

# Brake Dust Particle Filter VERT Forum

Martin J. Lehmann,  
Tobias Wörz, Lukas Bock  
2022-03-23

# Brake Dust Particle Filter

## Reducing non-exhaust emissions at the source

- 1 Welcome to Our World - MANN+HUMMEL
- 2 Relevance of Reducing non-exhaust Emissions
- 3 Stationary Solutions at local Hot Spots
- 4 Mobile Solutions as Car Community
- 5 At the Source - Filtration Solution
- 6 Conclusion



The banner features the SAE International logo on the left, with the text 'GOVERNMENT/INDUSTRY Digital Summit' in large, bold letters. Below this, it says 'February 2-3, 2021' and 'sae.org/gim'. The background of the banner shows a night view of the US Capitol building.

**Non-Exhaust Emissions - Relevance of reducing brake dust at the source**

Martin Lehmann,  
Tobias Wörz, Lukas Bock

**MANN+HUMMEL**

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The company in  
figures  
Over 80 years of  
innovation,  
expansion, and  
growth

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**1941**

Founding Year

---

**30+**

Countries

---

**21,480**

Employees

---

**80**

Locations

---

**3.8**

Billion Euros of  
Sales Revenue

---

**2,500**

Patents and  
Applications

---

**26**

Filters per Second



**Cleaner Mobility**



**Cleaner Air**



**Cleaner Water**

# Cleaner Mobility

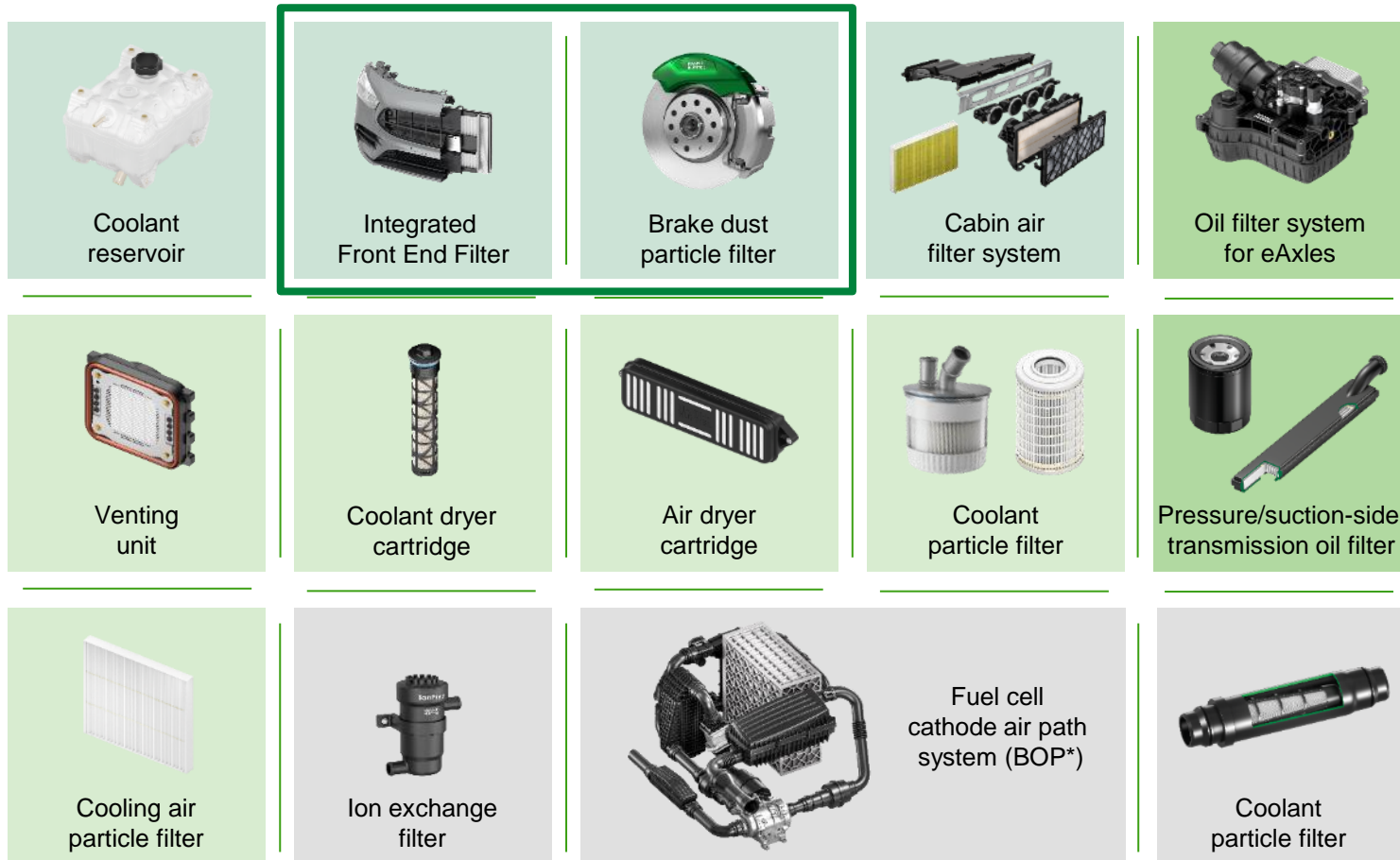
## Transition from ICE (internal combustion engine) to e-mobility



There is always a need for innovative filtration solutions.

