die Luftqualität in der Millionenmetropole New York sank rapide, sie war zwischenzeitlich so schlecht wie noch nie seit Beginn der Messungen. Die Färbung des Himmels entstand, weil die kurzwelligen Anteile des Sonnenlichts, Blau und Grün, auf dem Weg zur Erde von den Rauchpartikeln gestreut wurden, übrig blieben Rot und Orange.


London Smog 1952
TOLER

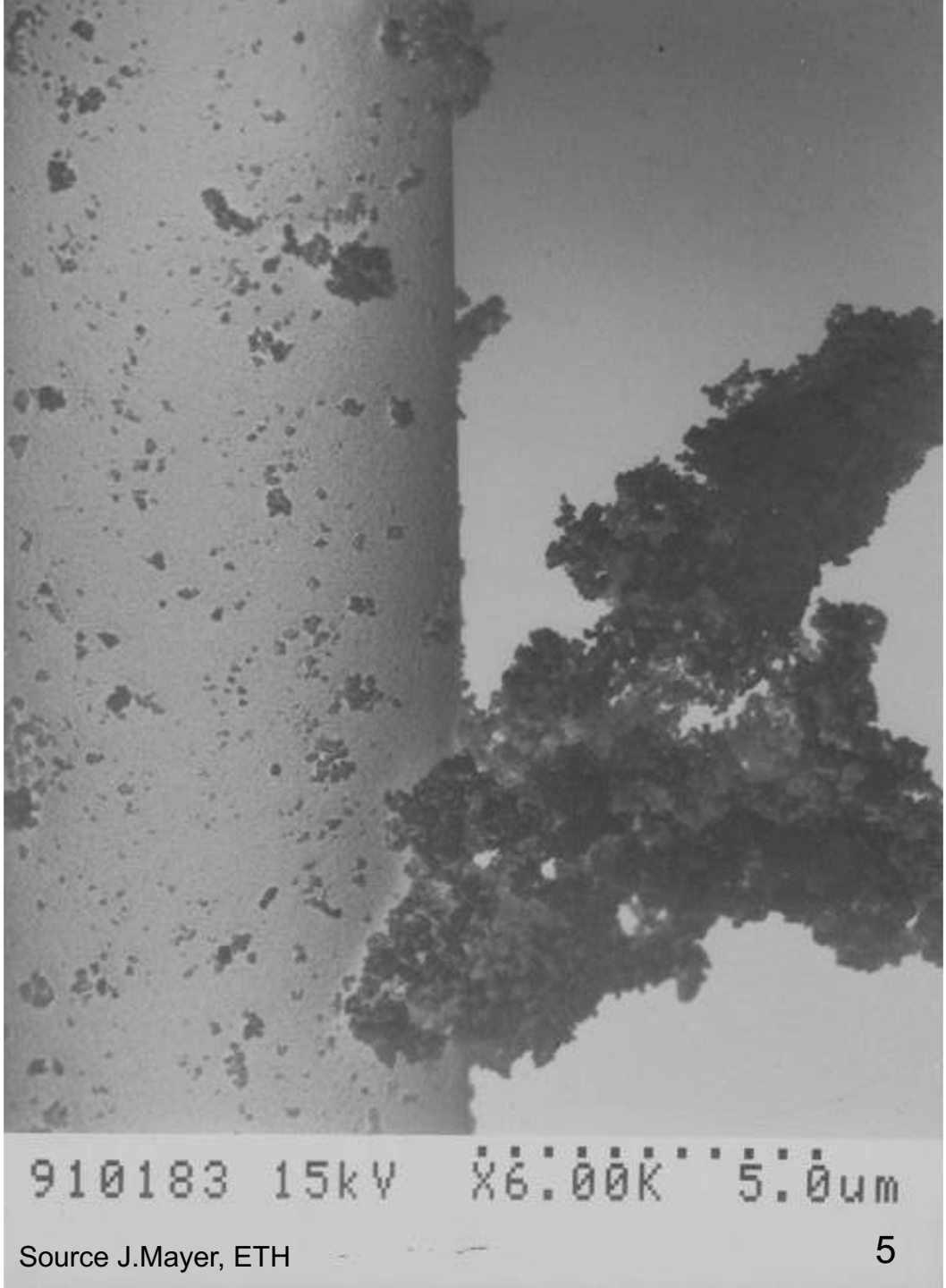

300 nm


his fellow James Watt started the industrial revolution
the world became populated (x10), wealthy (x20) and polluted (x100),

