Microfibres: the invisible pollution from textiles

Sources, distribution and interventions

19 January 2022

First Sentier MUFG
Sustainable Investment Institute

Contents

About the Institute

The First Sentier MUFG Sustainable Investment Institute (the Institute) provides research on topics that can advance sustainable investing. The Institute is jointly supported by First Sentier Investors and Mitsubishi UFJ Trust and Banking Corporation, a consolidated subsidiary of MUFG .

As investors, both First Sentier Investors and MUFG recognise our collective responsibility to society and that investment decisions should be made with consideration to our communities both now and in the future.

The Institute commissions research on Environmental, Societal and Governance issues, looking in detail at a specific topic from different viewpoints. The Institute recognises that investors are now looking in far greater depth, and with far greater focus, at issues relating to sustainability and sustainable investing. These issues are often complex and require deep analysis to break down the contributing factors. If as investors we can better understand these factors, we will be better placed to consider our investment decisions and use our influence to drive positive change for the benefit of the environment and society.

The Institute is jointly supported by First Sentier Investors (FSI) and Mitsubishi UFJ Trust and Banking Corporation, a consolidated subsidiary of MUFG. Representatives of both organisations provide input to the activities of the Institute.

An Academic Advisory Board has been established to advise the Institute on sustainability and sustainable investment research initiatives. The Academic Advisory Board comprises prominent leaders from academia, industry and nongovernmental organisations in the fields of Responsible Investment, climate science and related ESG endeavours. The Board provides independent oversight to ensure that research output meets the highest standards of academic rigour.

Contact

Institute@Firstsentier.com
www.firstsentier-mufg-sustainability.com
www.mufg-firstsentier-sustainability.jp

Acknowledgements

The Institute would like to thank the authors of this publication, Ella Harvey, Dr Rory Sullivan and Nicky Amos from Chronos Sustainability.

We would also like to thank Dr. Laura Foster from the Marine Conservation Society, as well as Fauna & Flora International and The Microfibre Consortium, who contributed to the report.

About Chronos Sustainability

The Institute commissioned Chronos Sustainability to develop this document. Chronos Sustainability was established in 2017 with the objective of delivering transformative, systemic change in the social and environmental performance of key industry sectors through expert analysis of complex systems and effective multi-stakeholder partnerships. Chronos works extensively with global investors and global investor networks to build their understanding of the investment implications of sustainability related issues, developing tools and strategies to enable them to build sustainability into their investment research and engagement. For more information visit www.chronossustainability.com and @ChronosSustain

About the Institute's sponsors

About First Sentier Investors

First Sentier Investors (formerly First State Investments) is a global asset management group focused on providing high quality, long-term investment capabilities to clients. We bring together independent teams of active, specialist investors who share a common commitment to responsible investment and stewardship principles. These principles are integral to our overall business management and the culture of the firm.

All our investment teams – whether in-house or individually branded – operate with discrete investment autonomy, according to their investment philosophies.

https://www.firstsentierinvestors.com

About MUFG

Mitsubishi UFJ Financial Group, Inc. (MUFG) is one of the world's leading financial groups. Headquartered in Tokyo and with over 360 years of history, MUFG has a global network with over 2,600 locations in more than 50 countries. The Group has over 180,000 employees and offers services including commercial banking, trust banking, securities, credit cards, consumer finance, asset management, and leasing. The Group aims to "be the world's most trusted financial group" through close collaboration among our operating companies and flexibly respond to all of the financial needs of our customers, serving society, and fostering shared and sustainable growth for a better world. MUFG's shares trade on the Tokyo, Nagoya, and New York stock exchanges.

https://www.mufg.jp/english

About the Trust Bank

Mitsubishi UFJ Trust and Banking Corporation, as a core member of MUFG, provides its customers with a wide range of comprehensive financial solutions leveraging unique and highly professional functions as a leading trust bank. Such financial solutions include real estate, stock transfer agency, asset management and investor services, and inheritance related services, in addition to banking operations. We aim to realize our vision to be the trust bank that creates "a safe and affluent society" and "a bright future with our customers together". We support our customers and societies through their challenges with Trust, and thus we build on a new key concept: "Create a Better Tomorrow". First Sentier Investors was acquired by the Trust Bank in August 2019.

https://www.tr.mufg.jp/english

Executive summary

All textiles shed microfibres, including natural, synthetic and semi-synthetic textiles.

Fibre fragmentation or 'microfibres' are the released microscopic fibres, some of which find their way into the natural environment. Microfibres have been found in the deep ocean, on beaches, in rivers and in the atmosphere, as well as in animals, plants and human food. Thus, microfibres are rapidly becoming an environmental and health concern.

An estimated 0.48-4.28 million metric tonnes (MMT) of synthetic and natural microfibres could enter the environment every year (internal estimate, see Exhibit 1 and Appendix 1). The amount of synthetic microfibres accumulated in the environment so far is thought to exceed 5.6 MMT.[1]

Existing studies have largely focused on microfibre shedding from synthetic textiles during washing, so there are significant knowledge gaps that would benefit from further research. Nonetheless, we attempt to consolidate the available data in this report to provide wider context for readers (Exhibit 1 and Appendix 1).

Despite the environmental and health concerns associated with microfibre pollution, microfibre release is still largely unregulated.[2] Moreover, the environmental presence of microfibres is expected to increase as global textile consumption increases; annual global fibre production of textiles is estimated to increase by about 33% to 146 MMT by 2030 (from 109 MMT in 2020).[3]

Microfibres pose a problem to humans and the environment for three key reasons:

1. Wide distribution in the environment

Microfibres have been found in virtually every type of habitat on the planet due to their ubiquity, small size and low density, all of which facilitate their transmission.

However, microfibres are not evenly distributed in the environment. For example, the Mediterranean Sea has been found to have a higher concentration of microfibres compared to other ocean basins. Such regional differences in pollution rates and concentrations could be relevant when contextualizing the impact of microfibre pollution and its solutions.

2. Lack of biodegradability

Synthetic microfibres biodegrade slowly under natural conditions, if at all. This leads to their accumulation in the environment.[4,5] This lack of biodegradability is problematic because microfibres can:

- Serve as breeding grounds for pathogens;[6]
- Act as concentrators for contaminants such as metals and other chemicals;[7,8]
- Be mistaken as food and ingested by marine biota.

When microfibres are ingested by organisms and move up the food chain, they can eventually contaminate human food. Microfibres have been found in bottled water, tap water, beer, salt, shellfish, fish, birds, vegetables, and fruit. Humans are estimated to consume or inhale between 75-120 thousand microfibre particles per year, which is roughly equivalent to a paper clip's worth of microfibres (assuming that 1,000 microfibres is roughly equivalent to 1 mg[9]).

3. Impact on the environment and human health

The acute health implications of microfibre ingestion or inhalation by marine fauna and humans has not been extensively studied, as most studies so far have examined the impact of microplastics more generally. However, microfibre exposure has been linked to several negative outcomes in aquatic species, including **endocrine disruption, toxicity, gut blockages, reduced reproduction and death**.[10,11,12] In humans, atmospheric microfibre exposure has been linked to respiratory complications including lung disease.[13]

The longer-term impacts of microfibres on ecosystems and human health are also not well understood. For example, it is unknown whether reduced reproduction or death at the bottom of the marine food chain could have cascading effects on marine populations, or how consumer awareness about contaminated seafood could impact related fishing industries (through lower consumer demand for example).

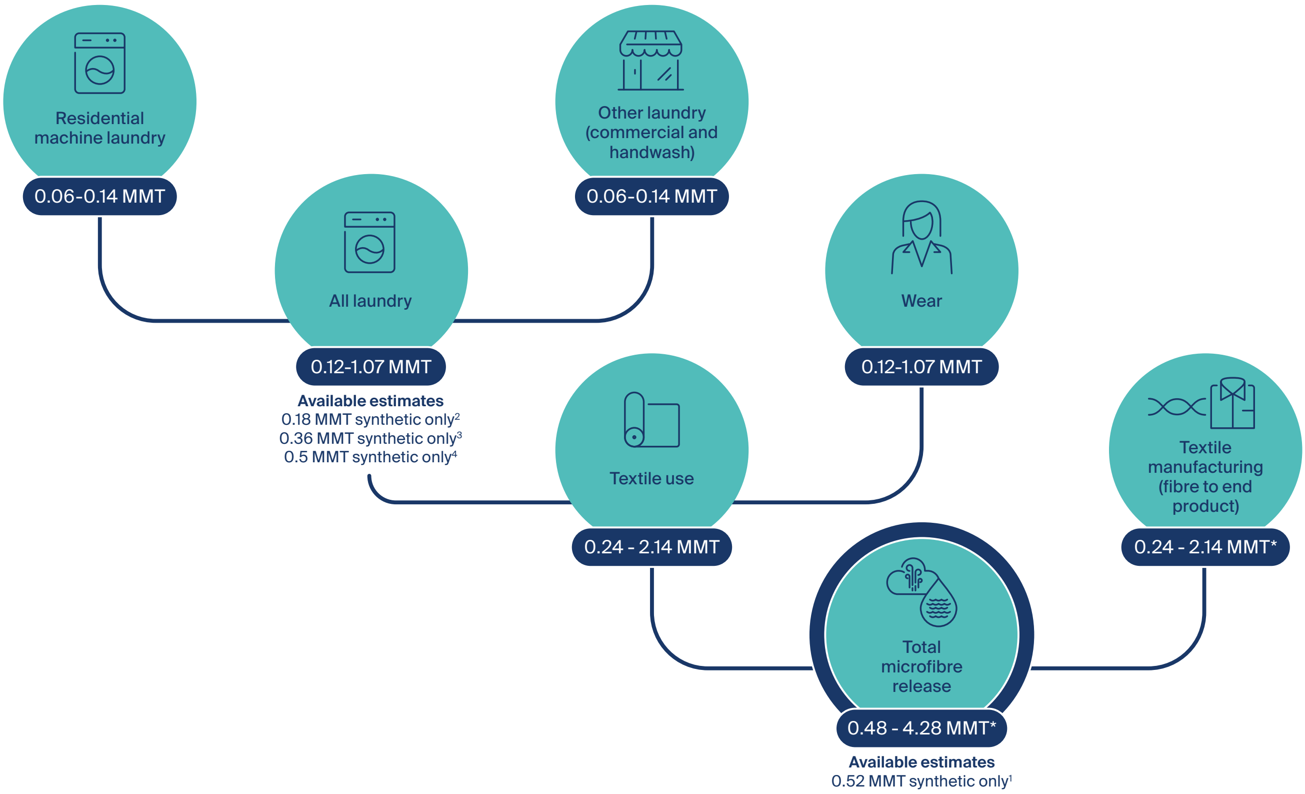
Executive summary

Pathways and drivers of microfibre release

Textiles and apparel contribute to microfibre pollution through their entire lifecycle: while being manufactured, while being used (washed and dried), and after they are disposed of.[14]

Microfibre release from all stages of the textile lifecycle would generally benefit from further research. Exhibit 1 below summarises estimates available in existing literature, as well as internal estimates drawing on existing knowledge.

