**14.VERT Forum** 22.03.2024

# Mitigate Global Warming

## With 300 Millions of Particle Filters in place worldwide and more to come

Andreas C.R.Mayer

# Global warming by greenhouse gases 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.

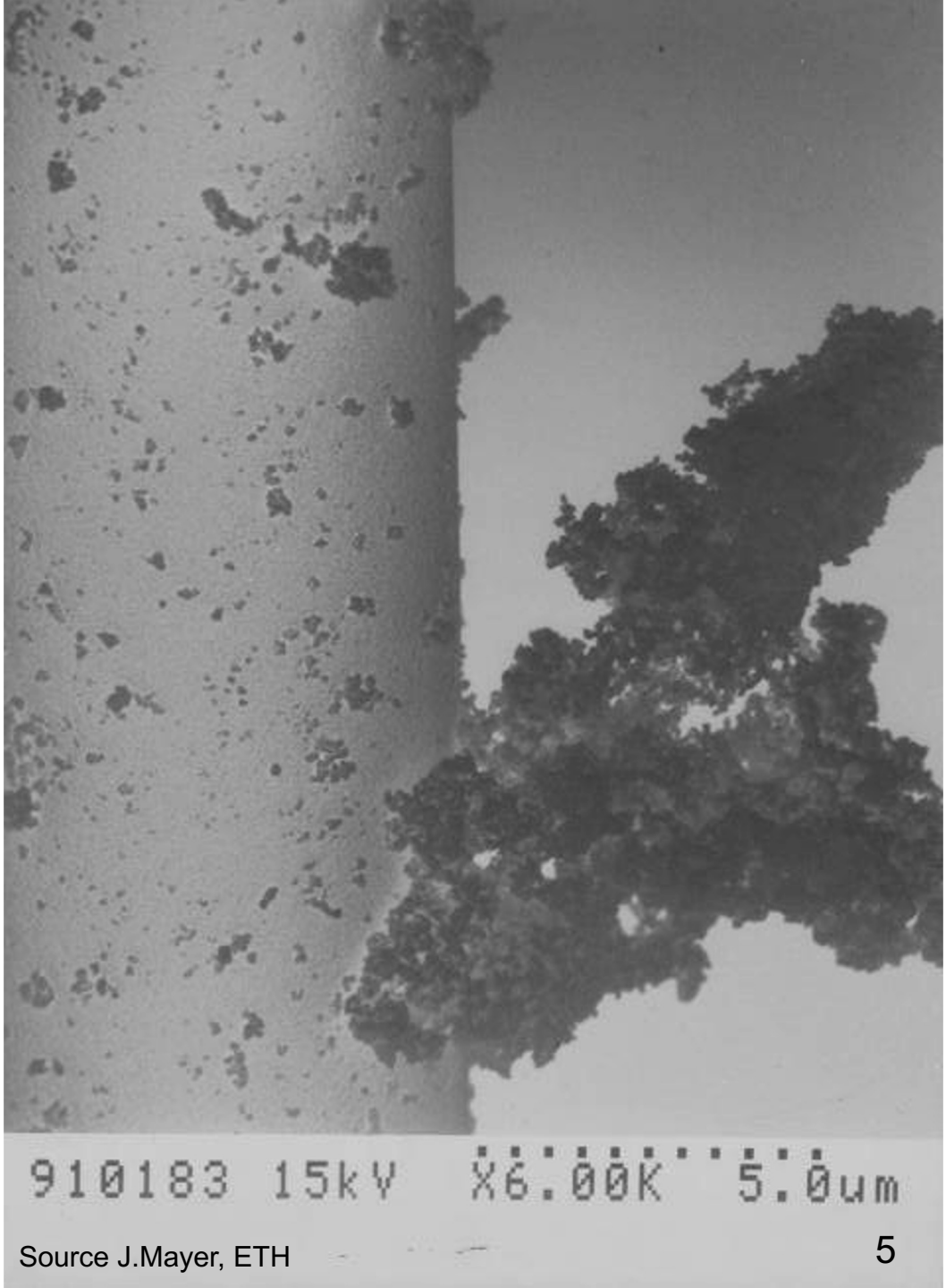
**1895 Svante Arrhenius calculated**: 5-6°C increase by doubling CO2 content in the atmosphere; based on experimental data of Tyndall he calculated an atmospheric model by hand during several months.

