Brake Wear Emissions

Status for the Introduction of "Non-Exhaust Regulations" and AVL Test & Engineering Solutions

Linke, Manfred

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Moving Towards Onboard Sensing, Analysis, and Reporting (OSAR)
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Today’s Presenter

Manfred Linke (AVL List GmbH)

23 years experience in emission testing at AVL in different positions, like Development Engineer, Product Manager, Business Development Manager.

Actual Team Leader Business Development for Aerosol and Gaseous Measurement

Work focus: Particle and PEMS measurement, future emission market trends and worldwide emission legislation

Agenda

Background

Relevance of non-exhaust emissions

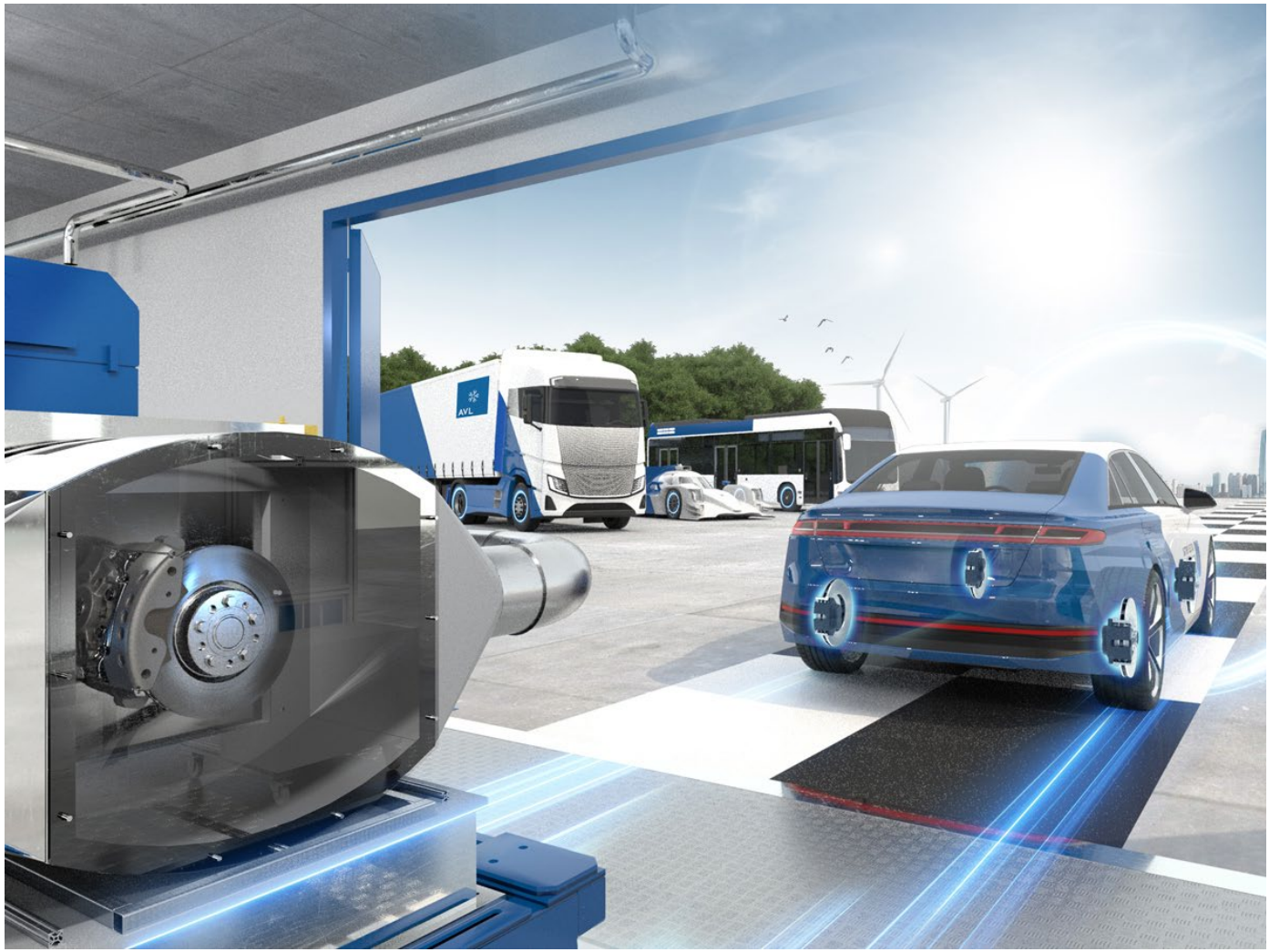
