ROYAL SOCIETY OF CHEMISTRY

Microplastics

While plastics are extremely useful, a decades-long increase in the amount we use and throw away has led to extensive contamination of the environment. Well-known examples include post-consumer waste littered or left in landfills, and plastic contamination in the oceans.

Moving towards better recycling for plastics not only helps deal with the environmental problems that come from waste, but allows us to remove our reliance on fossil resources as the raw materials for plastic production.

Along with other aspects of the 'plastics problem', the potentially threatening presence of micro- and nanoplastics have come to public attention more recently.

Microplastics have been found almost everywhere researchers have looked for them and are ubiquitous in the marine environment – they are present at the sea surface, shorelines, and seabed. They are also found on land and in the air we breathe.

Plastic size matters

The size of a piece of plastic is an important factor in determining its impact on the environment, along with its location, the surrounding ecosystem, and the type of polymer.

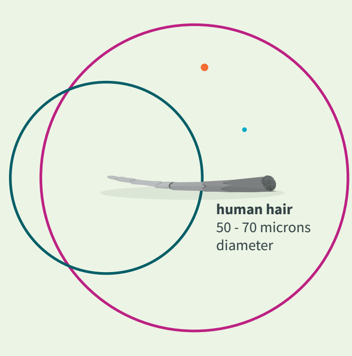
Commonly accepted size ranges are[1]:

Macroplastics: larger than 2.5 centimetres (25 millimetres) across

Mesoplastics: 2.5 centimetres down to 5 millimetres

Microplastics: 5 millimetres down to 1 micrometre (0.001 millimetre, also known as a micron)

Nanoplastics: smaller than 1 micrometre (<0.001 millimetre)



Primary microplastics are those *directly released* into the environment as small plastic particles. This could be via a voluntary addition to products such as in sun creams and other personal care products. They can also originate from the abrasion of large plastic objects during manufacturing, use or maintenance, such as the erosion of vehicle tyres when driving or the abrasion of synthetic textiles during washing.[2]

Secondary microplastics originate mostly from the *degradation [of large plastics]* into smaller plastic fragments once exposed to the environment.[2] Degradation can be the result of biodegradation, photodegradation, and other physical or chemical processes.

At present, the relative importance of primary versus secondary microplastics contamination is difficult to quantify reliably; however, it is likely that overall secondary sources make a greater contribution to the global microplastics challenge.

Impacts of microplastics and nanoplastics

The impact of microplastics in the environment depends on their location, concentration, and the surrounding ecosystem.

Due to their size, widespread occurrence and persistence in the environment, there is concern about the impact of microplastics on organisms including plant life, and ultimately humans. Exposure can occur via ingestion, inhalation, and potentially physical contact depending on the size of the particle.

The bioaccumulation potential of microplastics is high because of their size. Once ingested by smaller organisms such as plankton there is potential for build up and transfer of microplastics within food chains. Research shows that microplastics accumulate on the deep-sea floor, in the same place as diverse and dense communities of marine life.[3]

At present, drinking water, table salt and other daily used food items have been shown to be contaminated with microplastics.[4]

The concerns around microplastics can be split into three broad categories

1 PHYSICAL IMPACTS

Like other particles of a similar size, microplastics can cause physical effects. The risk from acute exposure in occupational settings, eg the inhalation of plastic dust as a result of manufacturing, has previously been documented.

Laboratory studies have shown that the presence of ingested microplastics in animals can affect their behaviour in a range of ways. Examples include decreased feeding (due to a false feeling of satiation), and increased buoyancy which affects feeding and swimming behaviour.[5,9] Microplastics can also cause damage to the mouths and digestive system of animals in a similar way to macroplastics.

Evidence suggests that nanoplastics may be a particular concern as research has shown that they are capable of entering tissues and crossing the blood-brain barrier.[9] Microplastics have been found in human tissues and organs such as the lungs and, more recently, also in blood.[6,7]

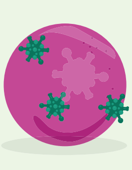
CHEMICALS LEACHING FROM PLASTICS 2

Additives are often not bonded to the polymer structure, and along with a small proportion of unreacted monomers present in the plastic they can leach into the environment, further enabled by weathering of the product.[8]

These chemicals can be toxic, carcinogenic or have endocrine-disrupting properties, and research has shown severe reactions to these in microalgae and mussels.[10] However, it is not yet clear how significant a role microplastics play in contributing to exposure to these chemicals in freshwater and soil.

3 MICROPLASTICS AS VECTORS FOR OTHER POLLUTANTS

Microplastics may also act as a vector, or carrier, for chemical pollutants and pathogens, meaning these pollutants can be transported inside organisms if ingested.