→ Forgot the aerosols

# 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)



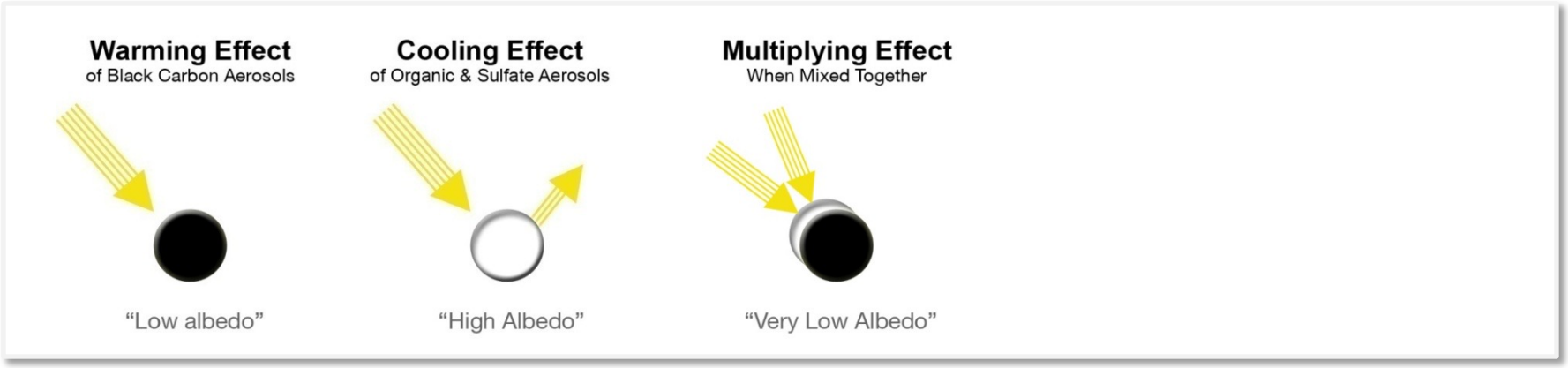

Source J.Mayer, ETH

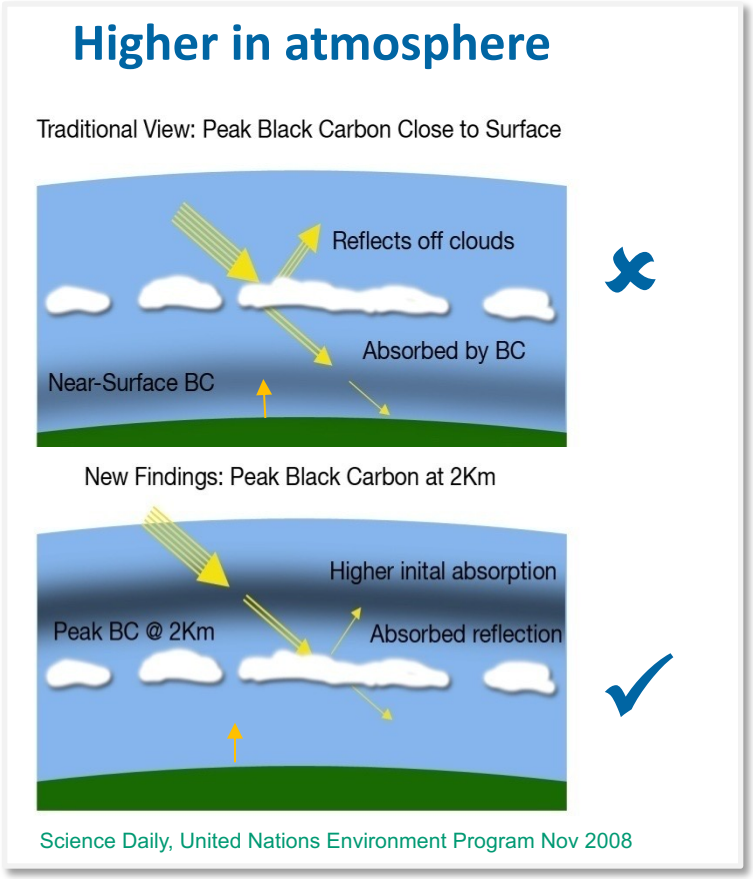
# The colour-play of airborne particles …….