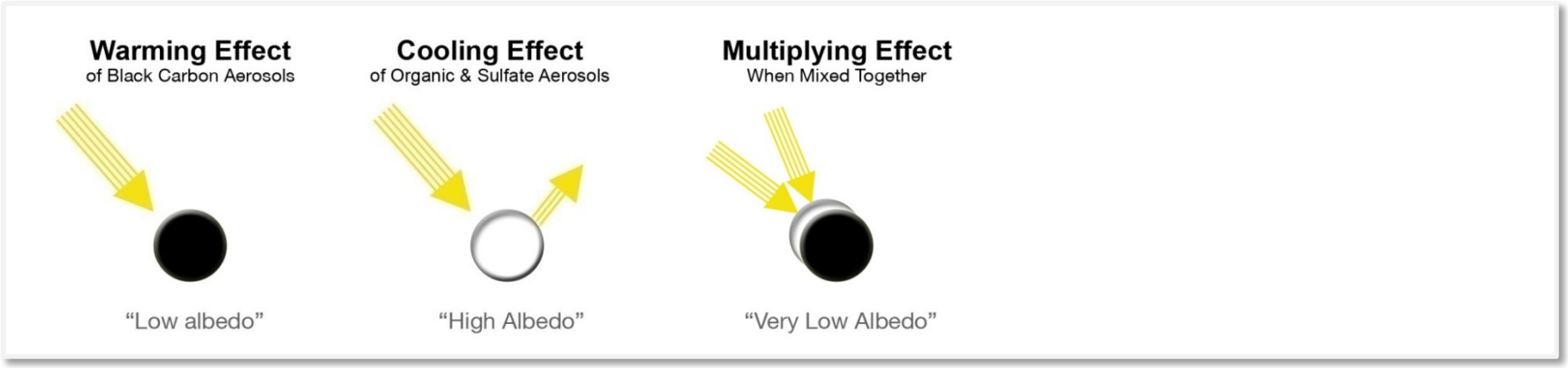
Soot Particles
a double Risk because of

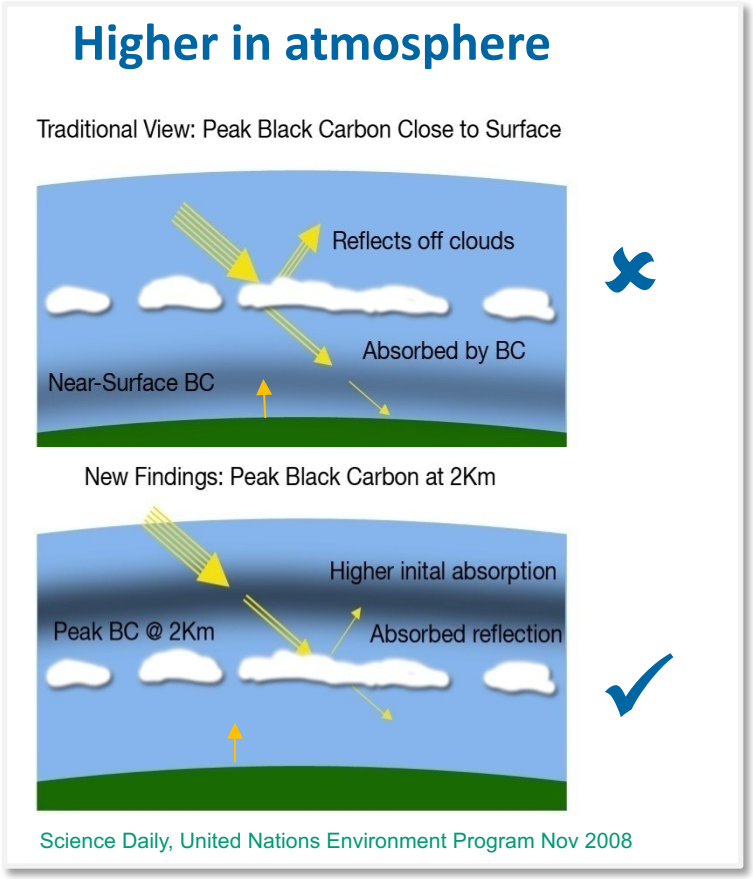
- **very small <100 nm**
- surface **> 100 m²/g**
- carrying toxics
- persistent in organism
- carcinogenic
- **black colour**

