



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

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VERT Association

*European Federation of Clean Air and Environmental Protection Associations (EFCA),
International Symposium*

Brussels July 3rd, 2024

AGENDA

- Introduction & Motivation
- VERT & DPF/GPF
- Global Warming and BC
 - GPF/DPF retrofit
 - Soot/CO₂ & GW Mitigation
- Summary



What is VERT?

- **VERT is a Non-Profit Association** of filter, catalyst manufacturers, instrument, engine manufacturers, universities and research associates, founded in 1993 in Switzerland
- **VERT** stands for **Verification of Emission Reduction Technologies** & it is a Particle Filter Testing, Certification & Quality Control System, a Trade Mark for Particle Filters of **Best Available Technology (BAT)**
- **The VERT® Association, founded in Switzerland in 1993, originated during the NEAT New Transalpine Railways Program**, which was one of the biggest tunneling projects in Europe at the time
- **Since then, VERT® has developed some of the most important particle filter testing procedures**, supported various international partners with **retrofit programs** and retrofit consulting and **established a worldwide scientific network of manufacturers of components, systems, engines, vehicles and PN measurement devices** as well as environmental, medical and technical research facilities **specialized in the field of “air quality” and nanoparticle emissions control**
- **VERT organizes international conferences** every year (i.e. the **VERT Forum**) and the **ETH Nanoparticle Conference in Zurich**