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

## changes radiation properties

**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.




# 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**

# and sedimented on snow, polar ice and Alpine/Himalaya/Anden glaciers

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**

# 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

# 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

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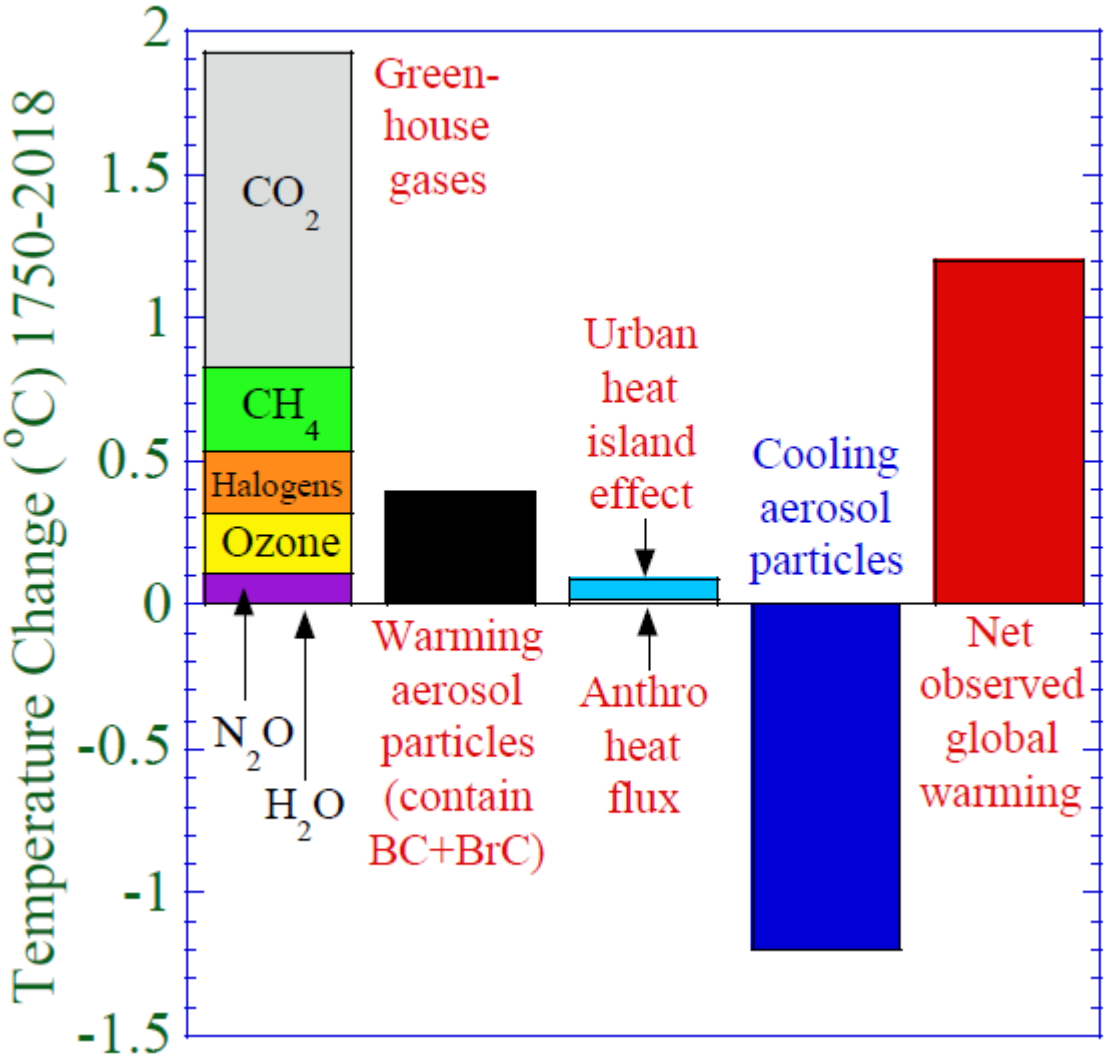
*Journal of Geophysical Research*, in press.

