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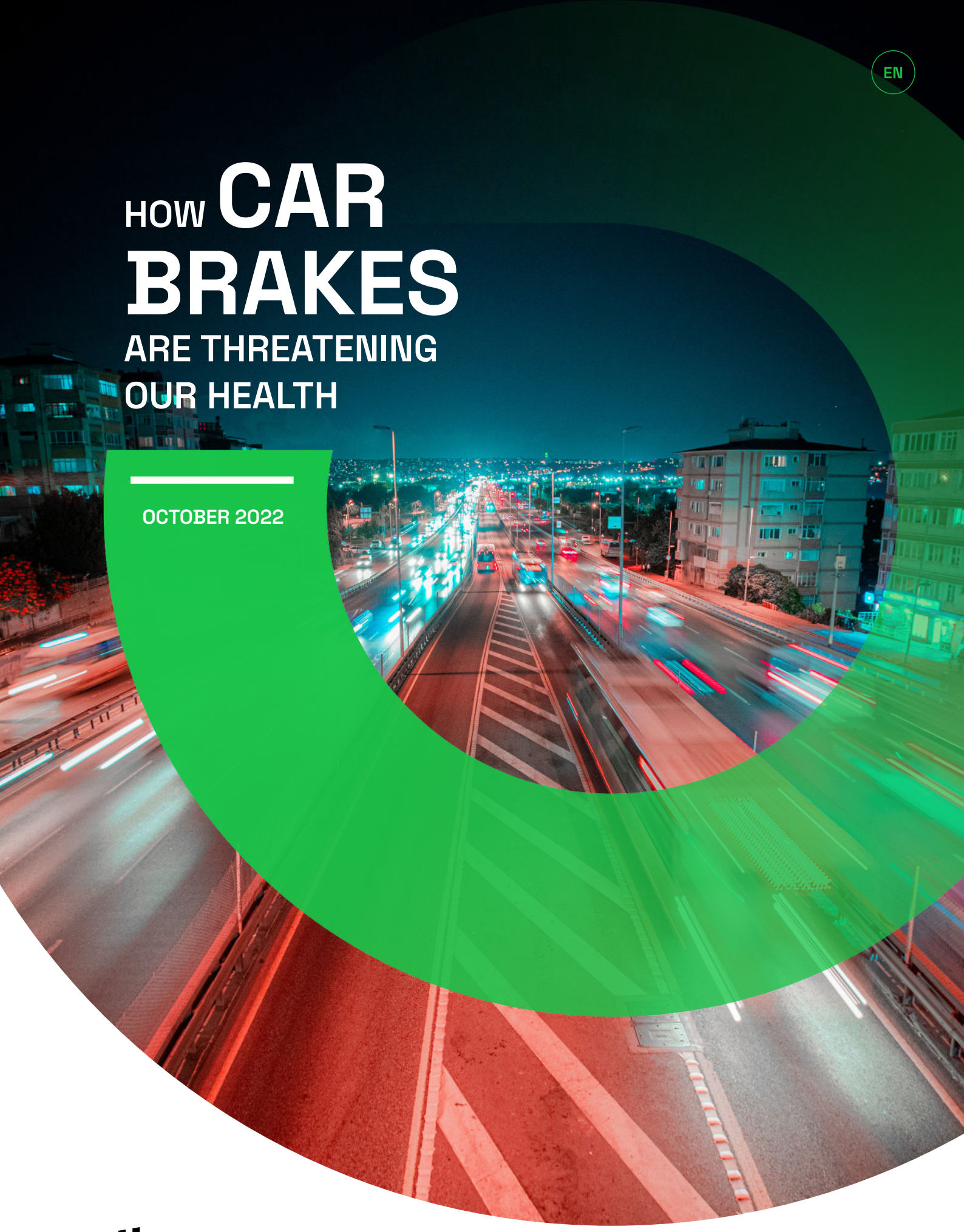
HOW CAR BRAKES ARE THREATENING OUR HEALTH



