Non-Exhaust Nanoparticles from Traffic Sources: Health Implications of Brake and Tire Wear Emissions

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Air pollution

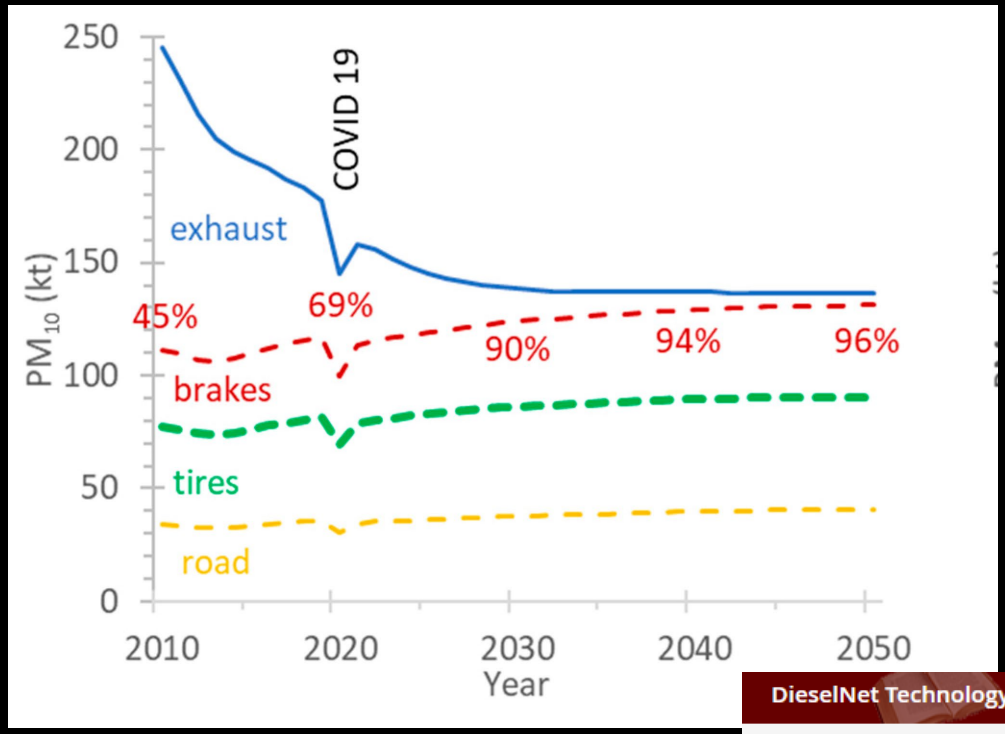
Although **air pollution emissions have decreased** significantly over the past two decades, it remains the **leading environmental health risk** in Europe;

As exhaust emissions have become more strictly regulated, **non-exhaust sources** - such as brake and tire wear - now represent a **growing concern** of traffic-related particulate emissions;

Upcoming **Euro 7 norm** will define new emission standards for light- and heavy-duty vehicles in the European Union.

EEA (European Environmental Agency) Air Pollution (2025)
WHO global air quality guidelines (2021)
Harrison *et al.* Atmospheric Environment (2021)
https://theicct.org/wp-content/uploads/2024/03/ID-116-%E2%80%93-Euro-7-standard_final.pdf

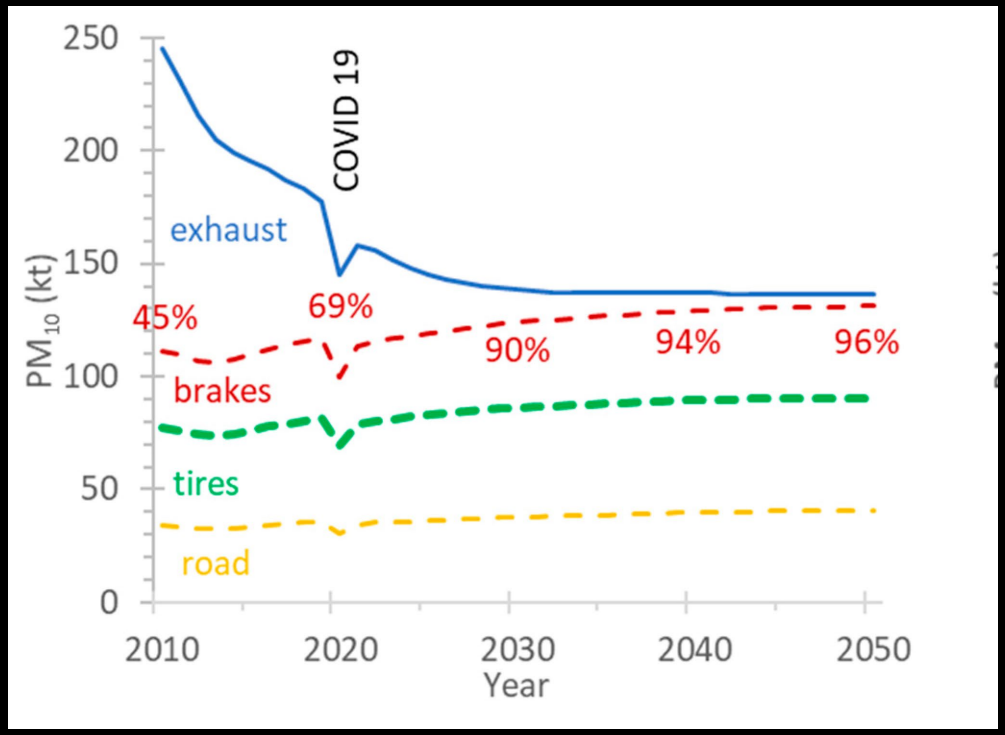
Projections of exhaust, non-exhaust (brake, tire, and road wear), and total PM emissions from road transport in EU27



Percentages give contribution of non-
total PM_{10} at years 2010, 2020, 2030,
2050. The decrease of emissions in 20
to the COVID-19 restrictions.