Exhibit 1: Internally estimated global microfibre release through the textile lifecycle (synthetic and natural fibres)
Where available, estimates from existing literature are also shown



Source: 1) Boucher & Friot (2017); 2)Belzagui et. al (2020); 3) Gavigan et. al (2020); 4) Ellen MacArthur Foundation (2018); Refer to Appendix 1 for calculation details; *Estimate range excludes one outlier estimate of over 10MMT. MMT = million metric tonnes

Despite scarce quantifiable data in some areas, there are specific problem drivers associated with textiles that are known to drive microfibre pollution. Understanding and addressing these problem drivers presents an opportunity to make a strategic impact in efforts to curb microfibre pollution. These drivers include:

1. The textile manufacturing process
2. Textile maintenance and use
3. Textile composition and weave
4. Wastewater treatment

1. Textile manufacturing process

Various stages of textile and garment production release microfibres due to the abrasive processes associated with dyeing, printing, and finishing textiles and apparel.[15]

The microfibre losses from textile production have not been well-studied but are expected to make up a significant portion of overall microfibre pollution.[15,16] Indeed, it has been suggested that textile production produces as many microfibres as textile use,[16] and it is possible that 10-15% of textile mass is lost during production in the form of microfibres.[1]

Pathways and drivers of microfibre release

Textile maintenance contributes to microfibre pollution because as fabrics are washed and dried, microfibres become detached from fabrics due to chemical and mechanical abrasion.[17]

2. Textile maintenance and use

An estimated 0.12-1.07 MMT of natural and synthetic microfibres could be released from textile laundering every year (internal estimates, Exhibit 1 and Appendix 1).

The number (and volume) of microfibres that is released with every load of laundry varies widely with estimates from 700,000[18] to 1.5 million[17] to 7 million fibres.[69] It is estimated that each wash releases approximately 0.5-1.3 grams of microfibres.[19]

It has also been suggested that textiles may shed as many microfibres when they are being worn as when they are being washed, although atmospheric microfibre losses are less well-studied than losses from washing.[20]

3. Textile composition and weave

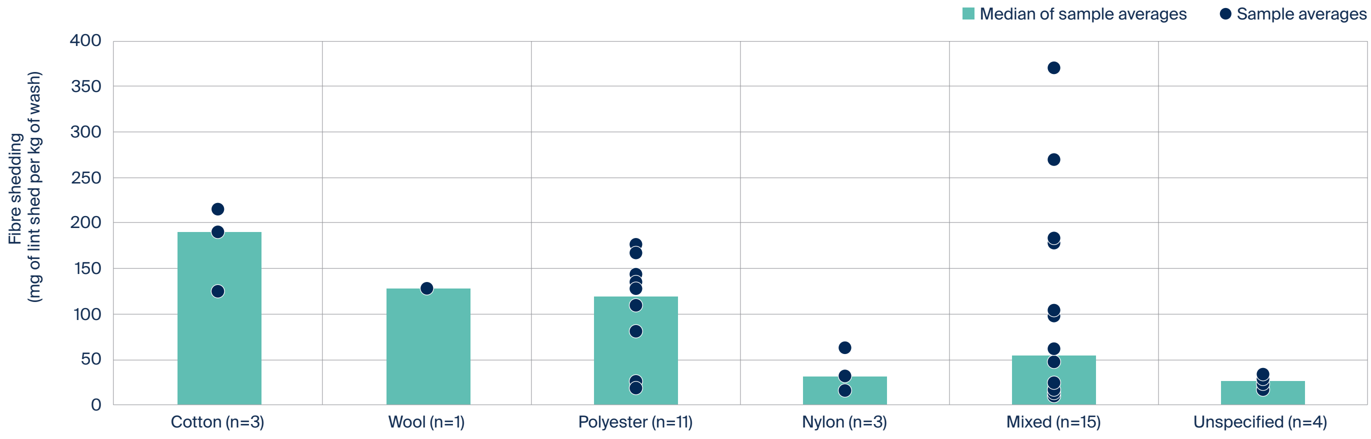
Textile composition and weave also affect shedding rates. For example, natural fibres, such as cotton and wool, tend to shed more than synthetic ones (Exhibit 2), and fabrics with a greater number of exposed filaments, such as fleece, tend to shed more compared to those with a tighter weave.[17,21]

4. Wastewater treatment

Microfibres can be intercepted before they are released into the environment when wastewater from residences or industry is treated at wastewater treatment plants (WWTPs). However, the effectiveness of wastewater treatment plants at intercepting microfibres depends on several factors:

- **Connectivity to wastewater treatment infrastructure:** Less than a third of the human population is connected to wastewater management infrastructure,[22] and an estimated 80% of wastewater globally is released to the environment without sufficient treatment.[23]
- **Capture efficiency of microplastics, including microfibres, by WWTPs:** The capture efficiency of WWTPs is often higher than 90%,[19,24,25] despite the fact that modern wastewater treatment infrastructure was largely not designed to filter out small buoyant particles.[19,26,27,28]
- **Application of sludge to agricultural lands:** Removing microfibres from wastewater effluent by sequestering them in sewage sludge does not necessarily prevent them from entering the environment. This is because sewage sludge, a semi-solid by-product from wastewater treatment that is high in nutrients and organic matter, is frequently applied as fertiliser to agricultural lands in North America and Europe.[26,29]

Exhibit 2: Shedding rates across major textiles



Source: Vassilenko et al. (2021).

Individual sample data depicts the average weight of lint over three laundry washes. Standard deviations are not pictured but vary between 1% and 61% for all samples. Category medians are calculated based on averages for the samples within a given subcategory. Two outlier samples are excluded from both the chart and the calculation of the category medians (polyester (778 mg lint/kg wash) and mixed fabrics (838 mg lint/kg wash)).

Interventions to reduce microfibre pollution

The most efficient opportunities for action prevent microfibres from entering the environment to begin with and are thus at the source of microfibre formation.

This is because, while technology to remove microfibres directly from the environment is emerging,[30] this process is generally considered very inefficient as microfibres are microscopic, lightweight, and widely dispersed in diverse, complex ecosystems.

Microfibre pollution prevention measures can be both **mandated by policymakers** and **voluntarily adopted by industry**. Further, **investors** could proactively work with industry to encourage the voluntary adoption of microfibre pollution prevention measures.

Some of the potential interventions require as a pre-requisite a standard, universally available testing methodology for determining the microfibre shedding rates of different textiles. At the time that this report was written, a universal and publicly available standard testing methodology did not exist.

While the regulation of textile shedding rates may still be on the distant horizon, microfibre capture technologies during laundry already exist and are affordable for consumers. The installation of such technologies would be important:

- In the medium term, until shedding rate regulations become more widely introduced;
- In the longer term, as low-shed fabrics are still largely under development.

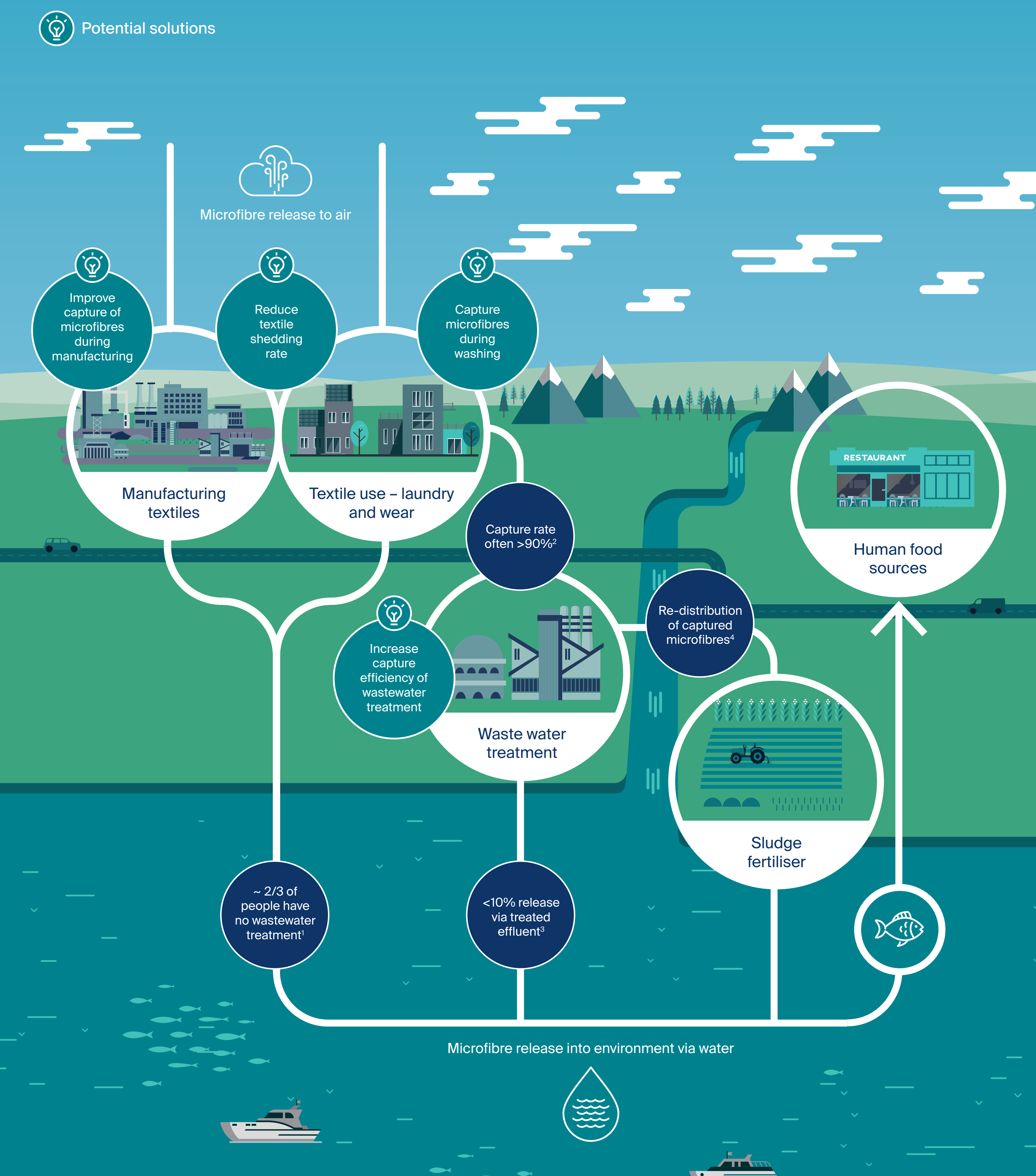
Exhibit 3: Summary of available interventions by action group