Particle Filter Implementation

Contribution of VERT and the interdisciplinary VERT Network

1994 NEAT Tunneling

1996 PN 10-500 nm criterion,

1997 ETH-NPC started

2000 CH-Tunneling: DPF mandatory

2002 CH-Construction: DPF mand.

2006 PMP- PN for EU type approval

2011 EU Diesel DPF, 2017 Petrol GPF

2018 China, 2019 Indien

2016 PN-PTI started, 2022 implemented

2020 Particle filters for viruses

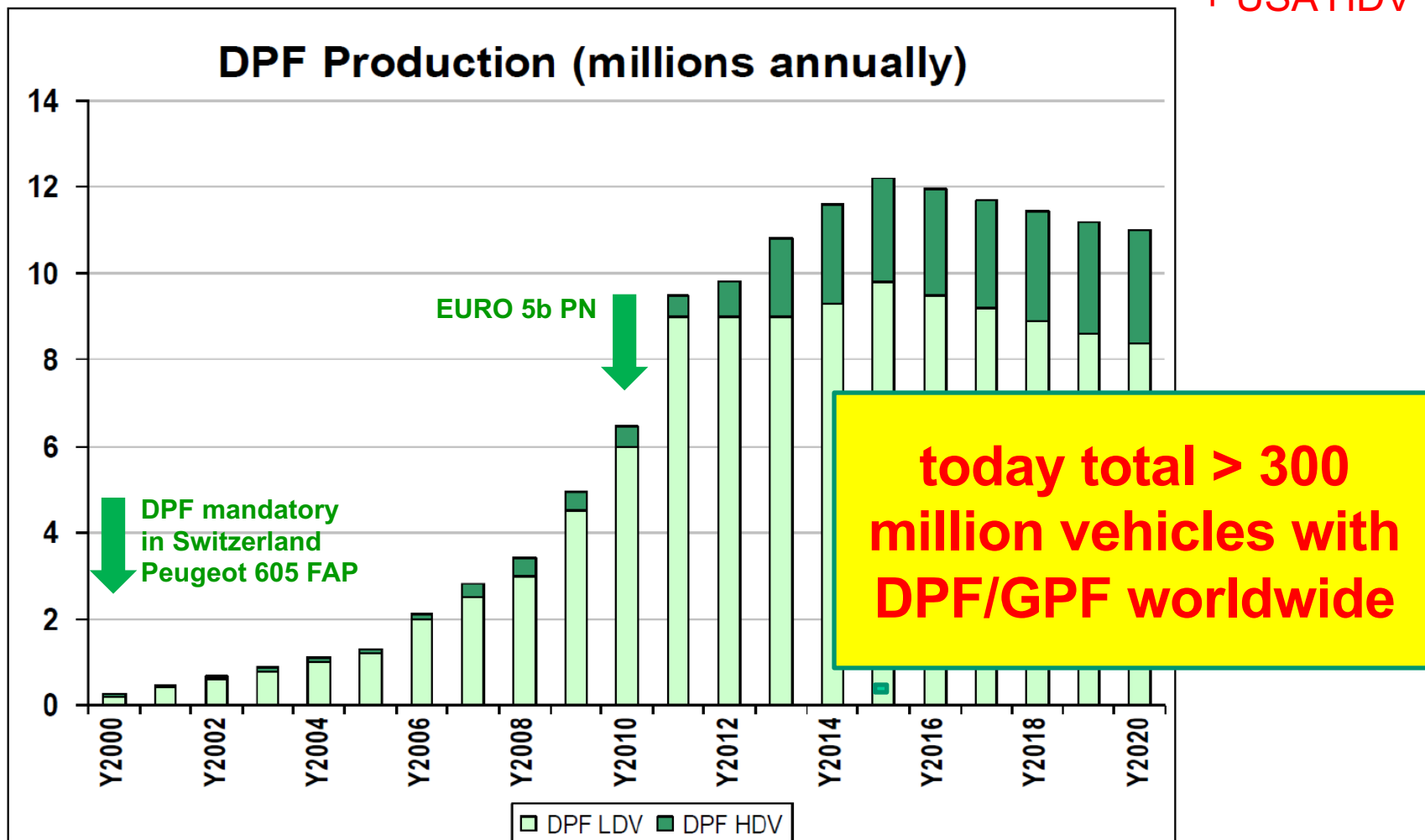


Solid Particle number 10-500 nm proved to be the key criterion for high filter quality and a guarantee for health protection in emission and immission

DPF-Production in Europe

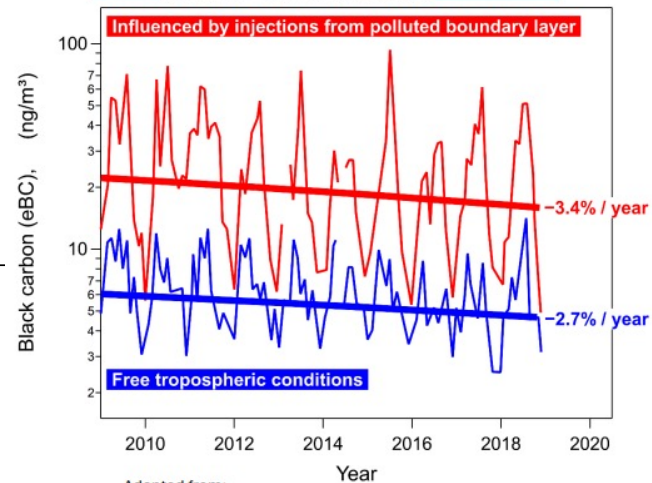
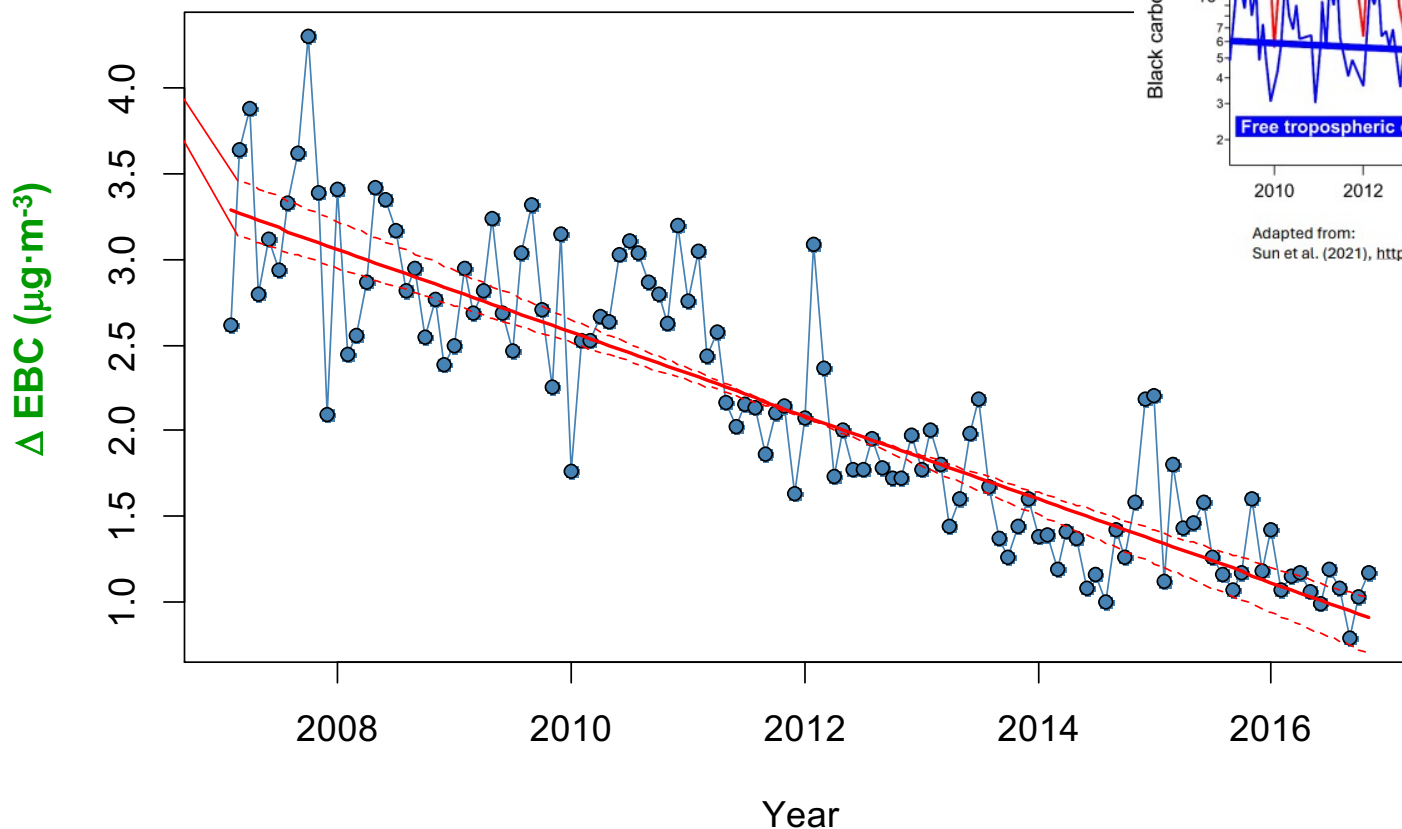
+ GPF from 2015

