Executive Summary

The Euro 7 regulation introduces binding limits for non-exhaust emissions, including brake wear particles (PM10), marking a significant shift in vehicle emissions legislation.

Non-exhaust emissions are no longer secondary – they are central to future compliance.

Brake wear emissions are projected to dominate urban particulate pollution as tailpipe emissions decline. With up to 40 % of non-exhaust PM10 originating from braking systems, reliable measurement and mitigation strategies are essential.

Brake wear matters – and it can be measured.

This whitepaper outlines the regulatory roadmap, technical challenges, and ZF-AIP's solution for brake particle quantification.

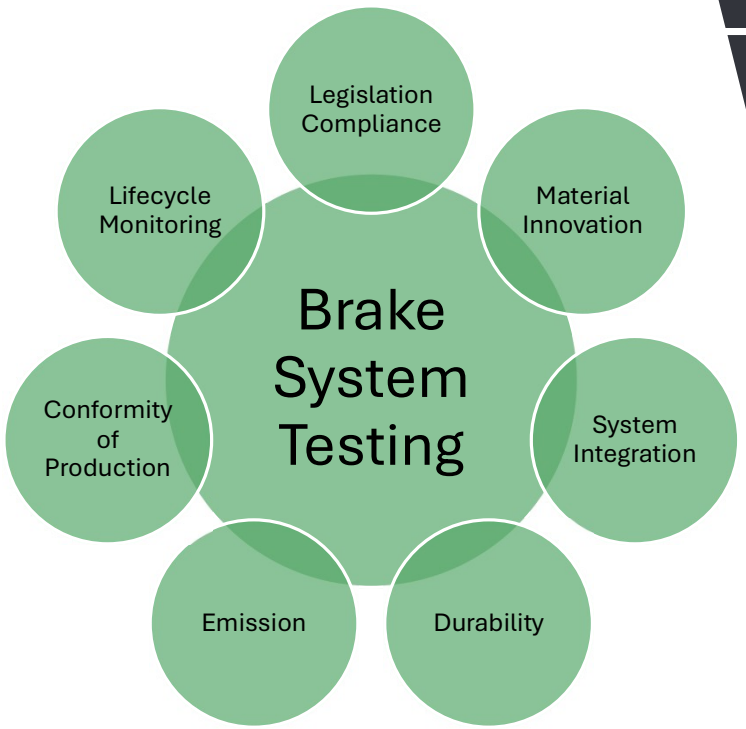
ZF-AIP's **dustIN** platform provides a modular, regulation-ready test environment for disc and drum brake systems, supporting homologation and development.

Results from the **Inter-Laboratory Study (ILS-3)** highlight the complexity of brake wear measurement and the importance of standardized setups.

ZF-AIP's internal study underscores that **filter holder optimization** has minimized bias on PM10 results, reinforcing the robustness of the measurement equipment.

From regulation to resolution – with ZF-AIP.

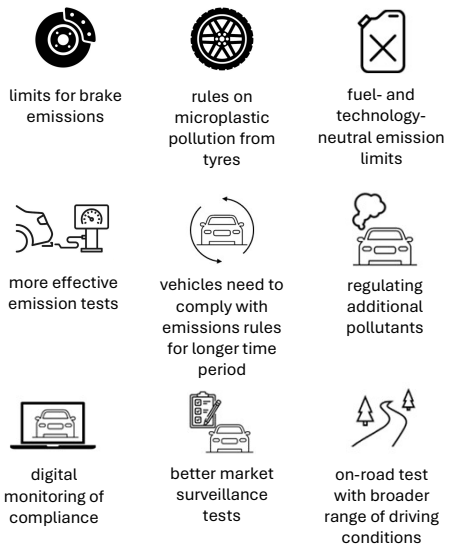
With validated infrastructure, scientific insight, and system-level expertise, ZF-AIP enables OEMs and suppliers to meet Euro 7 brake wear requirements with confidence.



Compliance starts with clarity – and ends with confidence.

Introduction

What's new in the Euro 7 regulation?



European Union, 2022 | doi:10.2873/99010

For decades, European vehicle emission standards focused exclusively on tailpipe emissions. However, with the Euro 7 Regulation (EU 2024/1257), the scope has expanded to include **non-exhaust sources** such as **brake and tyre wear**, reflecting growing concerns over **particulate matter (PM)** pollution and its impact on **public health and the environment**.

