Imperial College London

Tyre wear particles are toxic for us and the environment

IMPERIAL ZERO POLLUTION

Report by:
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Particles from car tyres pollute the environment and the air we breathe, whilst the long-term effects on our health and the ecosystem are unknown. These tyre wear particles are especially damaging due to the toxic chemicals that they are made from, which leach out of the particles into our rivers and oceans. These chemicals have a devastating impact on wildlife, and they accumulate into the food chain where they will ultimately pose a significant risk. Policy makers and scientists should set out an ambitious research agenda to investigate the problem, from the basics of how and why tyres wear and how this affects people and nature, to potential solutions, including particle capture technologies, new advanced materials and innovative business models, thus enabling a limit to the harmful impact of tyre wear particles on our health, water and air.

Contents

What happens to tyres when we drive?

Drivers are all too familiar with the annoyance of a flat tyre and we are told to frequently check our tyres for signs of wear and tear. In London alone, there are 2.6 million registered vehicles emitting approximately 9 million kg of tyre wear particles per year, releasing a range of toxins into the environment (Kole et al., 2017). Have you ever wondered what happens to the material lost as our tyre treads get worn down?

Automotive tyres are subjected to extreme loading conditions over many years, as they transport us around the country. The contact interaction between the tyre and the road is governed by factors such as vehicle weight, tyre material, driving style and road conditions and the type of wear particle generated depends on a combination of these factors. For example, tyres in contact with smooth roads will produce a greater amount of micro-wear particles and tyres driven on rough surfaces will result in larger abraded particles (Manas et al., 2009).

Along with microplastics, tyre wear particles contribute significantly to the amount of synthetic (or polymeric) particulate pollution being released into our environment. Large particles are transported by road runoff due to rainwater, resulting in the leaching of toxic chemicals and damaging the environment, while smaller particles, of the micro and nanoscale, may be small enough to become airborne and breathed in (Wagner et al., 2018). Scientists are investigating whether these micro and nano tyre wear particles can enter our bloodstream and/or cross cellular barriers, and what damage these particles and their constituent chemicals have on our health (Joshi et al., 2022).

Limiting vehicle weight and ensuring tyre materials have passed wear resistance regulations will help reduce generation of tyre wear particles.

What do tyre particles look like?

Particulate matter (PM) from vehicle emissions can either be characterised in terms of the sheer number of particles emitted, known as the particle number, or in terms of the mass of particles. Tyre wear particles are classified as non-exhaust emissions and are distinct from other particles emitted by road traffic vehicles due to their composition and the wide range of particle sizes and shapes (Raza et al., 2018).

Six million tonnes of tyre wear waste are produced globally and can range from visible pieces of tyre rubber to micro- (10^{-6} m) or even nano-particles (10^{-9} m) (Kole et al., 2017). Of these, particles are classified by aerodynamic diameter; $PM_{0.1}$ indicates particles smaller than 100 nm, $PM_{2.5}$ refers to particles smaller than 2.5 µm and PM_{10} represents those smaller than 10 µm. Studies have shown that the shape of the tyre wear particles depends on the underlying wear mechanism, they can be spherical or elongated and this influences their ability to interact with cells in our bodies (Chang et al., 2020; Knight et al., 2020; Park et al., 2018) (Figure 1). Scientists have found that the smaller nano-sized particles known as 'ultrafine particles' (Kumar et al., 2021) are abundantly released, which is worrying as they are small enough to interact with our cells, and more importantly, due to the toxicity of the chemicals used in tyre production, potentially cause harm to our body.

When talking about PM emissions, large pieces of tyre rubber will contribute the majority of the total particulate mass. However, in terms of the number of tyre wear particles, $PM_{2.5}$ and $PM_{0.1}$ particles are the most abundant. To be able to study the effects of tyre wear particles, it is crucial to better understand the size distribution of the generated particles (Baensch-Baltruschat et al., 2021; Baensch-Baltruschat et al., 2020). In one study, tyre wear particles up to 350 µm were found, exhibiting a bimodal particle size distribution with peaks around 5 µm and 25 µm. (Kreider et al., 2010). The latter particles are in the same size range as human cells, but the interaction between tyre wear particles and our cells has not been well studied, leaving us unsure what is happening inside our bodies. Due to the agglomeration phenomena of ultrafine particles into micro-sized particles, we may be significantly underestimating the abundance of ultrafine particles (Park et al., 2018).