Regulation

Developments towards a standardized test method

AVL Break Wear Solution

AVL Portfolio for Break Wear

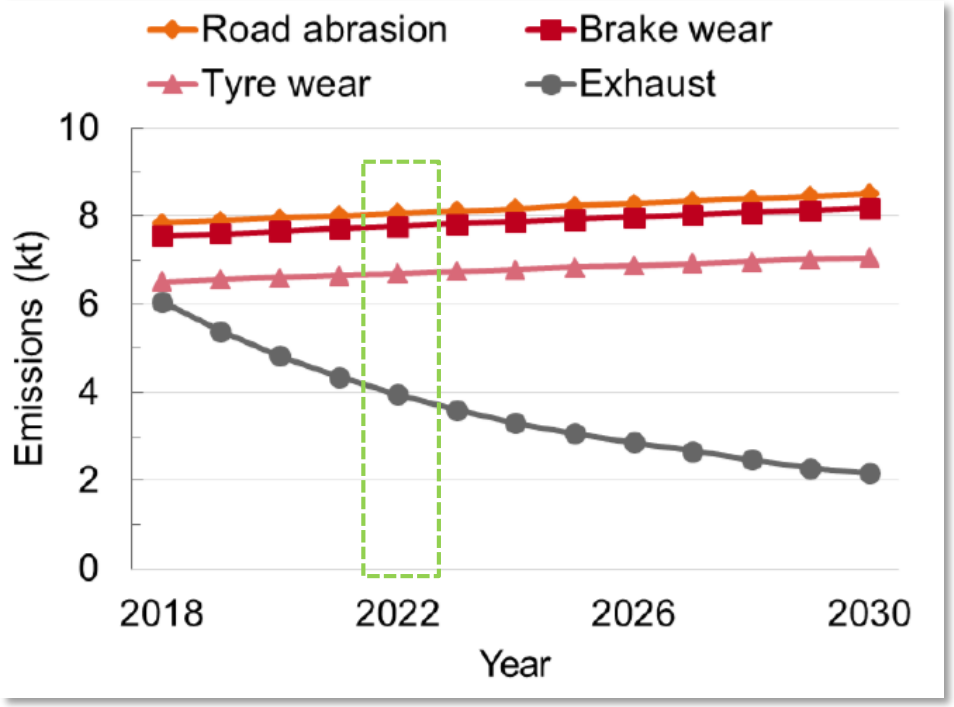
Outlook

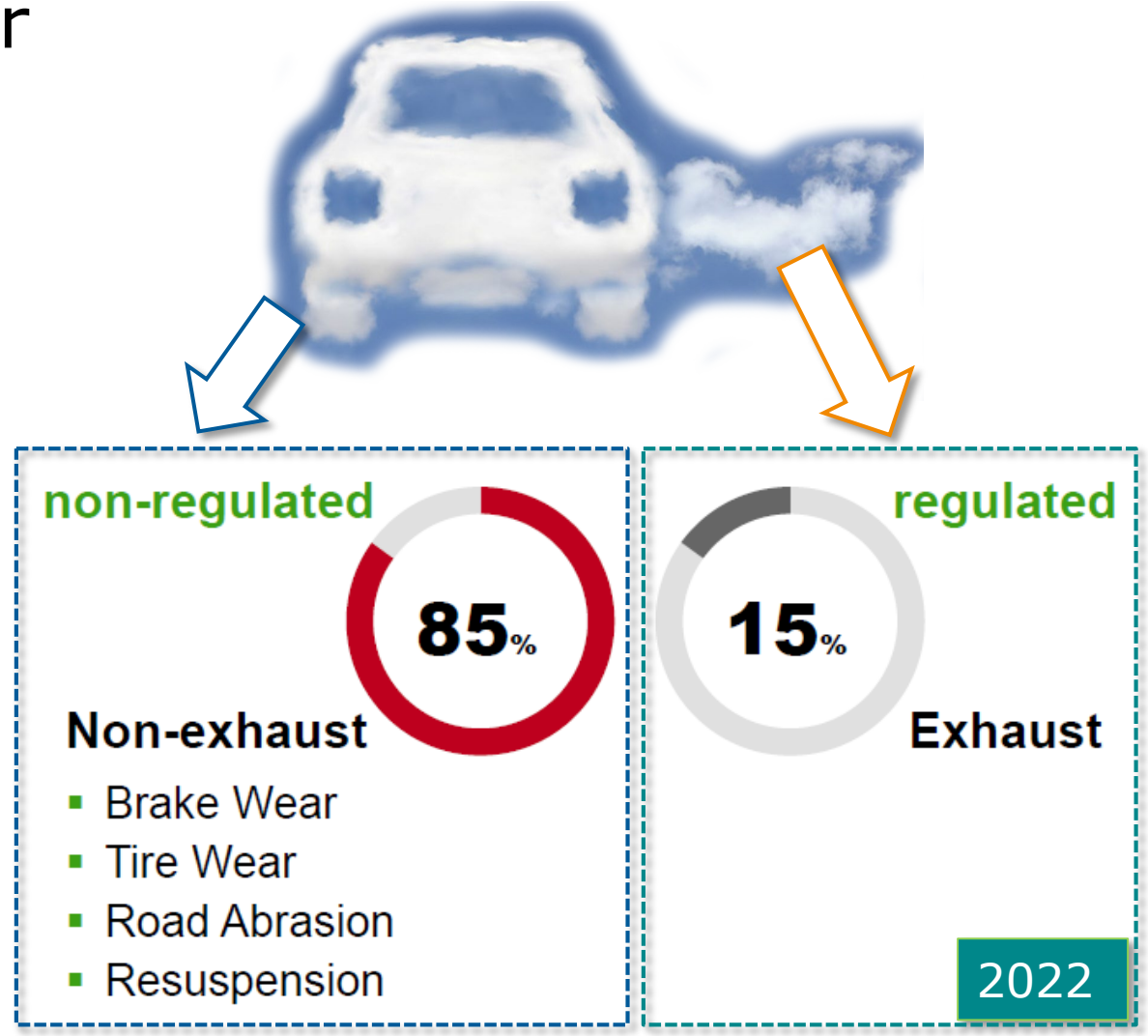


Background

Relevance of Brake & Tire Wear

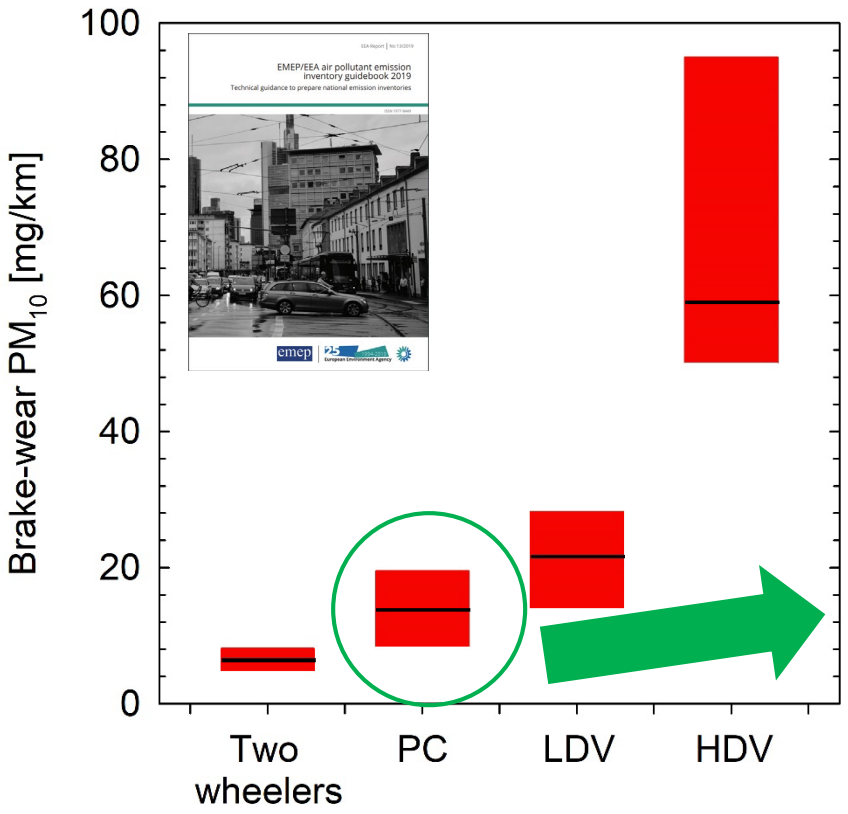
Study on categorization of German PM10 emissions from road transportation

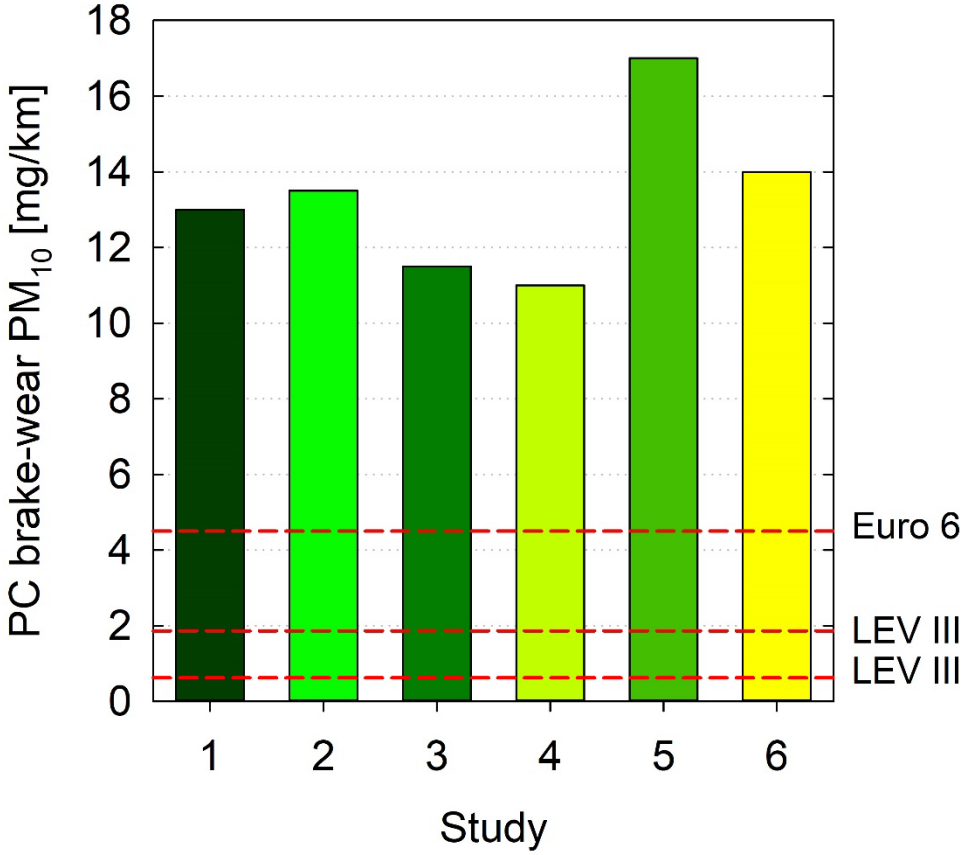




Sources: German Environment Agency (TREMOD v5.83); Victor R.J.H. Timmers, Peter A.J. Achten, Non-exhaust PM emissions from electric vehicles; Barlow *et al.*,Non-Exhaust Particulate Matter Emissions from Road Traffic: Summary Report; German Environment Agency, The Handbook Emission Factors for Road Transport; State Parliament of Baden-Württemberg, Drucksache16/1089