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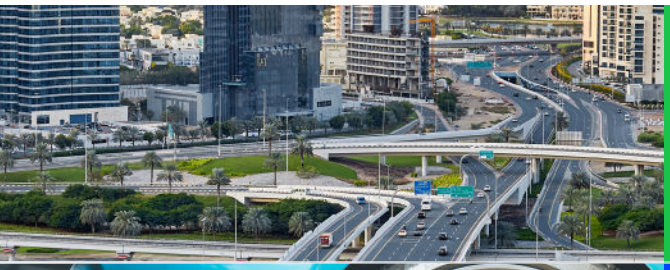
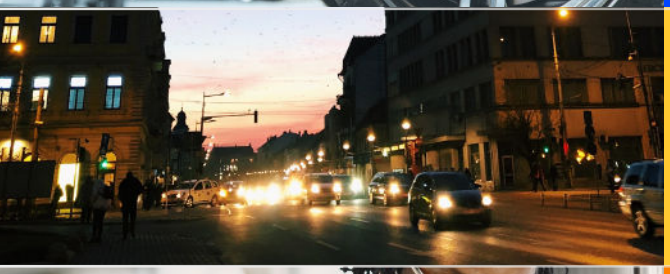
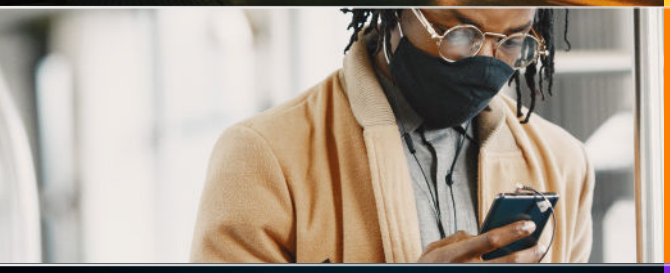
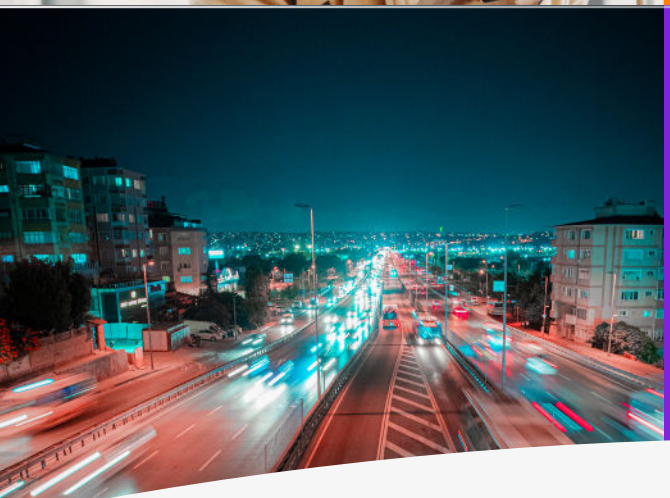








ABOUT

Fine friction particles: what's all the fuss?

**Sunday 10 July 2022, at the Spielberg circuit during the Austrian Formula 1 Grand Prix.
At the end of the race, a journalist asks Sebastian Vettel why he is covered in black dust. The German driver's reply: it's brake dust. And he adds,**

For the first time, a four-time Formula 1 world champion spoke out live on television about the dangers of fine particles generated by friction.
But what exactly are they?
What is brake dust?
What are the risks?

Sebastian VETTEL

To be honest with you, it's something I think manufacturers need to work on because the front axle blows all the brake dust in our faces. It's terrible. Obviously, breathing in carbon dust isn't really healthy. So I hope the FIA[1] will look into this very soon because it's unnecessary and easy to change.

FINE PARTICLES: DANGER AHEAD

It's no secret. We are exposed to fine particles every single day, especially in large cities. Exposure to particulates has an impact on human health, especially in children and the elderly. It can lead to respiratory and cardiovascular diseases. On average, if we could reduce air pollution from fine particles to the level recommended by the World Health Organization, we would gain more than two years of life expectancy in France – and up to ten years in New Delhi! In Europe alone, this pollution causes 307,000 premature deaths each year.
Harvard researchers believe that this figure is largely underestimated, and they attribute nearly 100,000 premature deaths in France per year to outdoor air pollution caused by fossil[6] fuels. Our roads and transport are responsible for at least a quarter of these fine particle emissions.

FINE FRICTION PARTICLES, AN UNKNOWN THREAT

In recent decades, public attention has been focused more on the fine particles in exhaust fumes rather than on those produced by brake and tyre wear. This difference is mainly due to regulatory reasons. The automotive industry has had to adhere to increasingly strict standards to reduce the fine particles generated by engines. As a result, more effective technologies have been developed. Filters are constantly improving, and electric cars should put an end to this type of pollution in a few years. However, those improvements do not apply to fine friction particles, which are yet to be regulated. And above all, the public has little knowledge of them.

RECENT STUDIES, LAWSUITS AND MEDIA COVERAGE: THE TIDE IS TURNING

It took a media trial in London, in December 2020, following the death of Ella Roberta Adoo-Kissi-Debrah – a nine-year-old girl officially recognised as a victim of fine particles from road traffic – for the issue to spark public debate. Over the past ten years there have been more and more scientific studies on the matter, particularly on the other side of the Atlantic, and the harmful nature of particles caused by brake pad abrasion has been revealed. Journalists have picked up on this health concern. Like Hugo Clément, who in July 2020 made videos[7] on the air quality inside the Paris Metro, which is three times more polluted than the air people breathe in the street. He went on to become the mouthpiece for investigations by the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) into the fine particles generated by brakes on Paris underground trains. Given this new public interest, there is now hope that regulations will be put in place to limit fine friction particles, starting with emission standards at European level (Euro 7 / VII) which should come into force soon.

This white paper aims to shed light on fine particles emitted from car braking systems and how harmful they are to our health. Where do they come from? What do they contain? Where are they found in high concentrations? Who is most at risk? What are the dangers to health? We will tackle all of these issues.

PART 1

What are fine friction particles?

Most people still don't know. Here is a guide to the subject so you can understand how they are formed, what they contain, and where they occur in high concentrations.

WHERE DO FINE FRICTION PARTICLES COME FROM?

Fine particles are generated by brake and tyre wear. On brakes, fine particles are emitted in two stages. First, at the beginning of the braking phase: particles measuring 1 to 2 µm are emitted while the pads rub against the discs. Then, with the increase in braking force and the heat it generates, other particles measuring 200 nm form when the brake pad components evaporate and condense. The phenomenon is still being studied to understand its full implications, as Liza Selley, a toxicologist who specialises in air quality research at the University of Cambridge explains:

Liza Selley

It is possible that heat and friction are the cause of brake wear. So when the brakes are used more, they become hotter and produce different types of particles. But we don't know yet whether their composition is different. It could be that as the brakes heat up, one type of metal breaks off first, and as they heat up more, another metal is more likely to wear out.