# Cleaner Mobility

## MANN+HUMMEL Products for E-Mobility & New Products (Cars)



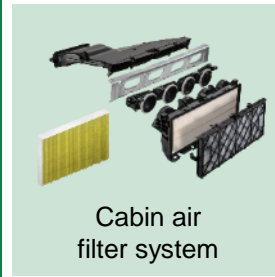
- All vehicle applications
- xEV applications
- HV battery systems
- Fuel cells



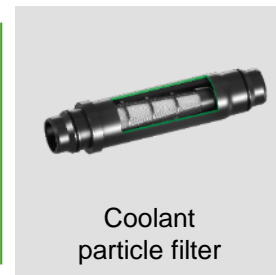
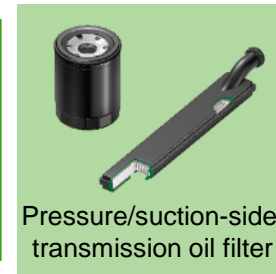
\* BOP - balance of plant

# Cleaner Mobility

## MANN+HUMMEL Products for E-Mobility & New Products (HD)



- All vehicle applications
- xEV applications
- HV battery systems
- Fuel cells



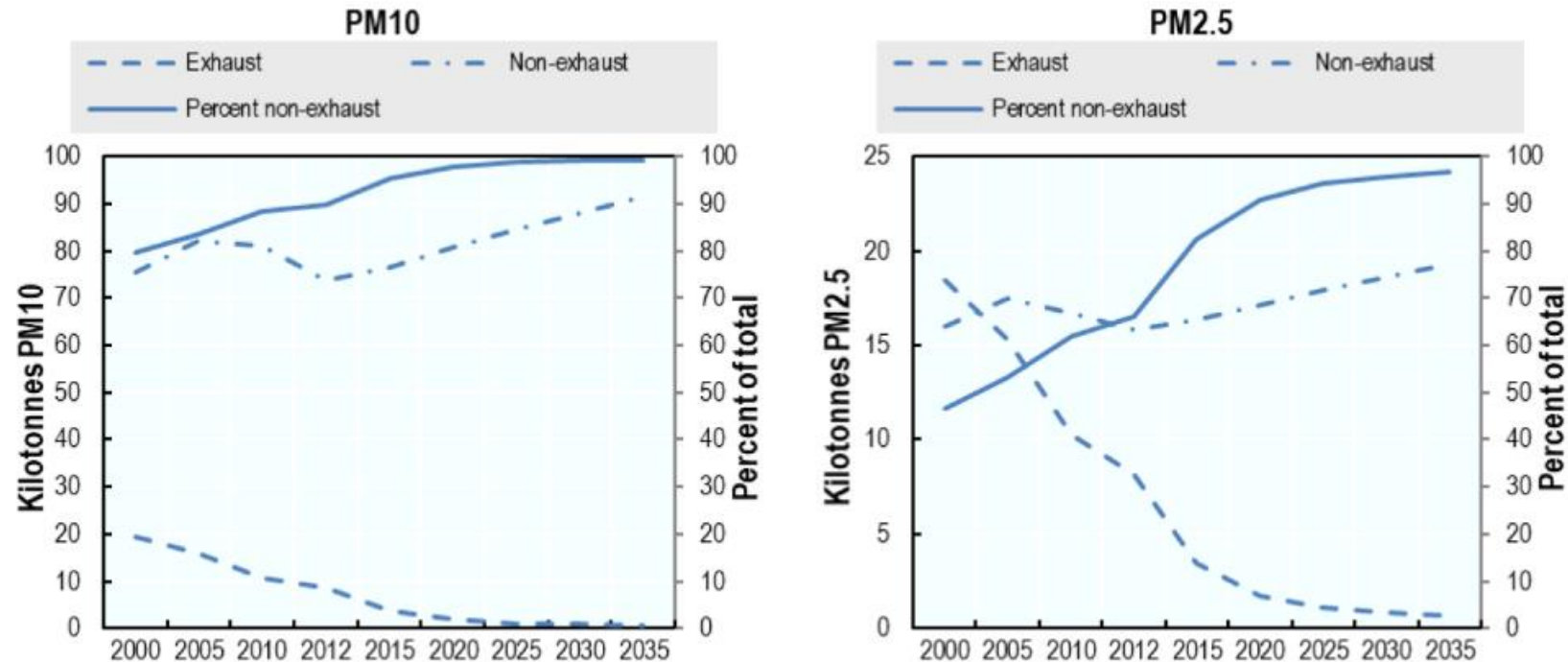
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# Relevance of Reducing non-exhaust Emissions

## Emissions of PM10 and PM2.5, California, 2000-2035



Exhaust emissions reduced, NON-exhaust emissions quite stable, slight increase

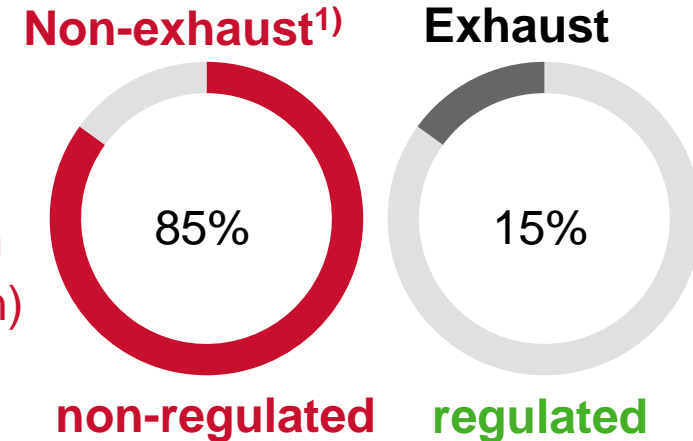
Source: OECD ENV/EPOC/WPIEEP(2020)4/FINAL, Fig. 2.3 California Air Resources Board (2019[77]).