Brake-Wear PM emission rates



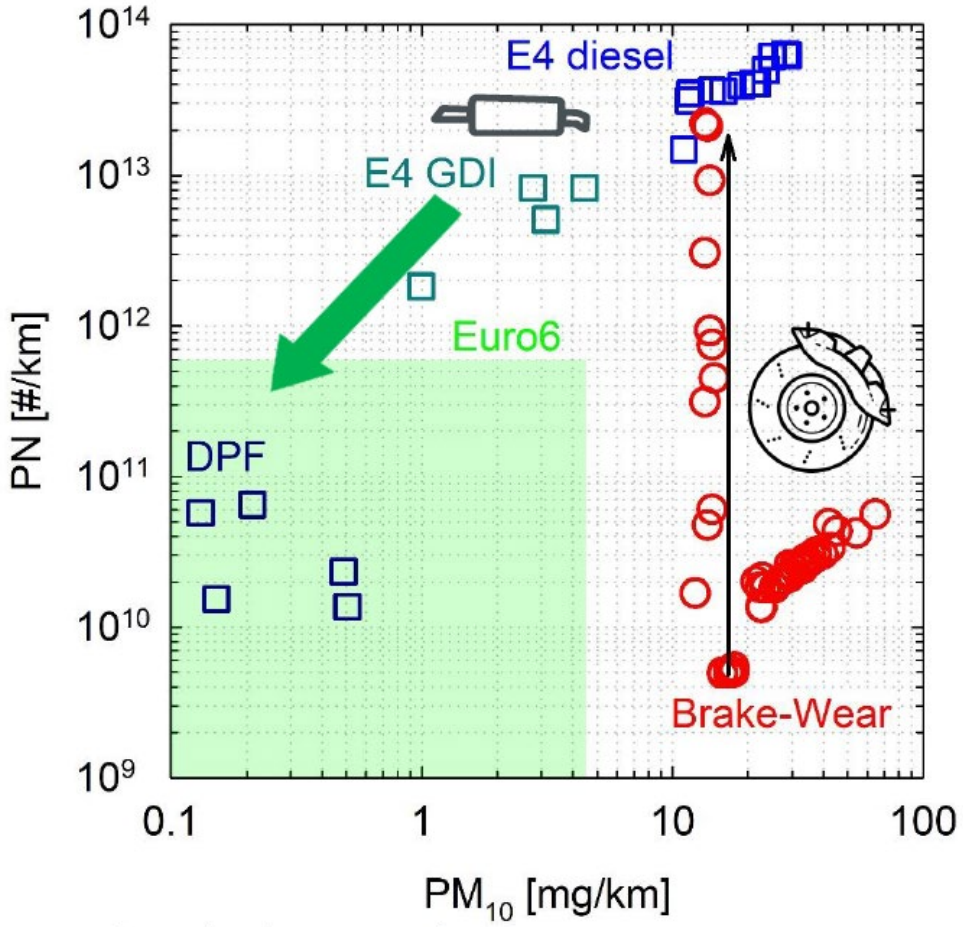


Focus on Passenger cars, limited experimental data on other vehicle categories

No rigid information on the effect/potential of regenerative braking

Sources: 1: Mamakos et al., Atmosphere, 2019, 10(11); 2: Zum Hagen et al. Environ. Sci. Technol. 2019, 53, 9, 5143–5150; 3: Hagino H. 50th PMP meeting, 2019; 4: Agudelo et al., SAE 2020-01-1637, 2020; 5: Mamakos et al., Atmosphere, 2021, 12(3), 377; 6: Hesse et al., Atmsophere, 2021, 12(4). Left-hand figure: European Environmental Agency - air pollutant emission inventory guidebook 2019.

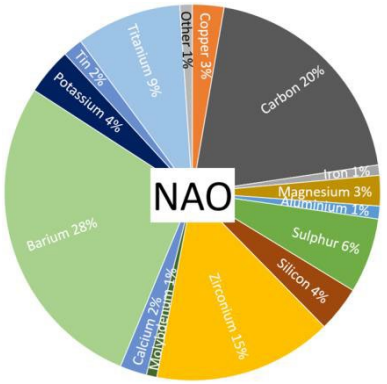
Differences between Brake-Wear and Exhaust Particles

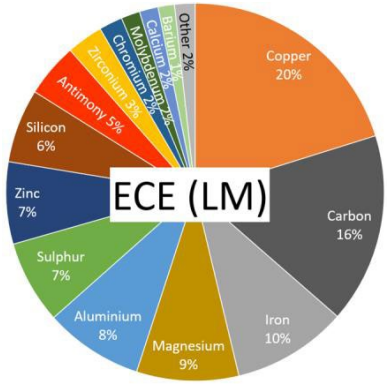


Exhaust data from Vogt et al. 2010

Brake-Wear Particles:

- are lower in number (PN)
  - High number at elevated temperatures (aggressive maneuvers)
- are higher in mass (PM)
- have a broad size distribution (10nm – 10µm)
- have a complex chemistry





Exhaust Particles:

- <200nm, lower in mass, dominated by soot

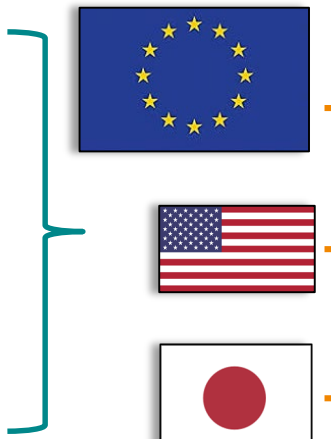
Regulation

Developments towards a standardized test method

United Nations

GRPE-PMP

Particle Measurement Program (PMP)



European Commission
Joint Research Centre

CALIFORNIA AIR RESOURCES BOARD

JARI

Organized in Task Forces:

- **TF1:** Definition of Brake Cycle
- **TF2:** Definition of Measurement Methodology
- **TF3:** Round – Robin Tests (Q4 2021)
- **TF4:** Influence of Recuperation (E2021)