More than half of the particles generated by this friction (55% to 70%) end up airborne in the atmosphere.[8] The other particles stay on the ground but may be lifted into the air when other vehicles pass.

More than half of the particles generated by this friction (55% to 70%) are swept into our atmosphere.[8]

A HARMFUL COMPOSITION

It is difficult to say exactly what brake dust contains. First because no two brake pads are the same. *"A brake pad manufacturer will offer hundreds of different formulas, including for the same vehicle"*, **confirms Loïc Adamczak, CTO of Tallano Technologie, a company that has developed a solution for capturing fine particles in a suction process when road vehicles or trains apply their brakes. And brake pads are composites.**
"They consist of fifteen or twenty different components. There are metallic, mineral and organic products. And they are held together using a resin, a benzene derivative", **explains Loïc Adamczak. His statement is confirmed by the researcher and air quality specialist, Fulvio Amato.**

"Brake pads include many elements such as abrasives, binders, lubricants, and strengthening elements that use organic compounds, mineral fibres, graphite, and a mixture of metallic components, mainly steel and iron".[9]

But brake dust is not composed of the same elements as brake pads. In high temperatures, the composition of the pads is modified. Bogdan Munteanu, a research engineer at the Institut de Recherches en Ingénierie des Surfaces (IREIS), explains. *"While the chemical composition of brake linings provides useful information as to what these particles contain, the very high pressures and temperatures during contact can trigger chemical changes in the materials. As a result, the chemical composition of the generated airborne particles is very complex and may be different from that of the initial materials."*[10]

The particles analysed confirm the presence mainly of carbon and iron, but also aluminosilicates, zirconium silicate, silicon, chromium, aluminium, barium, calcium, antimony, sulphur and zinc. And unlike the fine particles in exhaust fumes, they do not change their composition on contact with other pollutants in the atmosphere (such as ammonium or potassium sulphates). Laurent Gagnepain, Scientific and Technical Coordinator for light vehicle emissions, non-exhaust particles, cabin air quality and environmental assessment at ADEME (the French Agency for Ecological Transition), notes that *"they are very different from exhaust particles, which are mainly made up of carbon on which volatile organic compounds (VOCs) or polycyclic aromatic hydrocarbons (PAHs) can be adsorbed. Exhaust particles contain very few metallic elements."*

Liza Selley studies this composition in her Cambridge laboratory and points out the marked difference with fine exhaust particles. *"A diesel particle has a carbon core on which metals and endotoxins are grafted. Whereas brake dust is mainly metal. The sample I study most is about 77% iron, with other metallic elements. A 'diesel' particle therefore contains very few metallic components, unlike brake dust in which metal elements are in the majority."*

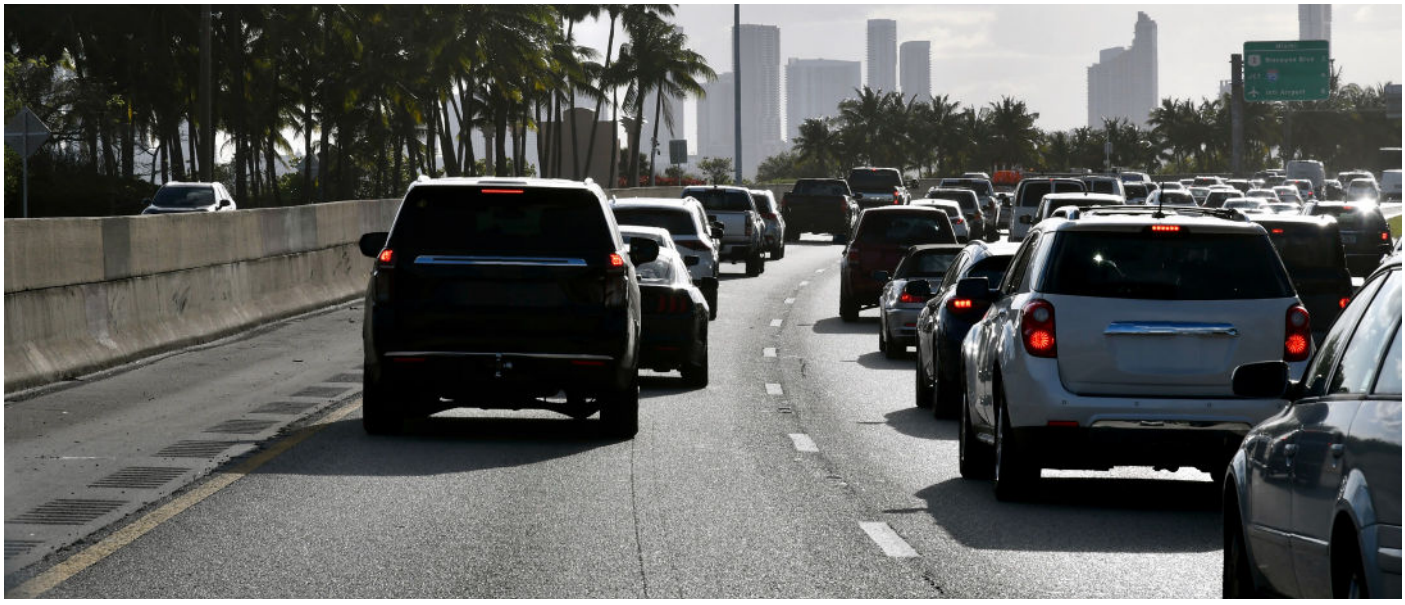
WHERE ARE THEY FOUND?