Giechaskiel *et al*. Atmosphere (2024)

Projections of exhaust, non-exhaust (brake, tire, and road wear), and total PM emissions from road transport in EU27



Percentages give contribution of non-exhaust to total PM_{10} at years 2010, 2020, 2030, 2040 and 2050.

Giechaskiel *et al*. Atmosphere (2024)

Electric vehicles are about 24% heavier than their gas counterparts:

- **Brake emissions are expected to increase**, but on the other hand, to **decrease due to their regenerative braking** and hence reduced use of friction brakes;
- An increase of **20%** in **tyre wear PM_{10}** and **30%** in **tyre wear $PM_{2.5}$** is estimated.

Timmers and Achten. Atmos Environ (2016)
Zhang *et al.* Atmos Environ (2023)

Brake wear particle emissions

Generated by the **friction between the brake pad/shoe** and **disc/drum**. A considerable part of the order, **40%, becomes airborne PM**;

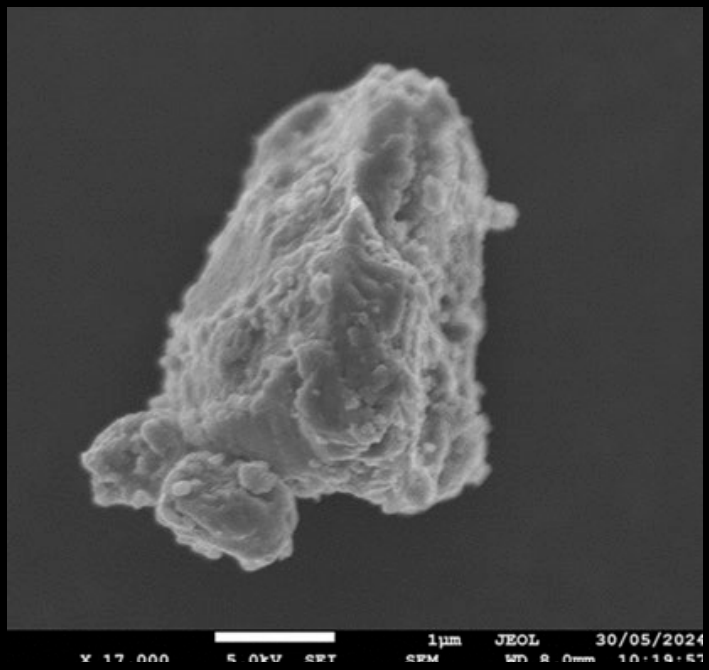
Categorized based on their friction material as organic or metallic:

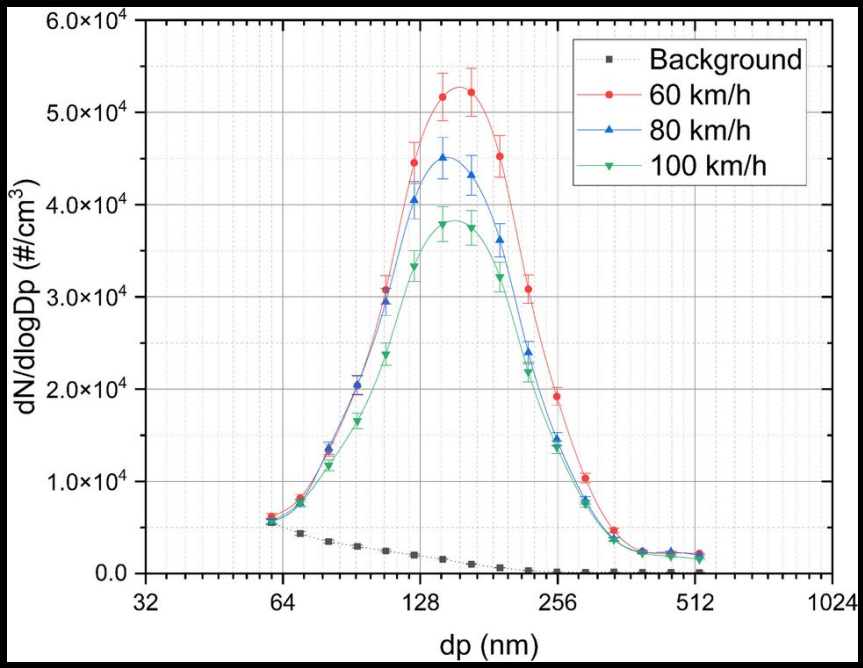
1. **Non-asbestos organic (NAO)**, mainly composed of organic compounds, mineral fibers and graphite. Commonly used in USA, Japan and Korea;

2. **Low-metallic (LM)** composed of a mixture of metal and organic compounds, and **semi-metallic (SM)**, metallic, mainly steel and iron, content. Commonly used in Europe.