# Cleaner Mobility – Non-exhaust Emissions

## Non-regulated vs. regulated emissions



- Brake Wear
- Tire Wear
- Road Abrasion
- (Resuspension)



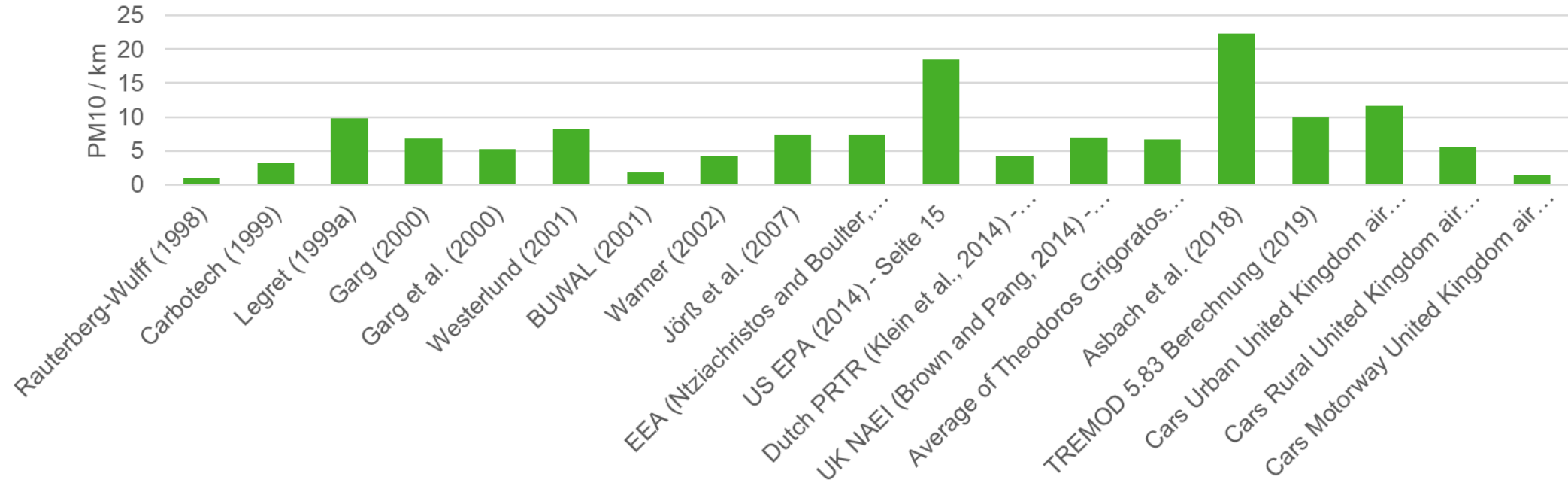
**“Brake wear emissions** can be **influenced** by a vehicle’s **weight**, rate of **deceleration**, the **composition of brake discs and pads**, rotor **temperatures**, **sliding speed**, and **contact pressure**. ...

Considerable uncertainty remains regarding the amount of PM that is emitted by non exhaust sources in real world driving conditions”<sup>2)</sup>

Source: 1) Victor R.J.H. Timmers, Peter A.J. Achten, Non-exhaust PM emissions from electric vehicles; Barlow et al., Non-Exhaust Particulate Matter Emissions from Road Traffic: Summary Report 2) OECD ENV/EPOC/WPIEEP(2020)4/FINAL, Fig. 2.3 California Air Resources Board (2019[77]).

# Cleaner Mobility – Non-exhaust Emissions

## Brief Literature Survey on Brake Dust Particle Emissions



**Average Emission<sup>(1)</sup> = 12.8 mg/km (PM<sub>10</sub>); Assumed 2/3 front brake 1/3 rear brake**

(1) Average value from 41 sources (Literature, values from customers, own test bench measurement and real driving tests)

# Cleaner Mobility

## Reducing fine dust emission – Filtration Solutions

### Filtration at the Source,

- Brake Dust Particle Filter



### Mobile as Community,

- Integrated Fine Dust Particle Filter



- Roof Box PureAir



### Stationary at Hot Spots

- Filter Cube



# Brake Dust Particle Filter

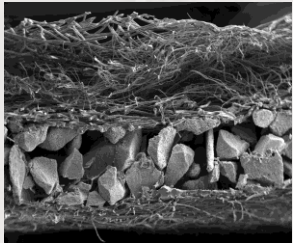
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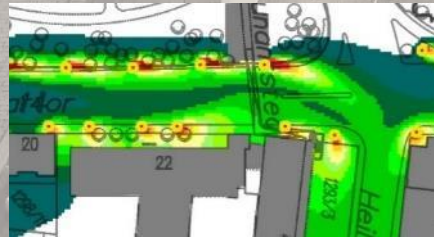
# The Fine Dust Filter Cube from MANN+HUMMEL Stationary Filtration Concepts for NO<sub>2</sub> and PM Reduction



## Technology Validation



## Simulation



## Design



## Installation



## Assessment



Bächler, P., Müller, T. K., Warth, T., Yildiz, T., & Dittler, A. (2021). Impact of ambient air filters on PM concentration levels at an urban traffic hotspot (Stuttgart, Am Neckartor). Atmospheric Pollution Research, 12(6), 101059.