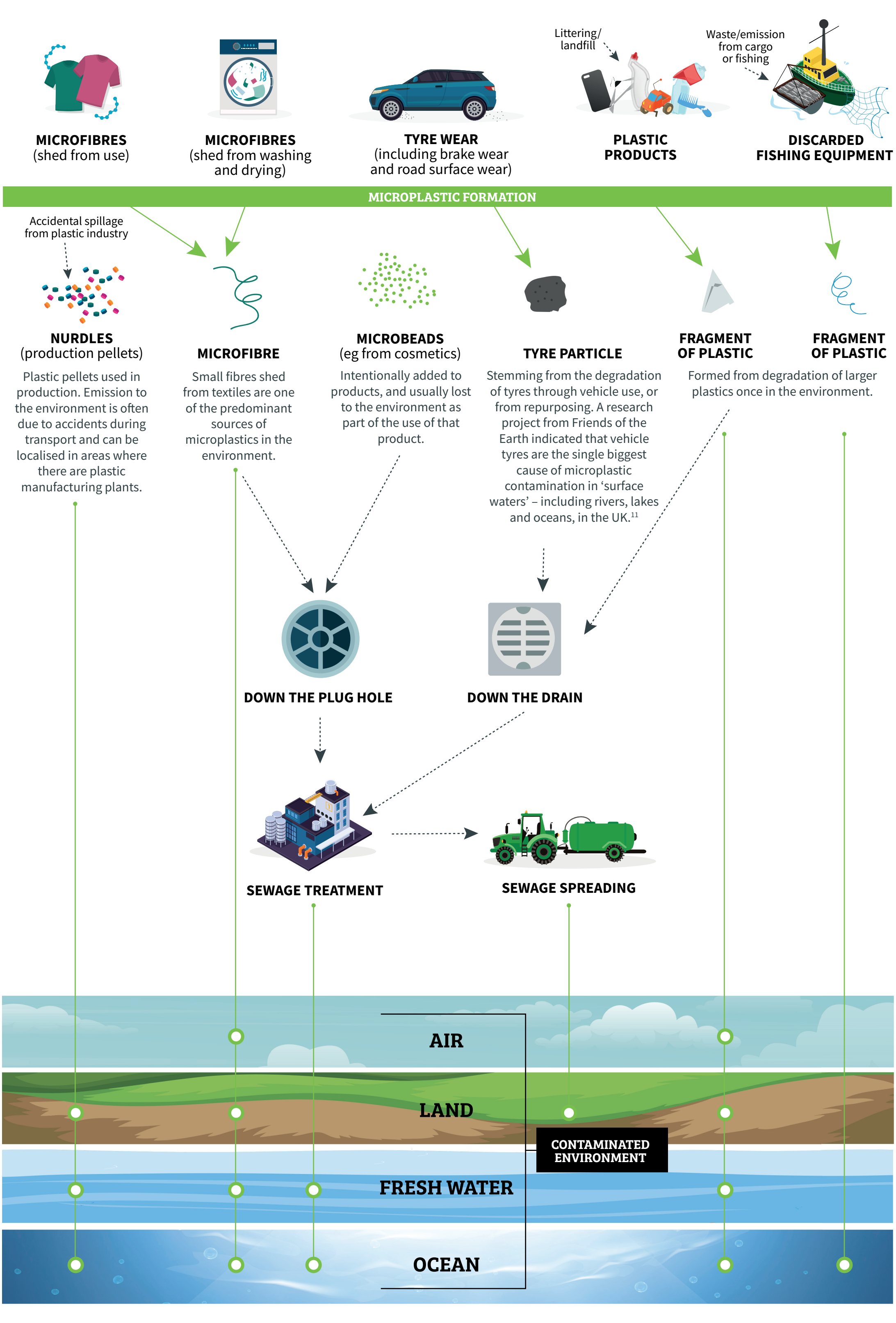
Hydrophobic persistent organic pollutants (POPs) are one class of pollutants which have a particular affinity for the surface of plastics, and they have the potential to bioaccumulate in food webs.[23]

While some pollutants have been shown to bind to particles, it is so far unclear whether they have the potential to leave the microplastic once inside the organism.[20] It is also difficult to attribute the recorded presence of these chemicals in organisms to microplastics over other potential exposure routes.

The evidence base is still growing on the long-term impacts of microplastics on human health at the concentrations observed in the natural world, especially as these systems are complex. Additionally, a lot of microplastics research is done with simple-shaped, purpose-made plastics and at very high concentrations, making translating the results into real world impact risk a difficult task.