Brake wear emissions are now recognized as a **dominant contributor to urban PM pollution**, accounting for up to **40 % of PM10** and **30 % of PM2.5** in non-exhaust emissions. With exhaust emissions declining due to electrification and aftertreatment technologies, **non-exhaust emissions are projected to exceed 90% of total PM by 2040**.

The Euro 7 regulation introduces **binding PM10 limits** for brake wear, making **brake particle measurement and mitigation** a central challenge for OEMs and suppliers. This shift demands **validated test protocols**, **material innovation**, and **system-level compliance strategies**.
This whitepaper outlines the regulatory context, technical challenges, and ZF-AIP's solution for brake wear quantification – supporting the transition from regulation to resolution.

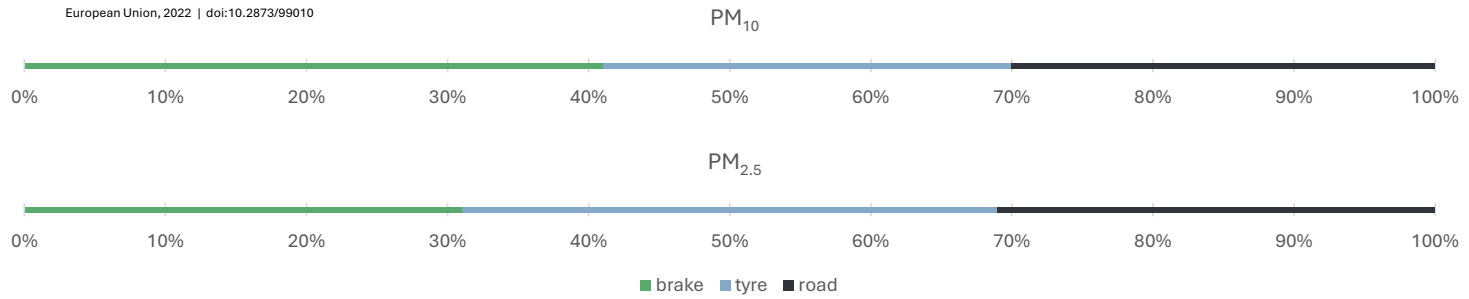


Fig.: Contribution of each source (brake, tyre, road wear) to total NEEs from road transport for years 2017-2021 in the European Union [1]

[1] European Commission. Directorate General for Internal Market, Industry, Entrepreneurship and SMEs. In Euro 7 Impact Assessment Study; Publications Office: Luxembourg, 2022.

Timeline and Milestones towards Euro 7 – Brake Wear

The Euro 7 brake wear regulation is the result of a multi-year international effort to standardize non-exhaust particle measurement.

Starting with the PMP working group in 2017, the process led to the release of UN GTR 24 in 2023, which defines the global test protocol, equipment, and cycle.
The ILS-3 campaign in 2025 provided essential validation data, supporting the staged implementation of PM10 limits:

- **2026** for light-duty vehicles (M1 & N1)
- **2030** for heavy-duty categories (M2, M3, N2, N3)

These limits apply across all powertrain types, including electric vehicles, and mark a significant step toward comprehensive air quality regulation.

Euro 7 Roadmap

Date	Powertrain Type	Vehicle Category		
		M_1&N_1 class I&II	N_1 class III	M_2/N_2 & M_3/N_3
Nov. 2026	PEV	3 [mg/km]	5 [mg/km]	None
	others	7 [mg/km]	11 [mg/km]	None
Jan. 2030	PEV	tbd	tbd	tbd
	others	tbd	tbd	tbd

Table: Euro 7 brake particle emission limits for particulate matter

2017
PMP - Working Group

Global Technical Regulation defines test protocol/equipment/cylce

Jun. 2023
UN GTR 24 official release Brake Emissions

2025
ILS - 3

Nov. 2026
Euro 7 Brake Wear (M_1 & N_1)

2030
Euro 7 Brake Wear (M_2, M_3, N_2, N_3)

European Commission

Navigating Non-Exhaust Emission Standards

Euro 7 compliance is no longer limited to the tailpipe – it demands precision, coordination, and innovation across the entire vehicle system.