The composition of these particles is harmful to human health, and they are found in high concentrations near junctions, traffic lights, pedestrian crossings, ring roads and very busy bends. Urban areas are more affected than rural areas. But, in rural spaces, slopes and motorway tolls – where drivers apply their brakes intensively – have high levels of fine particles. A study carried out in Switzerland found that in urban areas, the contribution of brake wear particles to PM10 emissions (i.e., particles with a diameter of less than 10 micrometres) unrelated to exhaust fumes is between 16 and 55% by mass, while significantly lower contributions (~3% by mass) have been measured on motorways where braking is less frequent.[11]

> ***"The most exposed populations are those who live closest to the source, that means high-traffic areas and places where drivers brake (regular traffic congestion, traffic lights, stop signs, etc.)"***
>
> *Laurent Gagnepain*

As a result, *"the most exposed populations are those who live closest to the source, that means high-traffic areas and places where drivers brake (regular traffic congestion, traffic lights, stop signs, etc.)" However, just a few metres from the roadside, the dilution effect is very rapid. Concentrations of brake particles are highest around the traffic and therefore where the passengers are sitting"*, **explains Laurent Gagnepain. Liza Selley also underlines the risks that drivers take.** *"They are on the front line, even more so than cyclists or pedestrians walking along the road. A bus or taxi driver will inhale a lot of these particles".*

Beyond the problem of air pollution, the largest particles and microplastics that are not airborne are drained by runoff water and end up in our rivers and oceans, eventually finding their way into our food chain.



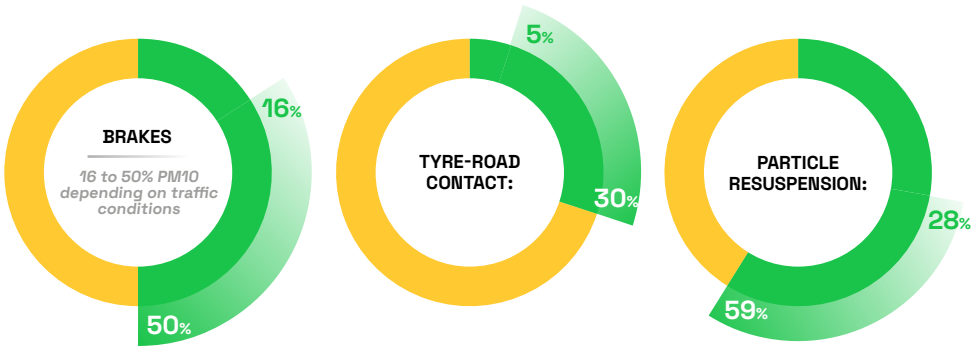
PART 2

Brake wear, a major source of traffic particles

In 2020, an OECD report found that wear on brakes, tyres and road surfaces would soon be the main source of particulate emissions in the atmosphere linked to road traffic, ahead of exhaust fumes.[12] In other words: it's time to change gear and turn our attention to the pollution generated by brake dust.

FINE PARTICLES: THE IMPACT OF BRAKING

Exhaust fumes from engines, especially those running on diesel, have long been seen as road traffic Public Enemy No.1 in terms of generating fine particles. Significant efforts have been made to reduce them, and now brakes – and tyres – are being singled out for criticism. But there's a good reason for that. More than half of the particles generated by road traffic in Europe are not from exhaust fumes. These non-exhaust particles are actually generated by brakes (16 to 50% of PM10 depending on traffic conditions), tyre-road contact (5 to 30%) and particle resuspension (28 to 59%).[13]



SOURCES OF PARTICLES FROM ROAD TRAFFIC, EXCLUDING EXHAUST FUMES

Source: Joint Research Centre, European Union, 2018

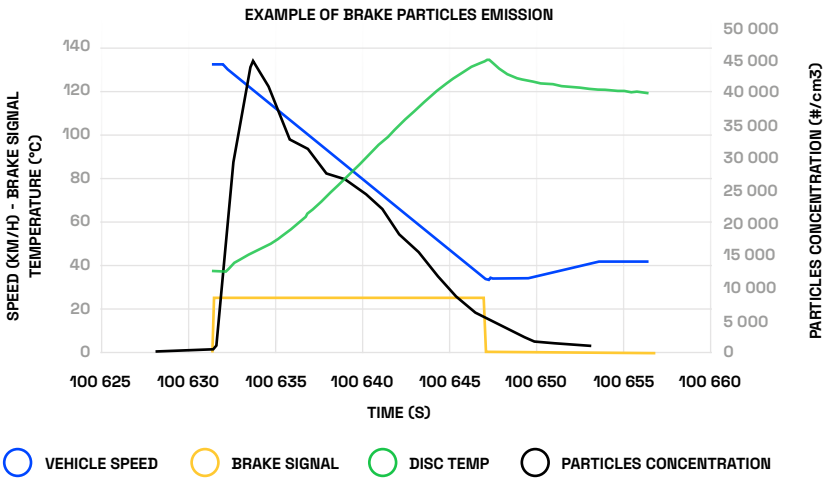
Scientific studies even estimate that the total particle emission when motor vehicle drivers apply their brakes is six times higher than those that are emitted by catalytic converters (30 mg/km against 4.5 mg/km).[14] In Europe, they represent nearly 110,000 tonnes/year, of which 50,000 tonnes are distilled into the air.[15]