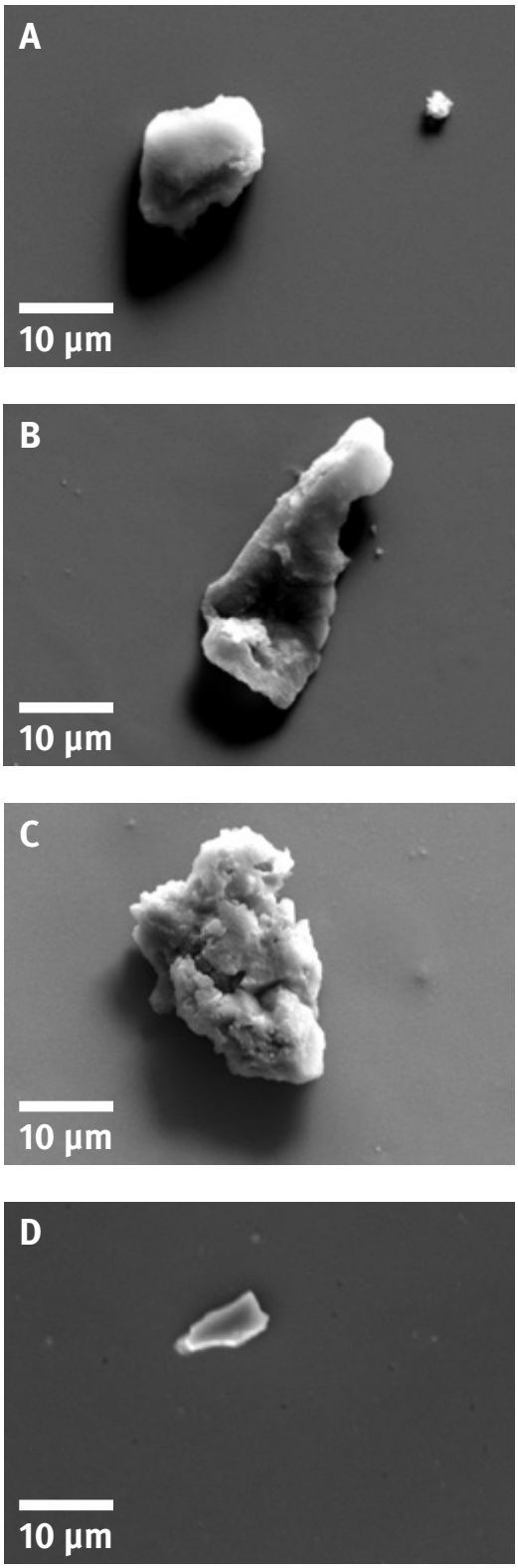

Figure 1. Different shapes and sizes of tyre wear particles imaged using scanning electron microscopy showing, relative to each other: (A) a PM_{10} spherical tyre wear particle, (B) a smooth, long and large tyre wear particle, (C) a large uneven tyre wear particle mass and (D) a PM_{10} tyre wear sharp fragment resembling a crystal structure similar to silica. Scale bar of 10 µm = 0.01 mm (Mao, 2021)

Where do these particles end up?

Tyre wear particles are generated on roads, and therefore most particles are formed in urban areas and the motorways that connect them. Scientists created models describing the behaviour of tyre wear particles for German highways, estimating that 45% of the total particle mass is accumulated near the road (Wagner et al., 2018), whilst the remaining 55% ends up in the environment through various mechanisms. Of these particles that enter the environment, 82% are carried by water and the remaining 18% of the particles are expelled into the air (Raza et al., 2018) (Figure 2).

It is estimated that if all surface water runoff can be put through filters, such as those employed in the treatment of stormwater, half of the particles can be filtered out and therefore be prevented from entering the environment (Aryal et al., 2010; Boogaard et al., 2017; Wagner et al., 2018). This means that existing technological interventions and environmental policies can help to control our ecological footprint to some extent. However, there are huge gaps in our knowledge, understanding, and ability to forecast the impacts of tyre wear pollution, making further research and development of new innovations and solutions vital so we can further limit pollution from tyre wear particles.