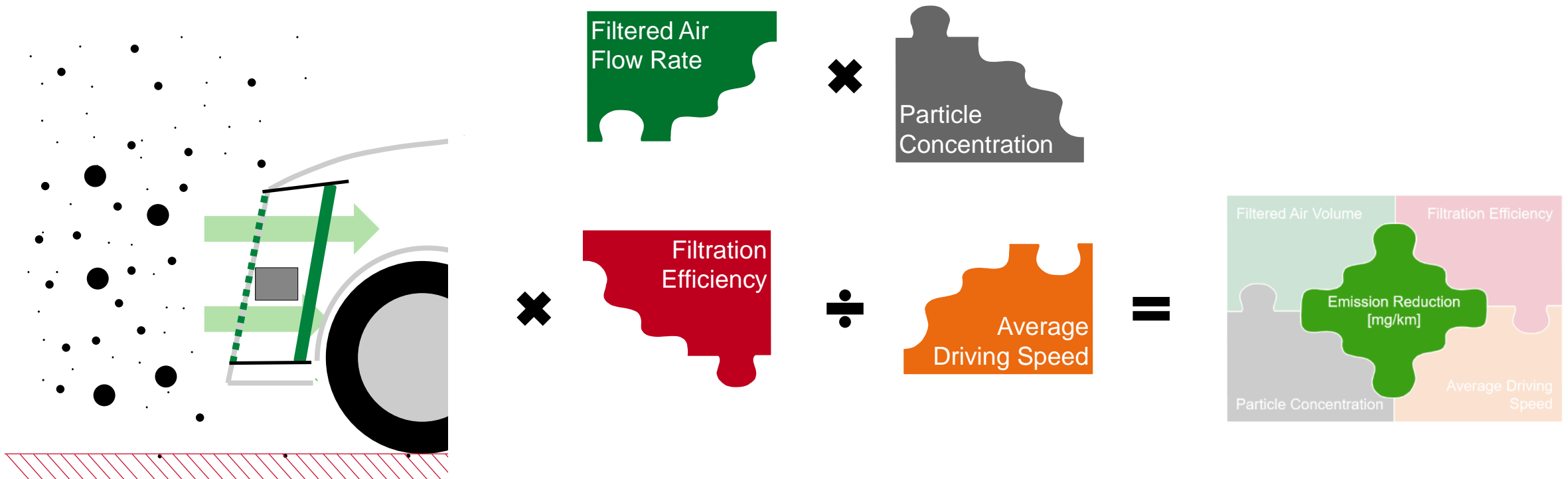
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# Cleaner Mobility – Reducing Fine Dust Emission

## Basic Concept for Community Approach of Reducing Fine Dust



Reducing emissions from road/tire abrasion, brake, resuspension, exhaust

# Cleaner Mobility – Reducing Fine Dust Emission

## Reducing PM10 concentration car-to-car



Mobile Front-End Fine Dust Filter Solution by MANN+HUMMEL & HBPO

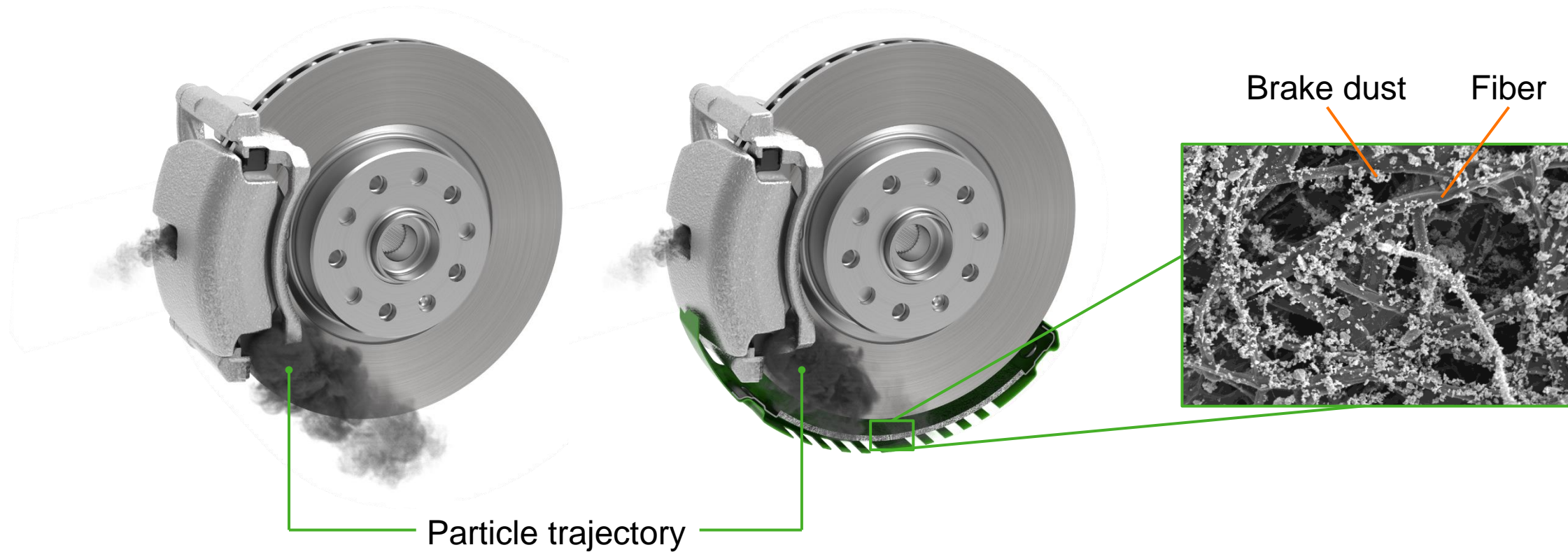
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# Brake Dust Particle Filter – Reducing Fine Dust at the Source