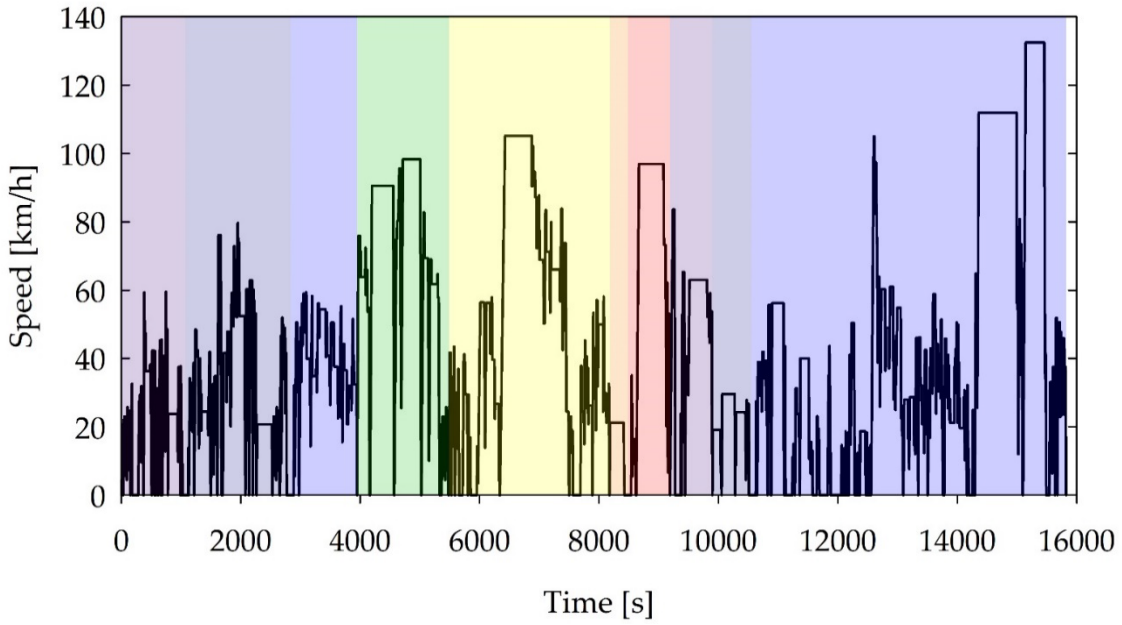
Currently focus on Passenger Cars

AVL
PMP Support

Other Members (Subset)

Audi
BMW
Ford
GM
Stellantis
HORIBA
AVL
LINK
TS
DEKATI
ITT
Engineered for life
brembo
Continental
TMD FRICTION
FEDERAL-MOGUL MOTORPARTS
TECHNISCHE UNIVERSITÄT ILMENAU

TF1: Definition of Brake Cycle



- Existing brake test cycles focus on performance and NVH testing
- A novel cycle (WLTP-Brake) was developed from analysis of real-word driving data (WLTP database)
- Cycle is split into 10 sections (trips) each starting with disc at <40°C
- Fresh brake systems need to be conditioned by running 5 WLTP-Brake cycles before the official test
- An official test lasts for more than 6 × 4.5 h → request for testing services are expected

TF2: Definition of Measurement Methodology

Particulate Mass - PM

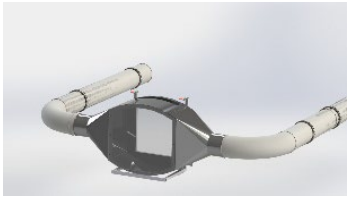
- Critical property with long-established correlation with adverse health effects (HEI, WHO).
- Key concern given the high emission levels (both $PM_{2.5}$ and PM_{10}) relative to exhaust and their relevance even for electric vehicles.
- Several studies verified the feasibility of representative measurements of PM_{10}.
- Gravimetric quantification of both $PM_{2.5}$ and PM_{10} will be required.

Particle Number - PN

- Strong interest in PN measurements mainly due to concerns about elevated emission of volatile nanoparticles.
- Limited experience on volatile PN measurements and concerns on repeatability/reproducibility ➔
  - Both solid and total PN under evaluation.
  - Methodology largely based on exhaust.
  - Focus on 10 nm – 2.5 µm range

Outcome of TF1 and TF2: New AVL Solution for Brake Emission Testing

Sampling System

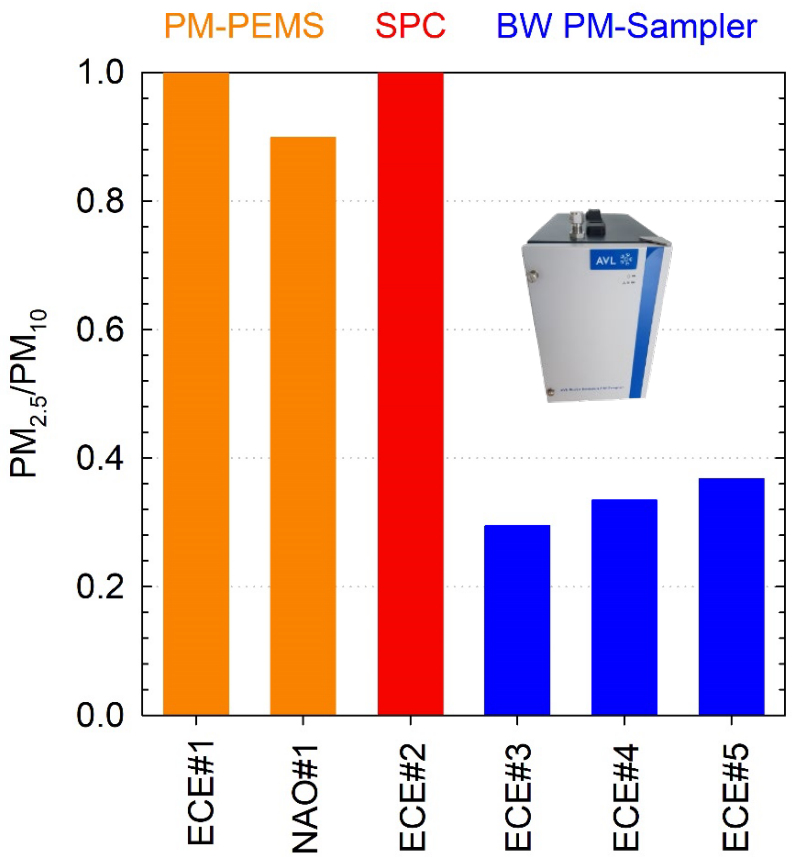


PM Sampler

APC-Brake*

*Re-use of existing instrumentation with application - targeted adoptions

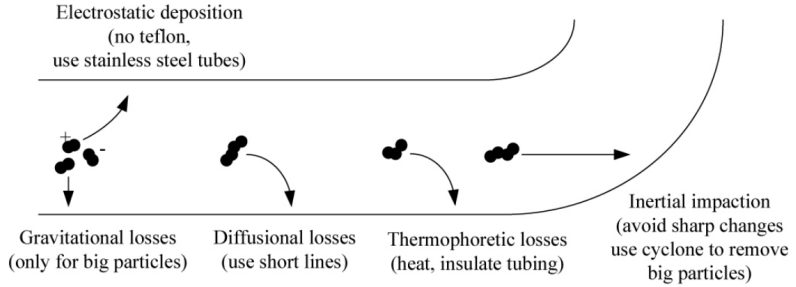
TF2: Definition of Measurement Methodology

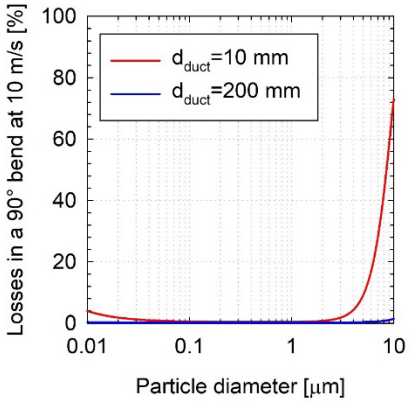


Challenge 1 ➔ Losses of µm-range Particles

1st Approach ➔ Use of standard exhaust PM Instrumentation:

- PM-PEMS + Partial-Flow Dilution Tunnel (SPC)
- Major losses for PM > 2.5 µmin the measurement system !!