Giechaskiel *et al*. Atmosphere (2024)
Piscitello *et al.* Sci Total Environ (2021)

Brake wear particles – physicochemical characteristics





Brake wear particles on-road under various real-world driving conditions

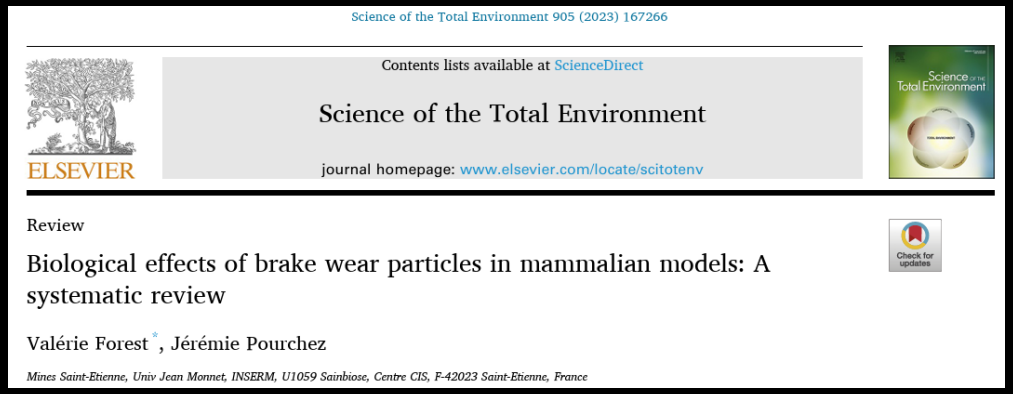
Al Wasif-Ruiz *et al.* Environ Sci Pollut Res (2025)

1) Particles occur in the **form of aggregates**. Depending on the formation — whether mechanical and/or thermal — the shape of the particles can vary from **irregular and rough to round**;

2) The most abundant **metallic element was iron (Fe), followed by copper (Cu), aluminium (Al), and zinc (Zn).** Other elements are magnesium (Mg), silicon (Si), sulphur (S), chromium (Cr), tin (Sn), barium (Ba), and zirconium (Zr);

3) Brake wear particles are mainly in the range of **1–10 µm.** During harsh braking events, a concentration of up 10^6 (#/cm^3) was measured for **particles under 8 nm**.

Brake emissions – current state of knowledge on health effects



Science of the Total Environment 905 (2023) 167266

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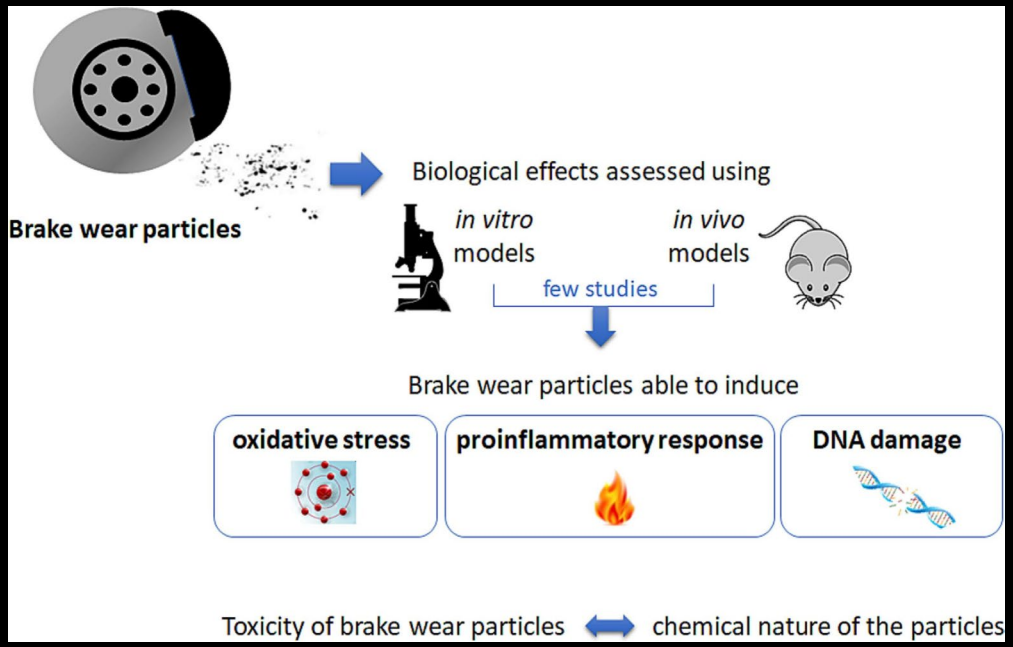
Review

Biological effects of brake wear particles in mammalian models: A systematic review

Valérie Forest *, Jérémie Pourchez

Mines Saint-Etienne, Univ Jean Monnet, INSERM, U1059 Sainbiose, Centre CIS, F-42023 Saint-Etienne, France



Bibliographic search of two databases (PubMed and Web of Science, June 1, 2023) focusing on **the toxicological effects of brake wear particles induced *in vitro* and *in vivo***;

Of the 291 papers, 19 (11 *in vitro*, 8 *in vivo*) were found to be relevant;

Two key findings:

1) The assessment of the brake wear particles toxicity in mammalian models is **still limited**;
2) **Brake wear particles** can induce **oxidative stress**, **proinflammatory response** and **DNA damage**.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 955390

ULTRHAS – Brake wear emission campaign

Journal of Hazardous Materials 482 (2025) 136609

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Journal of Hazardous Materials

journal homepage: www.elsevier.com/locate/jhazmat

Comprehensive elemental and physical characterization of vehicle brake wear emissions from two different brake pads following the Global Technical Regulation methodology