## Filter Concept in Principle



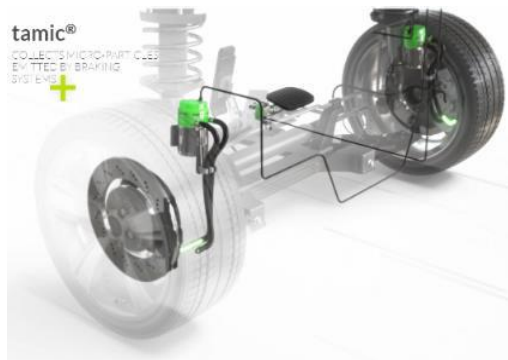
Passive filter – no additional energy required!

# Brake Dust Particle Filter – Reducing Fine Dust at the Source

## Alternative Concepts

### Active System

Suction system to centrally collect brake dust over vacuuming the particles through the brake pads



### Brake pad / disc material

Reduction of brake dust emission through different materials or coatings. Example Bosch iDisc



### Regenerative brakes

Combination of mechanical braking and the use of the electric motor of a hybrid or electric car as a generator



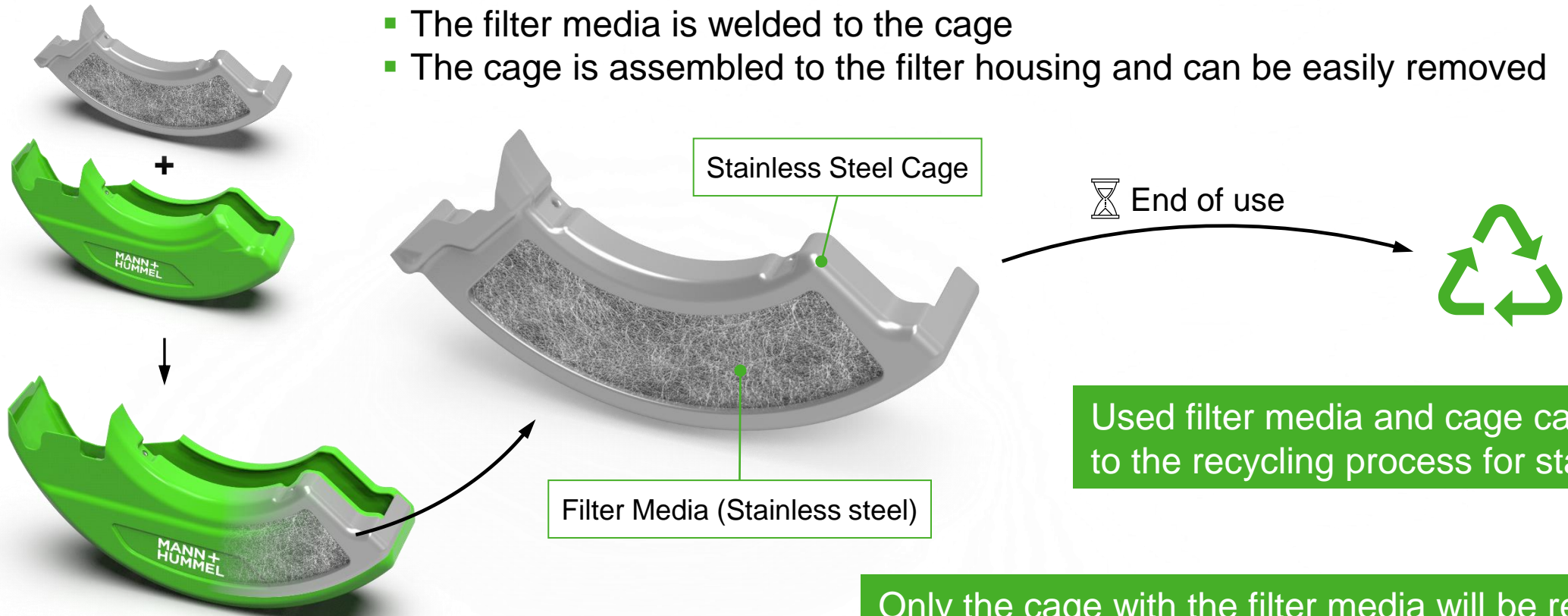
Today's friction braking system is quite complex but highly optimized! Changes are a challenge. Retrofit preferred.