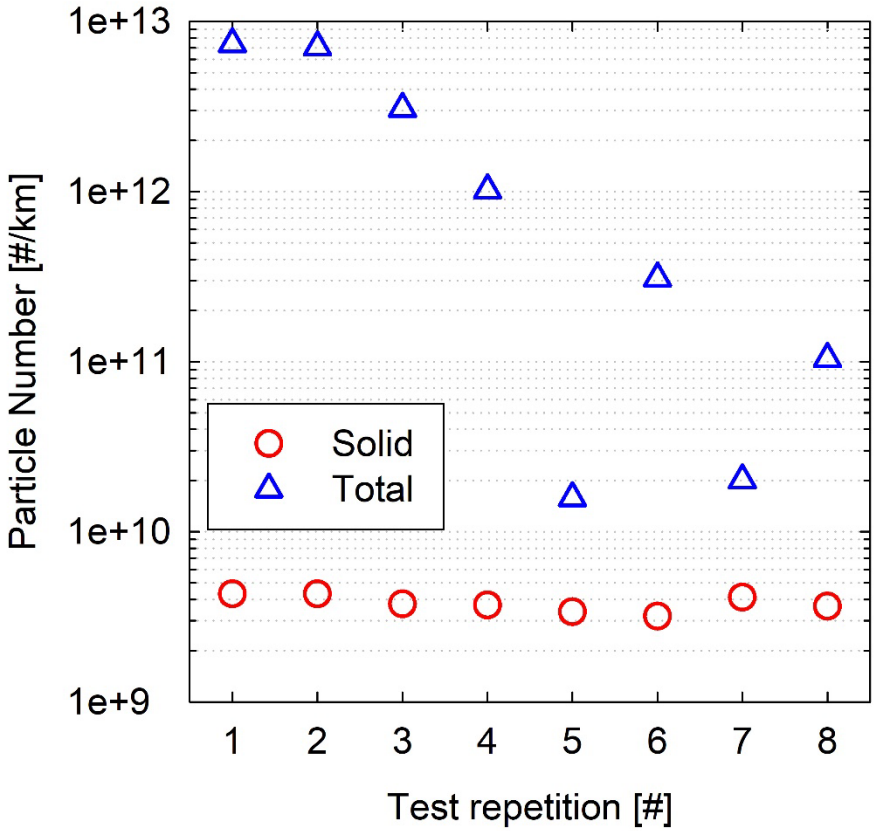




Conclusion ➔ Specific BW PM2.5 + PM10 Sampler Development:

- minimized losses + optimized duct diameters and orientation
- removed flow restrictions in instrumentation + sampling system

TF2: Definition of Measurement Methodology



Data from [Mathissen et al. 2019]

Challenge 2 ➔ Repeatable PN Measurement Solid vs. Total Particles

- High number of volatile particles, depending on the Brake cycle !!
- There is a regulator intention to measure the total PN to ban formulations that enhance release of volatile nano-particles
- Current measurements suggest that total BW PN measurements are neither repeatable nor reproducible
- Discussion ongoing, based on JRC Round-Robin results
- Definition of "volatile particles" & elaboration of a "new measurement procedure" would be required!!
- High reproducibility for solid PN
  → standard exhaust measurement method

TF3: Round – Robin Tests (Inter Laboratory Study – ILS)

GRPE-PMP

Objectives

- Verify the feasibility and applicability of the defined TF2 Output (specifications for sampling and measuring brake emission particles)
- Provide recommendations on further improving and/or extending the set of the defined specifications
- Examine the repeatability and reproducibility of PM and PN emission measurements
- Examine the repeatability and reproducibility of test conditions (i.e. speed, torque, temperature)
- Propose alternatives that can improve the efficiency (i.e. bedding procedure)

Actual Status:

- Completion of RR Test (End 2021)
- Data Analysis ongoing in PM

17 Participating Labs (Subset)

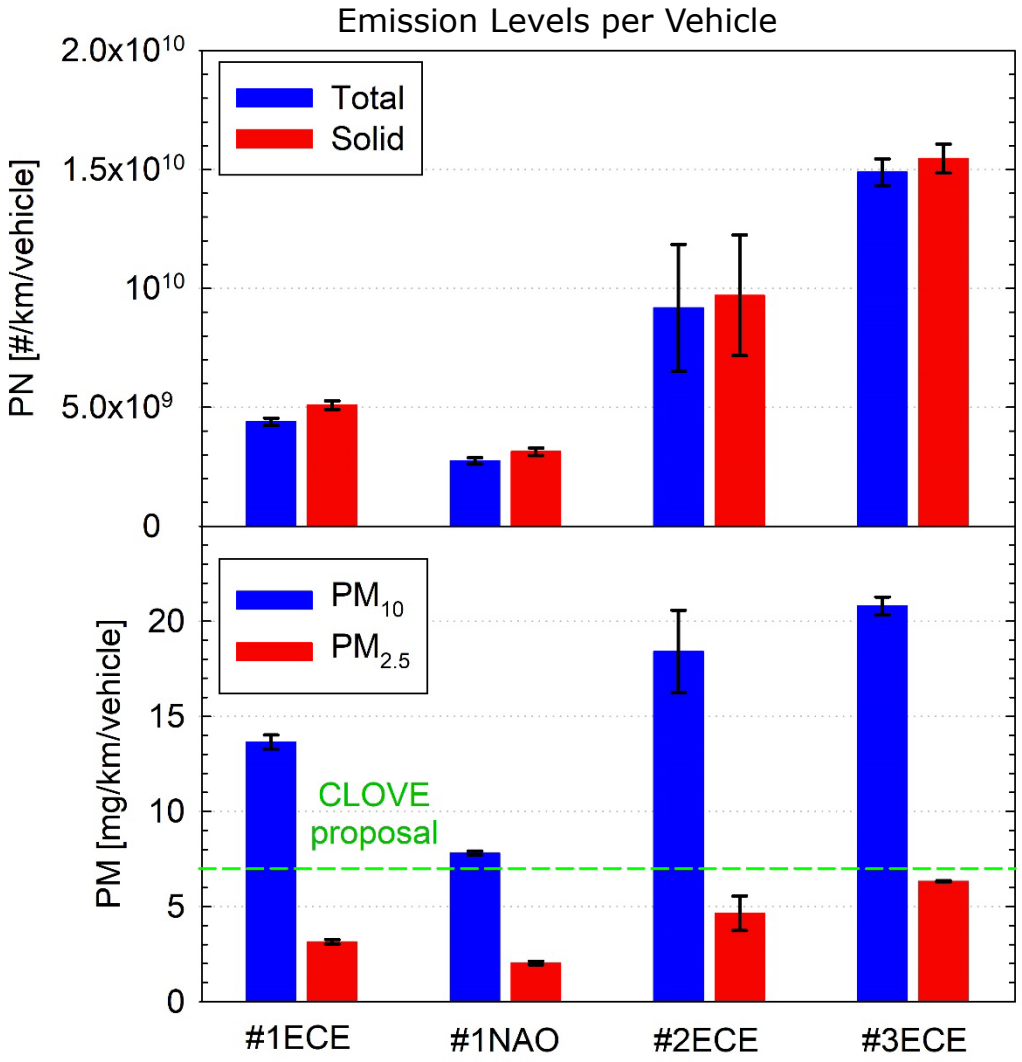
Audi, BMW, Ford, Applus IDIADA, AVL, HORIBA, dHARI, ITT Engineered for life, LINK US & EU, National Institute of Environmental Research, TMD FRICTION, brembo, TECHNISCHE UNIVERSITÄT DARMSTADT, UTAC, TECHNISCHE UNIVERSITÄT ILMENAU

4 OEM Brake providers

Audi, BMW, STELLANTIS, Ford

Source: PMP Web Conference 01.12.2021 - Transport - Vehicle Regulations - UNECE Wiki

TF3: Round – Robin Tests Measured BW emission levels



- AVL participated in the PMP BW Inter-Laboratory Study with the novel instrumentation, being fully compliant with the technical specifications.
- BW emissions from three reference brake systems (#1 to #3; all front brakes) were measured
  - Brake System #1 tested with ECE and NAO pad
- <u>Emission Results:</u>
  - CLOVE Proposal*: PM_{10}: 7 mg/km
  - Brake System #1 with NAO pads close to CLOVE Proposal
  - Brake Systems with ECE Pads → orders of magnitude above CLOVE Probosal