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



The Result: Cleaner Air by DPF

Monitoring BC at the motorway Härkingen and at the Jungfraujoch



Adapted from:
Sun et al. (2021), <https://doi.org/10.1186/s12302-021-00488-w>

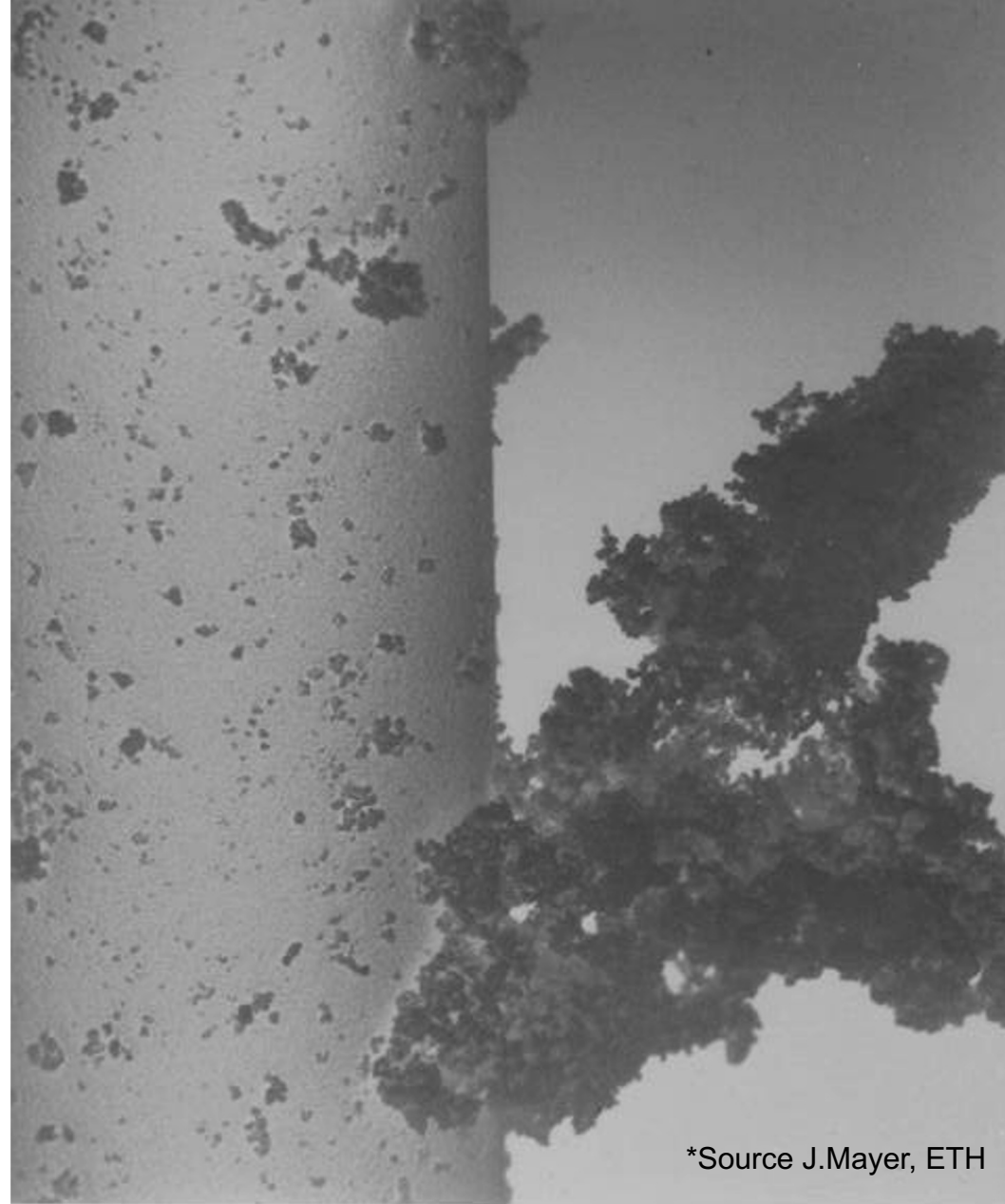
Limit <math>< 0.1 \mu\text{m}^3</math>
for 4/100'000
cancer cases
Source: DECOS

*Source
Chr.Hüglin EMPA

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 to 3500 m
(→ Jungfrauoch-Laboratory)



*Source J.Mayer, ETH

910183 15kV X6.00K 5.0um

The colour-play of airborne particles



Claude
Monet
1899



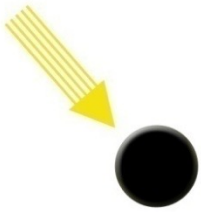
Skyline von New York City am 7. Juni 2023 Foto: Lokman Vural Elibol / Anadolu Agency / picture alliance

changing
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.

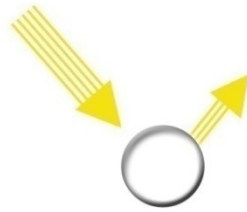
EFCA Brussels 3.July, 2024

Warming Effect of Black Carbon Aerosols



"Low albedo"

Cooling Effect of Organic & Sulfate Aerosols



"High Albedo"

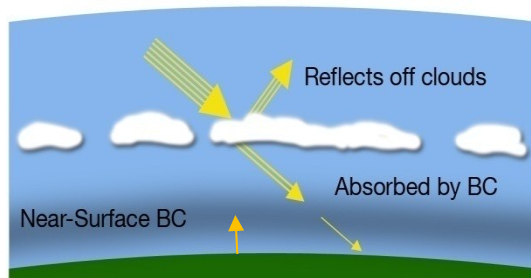
Multiplying Effect When Mixed Together



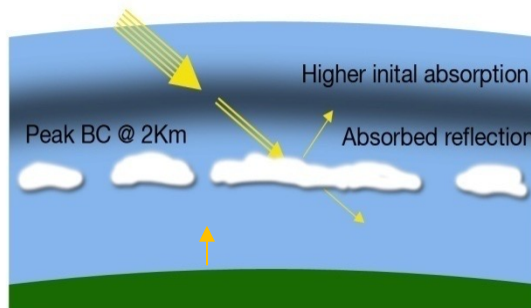
"Very Low Albedo"