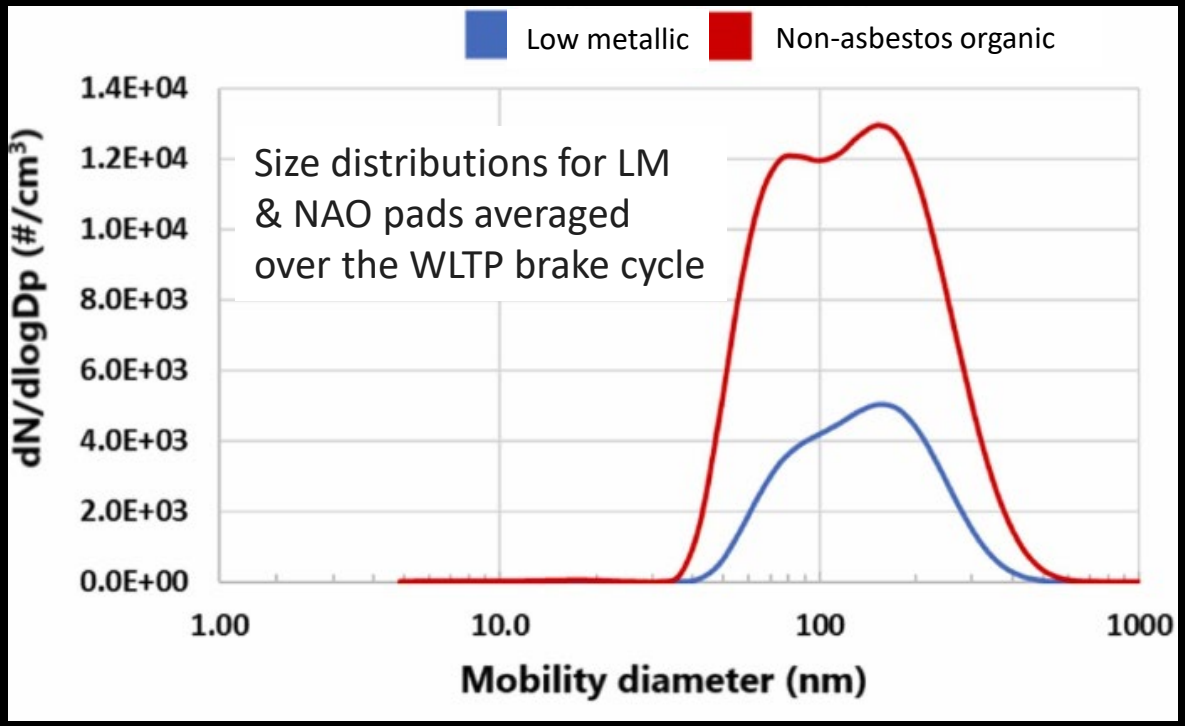
Carsten Neukirchen [a,b], Mohammad Reza Saraji-Bozorgzad [a], Michael Mäder [c], Ajit Paul Mudan [a], Philipp Czasch [c], Johannes Becker [b,d], Sebastiano Di Bucchianico [b,d,e], Christian Trapp [f], Ralf Zimmermann [b,d,e], Thomas Adam [a,d,*]

Custom-build brake dyno to generate brake wear to match the **Global Technical Regulation (GTR24) requirements** as close as possible;
(*i.e.,* testing of a brake assembly in an enclosure, using a brake dynamometer, and following the worldwide harmonized light vehicles test procedure brake (WLTP-B) cycle;

Utilized brake pads:

- **Low metalic** (LM) pad;
- **Non-asbestos organic** (NAO) pad.