While exposure to microplastics could pose a large and growing health risk, it is important to acknowledge that internationally other pollutants in drinking water (such as pathogens from waste) are currently an even more urgent priority for public health.[21]

Common microplastics, where they come from and how they reach the environment



Water treatment works filter out most microplastics but can struggle to remove particles that are particularly small (ie nano-sized).[12]

Where the facility does extract microplastics, they can unfortunately be trapped within sewage sludge, which is often subsequently spread onto farmland, re-releasing the microplastics to the environment.

All plastics are polymers – but not all polymers are plastics

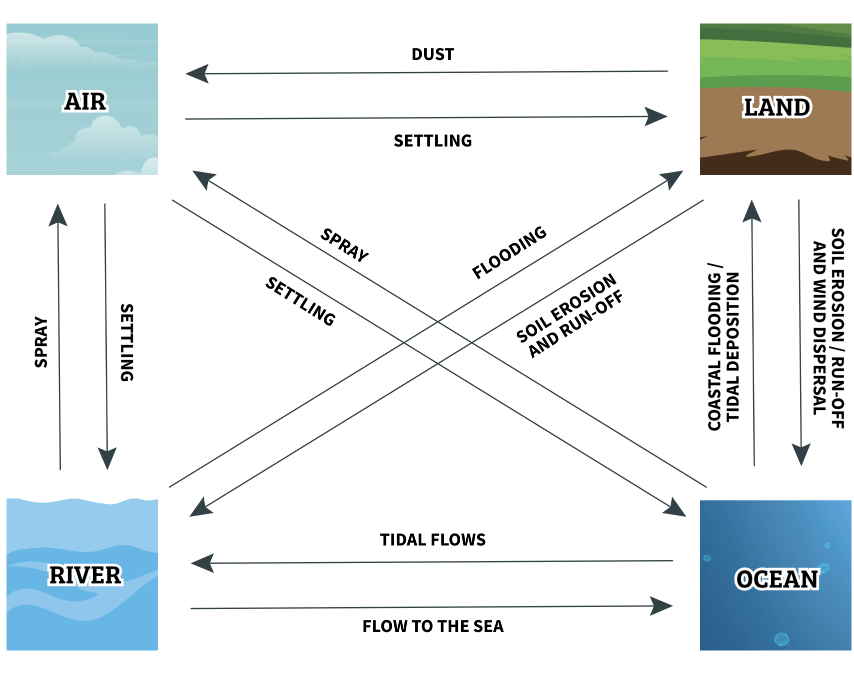
Solid plastic products are made from mixtures of polymers and additives. A separate group of commercially important chemicals is called polymers in liquid formulations (PLFs), which are key ingredients in paints, lubricants, and consumer products like shampoos.

Polymers used in liquid formulations typically have a relative molecular weight between 1,500 and 10,000 g/mol* and high functionality.[13] Contrastingly, polymers in plastics have a higher molecular weight, between 10,000 and 500,000 g/mol, and give rise to the solid materials that are the main source of microplastics.

PLFs in curable formulation systems (which turn solid during use) may also lead to the production of microplastics during use eg from paint flaking. To ensure that the PLF sector is environmentally sustainable in the future, work is ongoing (initiated and coordinated by the RSC alongside industry) to develop new approaches to PLF production, use and end-of-life treatment.

* The mass of a chemical compound is usually expressed in grams per mole (or molar mass), where 1 mole is equivalent to $6.02214076 \times 10^{23}$ particles of that compound.

Microplastics in different environments



Plastics, and especially microplastics, cycle through the earth's systems, from the atmosphere to the oceans, land, and sea ice.[14]

Microplastics in water are relatively easy to sample and test, less is known about microplastics on land and in the air.

Researchers studying atmospheric microplastics in central London found microplastics in every sample. Average deposition rates were also greater than had previously been reported in other major cities such as Paris. The majority of the particles identified were microfibres.[15]

Indoors, airborne microfibres from machine drying clothes could be a significant contributor to microplastic exposure.[16]

Comparability between the air and other environments is not always easy as the emission sources can be more complex, and the atmospheric transport of microplastics is less well-understood.

There are also few studies on microplastics in soil and terrestrial systems, and in part this is due to the difficulties of extracting microplastics from organic samples with complex compositions and structures. Although the research is still relatively new, microplastics in the soil have been shown to influence plant production. However, it is uncertain as to whether other non-biodegradable particles could have the same effect as microplastics.[15]

Detection of microplastics: How many are there? What is the scale and breadth of the problem?