<table>
<tr><th>Intervention</th><th colspan="3">Intervening group</th></tr>
<tr><th></th><th>Policymakers & Regulators</th><th>Industry</th><th>Investors</th></tr>
<tr><td rowspan="4">1. Regulate textile shedding rates</td><td>Test and approve industry-developed standards</td><td>Partner with research groups to develop the standard</td><td rowspan="5">Engage with textile and garment value chain to: 1) adopt shedding rate standard; 2) encourage pro-active reduction of fabric shedding

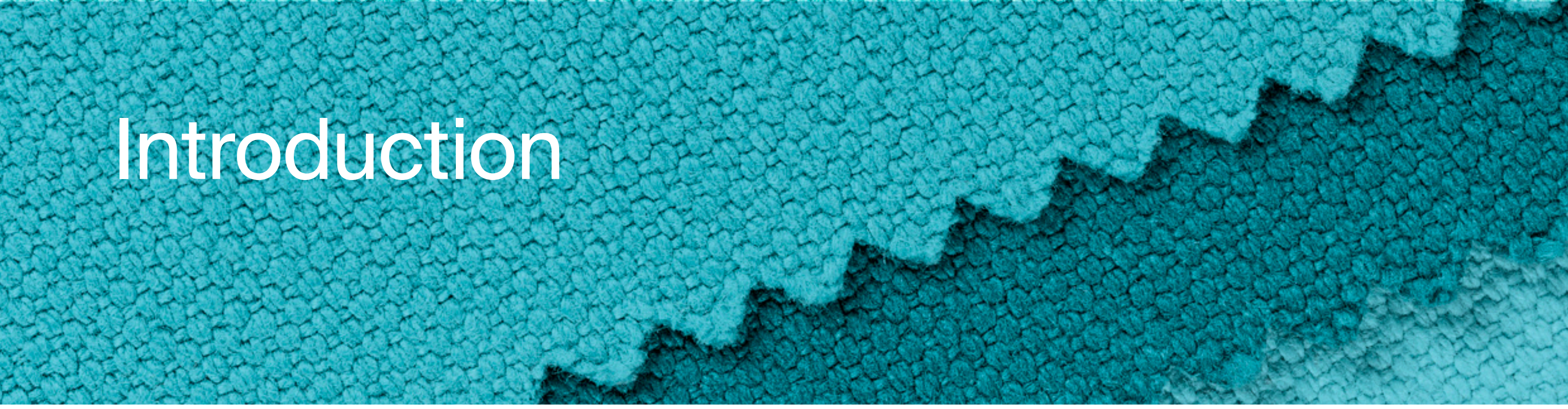
Understand economic impact on the value chain from potential wide-reaching shedding rate regulation (e.g. R&D costs, increased value chain costs)</td></tr>
<tr><td>Set a maximum textile shedding rate</td><td rowspan="3">Engage in voluntary initiatives to self-regulate shedding rates</td></tr>
<tr><td>Place a levy on higher emitting products</td></tr>
<tr><td>Require the shedding rates of different textiles to be disclosed on the product label</td></tr>
<tr><td>2. Curb microfibre loss during textile manufacturing</td><td>Require industry to adopt relevant best practices to minimise microfibre loss</td><td>Implement practices during fabric and garment manufacturing to curb microfibre loss</td></tr>
<tr><td>3. Use microfibre filters on washing machines</td><td>Pass legislation requiring all new laundry machines include a microfibre filter</td><td>Develop new product lines with filters or retrofit existing washing machines</td><td>Engage with washing machine manufacturers to encourage product development and commercialisation</td></tr>
<tr><td>4. Improve microfibre retention at wastewater treatment plants</td><td colspan="3">Implement tertiary and quaternary treatment stages in existing WWTPs or build WWTPs where they do not currently exist. Given the capital intensity of such initiatives, those are largely to be driven by government and regulatory bodies.</td></tr>
</table>

The lifecycle of a microfibre

The diagram illustrates principal sources and distribution of microfibres pollution, as well as possible pollution prevention actions.



Source: adapted from Eastern Charlotte Waterways;
1. Boucher & Friot (2017);
2. Prata (2018);
3. estimated based on Prata (2018);
4. Nizzetto et. al (2016)



Introduction

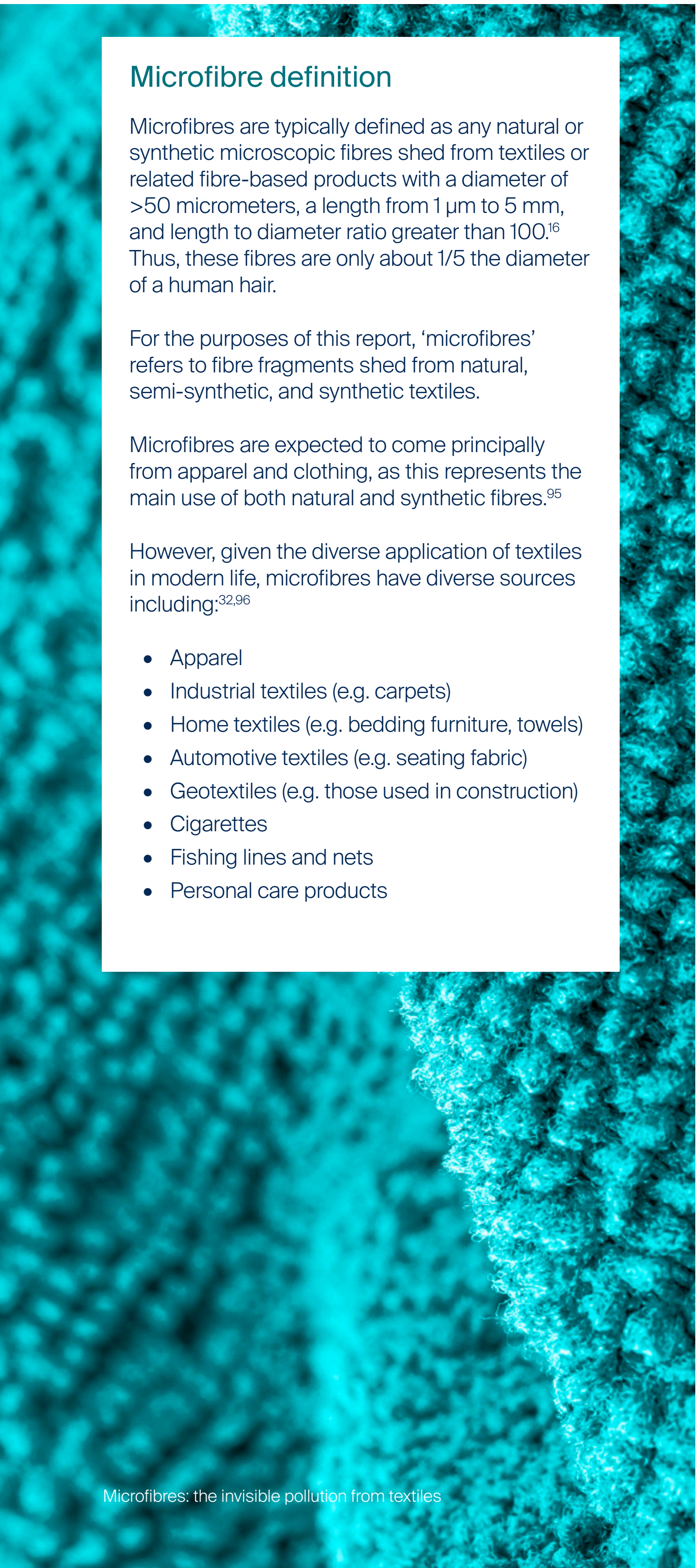
Microfibres were first understood to be an environmental issue in the 2000s.[31] Since then, microfibre sources, distribution and effects on human health and the environment have become increasingly studied. Even so, the full implications of microfibre pollution are still not well understood and remain the subject of continuing research.

Although we do not yet have a comprehensive understanding of the long-term effects of microfibre pollution, there is sufficient evidence to demonstrate that chronic exposure to microfibres has negative effects on both human and ecosystem health. Therefore, the aim of this report is twofold:

1. To synthesise existing knowledge about the sources and implications of microfibre pollution, and

2. To summarize possible areas of action for policymakers, companies and investors to reduce microfibre pollution.

Definition and types of microfibres



Microfibre definition

Microfibres are typically defined as any natural or synthetic microscopic fibres shed from textiles or related fibre-based products with a diameter of >50 micrometers, a length from 1 μm to 5 mm, and length to diameter ratio greater than 100.[16] Thus, these fibres are only about 1/5 the diameter of a human hair.

For the purposes of this report, 'microfibres' refers to fibre fragments shed from natural, semi-synthetic, and synthetic textiles.