*Online AGVES Meeting 8 April 2021

TF4: Influence of Recuperation on brake emissions

GRPE-PMP

Objective

- proposing a simplified approach for generalizing the PMP brake emissions testing procedure to electrified vehicles featuring regenerative braking (Mild-Hybrids, Full Hybrids, PHEVs, and BEVs)

Actual Status:

- Agreement on powertrain types to be reflected in the procedure
- Agreement on the test setup
- Agreement on test cycle (Same test cycle as for ICE vehicles)
- Agreement of implementation of recuperation strategies on brake dynamometer

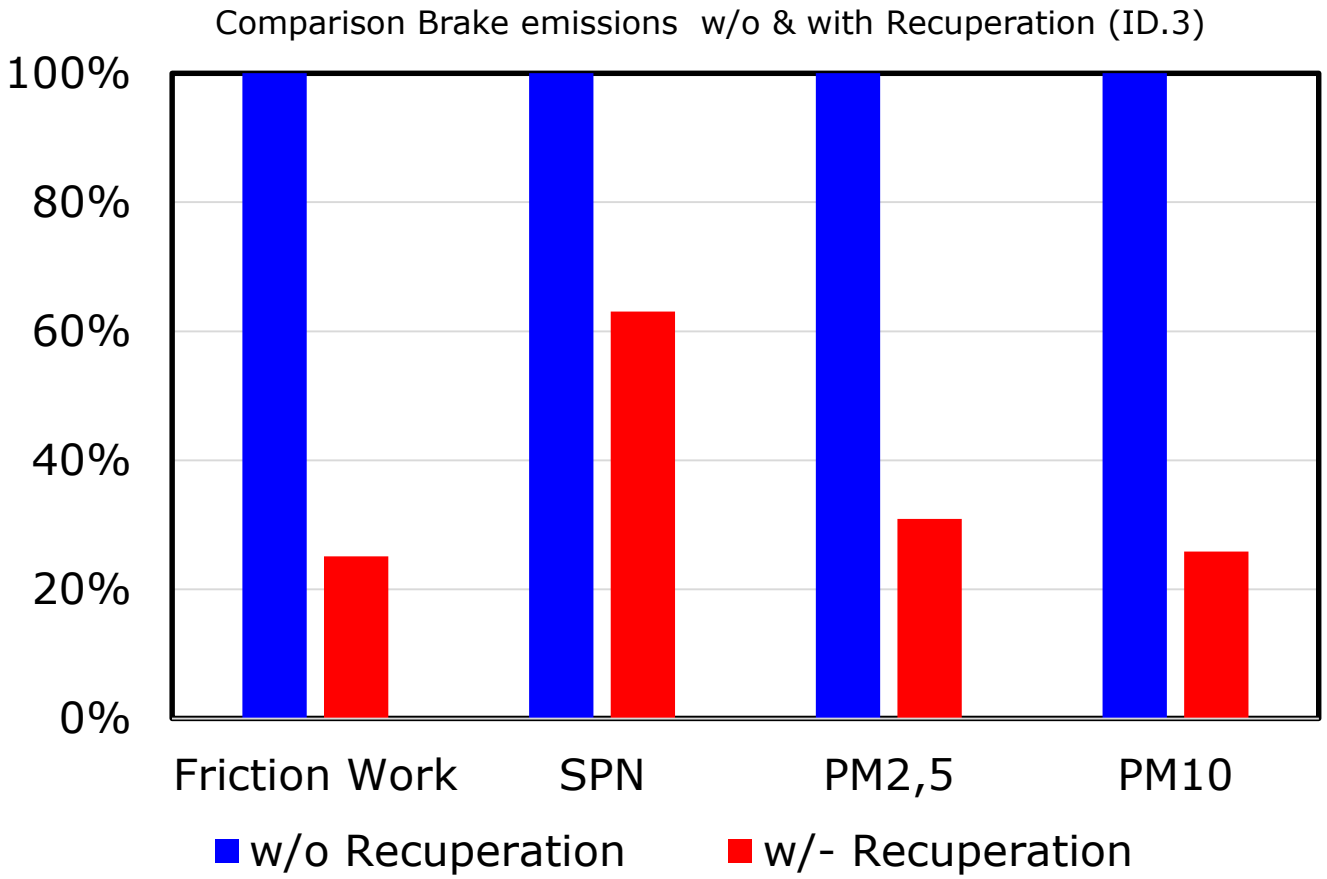
Next Steps:

- Agreement on realistic boundary conditions and settings for parameters specific for EVs (ensure that the test can be run by independent laboratories)

59 Participating companies (some examples)

Source: PMP Web Conference 01.12.2021 - Transport - Vehicle Regulations - UNECE Wiki

TF4: Influence of Recuperation – Emission results



Results:

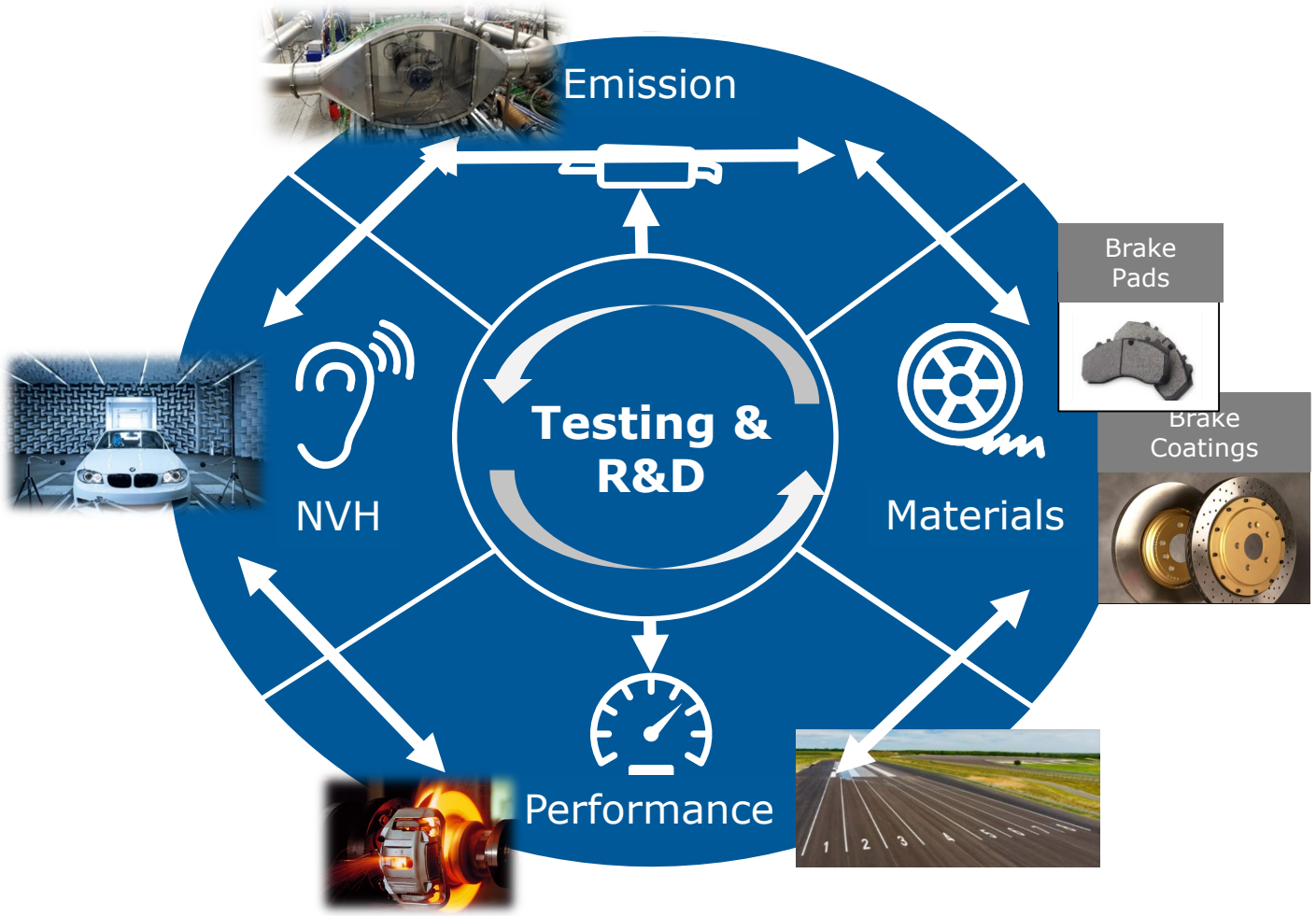
- Friction work reduced by 75%
- SPN (solid particulate number) reduced by 35%
- PM2.5 reduced by 70%
- PM10 reduced by75%