AGGRAVATING FACTORS RELATED TO VEHICLE CHARACTERISTICS

Initial studies revealed the complexity of the issue with regards to fine particles emitted by braking systems. As we have seen, the composition of brake particles varies according to a vehicle's discs and brake pads. But many other factors also come into play and influence their size and quantity: condition and maintenance of the vehicle, speed, vehicle weight, driving style, frequency and intensity of braking, and the condition of the road. Laurent Gagnepain underlines that *"the composition of particles emitted during braking varies depending on the type of braking, and specifically on the temperature reached when the brake pads and the disc come into contact. As a result, aggressive drivers heat up their brakes more, so will emit more ultrafine particles of around 10 nm with a different composition, more sulphur especially"*.

The amount of brake dust and the size of the particles generated depends on driving style. Another finding is that the heavier a vehicle, the more fine friction particles it generates. The popularity of SUVs and heavy vehicles therefore serves to aggravate the situation and raises questions for the future.

PARTICLE EMISSIONS DURING BRAKING



This diagram highlights the correlation between activation of the braking system and the particle peak.

Source : Tallano Technologies

WORRYING PROSPECTS FOR THE FUTURE

Laurent Gagnepain

In France, in 1990, non-exhaust PM2.5 emissions (brake, tyre and road wear) accounted for 9% of the total PM2.5 particle emissions from road transport. In 2019, this percentage rose to 45% and it does not seem to be stopping as older cars, which emit more exhaust particles, are being taken off the roads. As such, road vehicles are now producing more non-exhaust particulate emissions than exhaust particles, and vehicles currently being marketed and sold are even bigger culprits.

The ban on internal combustion engine vehicles from 2035 in the European Union should focus our attention even more on the fine particles that are emitted during braking. And this is even more important because electric vehicles also emit these harmful particles. Admittedly, *"they operate in current-generating mode during braking, which slows down the vehicle and the mechanical brakes are therefore under less strain, so emit fewer particles"*, notes Laurent Gagnepain. In fact, 3% of non-exhaust PM10 particles emitted by an electric vehicle come from braking, compared to 25% for a combustion engine vehicle.[16] Even though their regenerative braking system allows them to greatly limit the phenomenon compared to combustion engine vehicles, electric cars still contribute to this air pollution. And given the harmful effects that this metal dust can have on our health, and the current lack of regulations, important questions are raised.

PART 3

A key public health concern

Unsurprisingly, the composition of fine particles emitted during braking presents a long list of risks to our health. These include oxidative stress and respiratory or cardiovascular disorders... Our lives are at the mercy of this pollution. We'll explain why.

Three parameters are used to determine how dangerous a particle is. First of all, its size: the smaller, the more dangerous, because it can penetrate more deeply into the body. Second, its shape: the rounder, the more likely it is to carry other pollutants with it into the body. And finally, its composition. The first toxicological studies on brake particles estimate that those emitted during braking are dangerous to health due to the presence of metals such as copper, iron, barium, zinc, etc.

Christophe Rocca-Serra,
CEO of Tallano Technologies

Brake particles can measure up to 10 nanometers, which is the size of a very small virus. They can easily find their way into the body. And since they are metallic or carbon particles, you can imagine the stress they generate when they get there

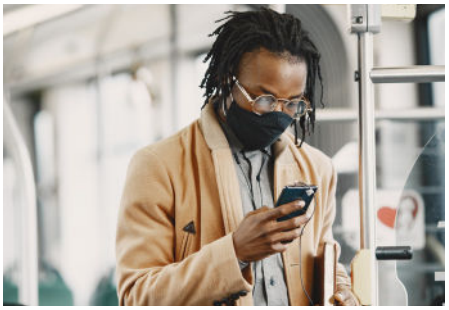
Are particles from braking as dangerous – or even more harmful – to our health, than those from exhaust fumes? They definitely are.
"They are thought to have a higher oxidative potential than particles from exhausts (results on in vitro measurements)", says Laurent Gagnepain. "There needs to be more toxicology studies, especially on the impact on other functions or organs such as the heart, brain and digestive system."

THE SAME RISK FACTOR, MULTIPLE DISEASES

"Generally speaking, exposure to atmospheric pollutants – and fine particles especially – leads to premature ageing."
Liza Selley

Inhaling fine particles means exposing yourself to respiratory and cardiovascular concerns, but also running increased risks of cancer, Alzheimer's, Parkinson's, and so on. *"Generally speaking, exposure to atmospheric pollutants and fine particles especially, leads to premature ageing."*[17] **And** *"the most vulnerable people are those who already suffer from respiratory tract diseases, that includes patients with asthma and chronic obstructive pulmonary disease, but also includes the elderly and the very young",* **says Liza Selley.**

However, it remains scientifically difficult to succeed in isolating the impact of brake dust from other urban particles in vivo. *"We know that urban particles can exacerbate diseases like asthma and chronic obstructive pulmonary disease. We also know that they can impact the growth of children's lungs, and that people suffer from respiratory illnesses and symptoms such as coughs and sore throats when living in heavily polluted areas. But we cannot yet make a firm connection with this and brake dust or any particular component"*, **says Liza Selley.**