Sampling and assessment of roadside tyre wear particles will provide insight into the particle size distribution, feeding into research aimed at establishing the effects of tyre particles on the environment and on human health.

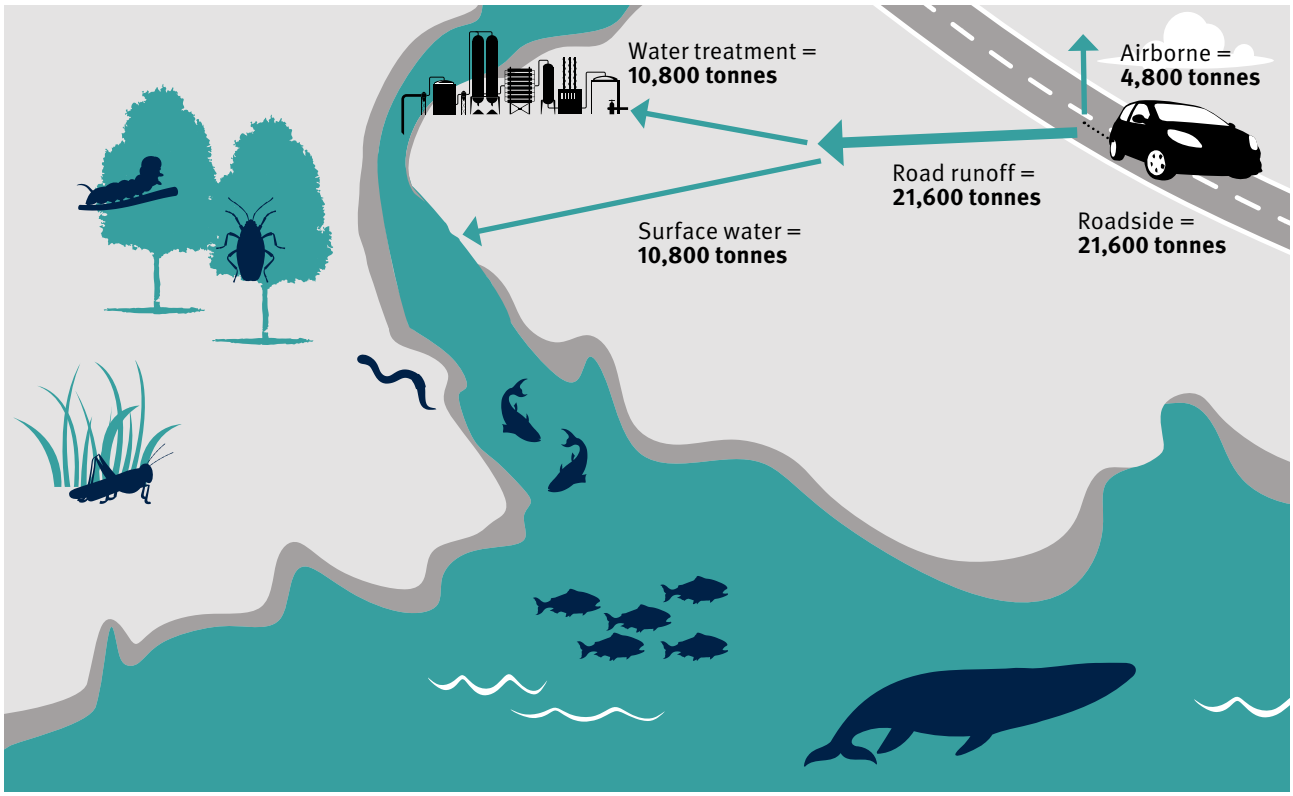

Figure 2.
Estimated final sites for TWP in the environment illustrated with model values from Wagner et al. (Wagner et al., 2018)

What do tyre particles do to humans?

The impact of tyre wear particles on human health is an increasing cause for concern. During the manufacturing process, chemicals are combined to form high-endurance rubber, which is then cast into a tyre form. Ingredients include harmful substances such as polyaromatic hydrocarbons (PAHs), benzothiazoles, isoprene, as well as heavy metals such as zinc and lead (Halsband et al., 2020). Toxicology studies into ambient particulate matter, which includes TWP, report that these particles contribute to negative cardiopulmonary, developmental, reproductive and cancer outcomes (Baensch-Baltruschat et al., 2020).