# Brake Dust Particle Filter – Reducing Fine Dust at the Source

## It's More Than Filtration e.g., Installation Space



# MANN+HUMMEL Brake Dust Particle Filter Service Concept



# MANN+HUMMEL Brake Dust Particle Filter

## Everyday Usage under Real and Severe Conditions



### Filter were tested under different conditions:

- Everyday usage on the road with more than 60.000 km combined
- Severe conditions like snow, sand, water, dirt ...
- No standardized tests used
- Focus on impact on the brake system and filter durability

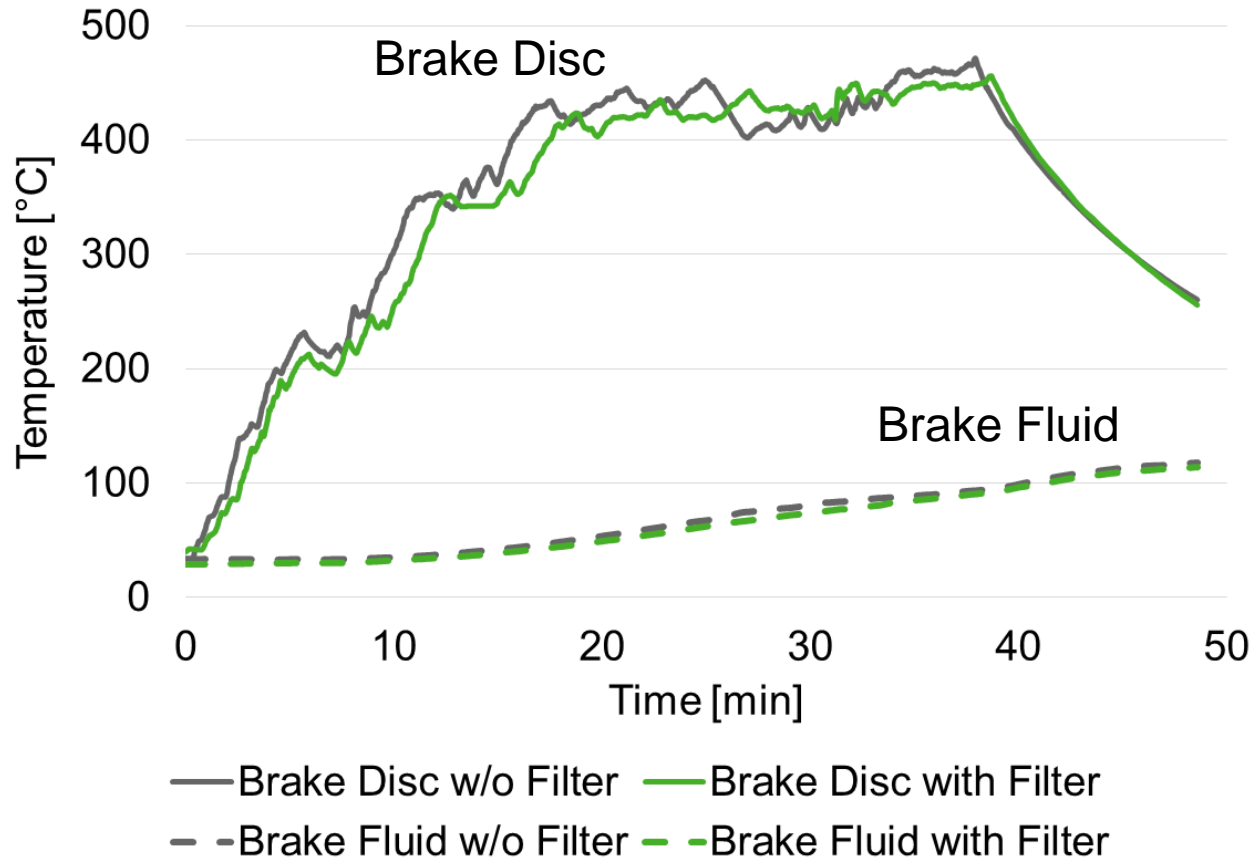
### Currently in progress:

- Investigate influences on the filter efficiency
  - Measure filter efficiency in new condition and after vehicle test

Everyday usage and severe conditions were successfully tested.  
Filter and surrounding parts remained unharmed. Brake fully functional.