EFFECTS OF FINE PARTICLES ON HEALTH

Source : Air and Health Monitoring Program, Institut national de veille sanitaire (Invs), 2014

SYSTEM INFLAMMATION AND OXIDATIVE STRESS:

- Increase in C-reactive protein
- Increase in proinflammatory mediators
- Activation of leucocytes and platelets

BRAIN:

- Increase in cerebral ischaemia
- Cognitive disorders
- Neurodegenerative disorders

LUNGS:

- Inflammation
- Oxidative stress
- Aggravation of chronic obstructive pulmonary disease (COPD) and faster progression of the disease
- Increase in respiratory symptoms
- Weakening of lungs

HEART:

- Modification in cardiac function
- Oxidative stress
- Increase in the frequency of heart-rate disorders
- Issues with cardiac tissue repolarisation
- Increase in myocardial ischaemia

REPRODUCTION AND CHILD DEVELOPMENT ISSUES:

- Fertility
- Miscarriages
- Foetal growth
- Premature birth
- Low birth weight

VASCULAR SYSTEM:

- Atherosclerosis, acceleration in the development of atheromatous plaques and platelet instability
- Endothelial damage
- Vasoconstriction and hypertension

BLOOD:

- Rheological disorders
- Increase in coagulability
- Particles pass through capillary walls
- Reduction in oxygen saturation

SYSTEMIC INFLAMMATION AND OXIDATIVE STRESS

Studies are conclusive: *"the toxicity of nanoparticles is indisputably linked to oxidative stress"*,[18] **which leads to many acute and chronic diseases. This oxidative stress is combined with systemic inflammation, an abnormal and persistent immune system response, which changes how organs, tissues or systems work. Liza Selley and her teams at the University of Cambridge observe,**

> ***"in the lab, we can demonstrate that brake dust may cause inflammation in cells to the same degree as diesel and oxidative stress. Immune cells protect the lungs against germs and infection and regulate inflammation, but we found that when exposed to brake dust, they stop being able to absorb and destroy bacteria".*** [19]

RESPIRATORY DISEASES

Larger particles get stuck in the upper airways and cause "conditions such as pharyngitis and tracheitis, especially in children."[20] However, finer particles penetrate even more deeply into the lungs, bringing the risk of oxidative stress, which triggers significant inflammatory responses.

This generates repeated respiratory disorders such as asthma or bronchitis, as well as chronic obstructive pulmonary diseases and weakened respiratory function. And that vulnerability has consequences. An American study[21] even noted *"that a small increase in long-term PM2.5 exposure leads to a large increase in COVID-19 mortality rate"*.

CARDIOVASCULAR DISEASES

Prolonged exposure to fine particles can also cause cardiovascular and cerebrovascular diseases: arrhythmia, heart attacks, thrombosis, and so on. A study carried out in Central Valley, California[22] highlights that fine particles linked to cars braking are a causal factor in ischaemic heart disease, an insufficiency in oxygen supply to the heart muscle.

CANCERS

17% of lung cancer deaths can be attributed to air pollution[23]

And that's not all. Two per cent of deaths from cancer can be attributed to air pollution,[24] and fine particles especially. That figure rises to 17% when deaths from lung cancer come into the equation.[25] The danger is real, according to the European Environment Agency's report dated 28 June 2022. *"Air pollution (indoor and outdoor) is linked to around 1% of all cancer cases in Europe, and causes around 2% of all cancer deaths. For lung cancers alone, this rises to 9% of deaths."*[26] **Indeed, as early as the 1970s, studies had already demonstrated the correlation between air pollution events by particles and a significant increase in mortality. While a 2002 study investigating the long-term effects of particle exposure concluded that it** *"is an important environmental risk factor for cardiopulmonary mortality and lung cancer."*[27]

NEURODEGENERATIVE DISEASES: ALZHEIMER'S AND PARKINSON'S

The brain is also affected. A report from the French Institute for Public Health Surveillance and a study carried out in 2019 in Mexico City[28] established that the risk of neurodegenerative diseases, in particular Alzheimer's and Parkinson's, is accentuated by exposure to fine particles generated by magnetic friction.

A TIME BOMB

Fine particles have a direct negative impact on our health and can cause deadly diseases with short or long-term effects, either by aggravating already existing pathologies or by weakening vulnerable populations (children, the elderly, etc.). And what we now know to be harmful is most probably just the tip of the iceberg, according to a report presented to the French Senate. *"The full impact of these particles is almost definitely minimised insofar as we do not know how much of it is attributable to what is known as the 'cocktail effect', i.e. the combination of atmospheric pollutants, or several types of pollution in the outdoor air. As this combination is not being considered, it is reasonable to assume that the impact on human health is much greater than what we are currently able to measure."*[29]

This pollution also has an indirect impact on health: the heavy metals released during brake abrasion end up in the soil and water, polluting our ecosystem in the long term. *"The larger particles fall to the ground and are carried away by runoff water. As plants capture them, they return to the food chain. And that's before we even mention the microplastics that are generated when brake pads become worn, eventually entering our rivers and oceans,"* **says Christophe Rocca-Serra, CEO of Tallano Technologies. The time bomb is ticking.**

REGULATIONS AT LAST?