Tyre Leachate Constituents	Public Health Effects and Symptoms
Polyaromatic hydrocarbons (PAHs)	*Acute health risks:* skin and eye irritation, vomiting. *Chronic health risks:* cataracts, kidney and liver damage, respiratory problems, decreased immune function (Patel et al., 2020)
Benzothiazoles (BZTs)	*Acute health risks*: Skin irritant, respiratory problems. *Chronic health risks:* endocrine disruption, carcinogenic and genotoxic (Liao et al., 2018)
Isoprene	*Chronic health risks:* Carcinogenic, mutagenic, reproduction cell abnormalities (Melnick, 1994)
Heavy metals (zinc and lead)	*Acute health risks:* abdominal pain, renal dysfunction, fatigue, sleeplessness, arthritis, hallucinations, and vertigo. *Chronic health risks:* neurological damage, birth defects, psychosis, paralysis, muscular weakness, brain damage, kidney damage, may even cause death (Jaishankar et al., 2014).

By simply walking on the pavement we are exposed to a range of particles emitted by vehicles because micro and nanoparticles are small enough to become airborne. The distance over which they disperse depends on their size, which puts city-dwellers at significant risk of exposure. Models show that ultrafine, nanosized particles can travel hundreds of metres (Kole et al., 2017). Such pollution may particularly affect members of the population who have pre-existing conditions such as asthma and chronic obstructive pulmonary disease (COPD), as it is well documented that pollution exacerbates these conditions (Kelly & Fussell, 2015). Therefore, it is essential that a risk assessment is carried out to determine the No-Observable-Adverse-Effect-Concentration (NOAEC) of inhaled tyre wear particles. Since the inhalation of tyre wear particles is just one route of exposure, more stringent measurements of leachates at water treatment facilities mandated by governmental policy will significantly improve our knowledge of its dispersion to the wider environment, which will help policy makers set limits and targets to safeguard our water supply.

The potential ingestion of tyre wear particles is a serious issue that is often overlooked and heavily under-investigated. Tyre wear particles and their compounds could accumulate in the food chain, following similar pathways to microplastic, and there is a need to investigate the concentrations of toxic particles in, for example, the meat and fish we consume.

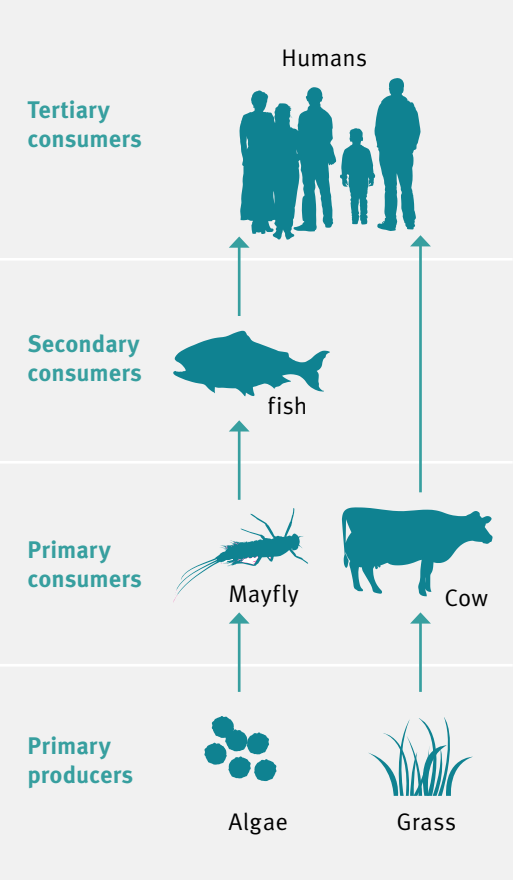

Figure 3. Accumulation of toxic tyre leachates concentrates higher up the food chain.

What do tyre particles do to the environment?