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**

# Don‘t mix aerosols with aerosols
# Soot is number two after $CO_2$



Hearing Summary

# HEARING ON BLACK CARBON AND GLOBAL WARMING

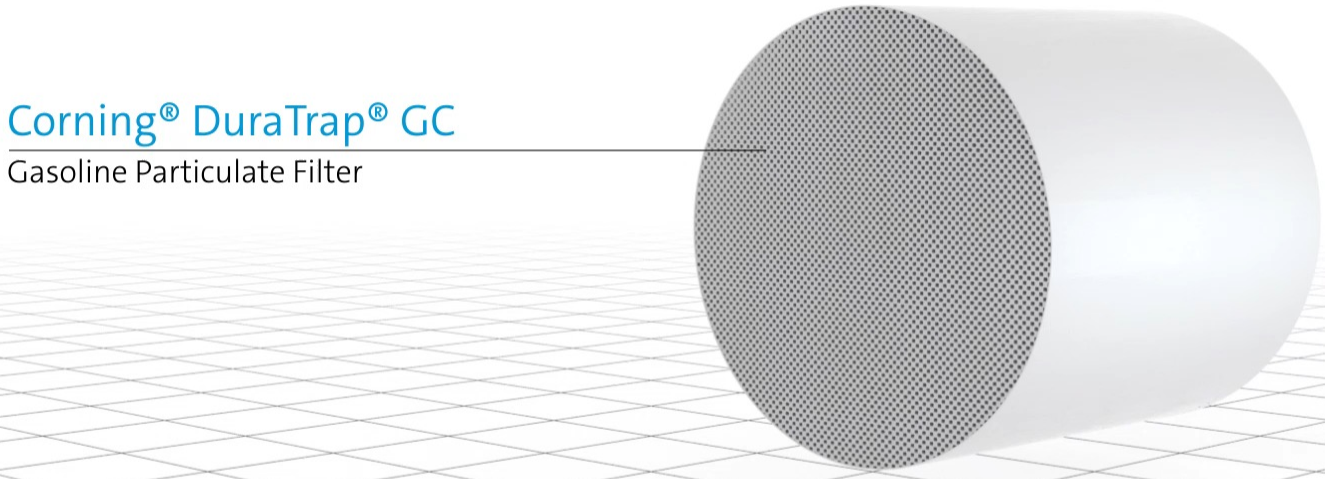
Rep. Henry A. Waxman
Chairman, Committee on Oversight and Government Reform