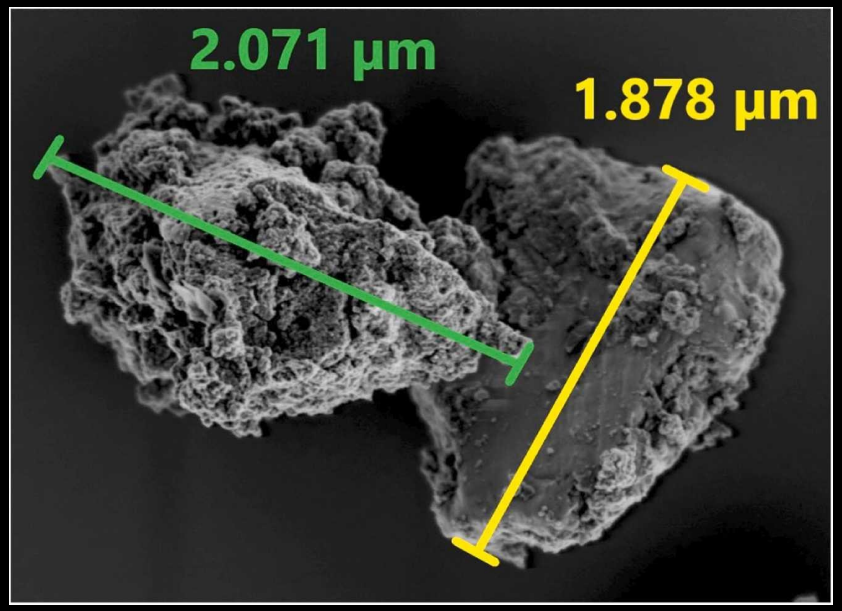
ULTRHAS – Brake wear emission campaign

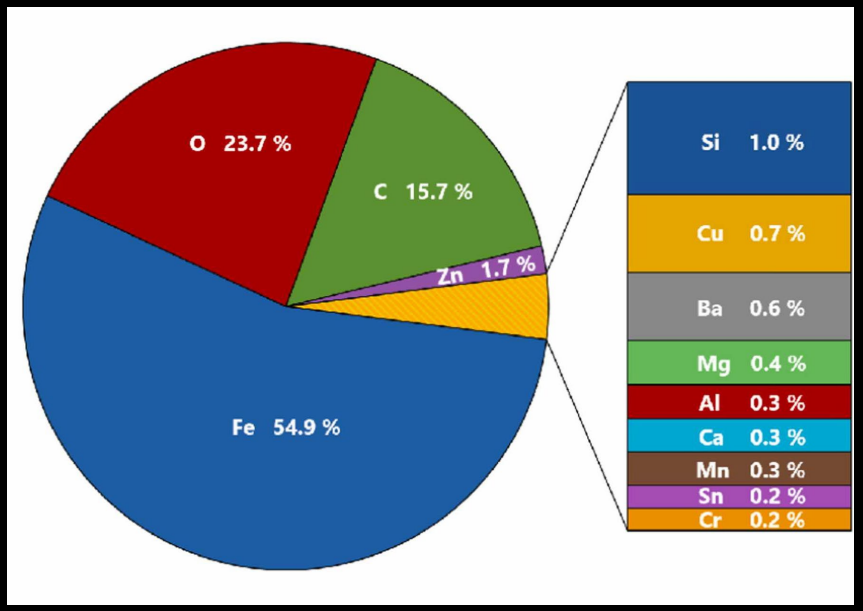


- **Bimodal PN size distributions** for both pads:
  - **LM pad**: 123 nm /86 nm, **NAO pad**: 143 nm / 86 nm;
- **NAO pad** produced a **larger share of smaller particles** compared to the LM pad.

Neukirchen *et al.* Journal of Hazardous Materials (2025)

ULTRHAS – Brake wear emission campaign



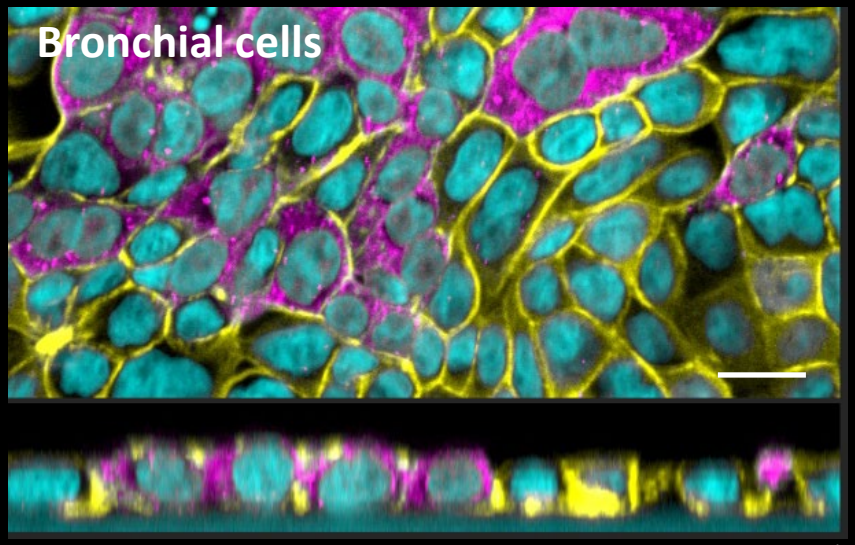


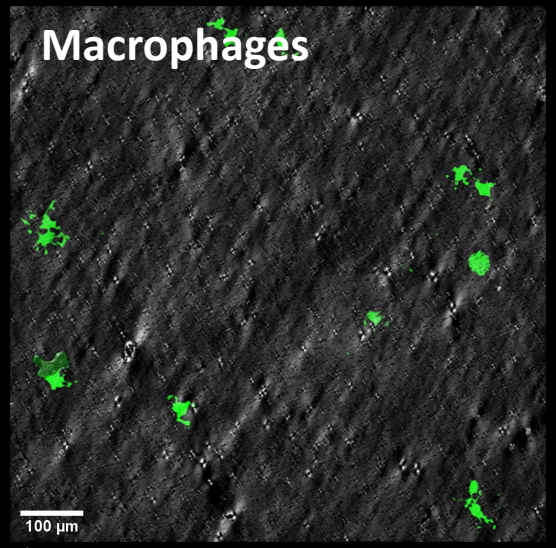
- **Spherical** and **flake-like shaped particles**;
- **Highly metallic particles** with 54.9–58.1 % of PM_{10} emitted as **iron** and other heavy metals, such as **Cu, Cr, Mn and Zn** in **varying concentrations** for both pads:
  - LM pad more Cr / NAO high Fe content;
- **Large emission contribution** from wear of the **brake disc** observed.

Neukirchen *et al.* Journal of Hazardous Materials (2025)


CLEAN AIR
Are the humidity sensors pluged in?