Upcoming Challenges

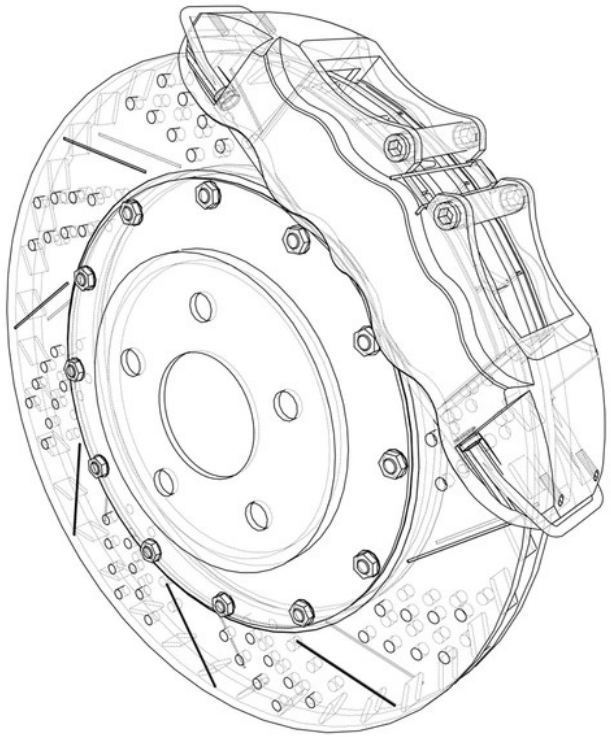
The Euro 7 Regulation (EU 2024/1257) introduces binding limits for non-exhaust emissions, including brake and tyre wear. This marks a fundamental shift in vehicle emissions legislation and presents new challenges for OEMs and suppliers alike.

Expanded Regulatory Scope
For the first time, particulate matter (PM10) from braking systems is subject to homologation-relevant limits: Tyre wear limits are expected to follow, with UN WP.29 tasked to define them by 2026–2030.

Shared Compliance Responsibility
While vehicle OEMs carry the regulatory liability, tier 1 suppliers must deliver components that meet agreed technical specifications. Collaborative compliance is essential to ensure system-level conformity.

Measurement Complexity & Uncertainty
Brake wear measurement involves multiple sources of uncertainty – from flow rate deviations and tunnel losses to filter handling and weighing effects. Specialized knowledge is necessary to overcome the diverse challenges.

Material & Design Innovation
Low-particulate brake pads and durable tyre compounds are key to meeting future limits. This requires cross-disciplinary R&D and adaptation of production processes.



dustIN: Designed for Euro 7. Built for insight.

dustIN is ZF-AIP's modular platform for brake particle emission testing, designed to meet the requirements of GTR24 for the upcoming Euro 7 legislation.

It enables precise, reproducible measurement of particulate emissions from brake systems under realistic operating conditions. **dustIN** combines advanced brake simulation, high-resolution flow measurement, and flexible particle analytics – providing a robust foundation for homologation, development, and compliance validation.

The system supports **multiple braking modes**:

- Deceleration braking with simulation of vehicle mass, driving resistances, and recuperation behavior
- Continuous braking, where vehicle speed is simulated via drive speed, allowing any speed and pressure profiles to be reproduced

The ZF-AIP Solution

Particle measurement is handled via a modular cabinet **system**:

- Base configuration includes a rack with pump and Particle Mass Controller for PM10
- Expandable to PM2.5, Solid PN (with catalytic stripper), and Total PN (without heating)
- Sampling prepared for up to 4 sample points

Flow measurement is based on proven RDE technology:

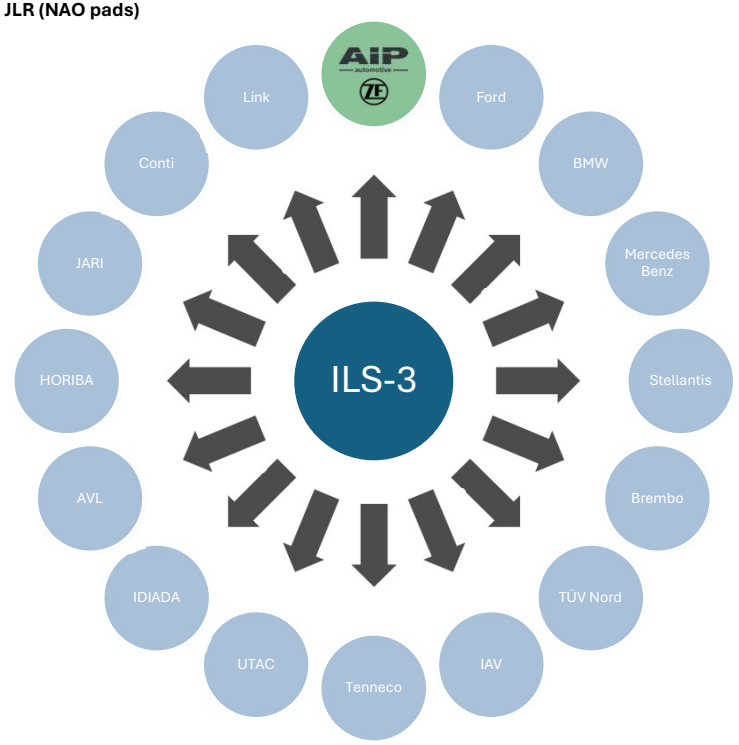
- Cascaded differential pressure sensors using the annubar principle
- Sampling rate up to 5 kHz
- Evaluation via EFM software, with all calibration data stored directly on the EFM