→long life toxic aerosol
weeks to month up tp 3500 m
(→Jungfraujoch-Laboratory)



Source J.Mayer, ETH





Global Warming by BC-Particles in Air

Prop. to particle mass (Lambert-Beer)

stongly depending on

- **reflection properties** (Diesel high, Wild fires low)
- **mixing properties with water droplets** (internal, external mix)
- **In-cloud effects like ice formation** Z.A.Kanji VERT Forum 2021
- **residence time**

Jacobson Fossil 2002 – ETH-NPC 2002

Control of fossil-fuel particulate black carbon and organic matter, possibly the most effective method of slowing global warming

Mark Z. Jacobson

Department of Civil and Environmental Engineering, Stanford University, Stanford, California 94305-4020, USA

Email: Jacobson@stanford.edu

Tel: (650) 723-6836

Journal of Geophysical Research, in press.

Submitted Oct. 8, 2001; Revised Feb. 4, 2002; Accepted April 12, 2002.

Radiative Forcing Equivalence Ratio per Unit Mass

BC / CO_2 : 640‘000 – 830‘000 : 1

Hearing Summary

HEARING ON BLACK CARBON AND GLOBAL WARMING

Rep. Henry A. Waxman
Chairman, Committee on Oversight and Government Reform

October 18.2007 – 5 leading researchers incl.M.Jacobson

- **BC is the second leading cause of Global Warming**
- BC is of particular importance in the Arctic (Albedo-Reduction)
- BC comes from Diesel engines and fires – wild and domestic
- Decreasing BC emissions will **immediately slow GW**
- Decreasing BC emissions will improve public health
- Opportunities to decrease emissions **exist now**

→ Obama-Administration: EPA must propose measures, re-define the role of BC-particles and adjust limit values to the state of the science

Jacobson 2009

On my question whether the numbers of CO2/BC equivalence ration might have changed since 2002: the result of new research is in the range of that in the 2002 paper, rather higher close to 1 Mio:1

360’000-840’000:1 ratio of ff BC warming per unit ambient mass in the atmosphere to that of CO2

or 120’000-280’000:1 for ff BC+OM to that of CO2

Confirmed by Hansen (NASA), Seinfeld, Chung, Bond, Ramanathan, Carmichael, Swiss Ad Hoc Expert Group 2023, Baltensperger (PSI)

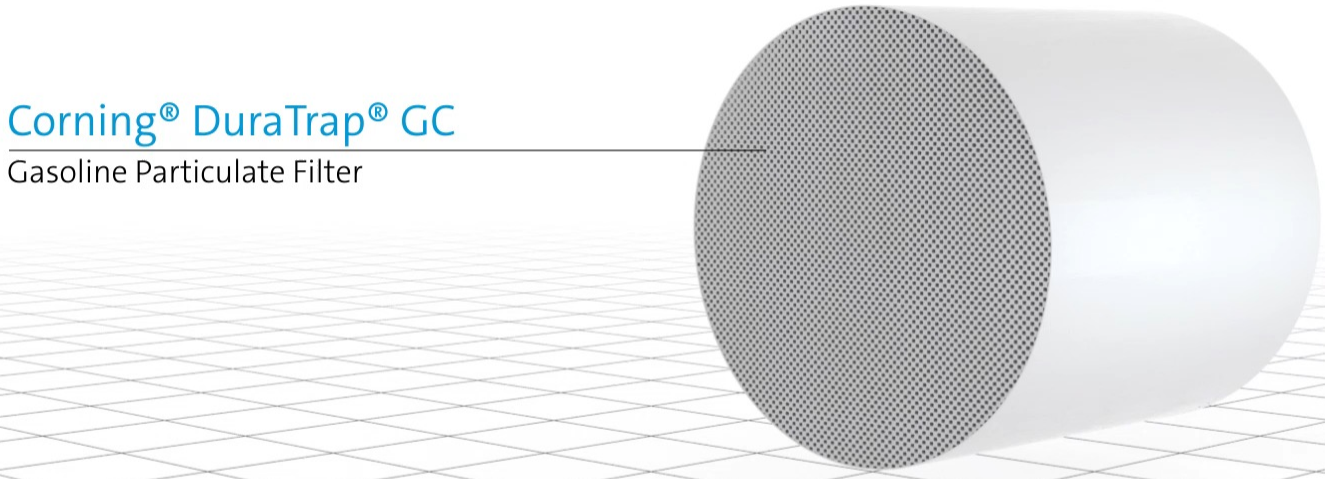
BC blackening the North Pole comes from Europe – acc. to NASA