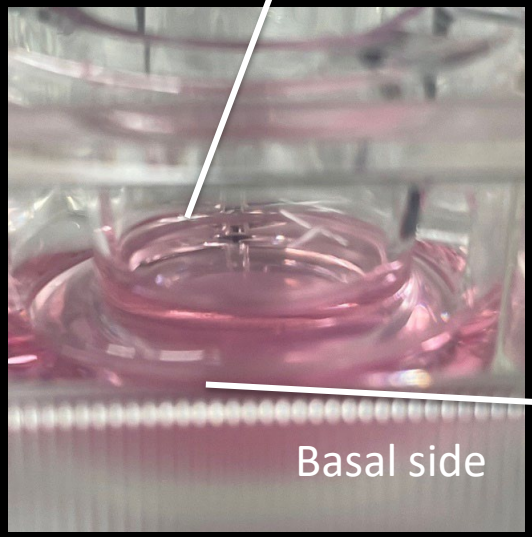
ULTRHAS – Brake wear emission campaign

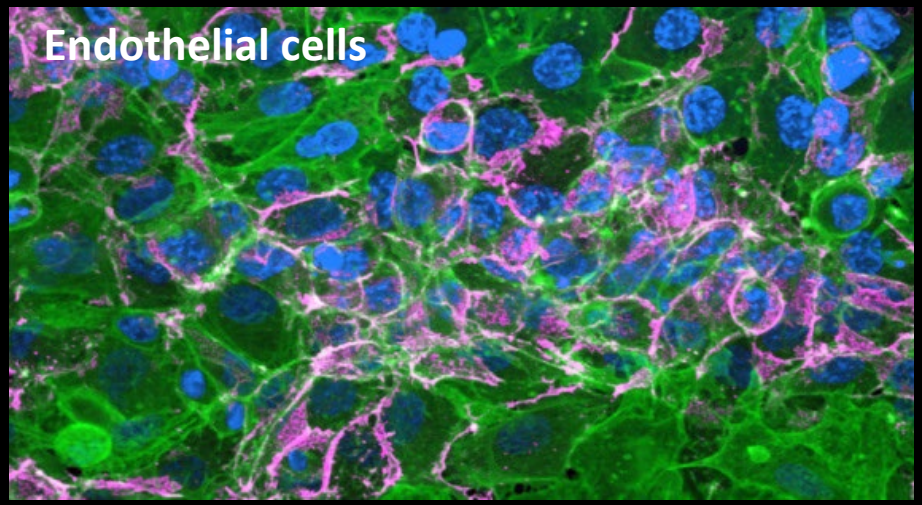




Braakhuis *et al.* Nanoimpact (2023)

Apical side





Jud *et al.* BioResearch (2015)

Tire wear emissions

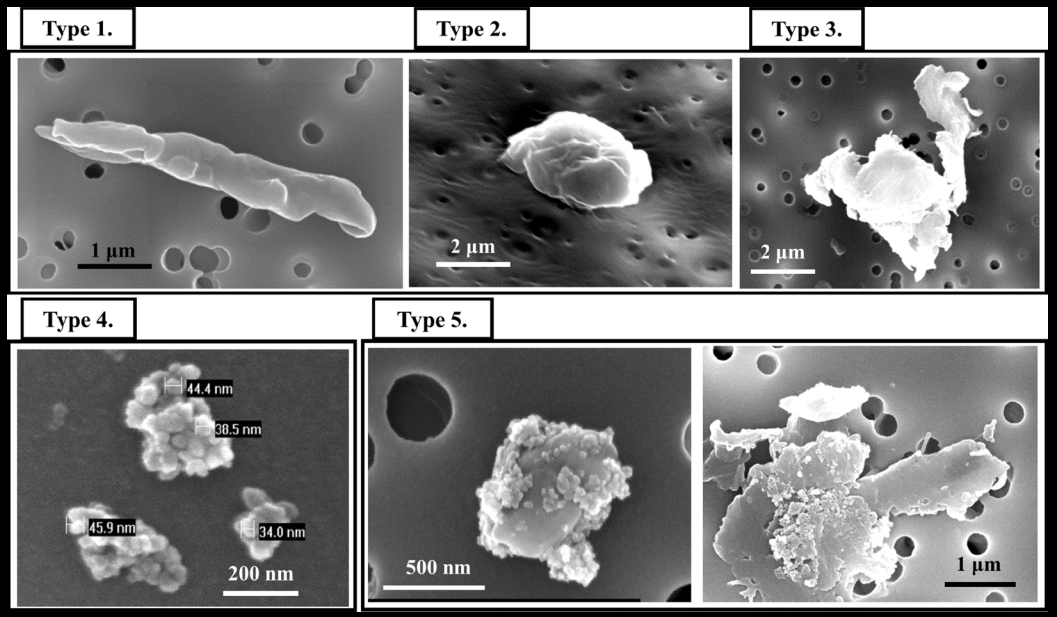
Tire wear emissions are mainly generated through **friction between tires and road surfaces**;
(difficult to separate them from road wear particles and particles are commonly referred to as tire road wear particles (TRWP);

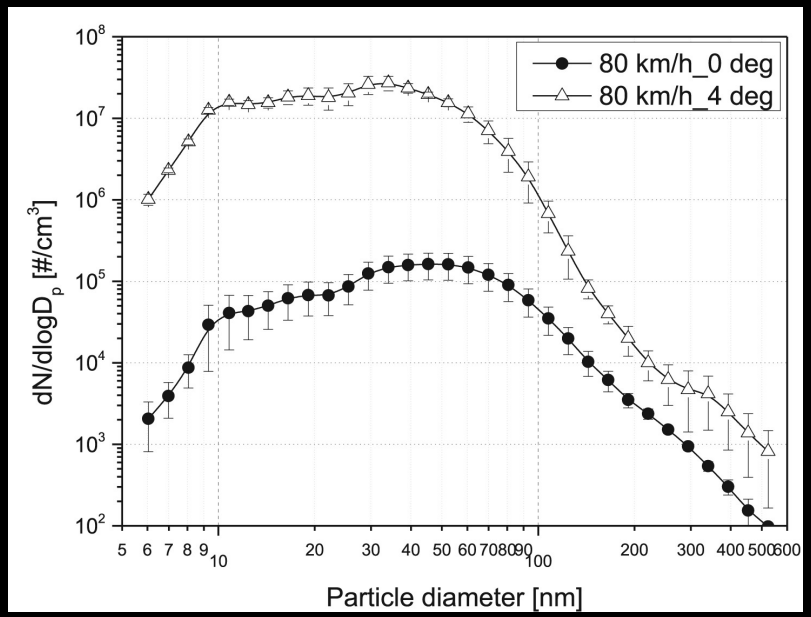
Tires are made of:

- **Rubber components** (Natural and synthetic);
- **Fillers** (Carbon black, silica);
- **Textile and metal reinforcement** (Polyester, Nylon, steel wire);
- **Softener** (oils, fatty acids);
- **Vulcanization agents** (Sulphur, zinc oxide);
- **Chemical additives** (Plasticizer, antioxidants).

Zhang *et al.* Atmospheric Environment (2023)
https://www.tireoutlet.com/blog/2957/what-are-tires-made-of/

Tire wear particles – physicochemical characteristics





Characteristics of tire wear particles generated in a laboratory simulation

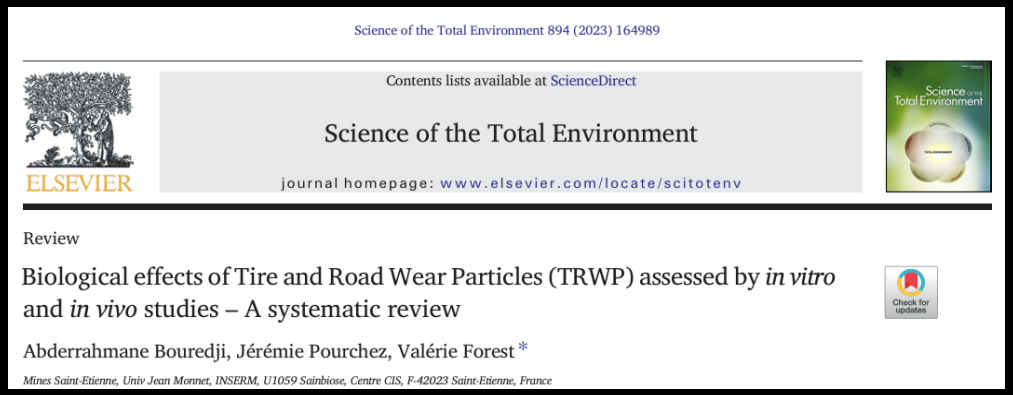
Park *et al.* Journal of Aerosol Science(2018)

1) **Different categories based on their morphology and size**: sausage-like or tube-shaped particles, spherical particles with a mean diameter of about 2.5 µm, micron-sized debris with irregular morphologies, tiny spherical clusters of particles that can form aggregates;

2) Elemental composition consited of **carbon, silica and sulfur**;

3) The **contribution of tire tread wear to airborne PM was low** (but depends on frictional conditions) and large particles settle readily due to gravitational sedimentation.

Tire and road wear emissions – Health implications



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Review

Biological effects of Tire and Road Wear Particles (TRWP) assessed by *in vitro* and *in vivo* studies – A systematic review

Abderrahmane Bouredji, Jérémie Pourchez, Valérie Forest *

Mines Saint-Etienne, Univ Jean Monnet, INSERM, U1059 Sainbiose, Centre CIS, F-42023 Saint-Etienne, France

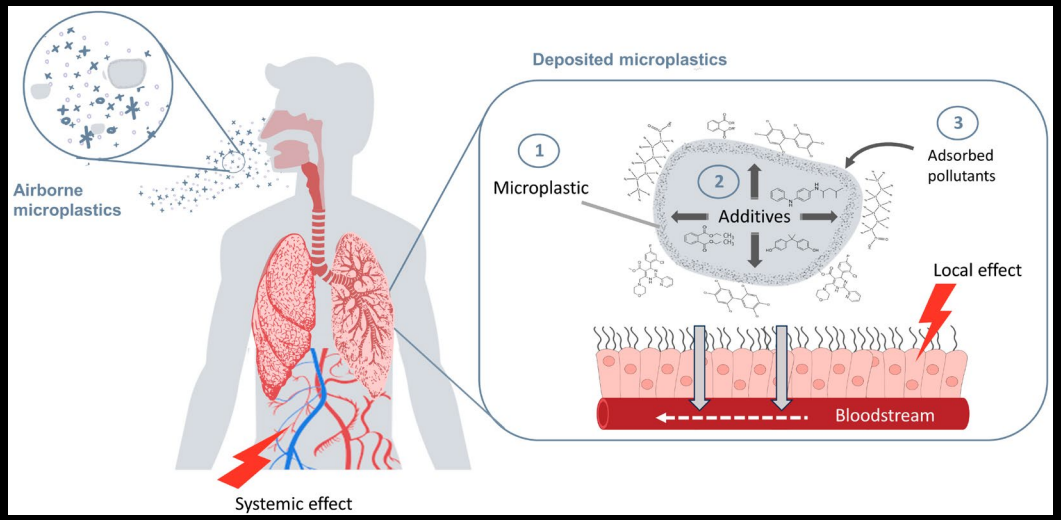
Bibliographic search of two databases (PubMed and Web of Science, March, 2023) focusing on the **toxicological effects of Tire and Road Wear Particles (TRWP) induced *in vitro* and *in vivo***;

Of the 400 papers, 22 were found to be relevant for human health;

Two key findings:

1) The assessment of the tire and road wear particle toxicity in mammalian models is **still limited**;
2) TRWP effects may be mediated mainly by a **pro-inflammatory response** and **oxidative stress**.