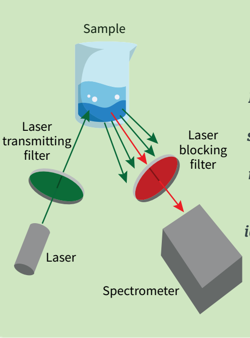
Of the 8.3 billion tonnes of plastics manufactured from 1950 to 2015, around 79% still survives either as landfill or in the terrestrial, freshwater, or marine environment.[17]

Research on the scale of microplastics contamination in the environment varies. Some report that 2.5 million tons of microplastics enter the ocean every year, with a burden of 75,000 to 300,000 tons of microplastics released into the environment each year in Europe alone. Another report estimated that the quantity of microplastics in the ocean ranges from 93,000 to 236,000 tonnes; however, these estimates are based on plastics visible on the surface of the ocean. This could be a substantial underestimate given other reports that only around 1% of the plastics in the ocean are on the surface with the remainder sinking to the seabed, and there are also freshwater, soil, and air environments to be accounted for in the total estimation.[19,20]

Over time, as fragment sizes decrease with gradual degradation, the number of micro- and nanoplastics will increase. Microplastics size distribution also depends on the sampling location (geographically and depth-wise) and the sampling technique and analytical methods applied.[10] Sampling methods can mean that smaller sized microplastics are not gathered, leading to potentially significant underestimation of microplastic contamination.

While we can get a sense of the scale of the problem, comprehensive assessment of the number of microplastics is limited by both the ability to capture all contaminants, and agreement on standardised sampling approaches and analytical methodologies. Without this harmonisation, studies and data can't always be accurately compared. Standardisation is important for ongoing monitoring of the distribution and types of microplastics. This is also vital for policy decisions, and regulatory requirements. However, we can be sufficiently confident in the ubiquity of microplastics, and that it is important we act now to reduce harm.

Factors to be considered in a standardised method include accurate measurements of the volume of medium sampled (eg air, soil, water), proper consideration of potential procedural contamination, and detailed reporting of the methods and analytical techniques used.[21]



Chemistry plays an important part in sample preparation and analysis. Fourier-transform infrared spectroscopy or Raman spectroscopy can be used to obtain a spectrum of the microplastic and compared to known databases of polymer types – identification of the polymer type can help investigate the source.

- Microplastics are part of a larger system of plastic waste, and efforts to kerb the number of plastics discarded into the environment will also help prevent microplastic contamination. This includes consumer waste, but also adapting fishing and agricultural practices to reduce waste.
- Better, more sustainable design and lifestyle thinking can create products less likely to form microplastics in use and more easily captured and recycled at the end of their lives.
  - For tyres, improving their materials and design could help with reducing particle emissions. There are broader interventions as well, such as thinking about whole vehicle design, road characteristics, and driver behaviour.
  - To reduce microfibre contamination, researchers need to look at textiles and sustainable fabrics that don't shed, but also beyond the fibre types, into textile construction.
- Labelling of products, especially clothing, on their potential for microplastics release could help to improve consumer awareness. This could include care instructions designed to reduce microplastic release.
- Water treatment plants could be a key intervention point, both for monitoring and removal of microplastics. Sludge processing should be improved to remove microplastics from the material before release to the environment.
- Including filters on washing machines and tumble driers provides a capture point prior to release to the water system. However, further investigation and communication is needed on the best way to dispose of or recycle the collected fibres.
- There are calls to categorise nurdles and other plastic production pellets as hazardous goods, which in turn would require stricter conditions for shipping.[22]
- Further research is needed to understand this challenge and potential solutions. This includes investigating the process of degradation and biodegradation of plastics, the impacts of this on the environment, and how microplastics can affect human health. Advances in chemical risk assessment approaches, including biomonitoring of pollutants in humans and wildlife, will play an important role in this.
- The EU estimates that total intentionally added microplastic contamination from Europe is around 36,000 tonnes a year. While the UK government has banned microbeads in wash-off cosmetic applications, they are reported to make up just 8.8 per cent of total microplastic contamination.[23] Other intentionally added microplastics include detergents, fertilisers, and some leave-on cosmetics including glitter-based ones. The government should consider widening restrictions on microbeads.

Once in the open environment, micro- and nanoplastics are very difficult to recapture. The best method of limiting their impact is to reduce the amount added to the environment through at-source prevention or capture. Successful interventions require collaboration between researchers, industry specialists, governments, and wider society.

[1] https://www.rsc.org/globalassets/22-new-perspectives/sustainability/progressive-plastics/c19_tl_sustainability_cs3_whitepaper_a4_web_final.pdf
[2] https://portals.iucn.org/library/sites/library/files/documents/2017-002-En.pdf
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