Abb. 3: Enstehungsgebiete und Verbreitungsrichtungen von Rußpartikeln auf der Nordhalbkugel

Woher kommt der Ruß in der Arktis?

Hansen und seine Kollegen haben auch gezeig
flächen der Arktis vorwiegend aus Europa stam
Rußemissionen aufgrund der herrschenden Wi
gel entweder über Sibirien oder direkt in die A
Zwar gelangen Rußpartikel auch aus Nordame
doch der größte Anteil aller Rußpartikel im a
Drittel aufgrund der Stärke und Richtung der V
dellierungen und Messungen im Gange, um d
Rußemissionen auf die Arktisregion noch bess

With combustion engines we can eliminate soot at the source



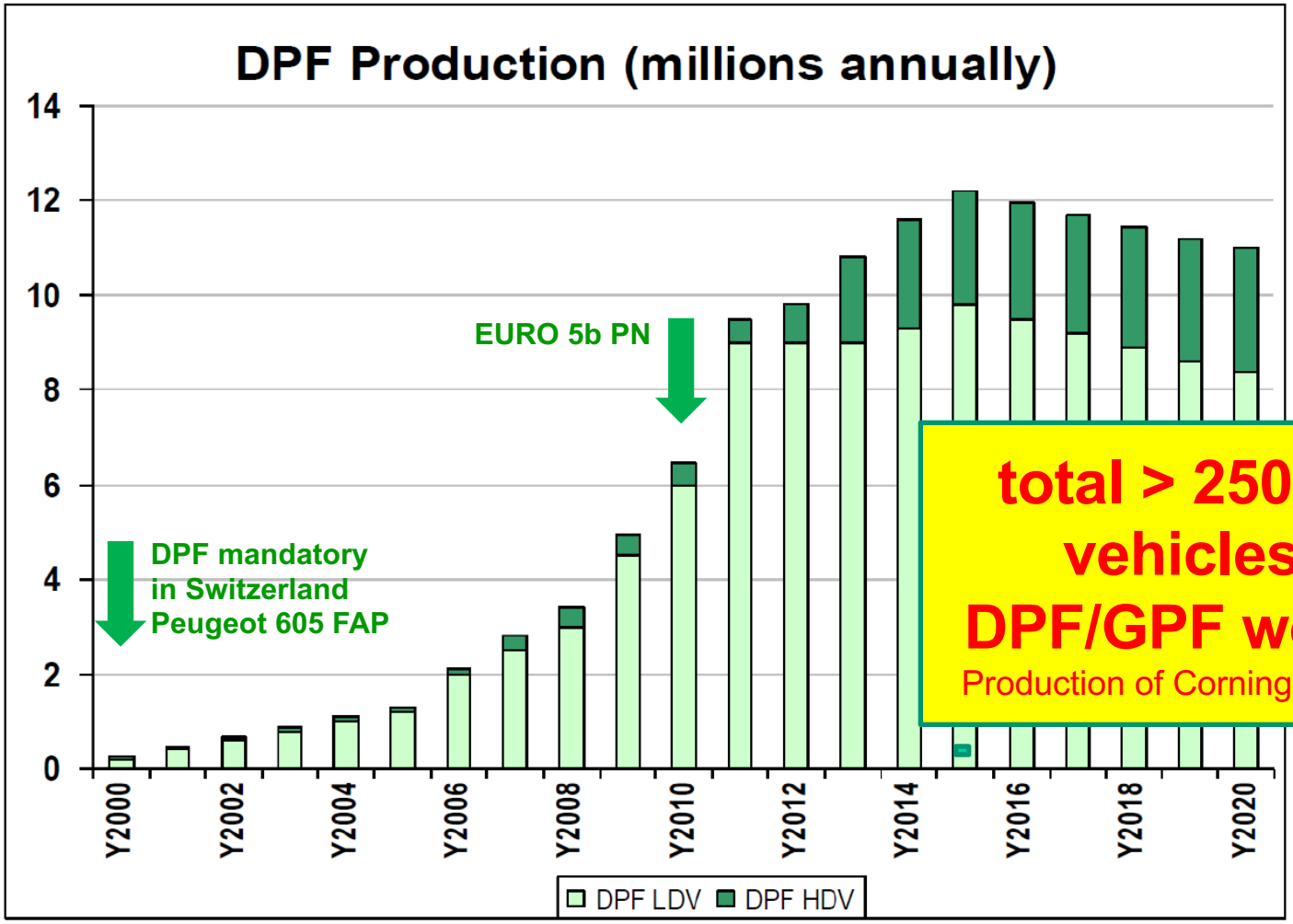
Source Corning

How a Vehicle Tailpipe can look
after 85‘000 km City Driving

DPF-Production in Europe

+ GPF from 2015

+ China,
+ India,
+ Israel,
+ Iran
+ Latin America
+ USA HDV



total > 250 million vehicles with DPF/GPF worldwide

Production of Corning + NGK + Ibiden

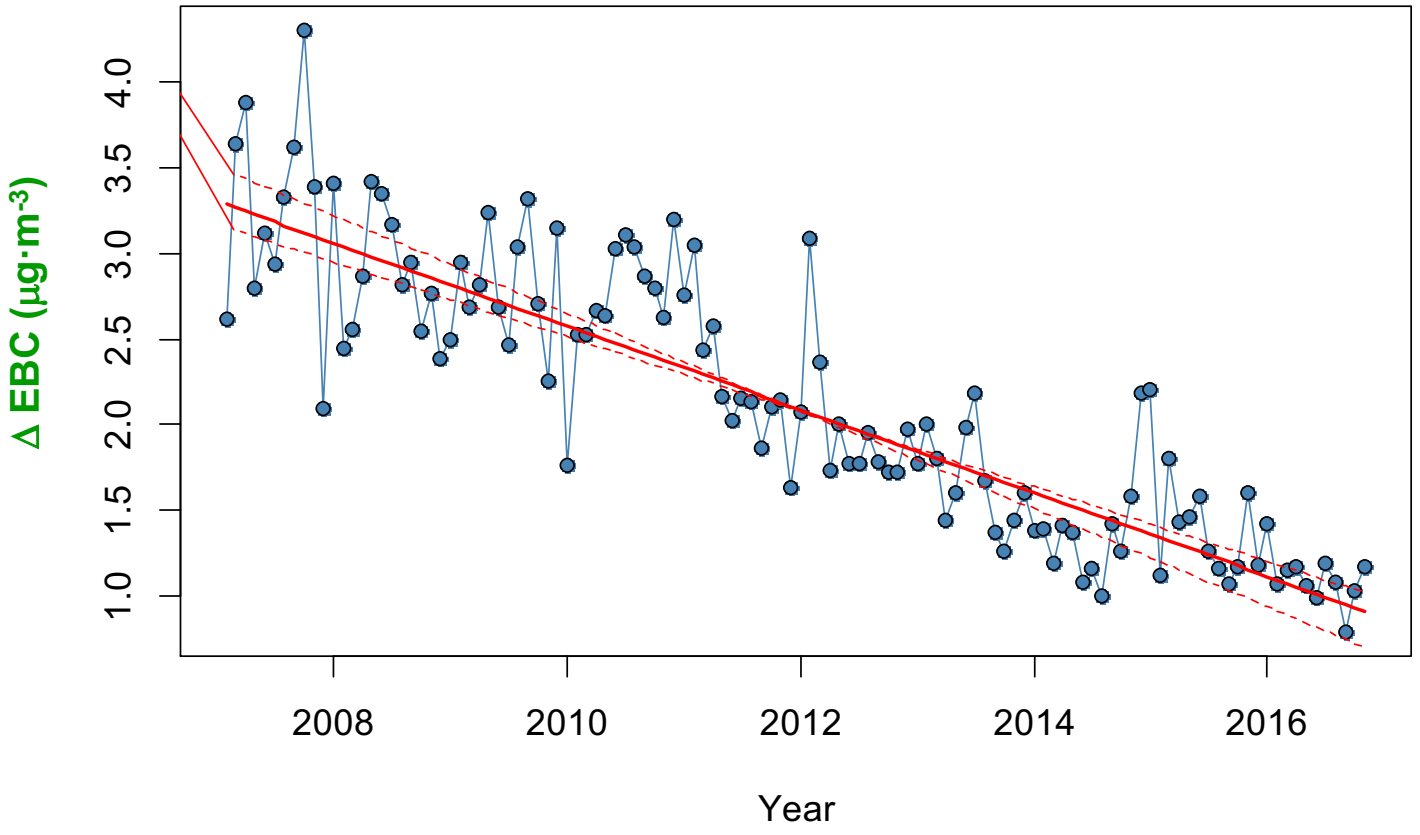
Source VERT

The Result: Cleaner Air by DPF in

Monitoring BC at the motorway crossing Härkingen

Very beneficial for health as epidemiological data confirm

Based on WHO data anually two millions less premature



Limit <0.1 µm/m^3 for 4/100'000 cancer cases

Source: DECOS

Source
Chr.Hüglin EMPA

How much contributes our DPF Fleet today to GWP-mitigation ?