Microfibres are expected to come principally from apparel and clothing, as this represents the main use of both natural and synthetic fibres.[95]

However, given the diverse application of textiles in modern life, microfibres have diverse sources including:[32,96]

- Apparel
- Industrial textiles (e.g. carpets)
- Home textiles (e.g. bedding furniture, towels)
- Automotive textiles (e.g. seating fabric)
- Geotextiles (e.g. those used in construction)
- Cigarettes
- Fishing lines and nets
- Personal care products

All textiles shed microfibres, including natural, synthetic and semi-synthetic textiles.

While 'natural' fibres come from plants and animals, 'synthetic' fibres are derived from plastics.[32] In between the two are what are referred to as 'semi-synthetic' fibres, which are regenerated, artificially produced cellulosic (i.e. plant-based) fibres.

Semi-synthetic fibres are originally derived from natural materials but undergo extensive chemical processing, and so are considered by some to be artificial[33] (Exhibit 4). Synthetic and semi-synthetic textiles, which together represent around 2/3 of current annual fibre production,[3] are often woven together with natural fibres to reduce cost and produce other desired characteristics such as performance, comfort and ease of care.[14]

Exhibit 4: Types of textiles

Type of fibre	Examples	Definition
Natural	Cotton Silk Wool	Minimally processed fibres from natural sources (e.g. plants, animals)
Synthetic	Polyester Polyethylene Acrylic Elastane	Plastic-based fibres
Semi-synthetic	Viscose (rayon) Acetate Lyocell Modal	Artificially produced fibres originally derived from plants but that have undergone extensive chemical processing

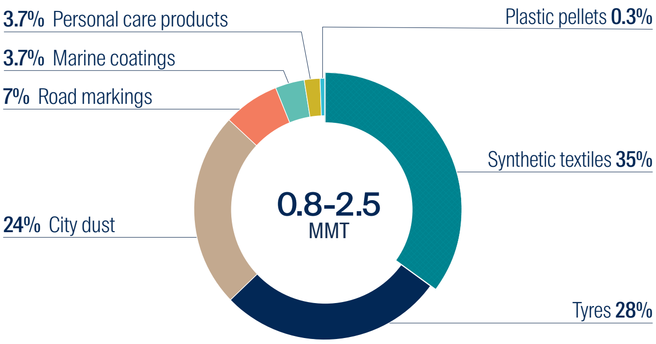
Source: Manshoven et al. (2021); Napper et al. (2020)

Scope of the problem

An estimated 0.48-4.28 MMT of natural and synthetic microfibres could enter the environment every year (internal estimate, Exhibit 8 and Appendix 1). At least 5.6 million metric tonnes (MMT) of synthetic microfibres were estimated to already be in the environment as of 2015.[1]

Synthetic microfibres constitute approximately 35% of annual microplastics release to the ocean[22] (Exhibit 5) and there is evidence to suggest that synthetic microfibres account for over 70% of accumulated microplastics in deep sea sediments.[34] For more information on the wider issue of microplastic pollution, please refer to our earlier paper on this topic: "Microplastics pollution: The causes, consequences and issues for investors", May 2021.[35]

Exhibit 5: Estimated annual synthetic microfibre release to the environment in the context of global releases of primary microplastics



Source: Boucher & Friot (2017)

Despite their concerning characteristics, microfibre pollution is still largely unregulated.[2] If left unaddressed, growth in textile consumption is likely to exacerbate microfibre pollution. By 2030, global apparel consumption could increase by as much as 63%, up to 102 MMT of product annually (from approximately 62 MMT in 2017).[36] Similarly, global fibre production, including fibres used for textiles other than apparel, is estimated to increase by 33% to 146 MMT per annum by 2030 (from 109 MMT in 2020).[3]

As a result, some suggest that annual microfibre release into the environment could increase by 54% by 2030[37] (or to approximately 0.5 – 6.0 MMT per annum when considering our internal estimates for current annual release). Another estimate suggests that further 22 MMT of synthetic microfibres could enter the environment by 2050.[38] This is approximately 0.75 MMT per year, under a simplified assumption of equal annual release over the next 30 years to 2050.

With respect to geographical microfibre generation and entry to the environment, some countries appear to contribute disproportionately to the total pollution. Some estimates suggest that China, Indonesia, the USA, Sri Lanka, and India are the top contributors.[39]

The larger contribution of these countries to microfibre pollution could be driven not only by population size and textile consumption patterns, but also because of their role in global textile production and relatively lower availability of wastewater treatment infrastructure per capita. For example, China produces almost 70% of the world's polyester, and together, China, India, and South East Asia produce over 80%.[39]

Introduction

Problematic characteristics of microfibres

Microfibres pose a problem to humans and the environment for three key reasons.

1. Wide distribution in the environment

Microfibres have been found in virtually every type of habitat on the planet due to their ubiquity, small size and low density, all of which facilitate their transmission. They have been found in the deep ocean,[40] on coastlines,[41] in Artic seawater,[42] in freshwater lakes and rivers,[27,43,44] in soil,[26] on mountaintops,[45] and in the air.[46,47]

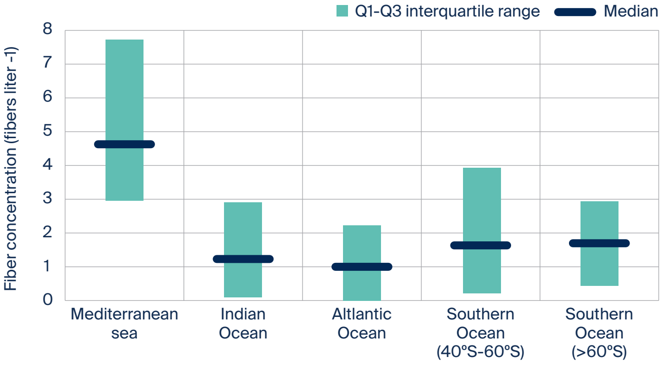
The presence of microfibres in terrestrial ecosystems has been less well-studied. However, it is known that microfibres exist in terrestrial systems due to the practice of applying sludge to agricultural soils as fertiliser.[26] Microfibres have also been identified in even very remote locations, such as the peak of Mount Everest.[45]

The abundance of microfibres in the marine environment has been especially well-documented. For example:

- The Indian Ocean has approximately 4 billion microfibres per square km of sediment;[48]
- Synthetic microfibres account for over 90% of the microplastic pollution identified in Arctic seawater;[49]
- The most commonly found type of synthetic microfibre in the ocean is polyester.[50]

Microfibres are not evenly distributed in the environment. For example, the Mediterranean Sea has been found to contain relatively high concentration of microfibres, despite the fact that it is not proximal to some of the largest entry points for microfibre pollution, such as Asia and the US. (Exhibit 6). Such regional differences in pollution could be relevant in contextualizing the impact of microfibre pollution and distribution.

Exhibit 6: Microfibre concentrations in different ocean basins



Source: Suaria et al. (2020)

Median value and interquartile range (Q1-Q3) of fibre concentrations (fibres per litre) found in oceanic basins and sub-basins; displaying corrected data only. The chart excludes outliers (defined as sample data falling outside the Q1-Q3 interquartile range), but all basins had samples with microfibre concentrations up to 11-14 fibres per liter.

2. Lack of biodegradability

Microfibres biodegrade slowly under natural conditions, if at all. This leads to their accumulation in the environment.[4,5] This lack of biodegradability is problematic because microfibres can:

- Serve as breeding grounds for pathogens;[6]
- Act as concentrators for contaminants such as metals and other chemicals;[7,8]
- Be easily ingested by organisms.

If a microfibre persists in the environment for a long time, it could have increased potential to serve as a vector for pathogens and contaminants that could then be released into organisms upon ingestion.[10]

The biodegradability of textiles ultimately depends on how accessible the essential nutrients in the material are to microorganisms. Although it is known that natural and semi-synthetic fibres degrade faster than synthetic fibres, there is limited data on the rates at which different polymers degrade and fragment in the environment, indicating that this is an area that requires further research.[51] For example:

- A polyester fabric remained largely intact after 100 days both in laboratory conditions and in a composting environment;[52]
- Natural microfibres and some semi-synthetics can biodegrade under the right conditions, and may degrade within weeks to months.[4,5,53] For example, natural fibres may be more likely to degrade in warm, moist environments in the presence of microorganisms and chemical, photochemical and mechanical abrasive forces.[53]

However, there is evidence to suggest that almost 80% of the microfibres identified in various oceanic basins are cellulosic (i.e. cotton, linen and regenerated cellulose like rayon and viscose).[95] This finding suggests that natural and semi-synthetic fibres may persist in the environment longer than we would expect them to.

One reason that cellulosic fibres may persist in the environment is because textiles often contain residues of chemicals used in fibre production and textiles processing that can interfere with the nutritional value of the fibre to microorganisms.[38] However, the extent to which these chemicals can interfere with the deterioration of different materials remains an open question.

Problematic characteristics of microfibres

3. Impact on the environment and humans

Once in the environment, microfibres **can be easily ingested by organisms**. In marine environments, organisms such as crustaceans, shellfish, zooplankton, and fish often mistake microfibres for food.[5,54,55] Indeed, microfibres appear to have a greater likelihood of being ingested relative to other microplastics due to their size and shape.[5] For example, nearly half of the microplastics found in the guts of common tropical fish were microfibres.[56]

Microfibres also move up the food chain **and eventually contaminate human food**. Microfibres have been found in bottled water, tap water, beer, salt, shellfish, fish, birds, vegetables, and fruit.[57,58,59] Humans are estimated to consume between 39-52 thousand microfibre particles per year, and to inhale between 35-69 thousand particles (mostly fibres), although these figures are likely to be underestimates.[60] Assuming that 1,000 microfibres is roughly equivalent to 1 mg,[9] these estimates roughly equate to consuming, either through ingestion or through inhalation, a paper clip's worth of microfibres annually.

The health implications of microfibre ingestion or inhalation by marine fauna and humans has not been extensively studied, as most studies so far have examined impact of microplastics more generally rather than microfibres in particular. Microfibre pollution has so far been linked to:

- Physical damage from ingestion, such as gut blockages;
- Toxicity through chemical release: both synthetic and natural textiles are often produced with chemicals to either enhance their properties (e.g. softeners, dyes, antioxidants, plasticizers, UV stabilizers, antimicrobials, antiwrinkle finishers, and flame retardants) or provide other functions (e.g. residual pesticides from cotton production). These chemicals can leach from microfibres into the environment and into the organisms that ingest them.[38,61,62,63]

An arrow worm in the plankton has eaten a plastic microfibre that has blocked the passage of food through its gut.