Tire and road wear emissions – Health implications



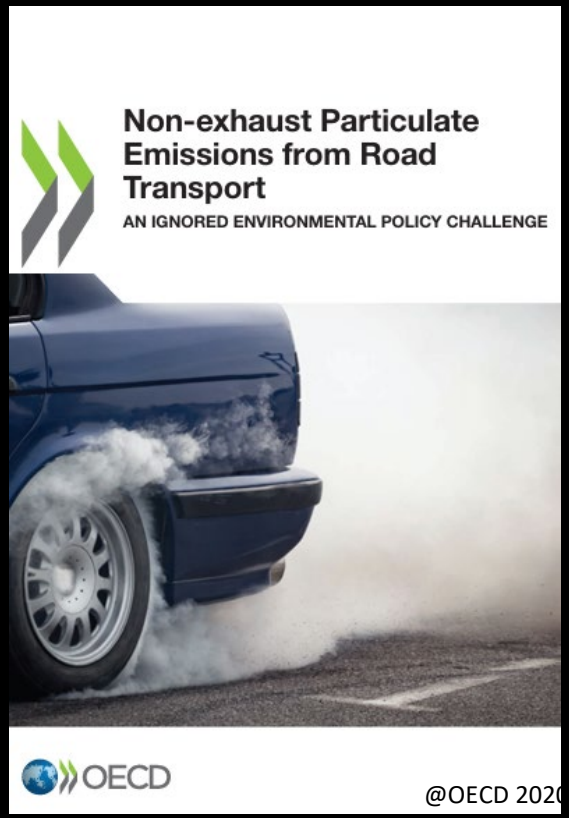
Health concerns due to **particles** themselves, the **additives** present in the plastics, and the **exogenous substances** adsorbed onto them.

Borgotta and Breider, Toxics (2022)

- **0.1% of the mass** on PM filters is **microplastic**;
- **Bio-persistence,** presence of **reactive sites,** and **soluble toxicants** are likely key properties in microplastic toxicity;
- Tire-derived microplastics consist of the **original rubber core with its various additives** (*e.g.,* Al, Ti, Fe, Zn, Cd, Sb, or Pb) but also of **potentially hazardous metals and metalloids contained in the attached brake-abrasion particles** (*e.g.,* Al, Fe, Cu, Sb, or Ba).

Wright and Borm, Frontiers in Public Health (2022)
Sommer *et al.* Aerosol and Air Quality Research (2018)

Knowledge gap and challenges



Measuring and sourcing non-exhaust emissions

- The need for **standardized methodologies** to measure brake, tyre and road wear emissions;
- **Complex mixture:** chemical composition and particle size vary by source and wear / friction condition;

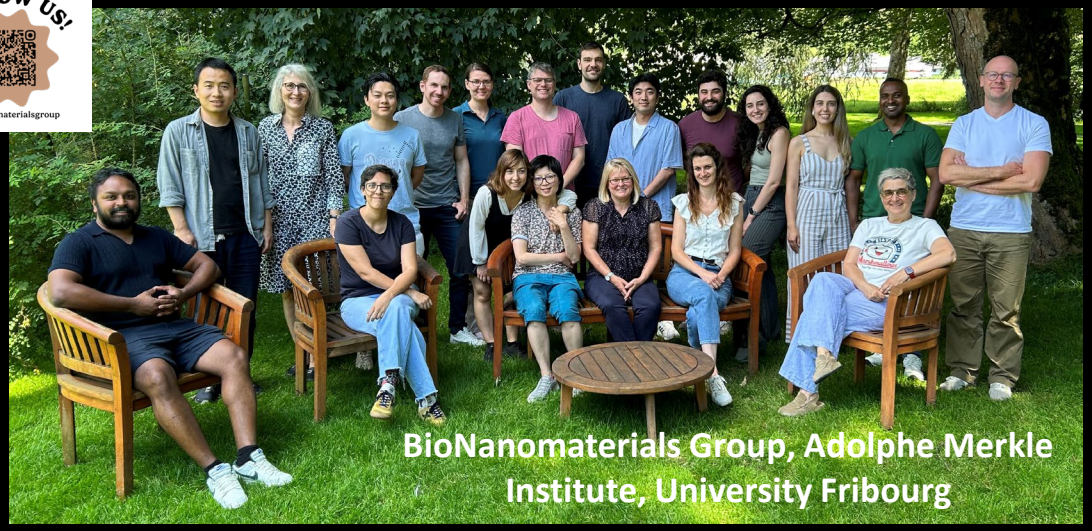
Measuring the damages caused by non-exhaust emissions

- **Non-exhaust emissions** have been associated with a number of **short- and long-term health effects**;
- This evidence is still inconsistent, except for copper, iron (often associated with brake wear) and zinc (often associated with tyre wear), which have been strongly linked to mortality from cardiovascular causes;

Effective mitigation measures to reduce emission factors

- Improved material design;
- Particle capturing systems;
- Reductions in traffic volumes, vehicle speed/velocity.

Acknowledgments



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