50 mg soot/km if we assume emission level Euro 3,
for the diesel passenger car without filter

10 years lifetime with a total mileage of 200'000 km
10 kg soot per car lifetime,
100 kg per truck/bus/excavator lifetime

250 million Diesel particle filters have been produced so far,
150 million particle filters are operative in LDV

100% filtration efficiency
→ **1.5 million tons of soot saved by LDV**
→ **3.0 million tons of soot (BC) saved by LDV+HDV+ with filters over a period of 10 years**

With a Soot/CO2 equivalent of only 100’000:1, this would be equivalent to the effect of 300 billion tons of CO2 over 10 years (lifetime of this fleet), respectively
30 billion tons CO2 Equivalent per year.

The worldwide yearly emission of CO2 today
is 35-40 billion tonnes.

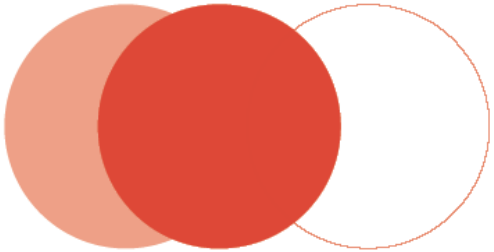
According to this highly simplified calculation, we would have achieved an effect with our particle filter action that is in the order of magnitude of the annual human made supply of CO2 to the atmosphere ☺

But this is not realistic

since residence time of soot particles in the atmosphere is much shorter than that of CO2. While CO2 might stay 20 years or more, soot aerosols may be cleaned out of the atmosphere by rain or become ineffective by hydrophylic coating or internal mixing so their residence time might be days to weeks to months in dry countries