Conclusion:

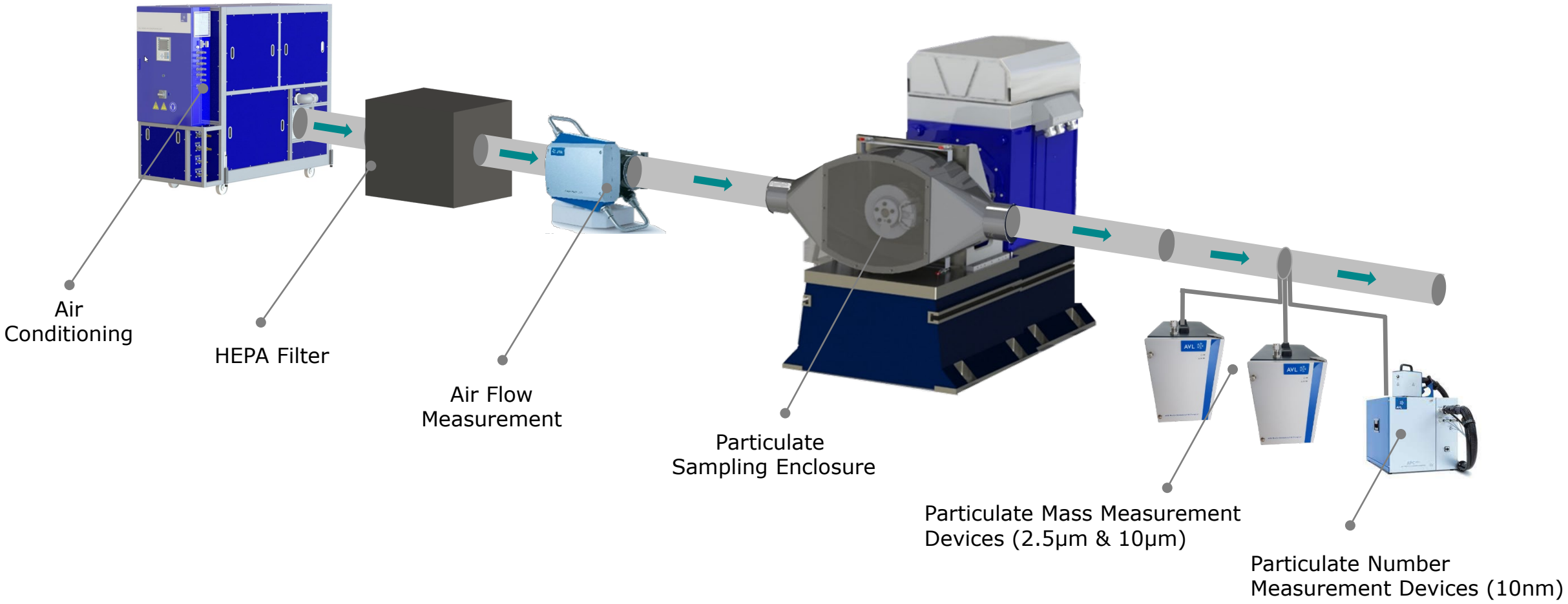
- Recuperation reduces brake wear emissions significantly
- How to implement recuperation strategies (influence of e.g. SOC) into GTR draft is still under discussion in the PMP

AVL Brake Wear Solution

Brake Development ➔ Will be a System Challenge



AVL Solution for Brake Emission Testing



AVL Solution for Brake Emission Testing

Active Dyno & Inertia Simulation

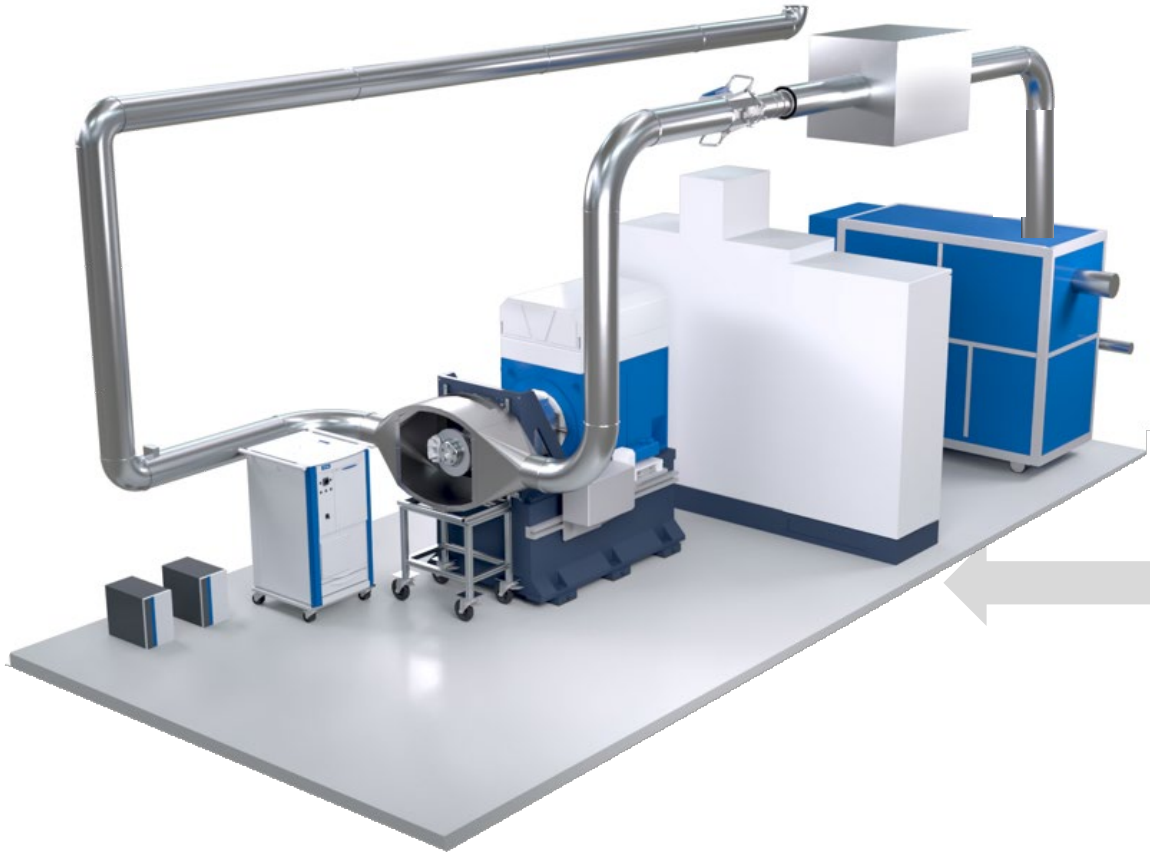
AVLs test system concept based on active dynos which enables to transfer Co-Simulation to brake emission testing.