# Brake Dust Particle Filter – Reducing Fine Dust at the Source

## It's More Than Filtration e.g., Temperature Tests – Großglockner



Standard test carried out with:



VALMET AUTOMOTIVE

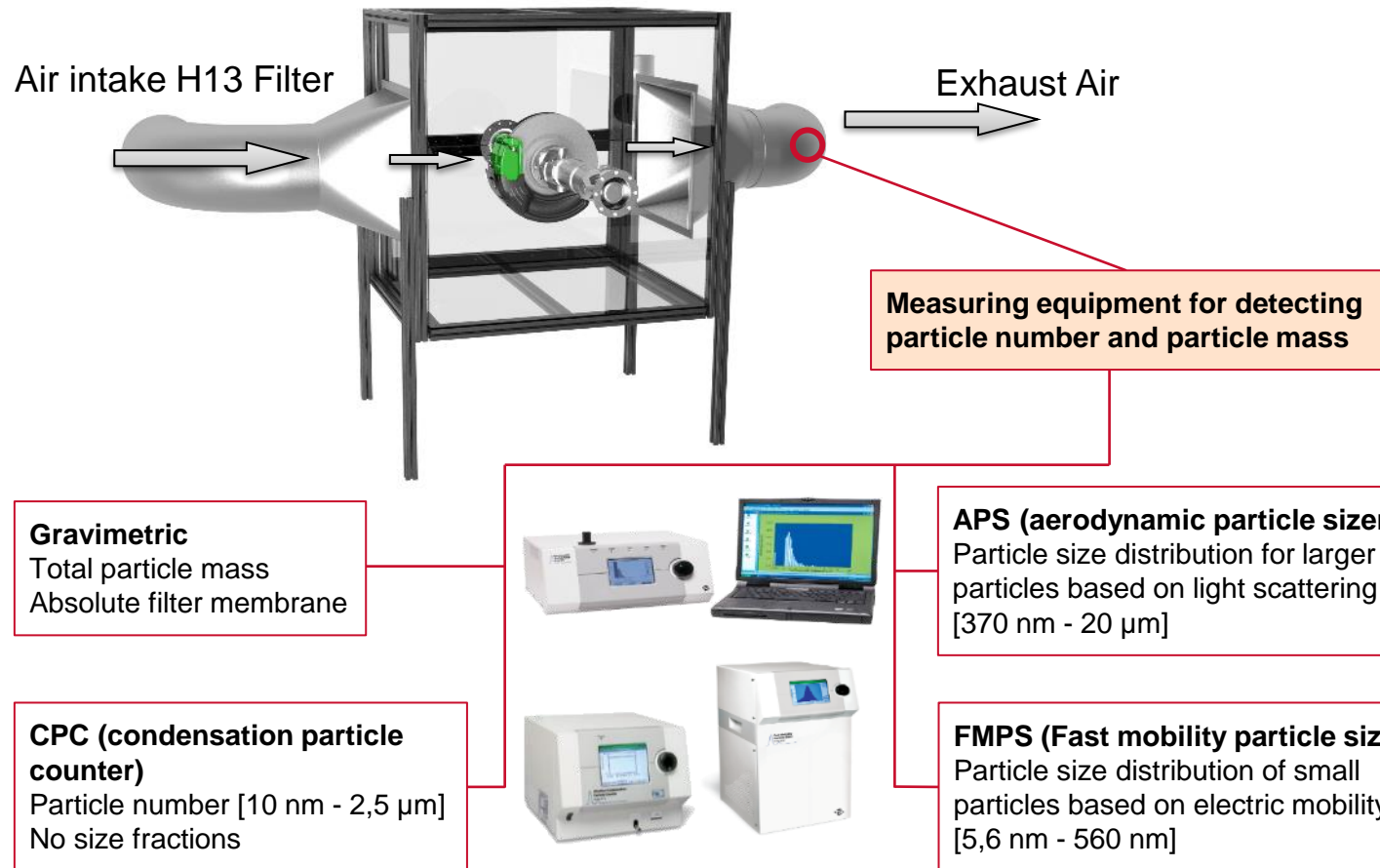
Tested system



All temperatures in uncritical range

# Brake Dust Particle Filter – Reducing Fine Dust at the Source

## How to Measure Brake Dust Particle Emissions?



Brake dyno test bench @ LINK



# Brake Dust Particle Filter – Reducing Fine Dust at the Source

## Excursus – Determining Filtration Efficiency

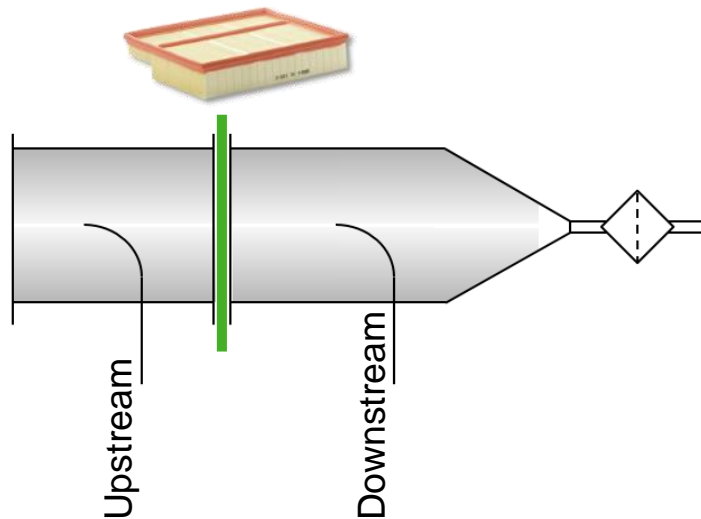
### Standard Filter Efficiency Measurement

All done during the same measurement

vs.