Additional research on the effect of microfibres on the environment and human health is required, especially if microfibre pollution continues to persist and grow. For example:

- More research would be required on the impact of microfibre pollution on marine and fish stock populations. For example, mortality in zooplankton and reproductive dysfunction in other species suggests that microfibres could have cascading effects up the food chain over the longer-term.
- It is currently poorly understood what the economic impact of microfibre pollution is on related industries. As consumers become more aware of the contamination of their seafood and the potential health implications of microfibre exposure, fishing or other food industries could be adversely affected.

Exhibit 7: Observed effects of microfibre exposure on organisms and humans

Effects on organisms
Reduced growth, reproduction and survival of water fleas and amphipods[11]
Gut blockages and nutritional deficiency in fish[12]
Reduced feeding in mussels, worms, and crabs[64]
Reduced growth in crabs[65]
Toxicity and mortality in zooplankton[10]
Translocation to organs after consumption in crabs[66]
Toxicity and endocrine disruptions[64]

Effects on humans
Respiratory complications, including obstructive lung disease[13]
Endocrine disruption and cancer (from bisphenol A (BPA))[67]

Pathways and problem drivers

Textiles and apparel contribute to microfibre pollution through their entire lifecycle: while being manufactured, while being used (washed and dried), and after they are disposed of (Exhibit 8).[14] The main pathways for microfibres into the environment are generally understood to include:

- Wastewater releases from textile manufacturing and laundering;
- Atmospheric releases from textile manufacturing, laundering, and other textile use;
- Terrestrial releases from improperly disposed textiles and geotextiles that disintegrate into the earth, releasing microfibres directly into the soil.

The relative contribution of each of the above pathways into the environment is not well understood, as fibre shedding during the use phase, and washing in particular, appears to be more researched than that during manufacturing and end of life treatment. The contribution of synthetic microfibres also appears better researched compared to that of natural ones (Exhibit 8).

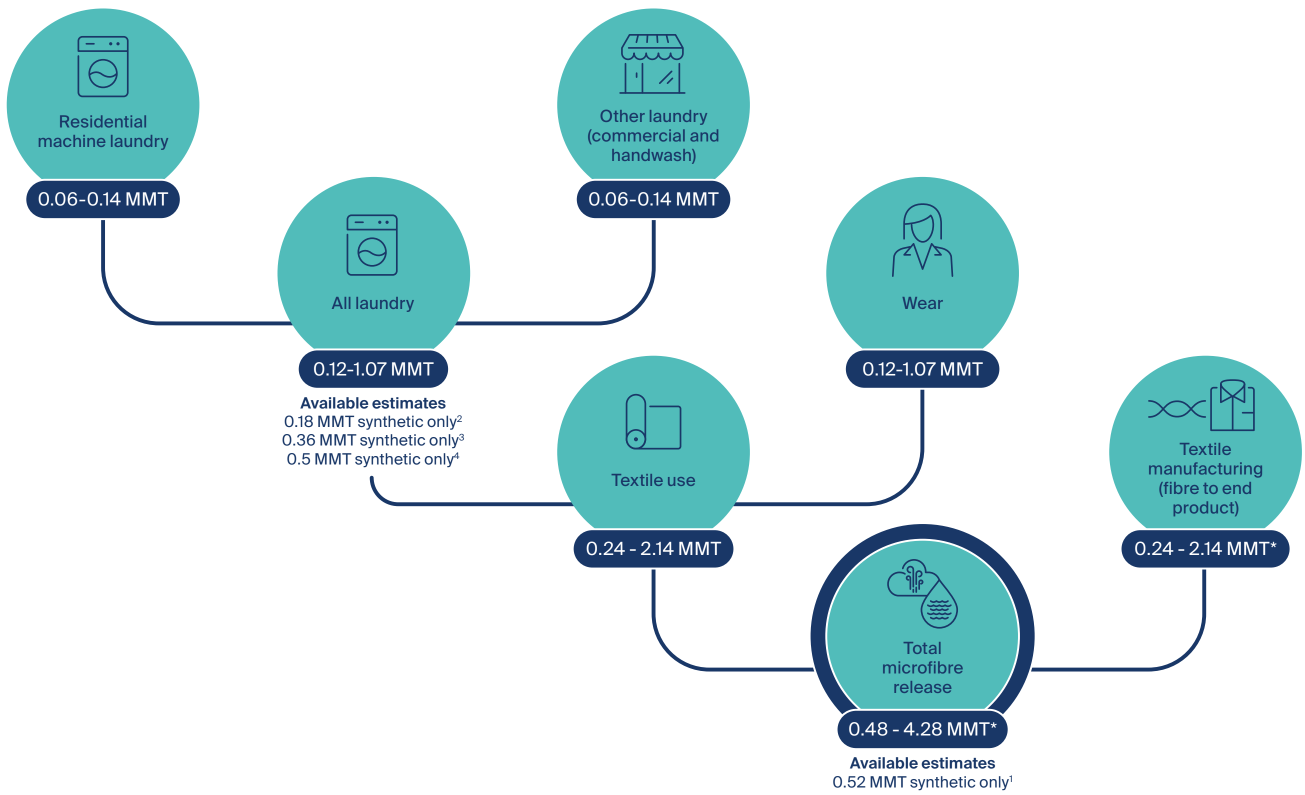
Thus, further research on microfibre shedding potential along the entire textile lifecycle would facilitate the identification and adoption of effective pollution prevention interventions. Whether they are released through wastewater, onto the land or directly into the air, microfibres could eventually transported to the ocean, similarly to other debris. For example, as rivers eventually flow into the ocean, they are the main pathway by which plastic waste enters the ocean. Indeed, 10 rivers around the world have been shown to carry more than 90% of the plastic waste that ends up in the ocean.[68]

Despite scarce quantifiable data in some areas, there are specific problem drivers associated with textiles that are known to drive microfibre pollution. Understanding and addressing these problem drivers presents an opportunity to make a strategic impact in efforts to curb microfibre pollution. These drivers include:

- The textile manufacturing process
- Textile maintenance and use
- Textile composition and weave
- Wastewater treatment

Exhibit 8: Internally estimated microfibre release through the textile lifecycle (synthetic and natural fibres)

Where available, estimates from existing literature are also shown



Source: 1) Boucher & Friot (2017); 2)Belzagui et. al (2020); 3) Gavigan et. al (2020); 4) Ellen MacArthur Foundation (2018); Refer to Appendix 1 for calculation details; *Estimates range excludes one outlier estimate of over 10MMT

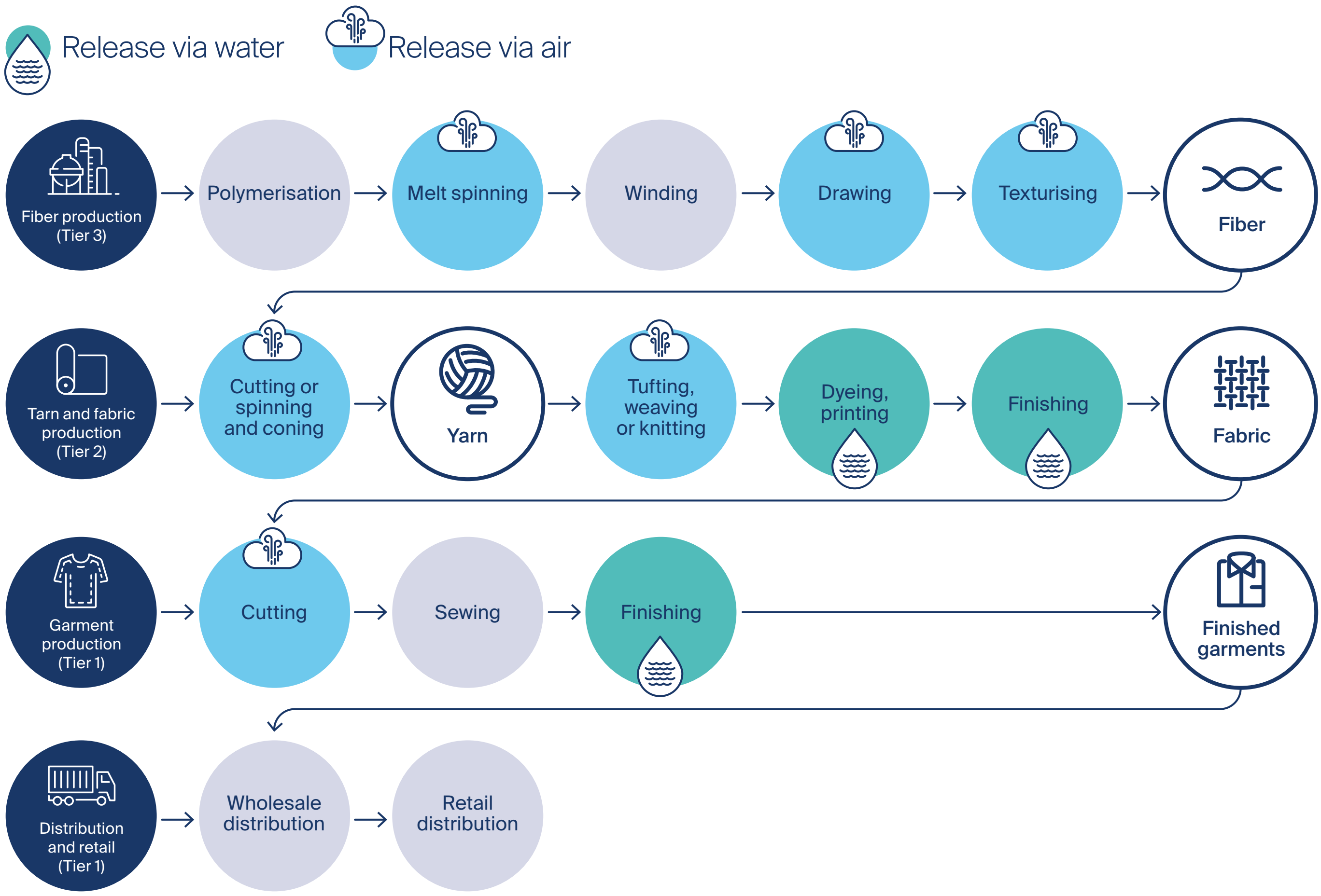
Textile manufacturing

Various stages of textile production, from fibre to garment production, release microfibres due to the abrasive processes associated with dyeing, printing, and finishing textiles[15] (Exhibit 9).