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

# With combustion engines we can eliminate soot at the source

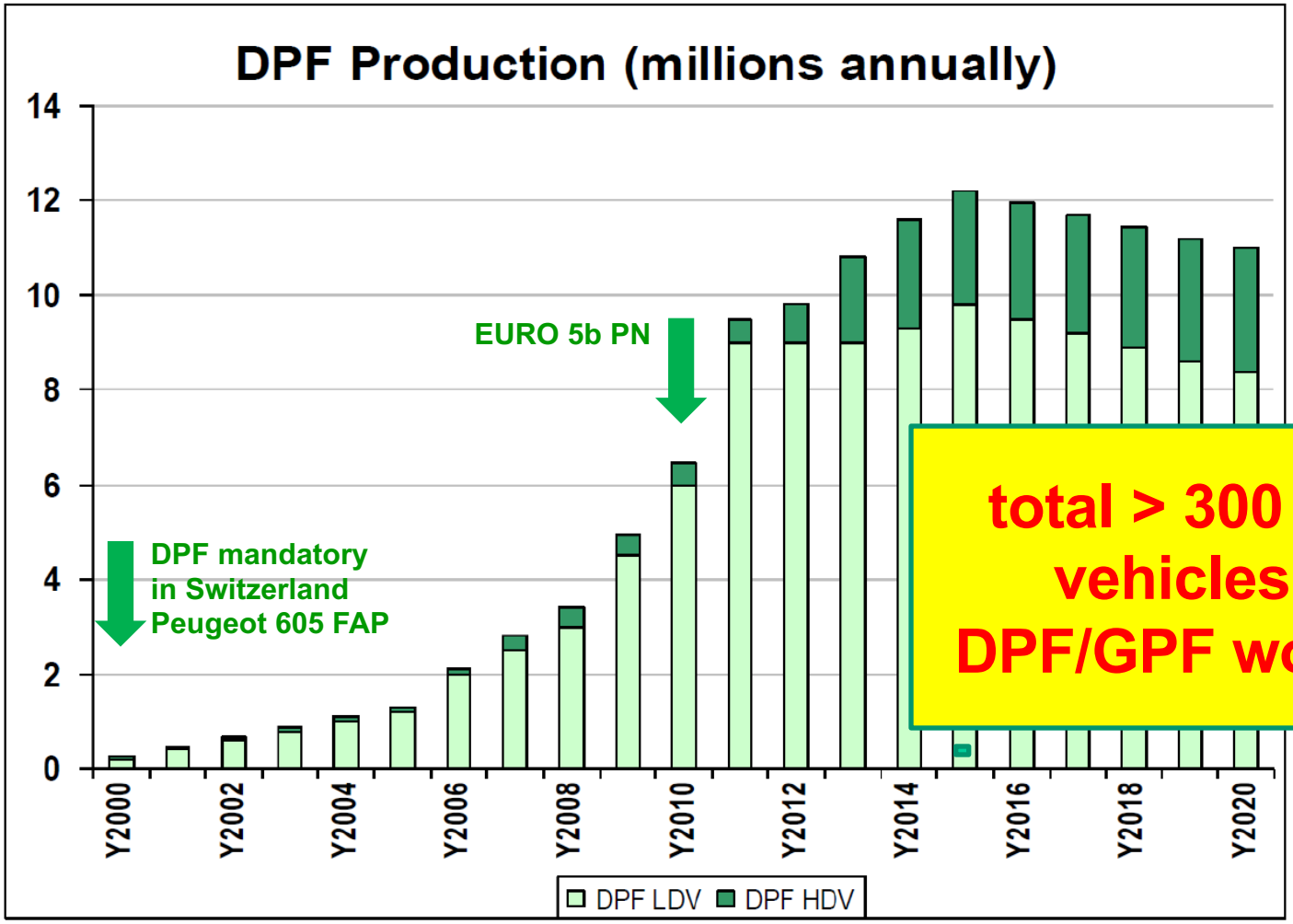



Source Corning

# DPF-Production in Europe

## + GPF from 2015

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




**total > 300 million vehicles with DPF/GPF worldwide**

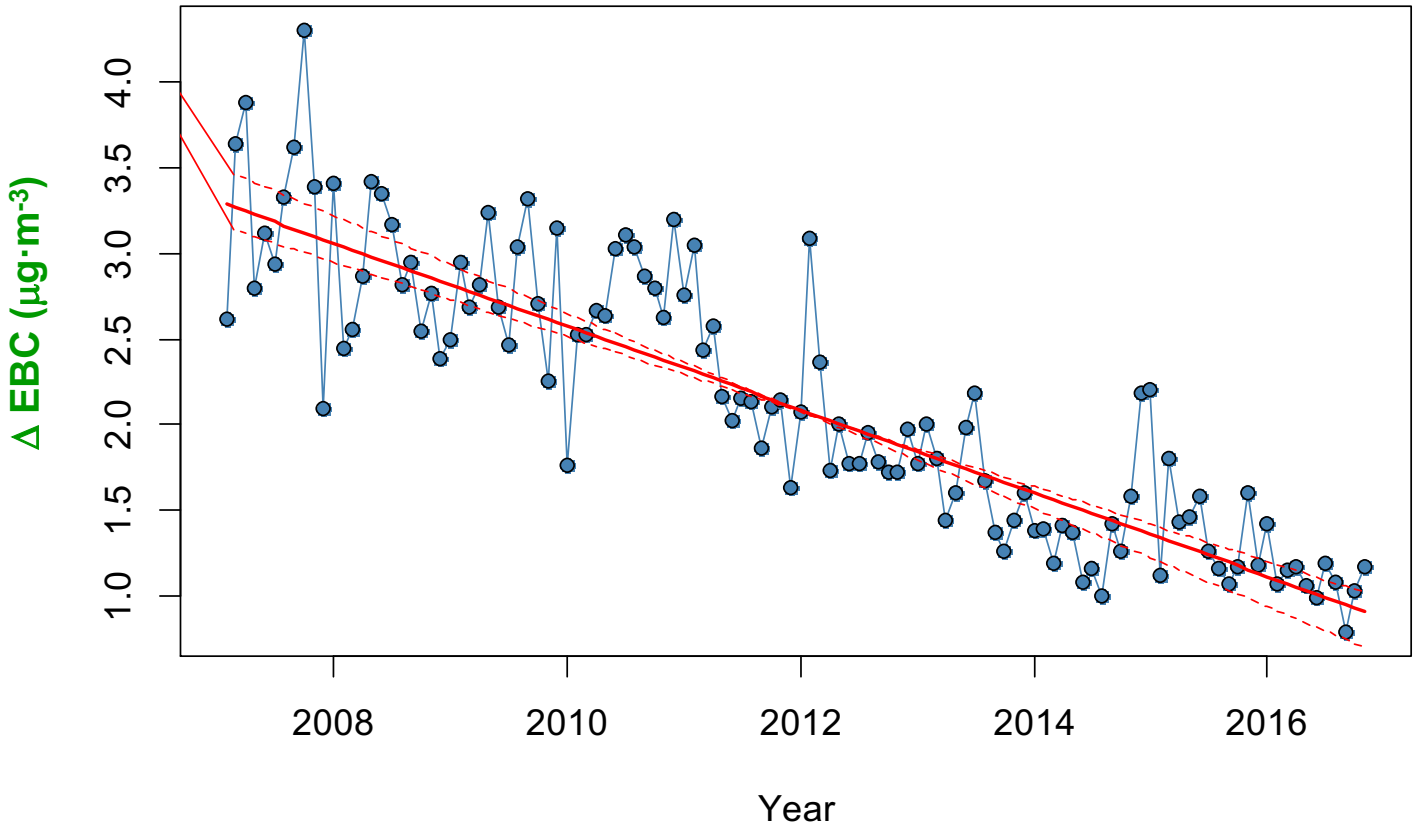
Source VERT

# The Result: Cleaner Air by DPF

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**

# Paper ECST public access Jan 2024

Emission Control Science and Technology
https://doi.org/10.1007/s40825-023-00236-x

## Particulate Filters for Combustion Engines to Mitigate Global Warming. Estimating the Effects of a Highly Efficient but Underutilized Tool

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Received: 25 August 2023 / Revised: 7 December 2023 / Accepted: 8 December 2023