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

Global Warming by BC-Particles in Air

strongly 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**
- **agglomerate structure**

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



Shindell, Faluvegi - April 2009



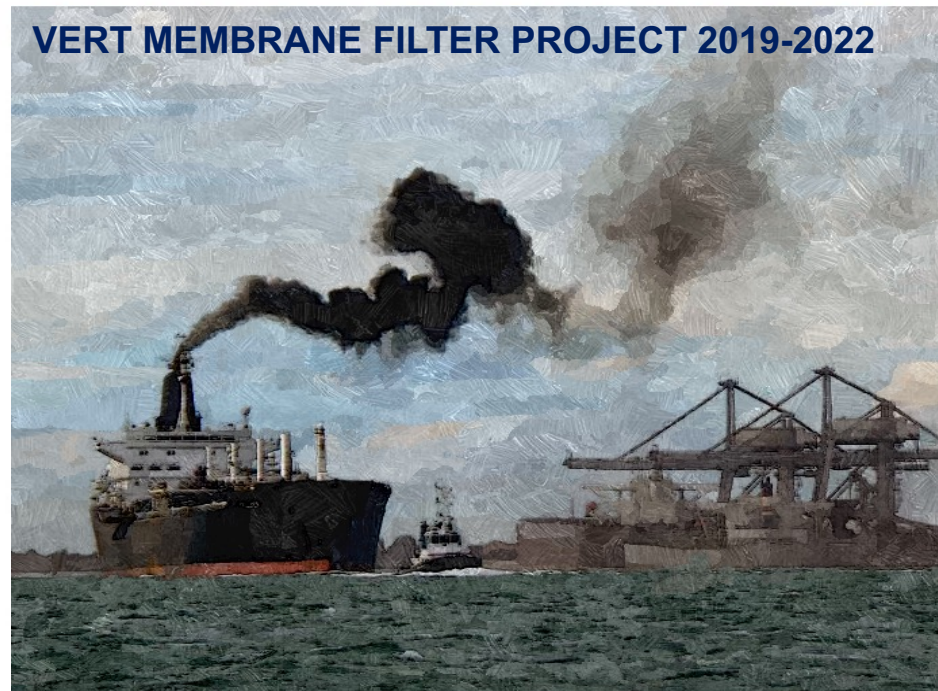
Black Carbon responsible for **50% or nearly 1.0° C** of the 1.9° C temperature increase in the Arctic from 1890 to 2007