Residence time ratio 240 :1 (20 years to one month)

→ Jacobson's equivalence factor **500'000: 240 = 2083**



January and
June 2009
M.Walsh

Table 1. Global Warming Potentials (GWP) drawn from the IPCC 4th Assessment Report

	GWP20	GWP100	GWP500
Black carbon	**1600**	**460**	**140**
Methane	72	25	7.6
Nitrous oxide	289	298	153
Sulfur oxides	-140	-40	-12
Organic carbon	-240	-69	-21
Carbon dioxide	1	1	1

Note: The methodology used for black carbon was also used for organic carbon and sulfur oxides. Values for black carbon, organic carbon and sulfur oxides were not published by the IPCC and are not official estimates.

Study by Alantic Consulting 2009

Table 1: Relative Global Warming Potential of a selection of key emisssions

Emission	Global Warming Potential[D] Relative to CO_2	
	20 Year Period	100 Year Period
CO_2	1	1
Methane	72	25
Nitrous Oxide (NOx)	289	298
Black Carbon	2200	680

again Jacobson 2009

«surface temperature response per unit mass»

Table 4. The 20- and 100-Year Surface Temperature Response Per Unit Emission Functions and the 100-Year Surface Temperature Response Per Unit Mass for Fossil-Fuel Soot, Biofuel Soot and Gases, Black Carbon in Both, and Methane[a]