Brake emissions play a major role in air pollution. And yet, today, the Euro 6 standard – in force since 2014 – still does not regulate emissions generated by brakes. There is an urgent need for solutions. In a 2020 report, OECD experts suggested encouraging the public to choose lighter vehicles and enacting strict standards on the composition of brakes, tyres and road surfaces.[30]

EURO 7/VII: HOPE IN EUROPE

The future Euro 7/VII standard, which is currently being developed, will be voted in soon and come into force from 2025. Will that bring the change we need? Yes, because it is set to force car manufacturers to regulate PM2.5 and nanoparticle emissions during braking on conventional and electric cars. Karima Delli, MEP (from EELV, the French green party), welcomes the move. *"The Euro 6 standard did not take certain particles into account, for example the ones from brakes. With the new standard, we can now regulate all the fine particles that have an impact on people's health"*[31]. We can do it with the Euro 7 standard. It's a feasible outcome. In terms of price, the Commission stated that it would cost between 100 and 500 euros per vehicle. Which is actually cheaper than the paint option on a Golf. Now the real question is what will the industrial policy look like for the cars of the future?"[32] The European Union is a worldwide exception, because it has already adopted the Euro 6 standard and is considering the Euro 7/VII standard. *"The forthcoming arrival of a European regulation is coming soon, which gives us reason to be optimistic. We already know that it will exist and that it will be the first time that an emission threshold for brake particles that must not be exceeded. The debate in the European Parliament will aim to set this level precisely,"* says Loïc Adamczak, CTO of Tallano Technologies.

"In terms of price, the Commission stated that it would cost between 100 and 500 euros per vehicle."

INITIATIVES AGAINST FINE PARTICLES IN THE FUTURE

Laurent Gagnepain

We have solutions for the future: the composition of brake discs and pads can be made less emissive. We can integrate brake particle capture systems as close as possible to the source. The Euro 7 regulations will be the first step towards reducing emissions and quantifying them in terms of braking on a test bench with a measurement protocol that has just been established (WLTC-Brake)",

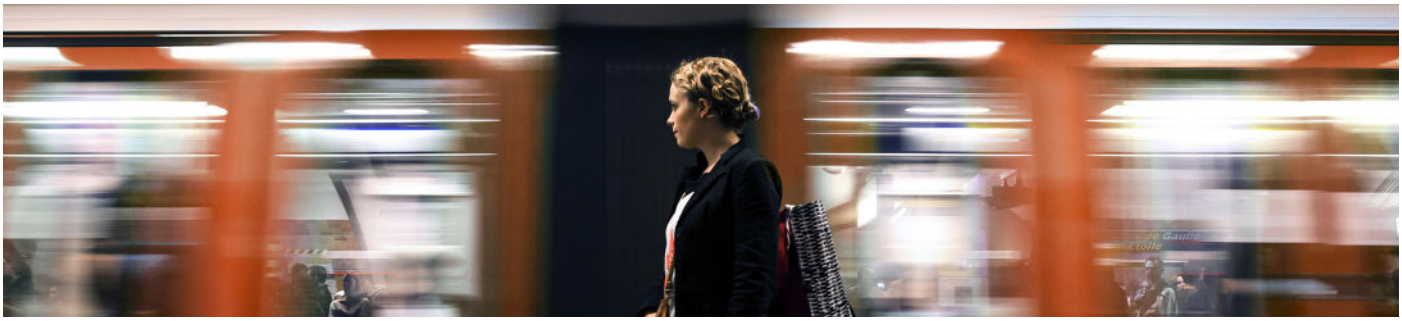
Some systems are already on the market and they could make it possible to capture polluting fine particles before they arrive in the atmosphere (such as the solution proposed by Tallano Technologie presented below). It is a way of taking stock of the challenges and reducing the air pollution that claims millions of victims each year. Those people are first and foremost the less fortunate, as Christophe Rocca-Serra points out. *"In general, people who live along busy roads or ring roads are not the most financially comfortable."*

Air pollution is a form of social injustice. It's an undeniable public health issue. A disaster for health. Remedies already exist to put an end to this danger. It is high time that regulations were brought in, that car manufacturers paid attention to the issue so that people will finally be able to breathe without worrying. And at Tallano, we are more than ready to support this essential movement to improve air quality on our planet. Let's all dare to dream that one day we can say, like Gilbert Cesbron, *"I knew a time when most pollution came from people shaking their rugs out the window."*

Christophe Rocca-Serra,
CEO of Tallano Technologies

We believe that active suction filtration is the right solution." Tallano Technologies has therefore designed a particle extraction system known as "TAMIC" that is fixed directly to the brakes of road or rail vehicles. The system makes it possible to reduce fine brake particles by more than 90%. Tested in the laboratory and proven under real-life conditions, this universal device has proven to be effective and can be adapted to any type of vehicle.

FIND OUT MORE



SOURCES

[1] Fédération internationale de l'automobile

[2] Source: https://www.airparif.asso.fr/les-particules-fines

DISCOVER

[3] The WHO recommends that the density of PM2.5 in the air should not exceed five micrograms per cubic metre on average over one year.