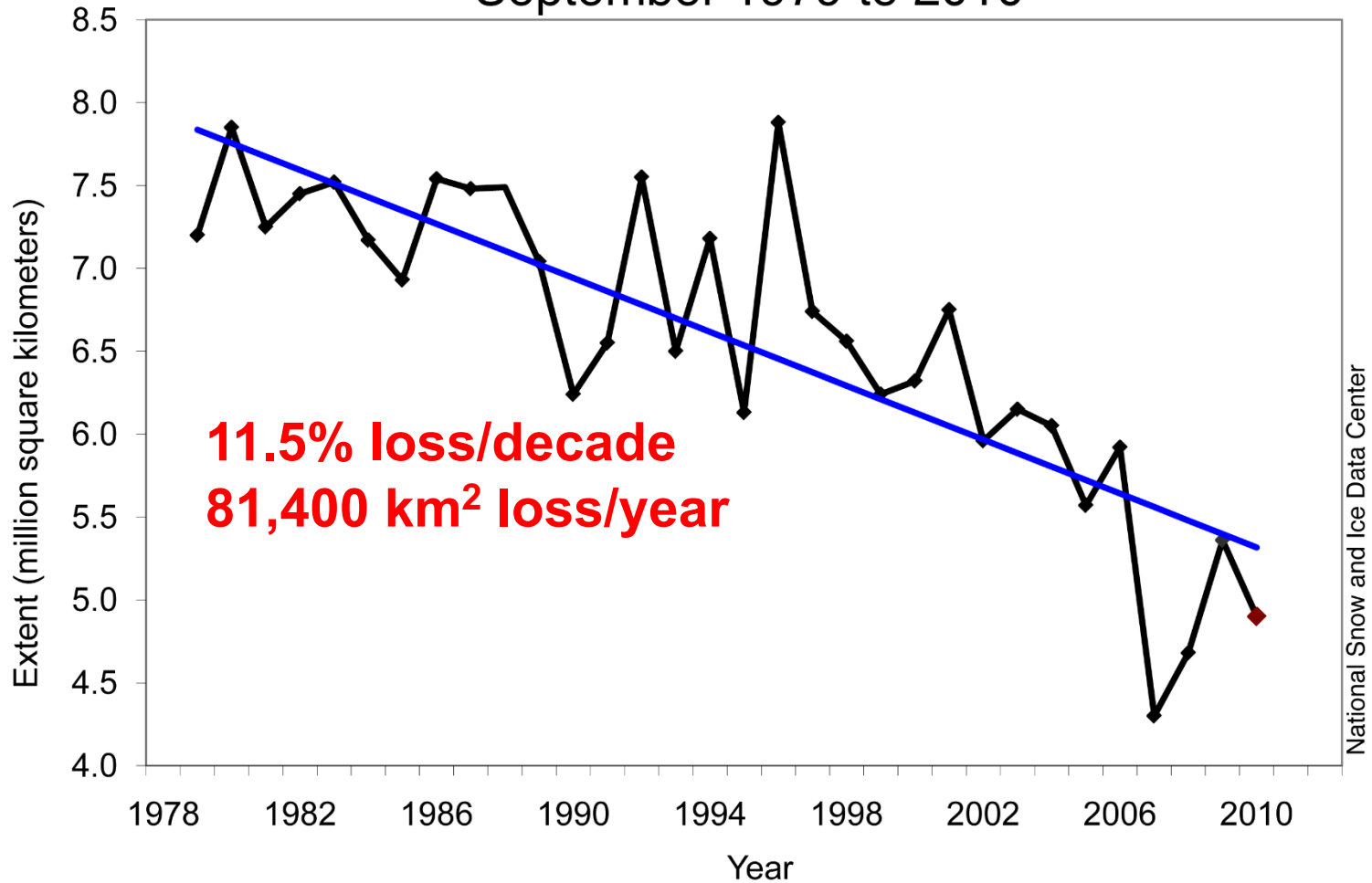
BC blackening the North Pole originates from marine emission