X	20-Year STRE	100-Year STRE	100-Year STRM
BC+POC in FS	2400–3800	1200–1900	$4.9–11 \times 10^5$
BC in FS	4500–7200	2900–4600	$1.05–2.4 \times 10^6$
BC+POC in BSG	380–720	190–360	$3.6–9.9 \times 10^4$
BC in BSG	2100–4000	1060–2020	$3.5–9.7 \times 10^5$
Methane	52–92	29–63	21–45

CO_2 (Figure 1), a result consistent with similar analyses of climate response [*Jacobson*, 2002b, 2004a, 2006] and radiative forcing [*Jacobson*, 2000, 2001b; *Chung and Seinfeld*, 2002; *Ramanathan and Carmichael*, 2008] of particles containing black carbon.

Equivalence Factors

	ICCT, M. Walsh 6/2009	Atlantic Consultants 2009	VERT 2012	STRE M.Jacobson 2009
BC (engine soot)	1600	2200	1440	2400-7200
CO_2	1	1	1	1

→ We continue with 2083

Realistic Impact of soot avoided by particle filters

During DPF lifetime 10 years: **3 million tons soot**
x equivalence factor 2083 equals **6,2 billion tons CO2**
Per year: 0.6 billion tons avoided (mainly in Europe)

CO2- emission of EU per year: 4,06 billion tons (2019)
CO2-Emission of Germany per year: 0.7 billion tons

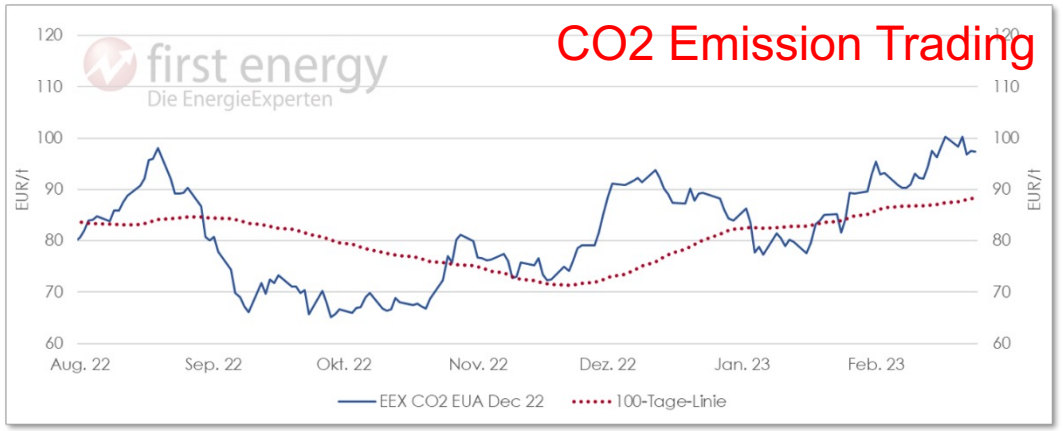
Global Warming Impact avoided by DPF compared to CO2 Europe: 15%

This means that with the DPFs, without waiting for the IPCC decisions, we have already effectively mitigated the rise in temperature since year 2000; without DPFs it would already be significantly hotter.

In fact, M. Jacobson, with his extensive calculations including all atmospheric phenomena known so far expects the effect of soot to warm the atmosphere 1.7°C. Thats why he recommended to US government to avoid emission of BC wherever possible.

We have submitted this to conference participants at Sharm el Sheikh but IPCC is not taking notice of this, saying that there are still doubts on the inventory. . . . .
Have we time for doubts?
Why not retrofit vehicles instead of sticking girls on roads?

Black Carbon deserves Credits for Emission Trading !



assuming 80 EUR per ton CO2 (EEX CO2 2022):

one kg not emitted Soot deserves a credit of 166 Euro

→ 1’660 Euro per LDV DPF retrofitted

→ 16’600 Euro per HDV DPF retrofitted

→ plus health benefit
(difficult to monetarize: WHO 1 Mio € per mortal case – by 100 vehicles)