Min. Footprint

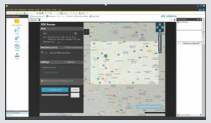
AVL concepts follows min. footprint which allows to max. testing capability by limited space requirements.

Integrated Solution

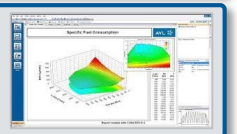
Comprehensive integrated solution for test- and emission measurement equipment.



Software Toolchain

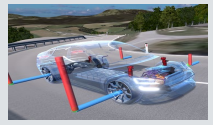


Result Analysis



DoE Parameter Variation

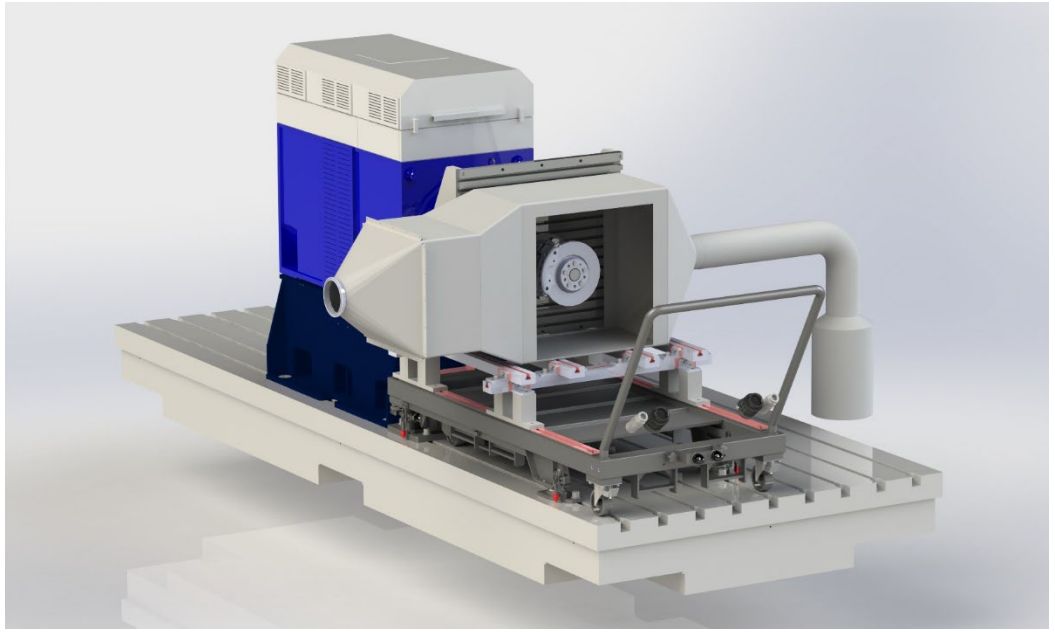
Vehicle Simulation



Covering Additional Brake Emission Testing need

A. Dedicated Brake Emission Test System

B. Adapt existing Engine Testbeds



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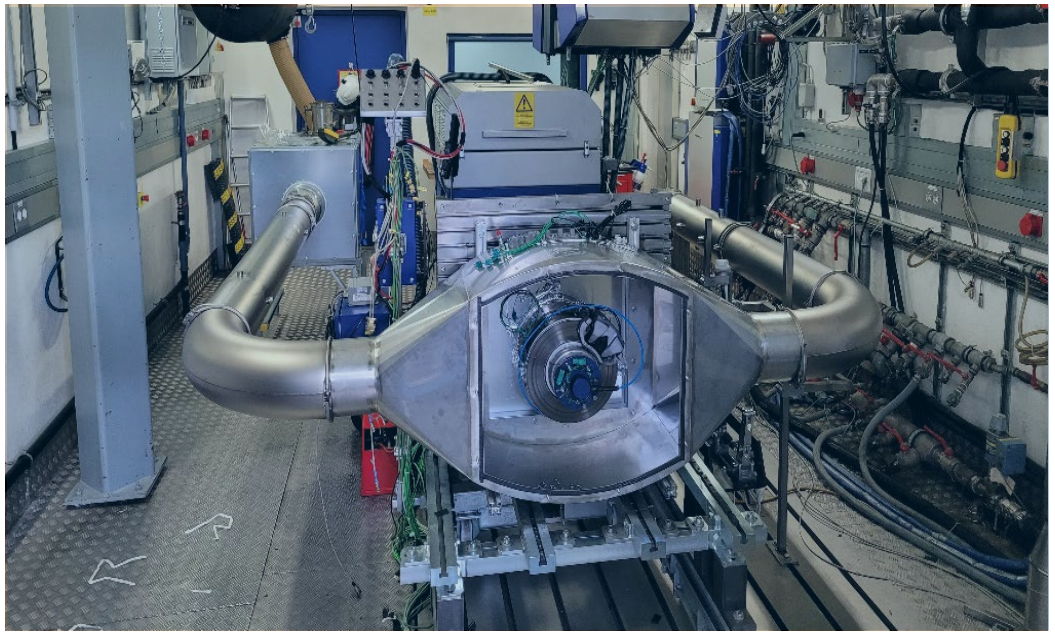


Outlook

Brake Wear – Potential Evolution of Legislation in Long Term

Legislation

Brake Dynos

Chassi Dynos

RDE Tests - „Brake PEMS“

Starting point for legislation

low

high

Complexity

high

Repeatability

low

Correlation to real world emission behaviour

weak

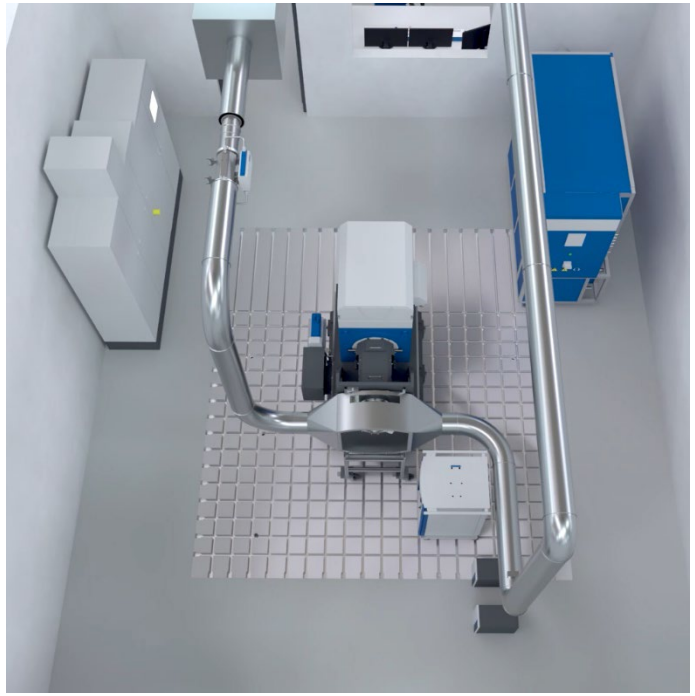
strong

Target

= driver for further legislation!

Conclusion

- Upcoming non-exhaust emission legislation requires significant increase of brake testing effort.
- Brake Emission Measurement is a new challenge and requires specific knowledge and know-how.
- A new and complex Measurement Procedure was evaluated during an inter-laboratory-study, AVL is supporting with state-of-the-art Instrumentation & Methodology
- AVL offers the transformation of existing testing infrastructure like engine testbeds to brake emission testing.
- Next Challenge ahead... Tire Wear, an even larger source of particulates (micro-plastics) for the environment
- PMP got the task to support an existing working group already



Thank you

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