### Brake Dust Particle Filter Measurement

At least two separate measurements needed



$$\eta = 1 - \frac{n_F}{n_R}$$

$\eta$  ... Separation Efficiency  
 $n_F$  ... Particle Number with filter  
 $n_R$  ... Particle Number raw emission



Variations in the particle emission of the brake itself have a high impact with this type of measurement

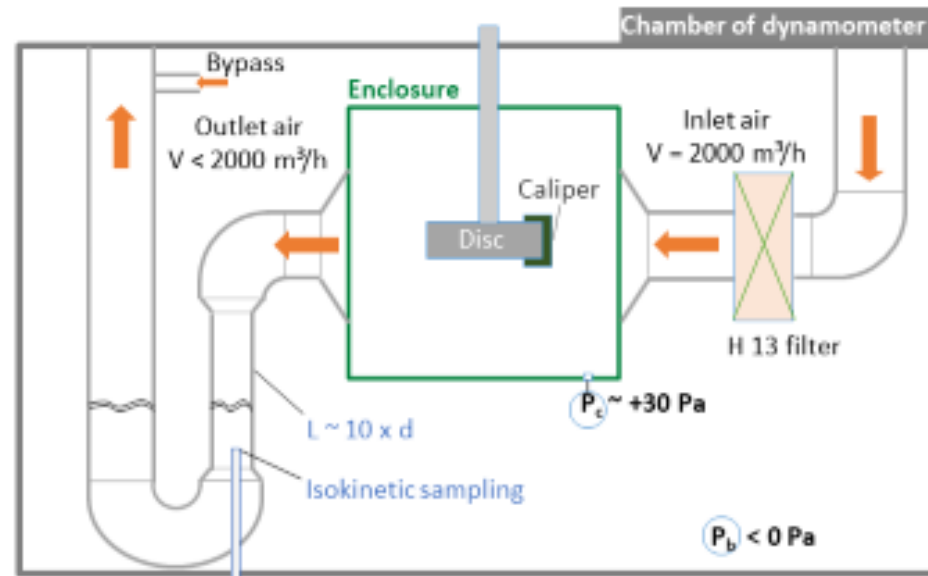
Brake Dust Particle Filter efficiency measurement is only possible with a reference measurement in comparison with a filter measurement

# Brake Dust Particle Filter – Reducing Fine Dust at the Source

## Enclosure-in-Chamber w/ near ZERO Background Concentration

### Realization – How to fit in a brake dynamometer? (5/5)

- **(outer) chamber** of dynamometer at slight negative pressure
  - Preventing emissions to workplace
- **(inner) enclosure** at slight positive pressure
  - Avoiding particle intake through gaps of enclosure
- Challenge: limited space, but **successful implemented**



*Schematic setup as installed in LINK M3900 chamber*

SAE International®  
Brake Colloquium Online

Paper 2009CV-0037

12

➔ Prerequisite: reliable measuring brake emissions (see SAE Brake Colloquium 2020)

# Brake Dust Particle Filter – Reducing Fine Dust at the Source

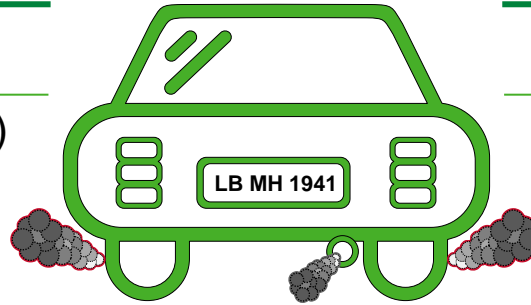
## Our Plus for Clean Mobility – Status quo and aiming for more

### Exhaust Emission PM<sub>10</sub>

Average Emission EU<sup>(1)</sup> = **4 mg/km** (PM<sub>10</sub>)  
Euro 5b-Euro 6c<sup>(1)</sup> = **2 mg/km** (PM<sub>10</sub>)  
Euro 6d temp<sup>(1)</sup> = **1 mg/km** (PM<sub>10</sub>)

### Brake Dust Particle Emission PM<sub>10</sub>

Average Emission<sup>(2)</sup> = **12.8 mg/km** (PM<sub>10</sub>)  
Assumed distribution:  
 $\frac{2}{3}$  front brake  $\frac{1}{3}$  rear brake



Brake Dust Particle Filter mounted



**Reduction of ~3 mg/km (PM<sub>10</sub>)**  
Compensation of 3 Passenger Cars  
(Euro 6d temp)

(1) HBEFA 3.3

(2) Average value from 41 sources (Literature, values from customer, own test bench measurement and real driving tests)

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# MANN+HUMMEL Brake Dust Particle Filter

## Brake Dust Particle Filter



### Product Features:

- Reduces brake dust emission directly at the source
- Easy, fast and clean service
- Robust and passive design, no moving parts
- Scalable for every vehicle
- Designed to fit in existing installation spaces
- Temperature & corrosion resistant filter media

### Concept Advantages:

- Improved environmental effects / reduced health hazards
- Holistic approach to vehicle particulate pollution
- New styling element

Effective solution to reduce total vehicle particulate emissions

**MANN+  
HUMMEL**

**Dr. Martin J. Lehmann**

Principal Expert Research Network & Public Funding

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Thank YOU and  
Tobias Wörz,  
Lukas Bock and our  
Brake Dust Filter Team!

**MANN+  
HUMMEL**