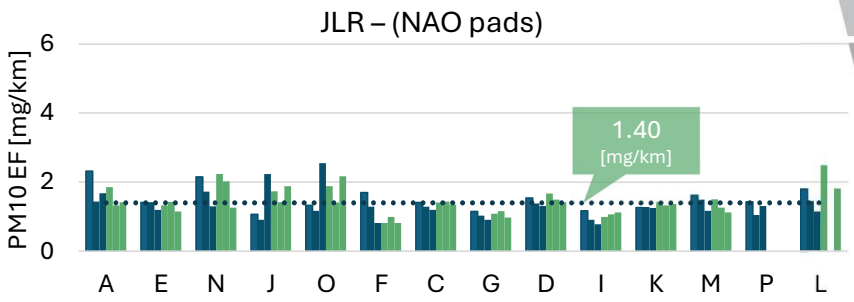
International Inter-Laboratory Study (ILS)

In the context of the Euro 7 regulation, the international Inter-Laboratory Study (ILS) provides valuable insights into the current status of brake particle emissions across various OEMs and test facilities (A-P). The third phase of the ILS campaign, conducted under the coordination of the PMP working group, revealed significant variability in PM10 emission factors – even when identical brake systems were tested under harmonized protocols.

The plots illustrate the PM10 emission factors recorded during the ILS-3 for two brake systems in repeated test cycles:

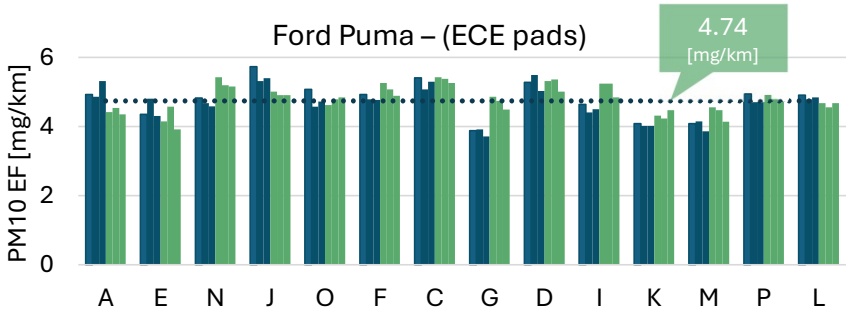
- **Ford PUMA (ECE pads)**
- **JLR (NAO pads)**





Results

The observed spread in PM10 emission factors across laboratories highlights the sensitivity of brake wear measurements to test setup, pad formulation, and procedural consistency. In particular, the results for ECE pad-equipped systems – such as those used in the Ford PUMA example – demonstrate how conventional friction materials can challenge compliance under Euro 7 conditions.



At ZF-AIP, we interpret these results not as a barrier, but as a benchmark. They reinforce the need for precise instrumentation, standardized procedures, and intelligent data interpretation – all of which are core elements of our **dustIn** platform.

[1] https://wiki.unece.org/display/trans/PMP+55th+session+-+Geneva+25.03.2025

Low Bias in every Component: CoP Testing Simplified

Accuracy & Robustness
ZF-AIP conducted an internal study using a BMW X5 brake system to compare single-filter and multi-filter configurations across three cooling airflow rates (500, 1000, 1500 L/min), according to the proposed referring UN regulation (GRPE-93-48-Rev.1 paragraph 12.1.3.1. (g)). Results show minimal differences in PM10 emission factors between configurations, well within expected measurement uncertainty. This confirms the robustness of ZF-AIP's sampling methodology for Euro 7-compliant brake wear quantification.

Efficiency for COP Testing
The multi-filter holder enables three legally required repetitions for Conformity of Production (CoP) in a single run - without intermediate filter changes. This reduces handling steps, minimizes contamination risk, and accelerates compliance workflows.