[4] Source : https://aqli.epic.uchicago.edu/news/air-pollution-cuts-life-expectancy-by-more-than-two-years-study-says/

DISCOVER

[5] Source : Report by the European Environment Agency, 2019

[6] Source : Harvard University study, 2021 : https://www.lemonde.fr/planete/article/2021/02/09/un-deces-sur-cinq-dans-le-monde-serait-lie-a-la-pollution-de-l-air_6069304_3244.html

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[7] Video by SurLeFront on air pollution in the metro: https://www.facebook.com/francetvslash/videos/2469384293352215/

DISCOVER

[8] Source : https://tel.archives-ouvertes.fr/tel-01278518/document

DISCOVER

[9] Source : https://www.sciencesetavenir.fr/nature-environnement/pollution/freins-et-roues-principales-sources-de-particules-fines-dans-les-villes_149844

DISCOVER

[10] Source : Bogdan Munteanu. Actions de particules d'usure aéroportées sur les propriétés mécaniques et physicochimiques des "films" de surfactant pulmonaire : Conséquences sur la conception de particules tribo-bio-compatibles. INSA de Lyon, 2015. https://tel.archives-ouvertes.fr/tel-01278518/document

DISCOVER

[11] Source : Bukowiecki et al. 2009a, https://www.sciencedirect.com/science/article/abs/pii/S1352231010002657

DISCOVER

[12] Source : OCDE, Non-exhaust Particulate Emissions from Road Transport. An Ignored Environmental Policy Challenge, 2020

[13] Source: Joint Research Centre, European Union, 2018

[14] https://www.latribuneauto.com/reportages/environnement/11488-les-freins-sont-le-premier-emetteur-de-particules-fines-sur-la-route#:~:text=La%20norme%20Euro%206%2C%20en,des%20%C3%A9missions%20dues%20au%20freinage

DISCOVER

[15] Source : INSA Lyon 2011 https://www.latribuneauto.com/reportages/environnement/11488-les-freins-sont-le-premier-emetteur-de-particules-fines-sur-la-route#

DISCOVER

[16] ADEME expert report – Émissions des véhicules routiers, les particules hors échappement https://librairie.ademe.fr/air-et-bruit/5384-emissions-des-vehicules-routiers-les-particules-hors-echappement.html

DISCOVER

[17] Report No. 610 (2014-2015) by Leila Aïchi, made on behalf of the EC on the economic and financial cost of air pollution, filed on 8 July, 2015, Pollution de l'air : le coût de l'inaction http://www.senat.fr/rap/r14-610-1/r14-610-1.html

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[18] Source : Yue-Wern Huang , Chi-heng Wu et Robert S. Aronstam, Toxicity of Transition Metal Oxide Nanoparticles: Recent Insights from in vitro Studies, Missouri University of Science and Technology, 2010.

[19] Source : https://inews.co.uk/news/environment/brake-dust-major-source-air-pollution-study-finds-383233

DISCOVER

[20] Source : http://www.senat.fr/rap/r14-610-1/r14-610-11.pdf

DISCOVER

[21] Source : Wu, X., Nethery, R. C., Sabath, M. B., Braun, D. and Dominici, F., 2020. Air pollution and COVID-19 mortality in the United States: Strengths and limitations of an ecological regression analysis. Science advances

[22] Thomas A. Cahill , David E. Barnes , Nicholas J. Spada , Jonathan A. Lawton & Thomas M. Cahill (2011): Very Fine and Ultrafine Metals and Ischemic Heart Disease in the California Central Valley 1: 2003–2007, Aerosol Science and Technology.

[23] Source : Prüss-Üstün et al., 2016 ; AEE, 2020c https://www.eea.europa.eu/publications/environmental-burden-of-cancer/air-pollution

DISCOVER

[24] Source : IHME, 2020

[25] Source : Prüss-Üstün et al., 2016 ; AEE, 2020c

[26] European Environment Agency, Report Exposure to pollution causes 10% of all cancer cases in Europe, 28 June 2022

[27] Source: Arden Pope III ; Richard T. Burnett, Michael J. Thun, Eugenia E. Calle, Daniel Krewski, Kazuhiko Ito, George D. Thurston, Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution, Jama, 2002

[28] Calderón-Garcidueñas, González-Maciel, Mukherjee, Reynoso-Robles, Pérez-Guillé, Gayosso-Chávez, Torres-Jardón, Cross, Ahmed, Karloukovski, Maher, Combustion- and Friction-Derived Magnetic Air Pollution Nanoparticles in Human Hearts, 2019. https://doi.org/10.1016/j.envres.2019.108567

DISCOVER

[29] Source : http://www.senat.fr/rap/r14-610-1/r14-610-11.pdf

DISCOVER

[30] Source : https://www.oecd.org/fr/environnement/non-exhaust-particulate-emissions-from-road-transport-4a4dc6ca-en.htm

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[31] Source : https://www.publicsenat.fr/article/politique/norme-antipollution-euro-7-la-voiture-bientot-un-produit-de-luxe-190974

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[32] Source : https://www.publicsenat.fr/article/politique/norme-antipollution-euro-7-la-voiture-bientot-un-produit-de-luxe-190974

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This white paper was written by Tallano Technologies
Editorial direction: *Baptiste Roux Dit Riche*
Writing: *Stéphanie Prouvost*
Translation: Ruth Simpson (Anglais), Cécile Kleszcz (Allemand)
Graphic designer:
Corentin Daudin - YelloDesign

HOW CAR BRAKES ARE
THREATENING OUR HEALTH

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