The microfibre losses from textile production are generally unknown, however, it is possible that these losses are even higher than microfibre releases from textile maintenance and use.[15,16] Another estimate suggests that 10% to 15% of textile mass is lost during the apparel production process.[1] This would represent around 10-16MMT of loss for 2020 (based on 109 MMT global fibre production for 2020[3] (Exhibit 8 and Appendix 1).

However, it is important to note that not all of these microfibres would be released into the environment, as a proportion of them could be captured during the manufacturing process (e.g. through air filtration).

Exhibit 9: Simplified supply chain for textile manufacturing



Source: Adapted from The Nature Conservancy & Bain & Company (2021)

Pathways and problem drivers

Textile maintenance and use

Textile maintenance (washing and drying) contributes to microfibre pollution because as fabrics are washed and dried, microfibres become detached from fabrics due to chemical and mechanical abrasion.[17] The microfibres are then rinsed from the textiles and discarded in wastewater or emitted into the air, in the case of dryers.

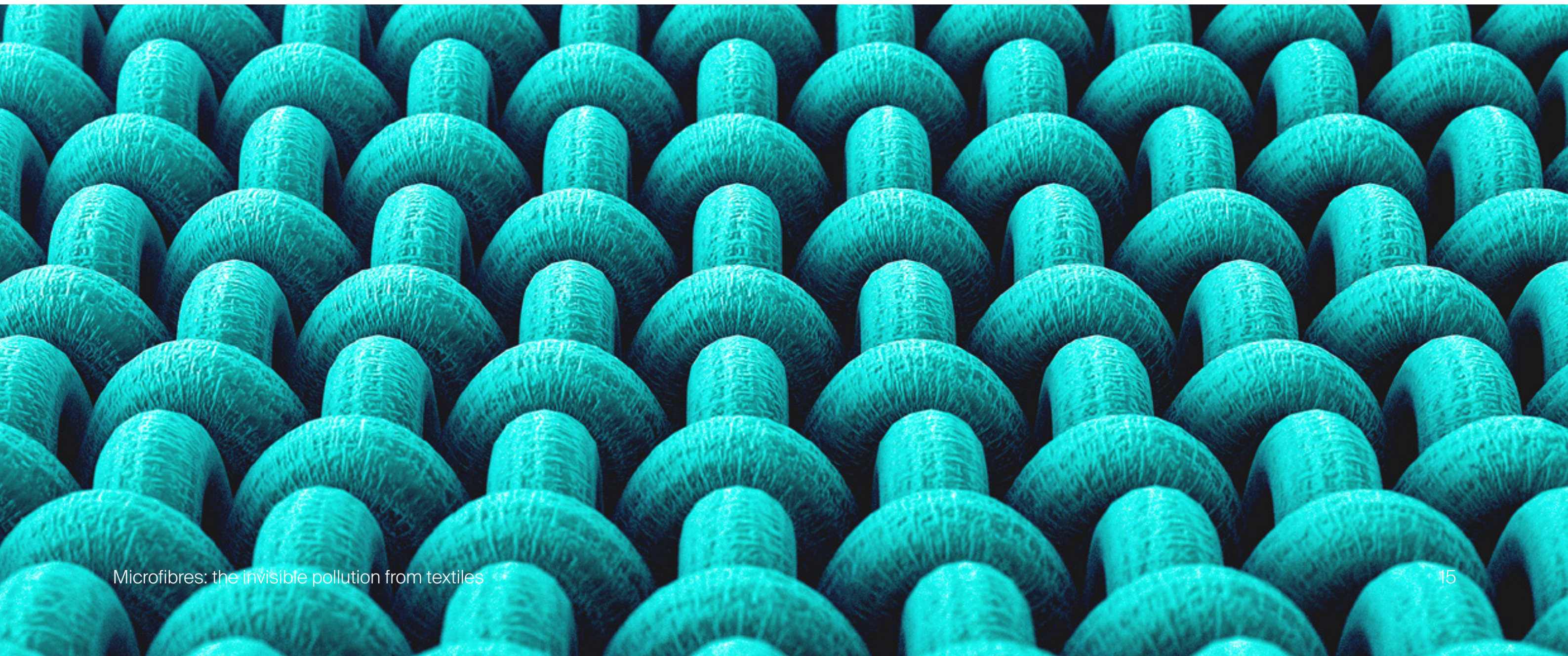
The number (and volume) of microfibres that is released with every load of **laundry** varies widely and depends in part on the contents of the wash. The estimates of the total number of microfibres produced per wash range from 700,000[18] to 1.5 million[17] to 7 million.[69] In terms of volume, approximately 0.5-1.3 grams of microfibres are expected to be released in every wash[19] and the average household in North America, for example, releases approximately 135g of microfibres from laundry every year.[9] Estimates of global synthetic microfibre release from washing clothes range from 0.18 MMT[70] to 0.36 MMT[1] to 0.50 MMT[38] annually. We further estimate that synthetic and natural microfibre release from laundry could be in the range of 0.12-1.07 MMT annually (Exhibit 8 and Appendix 1).

Some of the factors that enhance microfibre loss during washing include:

- The use of powder detergent[21,71]
- The use of top-loading washers[72]
- Drying clothes using tumble dryers[73]

In addition to laundering, **textile use** also leads to microfibre shedding. Although most studies on microfibre shedding have focused on microfibre loss during washing, it has been suggested that textiles may shed as many microfibres when they are being worn as when they are being washed.[20] For example, a study estimated that between 3-10 metric tonnes of microfibres would fall on an urban area the size of Paris every year via atmospheric deposition.[74]

Garment age may also have an impact on shedding rates depending on the composition of the garment in question. For example, researchers have found that aging may increase shedding rates in certain blends but decrease them in others.[17,21]



Textile composition and weave

Different types of textiles and fibres shed microfibres at different rates, meaning some types of textiles contribute to microfibre pollution more than others.

Textile composition affects shedding rates because natural fibres, such as cotton and wool, tend to shed more than synthetic ones[17] and among the synthetic and semi-synthetic textiles, polyester typically sheds more than nylon[69,75] (Exhibit 10).

Textile weave also has a considerable effect on shedding rates, as fabrics with a greater number of exposed filaments, such as fleece, tend to shed more compared to those with fewer exposed filaments[17,21] (Exhibit 11).

Exhibit 10: Shedding rates across major textile categories

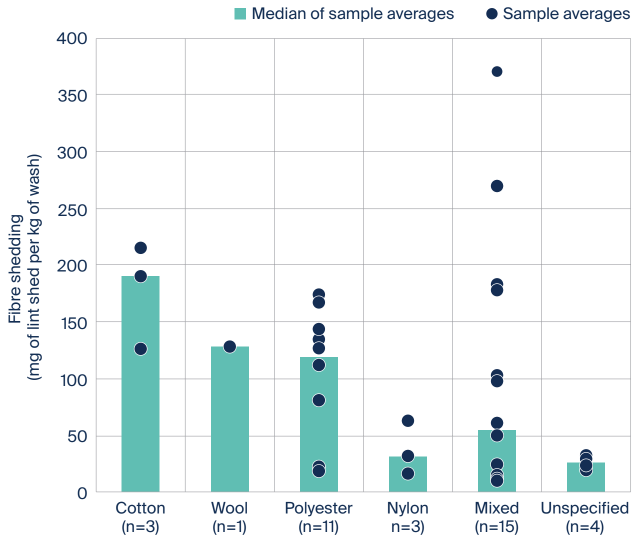
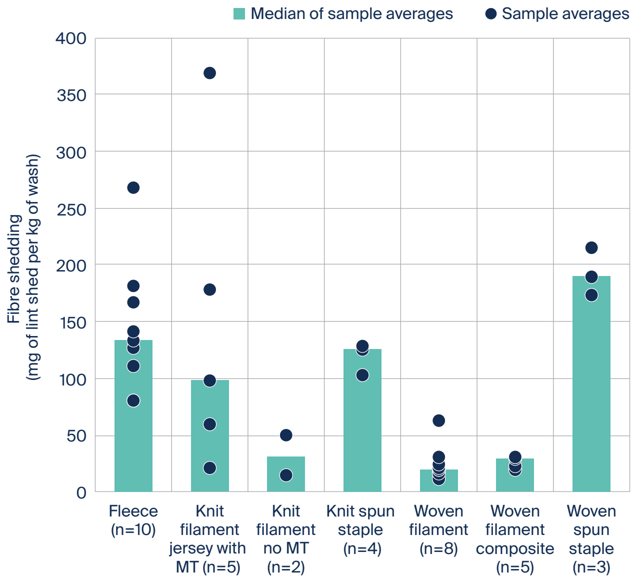


Exhibit 11: Shedding rates across textile weave patterns



Source: Vassilenko et al. (2021).

Individual sample data depicts the average weight of lint over three laundry washes. Standard deviations are not pictured but vary between 1% and 61% for all samples. Category medians are calculated based on averages for the samples within a given subcategory. Two outlier samples are excluded from both the chart and the calculation of the category medians (Exhibit 10 - polyester (778 mg lint/kg wash) and mixed fabrics (838 mg lint/kg wash) and Exhibit 11 - fleece (778 mg lint/kg wash) and knit spun staple (838 mg lint/kg wash)).

Wastewater treatment

Residential and commercial wastewater can be sent to wastewater treatment plants for processing before the decontaminated effluent is released back into the environment. Therefore, wastewater treatment can act as a barrier for microfibres, but its effectiveness as a barrier depends on a number of factors including:

- Connectivity to wastewater treatment infrastructure;
- Capture efficiency of microplastics, including microfibres;
- Application of sludge to agricultural lands.

Connectivity to wastewater treatment infrastructure

Less than a third of the human population is connected to wastewater management infrastructure,[22] and an estimated 80% of wastewater globally is released to the environment without sufficient treatment.[23]

Therefore, in many cases there is no mechanism to remove waste products from effluent before it reaches the environment.