**Abstract**
Particulate filters are state-of-the-art and are used in internal combustion engines worldwide to eliminate carcinogenic nanoparticles. Health studies estimate that this prevents about one million premature deaths annually. What is less known and often neglected is their equally powerful effect on mitigating global warming. This is because these ultrafine particles form stable aerosols in the atmosphere, absorb sunlight, and heat the atmosphere due to their jet-black color. In addition, once deposited on the ground, they reduce albedo especially when deposited on ice or snow. They also thin clouds and reduce their reflectivity. In this paper, we estimate for the first time the cumulative effect of more than 300 million particulate filters currently installed globally on vehicles, showing that, while they reduce ~0.5 Mt of soot per year, their effect on slowing global warming is equivalent to reducing 1 Bt of $CO_2$ per year or about one-third of the $CO_2$ emissions of all European Union Member States combined. Despite its strong potential, this highly efficient, proven, and low-cost technology is not yet regarded as a priority in curbing global warming, even though it is possibly the easiest and quickest to implement. If used in retrofitting more diesel and petrol engines worldwide, it could triple the aforementioned effect. While modern internal combustion engines are on track to be replaced with zero-emission vehicles, it is also crucial, and we strongly suggest that, in the interim, all remaining internal fossil fuel combusting engines be fitted with particulate filters. Evidence is presented in this paper that the potential benefits of such retrofit on climate and human health will be impactful and lasting.

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.

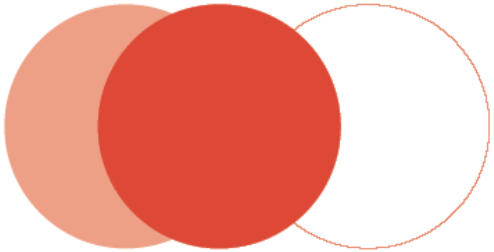
**According to this highly simplified calculation, we would have achieved an effect with our particle filter action that is in the order of magnitude of the annual human made supply of CO2 to the atmosphere ☺**

# 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

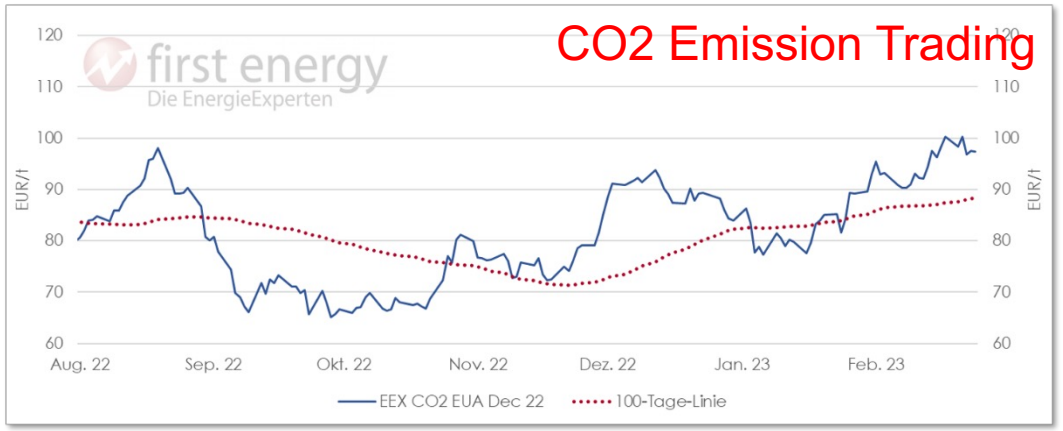
# Realistic Impact of soot already avoided by particle filters