Feature	CoP Requirement (UNR)	Multi-Filter Holder Advantage
Repetitions	1× cooling, 5× bedding 3 measurements per CoP test	All 3 in one continuous run, no interruptions
Efficiency	Time-consuming, contamination risk	High time savings, minimal risk

Results

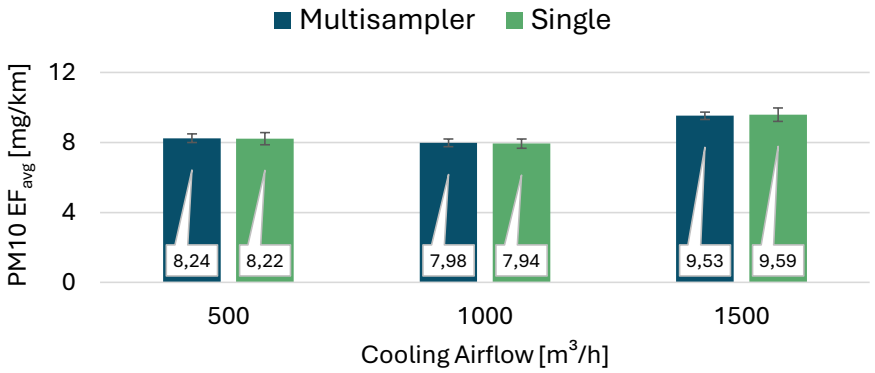


Fig.: Average PM10 emission factors for single and multi-filter configurations across three cooling airflow rates. The results show consistent values with minimal variation between setups.

$$Bias = \left(\frac{PM10\ EFavg\ Multisampler}{PM10\ EF_{avg}\ Singlesampler} - 1\right) \cdot 100$$

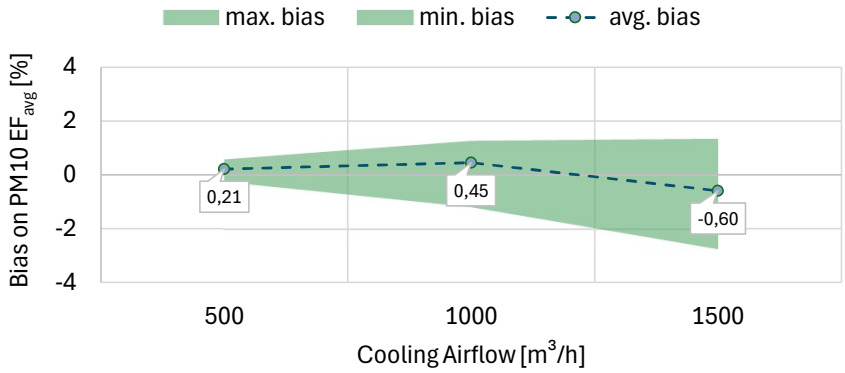


Fig.: Relative deviation between multi- and single-filter configurations as a function of cooling airflow. The shaded area represents the range of variation across six test repetitions per flow rate.

From Regulation to Resolution

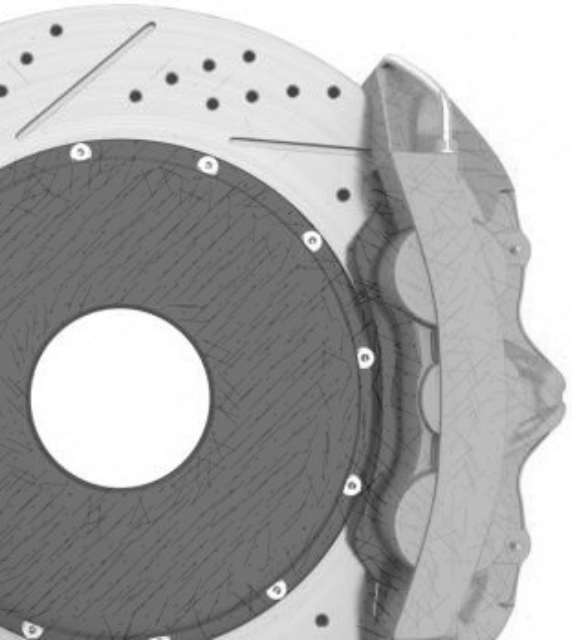
Regulatory Shift
Euro 7 expands emissions legislation to include non-exhaust sources like brake and tyre wear – with binding PM10 limits and a clear implementation roadmap.

Measurement Matters
Brake wear quantification requires standardized protocols, validated setups, and awareness of uncertainty sources.