Capture efficiency of wastewater treatment processes

Although modern wastewater treatment processes were not designed to filter out small buoyant particles,[19,26–28] the capture efficiency of WWTPs is relatively high, often higher than 90%.[19,24,25] However, given the large volumes of wastewater that these plants process, the resulting volume of microfibres entering the environment from WWTP effluent can still be large.

WWTPs typically have primary, secondary and tertiary treatment processes, although this depends on the location of the plant and the intended end use for the treated water.[29,76] Microparticles, such as microfibres and microplastics, appear to mostly be removed during primary treatment (the sludge settling and skimming processes).[76]

- **Primary stage:** the removal of heavy solids, large materials, and buoyant compounds through course screening, and the removal of settleable compounds by sedimentation;
- **Secondary stage:** the removal of residual organics and suspended solids using aerobic biological treatment processes;
- **Tertiary stage:** the removal of metals, chemicals and dissolved solids.

Application of sludge to agricultural lands

Removing microfibres from wastewater effluent by sequestering them in sewage sludge does not necessarily prevent them from entering the environment. This is because sewage sludge, a semi-solid by-product from wastewater treatment that is high in nutrients, is frequently applied to agricultural lands in North America and Europe as fertiliser.[26,29]

The sludge could be also incinerated, sent to landfill or added to cement, with varying degrees of success in retaining microfibres.[27] For example, roughly 93% of the WWTP sludge produced in the UK is applied to agricultural or other lands, while 4% is incinerated and 3% is used in industry.[77] In addition, untreated or minimally treated wastewater can be used in irrigation, also leading to the application of microfibres and other contaminants to terrestrial systems.[5,29]

Interventions

This section provides an overview of the key opportunities for **policymakers, industry and investors** to address and reduce microfibre pollution.

While technology to remove microfibres directly from the environment is emerging,[30] this process is generally considered very inefficient as fibres are microscopic, lightweight, and very widely dispersed in diverse, complex ecosystems.

Therefore, the most efficient opportunities for action focus on solutions at source – i.e. preventing microfibres from entering the environment to begin with (Exhibit 12).

Policymakers are key enablers of microfibre pollution reduction, as they can create incentives and opportunities for industry to scale up action. Relevant policy tools include setting standards and regulations, fostering innovation by providing funding for research and development, providing financial incentives for action through economic instruments, running public awareness and educational campaigns and convening key players.

In terms of **industry**, textile and clothing manufacturers and apparel retailers represent some of the most important industry players. As key contributors to the microfibre pollution externality, these industries will be at the receiving end of policy interventions. In addition, industries involved at key leverage points, such as washing machine manufacturers and wastewater treatment providers, are also implicated in microfibre pollution interventions.

Finally, **investors** can engage and influence corporate responses to microfibre pollution. Investors may be driven by risk management in anticipation of policy intervention, by an incentive to take advantage of economic opportunities, or by moral imperatives. Where regulatory response is lacking, investor influence could help speed up the efforts required to effect large-scale change.

Exhibit 12: Summary of available interventions by action group

Intervention	Intervening group		
	Policymakers & Regulators	Industry	Investors
1. Regulate textile shedding rates	Test and approve industry-developed standards	Partner with research groups to develop the standard	Engage with textile and garment value chain to: 1) adopt shedding rate standard; 2) encourage pro-active reduction of fabric shedding Understand economic impact on the value chain from potential wide-reaching shedding rate regulation (e.g. R&D costs, increased value chain costs)
	Set a maximum textile shedding rate	Engage in voluntary initiatives to self-regulate shedding rates	
	Place a levy on higher emitting products		
	Require the shedding rates of different textiles to be disclosed on the product label		
2. Curb microfibre loss during textile manufacturing	Require industry to adopt relevant best practices to minimise microfibre loss	Implement practices during fabric and garment manufacturing to curb microfibre loss	
3. Use microfibre filters on washing machines	Pass legislation requiring all new laundry machines include a microfibre filter	Develop new product lines with filters or retrofit existing washing machines	Engage with washing machine manufacturers to encourage product development and commercialisation
4. Improve microfibre retention at wastewater treatment plants	Implement tertiary and quaternary treatment stages in existing WWTPs or build WWTPs where they do not currently exist. Given the capital intensity of such initiatives, those are largely to be driven by government and regulatory bodies.		

Intervention 1: Regulate textile shedding rates

Depending on the effectiveness of the measures taken, the reduction of shedding rates is perhaps the most powerful pollution control approach as it tackles pollution at its source. Therefore, even marginal improvements in shedding rates could have meaningful impact.

There is currently **no single, standardised testing methodology** for determining the microfibre shedding rates of different textiles and this **has been a major barrier to both regulatory and voluntary action**. Without a standard method to measure shedding rates, a policy requirement is unlikely to be set or monitored. Therefore, developing a standard shedding rate testing methodology is a necessary prerequisite to enable policy response.

There are already a handful of industry-led efforts to develop such a standard, including those by The Microfibre Consortium (TMC), the European Cross Industry Agreement (CIA) and The American Association of Textile Chemists and Colourists (AATCC). In particular, the CIA is now working with the European Committee for Standardisation (CEN) to turn their method into a CEN standard and subsequently into an ISO standard.[98] In summary, such a standard would enable:

- Policymakers to regulate shedding rates;
- Textile and apparel manufacturers to measure their microfibre footprint using an accepted methodology;
- Investors to benchmark the performance of companies, and to engage with companies on the topic of microfibre pollution.

Once a common standard exists, **policymakers** have a number of available tools:

Setting a maximum allowable shedding rate through legislation

This type of regulation would require textile manufacturers and retailers to only place products on the market that meet a set textile shedding criteria. This approach therefore has the potential to effectively prohibit certain types of textiles from manufacture and sale, such as certain fleeces, jerseys, natural textures, and blends.[69]

At the time of writing this report, no such regulation appears to have been proposed, so it is difficult to gauge the likelihood and reach of such regulatory action. It is possible that this is because of the lack of a standard shedding rate methodology. We have yet to see if the removal of this barrier would pave the way for such regulatory response.

Placing a levy on higher emitting products

This type of regulation may incentivise consumers to purchase products with a lower microfibre shedding rate. It may also incentivise retailers to sell products with lower shedding rates to remain competitive.

Such levies have been suggested, but not implemented. For example, the UK Environmental Audit Committee has called for a 1p levy per garment at the point of sale.[99] Levies on consumer goods, especially fundamental ones such as clothing, may be politically unpopular and therefore difficult to implement. Also, the consumer response would ultimately depend on the materiality of the levy to the consumers' expenditure.

Label product shedding rates

Instead of limiting product choice on the market, another option is to legally require textile and apparel retailers to disclose product shedding rates through labels. This type of regulation would theoretically direct environmentally conscious consumers away from garments that shed excessive amounts of microfibres.

Several jurisdictions have attempted to pass such laws. For example, The California State Assembly put forward a bill (California's Assembly Bill AB 2379) in February 2018 which from January 2020 would have prohibited the sale of all garments containing >50% polyester unless the following warning was attached: "This garment sheds plastic microfibres when washed. Hand washing recommended." The bill did not pass 3rd reading and is considered dead.

At the time of writing this report, there was no labelling regulation in force and it is difficult to evaluate likelihood and speed of potential regulatory response. The effectiveness of such measures in preventing microfibre release is uncertain, as these measures would largely rely on consumer awareness and related changes in purchasing decisions.

Intervention 1: Regulate textile shedding rates

Fibre and textile manufacturing, as well as **apparel retail industries**, would be on the receiving end of the above regulation and standardsation of shedding rates. At present, the two most widely produced fibres are polyester and cotton (Exhibit 13), both of which tend to have relatively high shedding rates (Exhibit 10). Textile manufacturers who are unable to find low-shed replacement materials for their products may lose market share if shedding rates are capped. Thus, industry at large could work to develop low-shed textiles.

There does not appear to be evidence that reducing the shedding rates of different fabrics would result in the fabric losing other commercially desirable qualities. On the contrary, textiles that show reduced microfibre shedding rates are expected to maintain their integrity and shape for longer, as they lose less material during normal wear and tear.

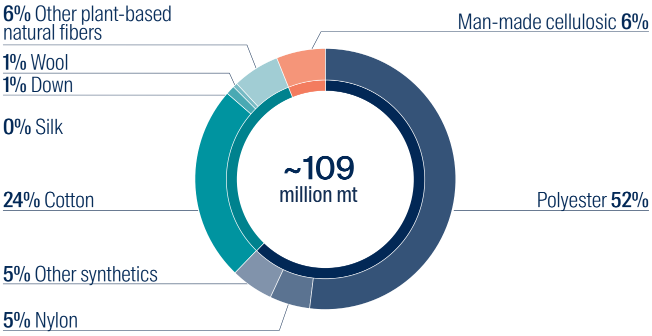
Low-shed textiles are already on the market. For example, the apparel company Polartec has developed a high-performance fabric that is similar to fleece but which sheds 5 times less than ordinary fleece.[78]

Our research was unable to determine if reduction of shedding rate increases the cost of production and if that could impact industry margins in case costs were not passed onto consumers.

Depending on materiality or environmental impact considerations, investors could seek to understand their exposure to potential regulatory response and proactively engage with industry to reduce microfibre pollution.

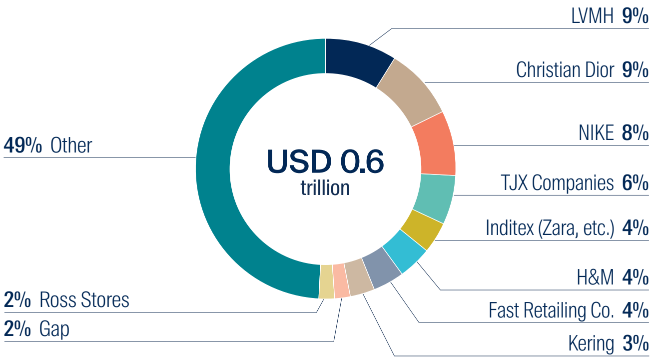
The textiles and apparel industry is relatively concentrated, with the top 10 companies accounting for around 50% of the market share, based on revenues (Exhibit 14). Therefore, targeted engagement has the potential for substantial impact. The industry is also concentrated geographically, with retailers headquartered in France and the US accounting for almost 65% of that investable universe (Exhibit 15).