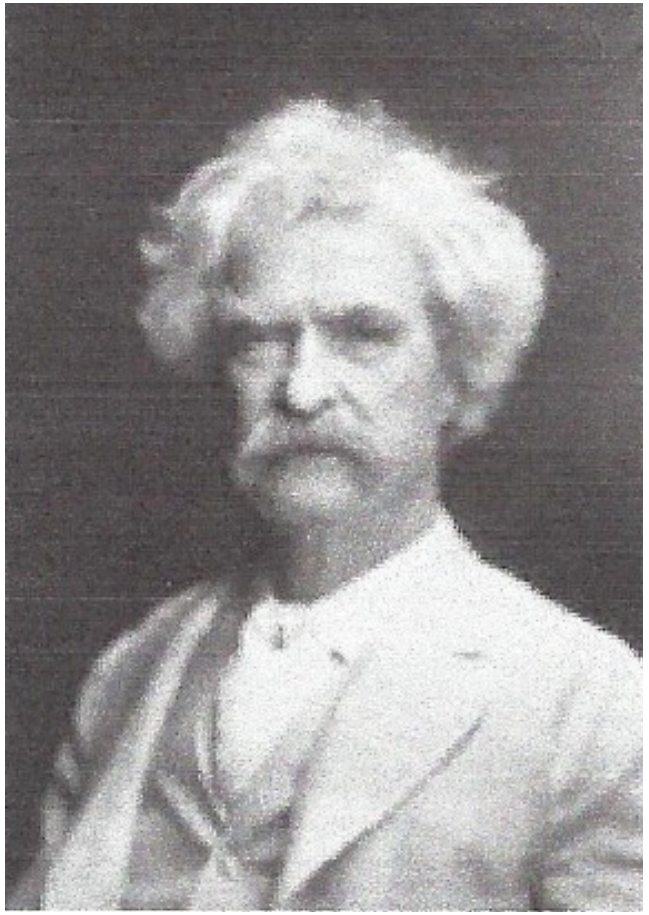
Our Conclusions

- **All new combustion engines must have filters**
- **Retrofit of all in-use Diesels with DPF**
- **Retrofit in-use Petrol Engines with GPF**
- **Establish a monetary soot credit value**

→This will multiply the existing effect by **Factor 4** generate health protection, global warming mitigation and bring money in developing countries, where extremely dirty engines will be used for many years to come.

«What gets us into trouble is not what we don't know It's what we know for sure that just ain't so»

Mark Twain



And this is my message to all those who still believe in a single silver bullet to control climate effects. We will need many and we might not have enough silver – **but here is at least one, ready to apply**.

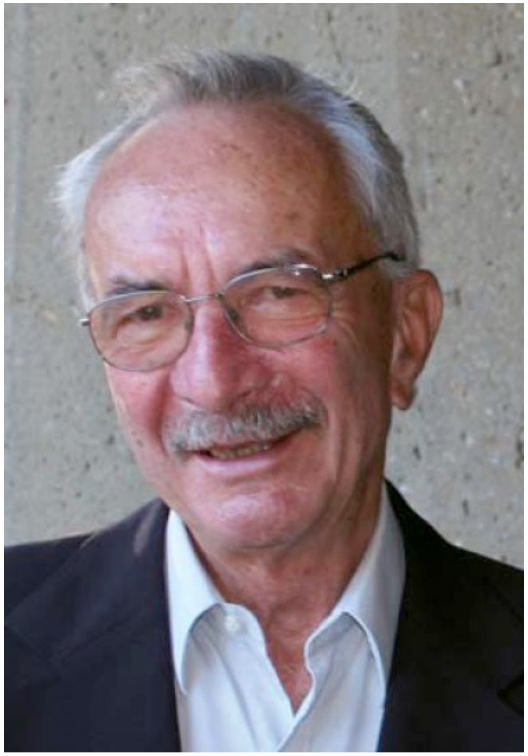
Lebenswerk Luftverschmutzung:

Es zeigt sich eine tragische Unfähigkeit unserer Gesellschaft für vorsorgliches Handeln.

H.C. Siegmann, Stanford

übermittelt an A.Mayer 2.Oct.2006

gest.19 Juni 2009



„Als ich Gerlach und Hahn stolz mitteilte
dass ich das Problem gelöst hatte,
und dass die elektrische Leitfähigkeit der Luft
tatsächlich von der Konzentration der Autoabgase
bestimmt wurde, **verloren beide jedes Interesse“**

VERT

we can control and eliminate nanoparticles for health and climate