The effect of tyre wear particles on the environment and aquatic species has been more broadly studied through in vivo models on algae, bacteria and other simple aquatic organisms that make up the bottom level of the food chain (Baensch-Baltruschat et al., 2020). Rubber particles and the chemicals that leach out of tyre wear particles can cause increased mortality of aquatic species such as trout, and frogs (Halle et al., 2019). Scientists at Imperial College London working on tyre particles and their effects are now calling for a more concerted research effort to establish standardised testing protocols that would allow us to critically determine the toxicity levels of tyre wear particles and leachate chemicals in the environment. Furthermore, there has been little investigation of the long-term effects of tyre wear particles in the environment. This includes degradation mechanisms, either by light, bacteria, or oxidation (Baensch-Baltruschat et al., 2020). Although the polymers that form the backbone of natural and synthetic rubbers are biodegradable, the additives in the tyre material formulation hinder its degradability (Capolupo et al., 2020). Whilst this reduced degradation is beneficial during the useful life of a tyre, it is a short-term solution that does not consider the tonnes of tyre wear particles that end up in river sediment, much less the mountain of waste car tyres that do not degrade and are extremely difficult to recycle.

Stricter limits on leachate concentration measured in the environment should be mandated to reduce harm on terrestrial and aquatic species.

Why is it important to act now?

As a society, we understand the challenges of pollution and have made major technological steps to reduce automotive emissions. However, these steps have a strong focus on tailpipe emissions, whilst non-tailpipe emissions such as tyre particles have mostly been ignored. Tyre wear pollution is a significant source of microplastics in river ecosystems (Baensch-Baltruschat et al., 2020) and oceans (Parker-Jurd et al., 2019) and new evidence suggests that tyre wear pollution in urban areas could pose up to four orders of magnitude higher environmental risk than other microplastics found in European rivers (Tamis et al., 2021). In order to forecast the impacts of tyre wear pollution we need to understand and quantify the interplay between tyre wear particle generation and transport processes that lead to pollution in rivers and impacts on biodiversity and health. Policy makers must ensure that there is an incentive to also reduce non-exhaust emissions, such as by developing technologies and approaches to enable local access control and ride-sharing schemes to limit the total number of vehicles (Katsikouli et al., 2020). It is strongly suggested that an equal investment as was devoted to zero tailpipe emission technology should be given to the development of technologies that will reduce the amount of tyre wear particles being released into the environment.

Reduction of tyre wear particles is as important as reducing exhaust emissions. This requires a combination of research and regulatory efforts.

Research aimed at solving the tyre particle problem

Preventing harmful effects due to tyre wear particles will require the combined effort from researchers, industry, and policymakers. Researchers from the four Faculties at Imperial College London are jointly taking a multi-scale approach to solving this issue, with research ranging from the microscopic contact between road and tyre to solutions at the vehicle level and the aggregate effects of a fleet of vehicles in a major city such as London. Some examples of studies that are currently being performed within this joint initiative include:

- The mechanics of rubber wear and how tyre particles are generated
- Monitoring and modelling of generation, transport and leaching of chemicals from tyre particles into water and the environment
- Advanced real-time monitoring of airborne particulate matter
- Measuring tyre material in environmental samples
- Human cells and human body response to tyre wear particles
- On-board capture and collection of particulates
- Vehicle control and modulation to reduce tyre particle emissions
- Tyre business and ownership models to promote continued innovation
- City-wide access control and route optimisation to mitigate local peak-emissions

These studies are all performed in conjunction with and within the framework of the Imperial College London Transition to Zero Pollution initiative, aiming to deliver technological innovation and providing advice to governments on future policies.

Acknowledgements

The research resulting in this white paper was funded by the Institute for Molecular Science and Engineering (IMSE) and the Imperial College London Transition to Zero Pollution initiative.

Suggested citation:
Tan Z, Berry A, Charalambides M, Mijic A, Pearse W, Porter A, Ryan MP, Shorten RN, Stettler MEJ, Tetley TD, Wright S, Masen MA. Tyre wear particles are toxic for us and the environment. Imperial College London (2023). doi: https://doi.org/10.25561/101707

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About the Transition to Zero Pollution initiative

Transition to Zero Pollution began in 2020 as a flagship initiative of Imperial College London's Academic Strategy, capturing Imperial's vision to transform the way we think about pollution by bringing together ideas around resource management, health and environmental impacts, socio-economic and human behaviour in a 'whole system' approach. This initiative is the research, education and innovation programme of sustainability at Imperial under **Imperial Zero Pollution**. With a vision to realise a sustainable zero pollution future, at Imperial we embed a consistent and credible commitment to sustainability into all our work – from our world-leading research and education to how we run our campuses and interact with industry.

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