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



Average Monthly Arctic Sea Ice Extent September 1979 to 2010



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

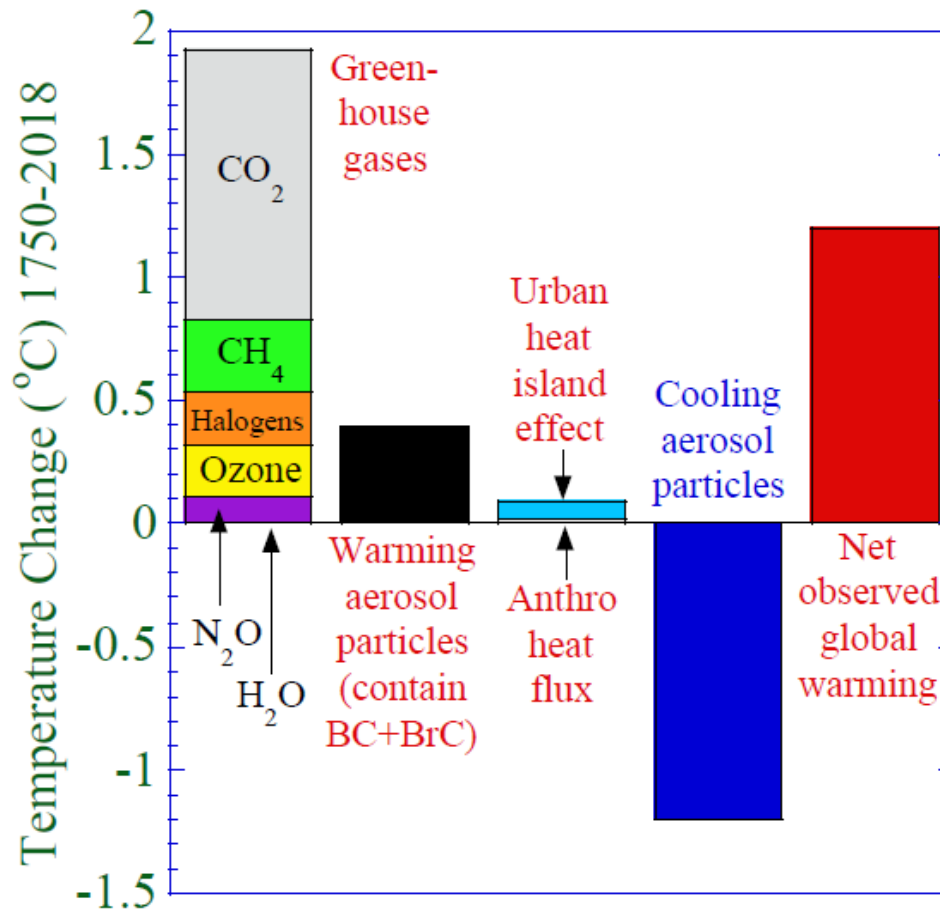
Tel: (650) 723-6836

Journal of Geophysical Research, in press.

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

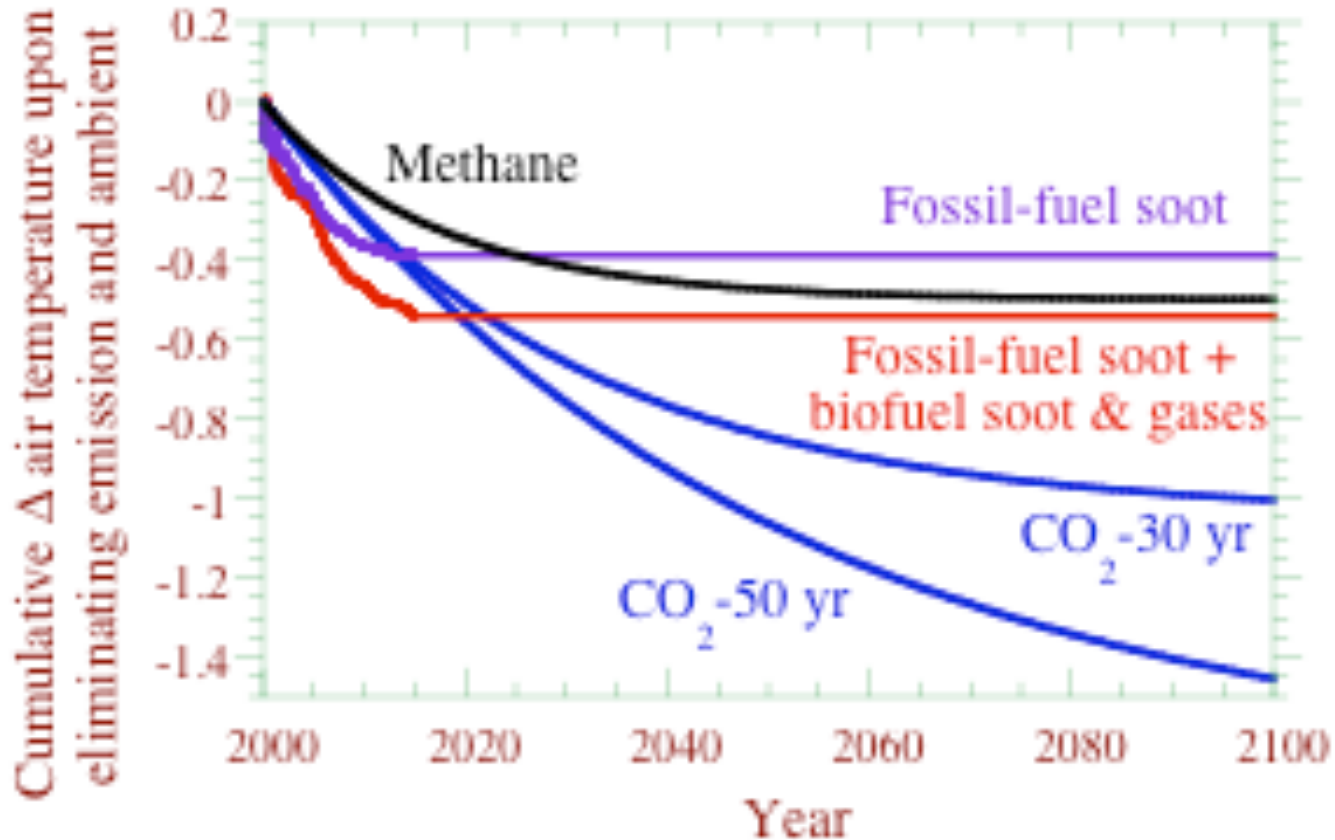
**Radiative Forcing Equivalence Ratio per Unit Mass
BC / CO₂ : 640'000 – 830'000 : 1**