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%**

# 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**

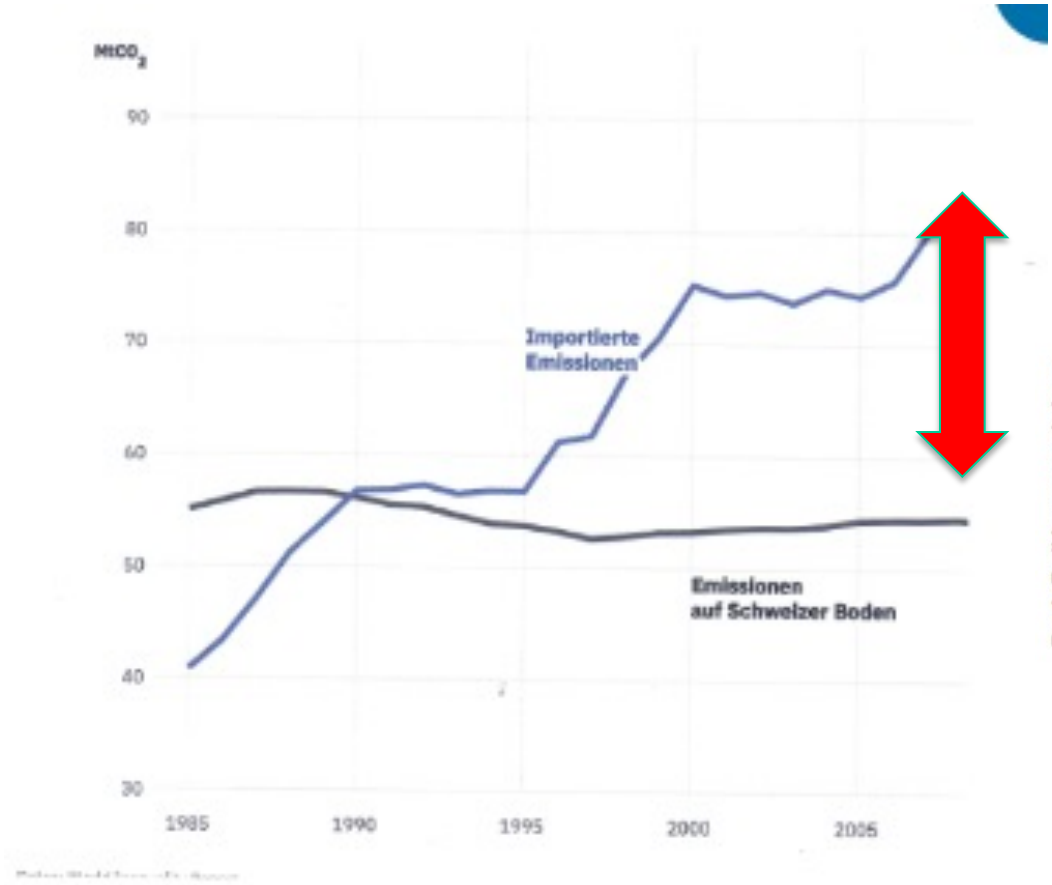
**→ 1’660 Euro per LDV DPF retrofitted**

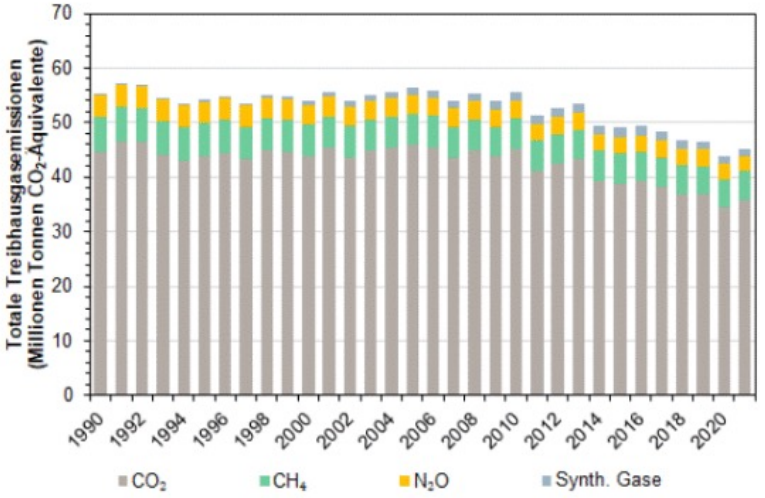
**→ 16’600 Euro per HDV DPF retrofitted**

→ plus health benefit

# NEW VERT-Project

- **Switzerland has a Problem - maybe others also**
- **VERT offers retrofit for $CO_2$ credits**
- (1600 $ for LD-diesel, 16‘000 $ for HD-Diesel)



# 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 3** generate health protection, global warming mitigation and bring money in developing countries, where extremely dirty engines will be used for many years to come.