System-Level Responsibility
Compliance is a shared task: OEMs carry regulatory liability, but tier 1 suppliers must deliver technically conforming components.

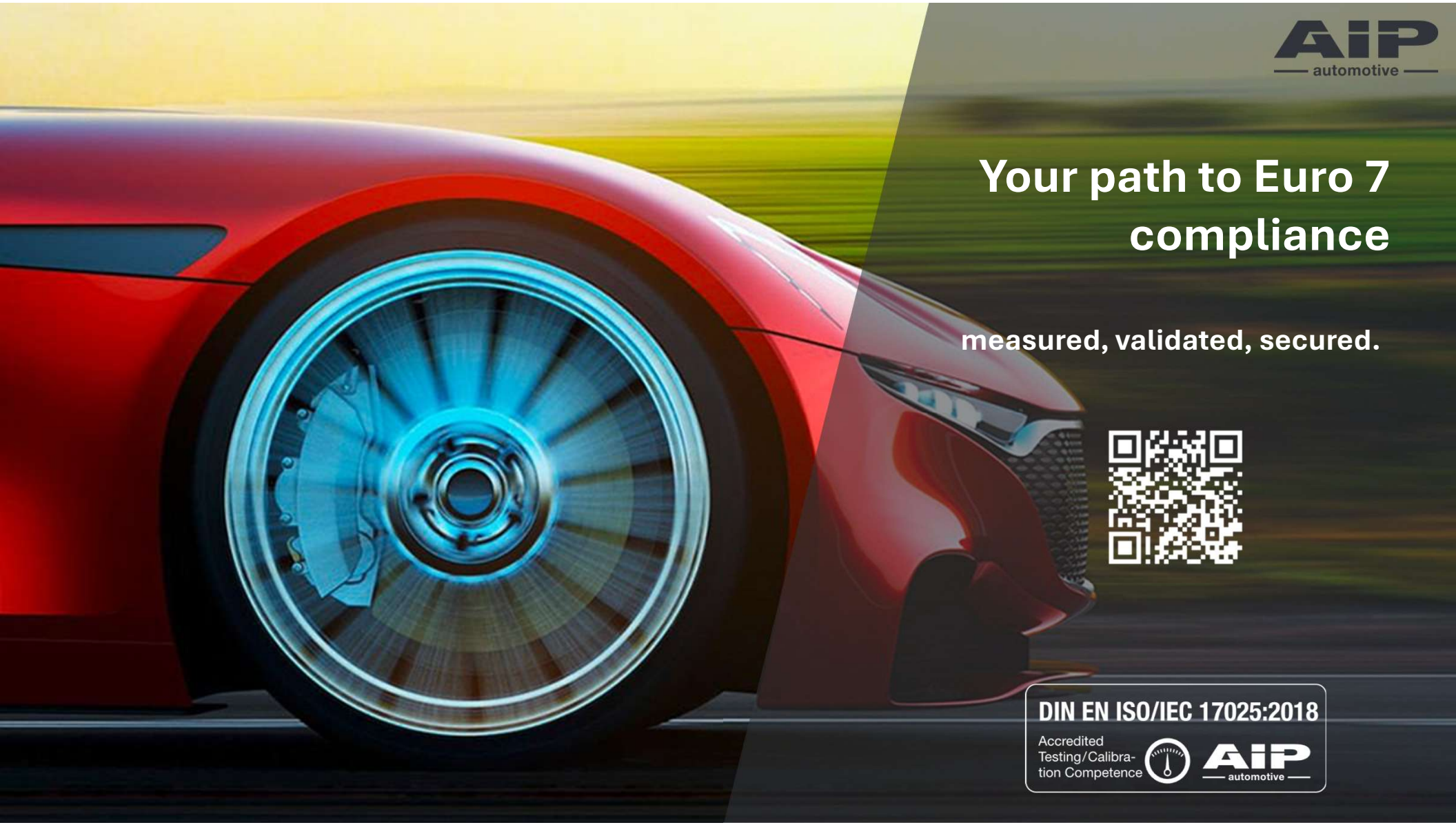
ZF-AIP's Solution
dustIN provides a modular, regulation-ready platform for brake particle measurement – supporting homologation, development, and CoP validation.

Validated Results
Internal studies confirm minimal influence of filter holder configuration and demonstrate robust, reproducible PM10 data across cooling airflow conditions.



Conclusion

Brake wear compliance is measurable. And manageable – with the right tools and expertise.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