Soot is number two after CO₂



*Source: M.Jacobson 2017 as a result of a global atmospheric model calculation

Fossil-Fuel Soot and Biofuel Soot Controls may be Fastest Method of Slowing Global Warming and Saving Arctic Ice



*Source= www.stanford.edu/group/efmh/jacobson/controlfossilfuel.html

How much contributes our DPF/GPF 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 for LDV

,
100% filtration efficiency

→ **1.5 million tons of soot saved by filters for LDV**

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

7.5 Mio tons BC worldwide annually acc. to

Journal of Geophysical Research – Atmospheres (im Druck, 2013).

onlinelibrary.wiley.com/doi/10.1002/jgrd.50171/abstract

But... we also must respect the different RF-active times of BC and CO₂

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**

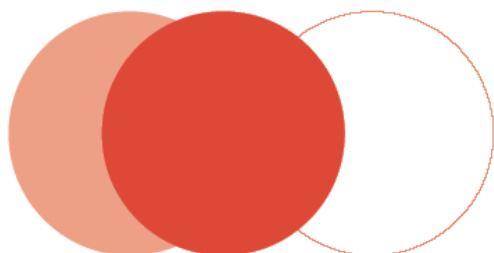


Table 1. Global Warming Potentials (GWP) drawn from the IPCC 4th Assessment Report

	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.

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

CO₂ (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.

U.Baltensperger 2003, 2022 / T.C.Bond 2013/ J.Hansen 2011, 2023/
Z.A. Kanji 2020/ S.Pratsinis 2022/ U.Lohmann 2020/ Gysl-Beer 2024

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 assume 2083

Realistic Mitigation by use of Particulate Filters

During DPF lifetime of 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-Emission of Europe: 15%**

VERT Paper ECST 1/24

Filtration for Global Warming Mitigation

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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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 CO₂ per year or about one-third of the CO₂ 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.

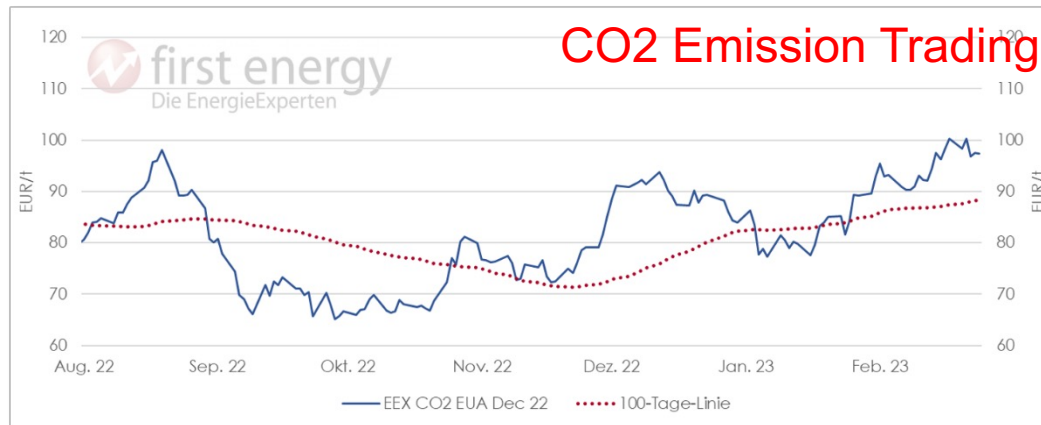


Skyline von New York City am 7. Juni 2023 Foto: Lokman Vural Elibol / Anadolu Agency / picture alliance

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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

Conclusions

- **All new combustion engines must have filters**
- **Retrofit of all in-use Diesels with DPF**
- **Retrofit of all 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.

Acknowledgement

Co-authors – VERT Association



Dr. A. Mayer



Prof. J. Cerwinski



Mr. T. Lutz

- Dr. M. Jacobson, Dr. T. V. Johnson

THANK YOU FOR YOUR ATTENTION!



aerosolfd-project.eu



<https://www.vert-dpf.eu/>

Questions?

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