Exhibit 13: Global fibre production in 2020



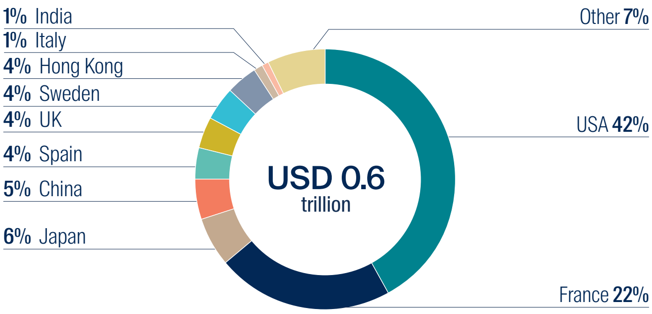
Source: Textile Exchange (2021).

Exhibit 14: Top 10 apparel retailers based on revenue



Source: Factset, as of November 2021
Companies in the Apparel/Footwear and Apparel/Footwear Retail industries based on Factset industry classification; companies with market capitalisation of over USD 1 billion only.

Exhibit 15: Geographic spread of apparel retailers based on revenue



Source: Factset, as of November 2021
Companies in the Apparel/Footwear and Apparel/Footwear Retail industries based on Factset industry classification; companies with market capitalisation of over USD 1 billion only.

Intervention 2: Use microfibre filters for laundry machines

The installation of microfibre filters on washing machines could reduce the release of microfibres into the environment, as filters would intercept microfibres before they reach wastewater.

Filtration technologies already exist and costs to consumers do not appear to be prohibitive (Exhibit 16). The installation of such technologies would be important:

- In the medium term, until shedding rate regulations become more widely introduced; and
- In the longer term as zero-shed fabrics have still not been developed.

The long-term efficiency of this measure to prevent microfibre pollution would be driven by:

- The capture efficiency of the available technologies, as the efficiency of available technologies averages around 50% (Exhibit 16). However, the effectiveness of filter technologies appears to be superior to in-drum devices;
- The scale of adoption, as filtration technologies would need to be adopted globally to have a substantial effect;
- The treatment of captured microfibres, as this approach relies on consumers to appropriately dispose of the captured microfibres by depositing them in the trash instead of washing them down the sink.

Based on the above, a 50% reduction in microfibre release from residential laundry could account for between 25-71 million kg of microfibres per year (Appendix 1).

While consumers can already buy microfibre filters, it is up to **policymakers** to mandate their wider adoption, either through minimum product standards requiring filtration technology to be installed, or through product labelling to facilitate informed consumer choice. It is possible that product specification requirements would be more effective as they would not rely on consumer awareness and choice. Below are examples of existing and proposed legislation and policy relating to microfibre filters:

- France includes in its 2020 Circular Economy Law a requirement that by 2025, all new washing machines sold domestically must be able to filter out microfibres;
- A bill (the Microplastic Filters (Washing Machines) Bill) was tabled in November 2021 in the UK House of Commons that if passed into law would require washing machine manufacturers to fit microplastic-catching filters to new domestic and commercial washing machines.[79]
- Australia announced in March 2021 with its National Plastics Plan that it intends to work towards an industry-led phase-in of microfibre filters on all new washing machines by 2030;[100]
- California's State Assembly has proposed bill AB-802 on microfibre pollution, which would require microfibre filtration in laundry facilities. At the time of writing this report, this bill is still in committee.

Exhibit 16: Examples of existing devices for capturing microfibres produced domestically

Type of device	Examples	Approximate cost	Effectiveness (given by Napper et al. 2020)	Manufacturer reported effectiveness
In-drum devices (for laundry)	Cora Ball	£22	31%	31%[79]
	GuppyFriend washing bag	£26	54%	86%[80]
	Fibre Free (not currently available for individual sale)	Not available	Not available	40%[81]
	Eleanos Reusable Floating Net Bags	£6	Not available	Not available
External (add-on) filters (for laundry)	Xfiltra (not currently available for residential use)	Not available	78%	78%[82]
	Lint LUV-R filter kit + wall mount	£112	29%	65%[80]
	MicroPlastics LUV-R	£156	Not available	87%[83]
	Planetcare	£9	25%	90%[84]
	The Microfibre Filter (Girlfriend Collective)	£32	Not available	90-99%[85]
Tap water filters	Filtrol	£100	Not available	89%[86]
Laundry machines with built-in filters	GRUNDIG FibreCatcher Washing Machine	£500	Not available	>90%[87]

Intervention 2: Use microfibre filters for laundry machines

Some **industry** participants have already tapped into the demand from environmentally aware consumers by providing various technological solutions (Exhibit 16). For example, the manufacturer of the microplastic laundry filter Lint LUV-R reports that over 7,500 units have been sold since 2001.[88]

Gaining a better understanding of microfibre loss hotspots in the supply chain can also help companies identify opportunities to participate in the growing market of products designed to reduce or combat microfibre pollution. The cost to industry of this type of action would be associated with the changes to product design and the manufacturing process, as the filtration technology already exists. While there is one known manufacturer who sells machines with integrated filters at a cost-competitive price, this suggests a relatively level playing field for manufacturers (Exhibit 16).

Requiring all commercial washing machines to be retrofitted with microfibre filters would pose a similar barrier, further complicated by the need to enforce said regulation as the responsibility for implementing this change would likely fall on the owners of the commercial enterprises. While regulatory and industry response may appear relatively slow, **investors** could encourage faster voluntary actions by washing machine manufacturers. Such actions include:

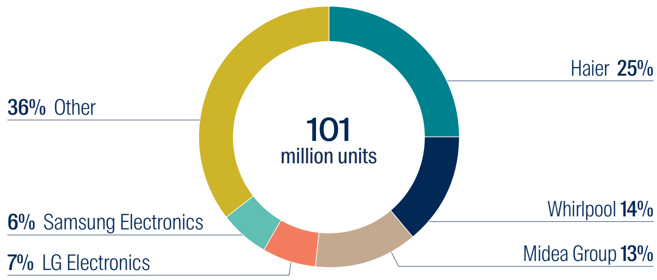
- Adding microfibre filters to existing products or offering new products that include filters;
- Designing and selling add-on filters that can be retrofitted to existing products;
- Investing in research and development to design ultra high-efficiency microfibre filters, given that no filter on the market can currently capture 100% of microfibres.

Given that regulation requiring washing machine filters already exists, engagement in this area could also be beneficial for investors from a risk management perspective. There could be a risk of regulation, as relatively fast regulatory responses have been seen with respect to similar issues (e.g. the global regulatory response to microbead pollution[89]).

The global washing machine manufacturing industry is relatively concentrated, with 5 companies accounting for over 60% of global production (Exhibit 17).

While this concentration implies a corresponding concentration of regulatory risk exposure, it also suggests that engagement with the industry could have impact at scale.

Exhibit 17: Market share of washing machine manufacturers



Source: Tadviser. (2021). Washing machines (global market)

Examples of investor engagement programmes led by Asset Managers

In 2020, the asset manager First Sentier Investors (FSI) started leading an institutional investor engagement group to engage with the manufacturers of domestic and commercial washing machines to fit microfibre filtration technology to their products as a standard feature by the end of 2023. FSI started the programme due to the slow adoption of microfibre filtration technology in the washing machine industry. The engagement group was established with the support of researchers at the UK Marine Conservation Society (MCS).

Thirty investors globally are already involved in the initiative and are engaging directly with manufacturers and their trade associations to this end. Initial engagements demonstrate that while some manufacturers are willing to take leadership on this issue by adding microfibre filters to their new machines, others will require policy cues to take substantive action. For more information, see https://www.firstsentierinvestors.com[97]

Intervention 3: Curb microfibre releases from textile manufacturing

Research on microfibre release during the production phase is scarce, but some existing estimates suggest that this could be even greater than release during the use phase[15,16] or as high as 10-15% of input fibre.[1] The implementation of industry best practices known to reduce microfibre shedding could have a meaningful impact on the microfibres lost during textile and apparel manufacturing. The OECD reports that changing the design and manufacture of textiles and garments can decrease shedding rates by up to 80-90%.[90]

As microfibre release during manufacturing is less well researched so far, initial actions are likely to be **industry-led** and follow existing best practices known to reduce shedding:

1) Identify microfibre release points during the manufacturing process;

2) Identify existing practices and processes that could reduce microfibre pollution during production at these release points, such as:[21,38]

    - Prewashing garments
    - Installing vacuum exhaustion
    - Using ultrasound cutting techniques
    - Applying non-shed coatings (to the extent those do not present additional environmental concern)
    - Reducing brushing

3) Implement relevant practices internally and promoting their use among peers;

4) Develop a publicly available inventory of microfibre reduction best practices for the entire supply chain, such as that by Operation Clean Sweep for preproduction plastic pellets.[91] This inventory could be updated as technology and data collection processes improve.

Role of policymakers: While industry can voluntarily adopt the practices described above, regulators can also require that industry adopt relevant practices or best available technology (BAT). For example, the US Clean Water Act refers to best practices with respect to wastewater treatment and toxic pollutants and the US Environmental Protection Agency has used this in reference to permit regulations.[92] Similar policy could be implemented to scale up the adoption of BAT designed to control microfibre pollution.

At the same time, **investor-led** engagement could encourage:

- The collection of robust life cycle data on the microfibre loss associated with products;
- The adoption of existing best practices across supply chains to minimise microfibre loss during textile and apparel manufacturing;
- The setting of targets and commitments relating to the management of microfibre loss in supply chains. This could include quality and durability standards for fibre length and shedding rates and commitments to only produce products that are below a certain threshold shedding rate.

Microfibre loss risk assessment tool for textile manufacturers

To help companies in the textile value chain identify microfibre hotspots in their production processes and product lines, the UK-based international wildlife conservation organisation Fauna & Flora International (FFI) is developing a risk assessment tool to help companies to pinpoint high risk processes that increase the danger of microplastic fibre loss to the environment.

The tool will include simple, practical steps that companies can take to understand potential sources of microplastic fibre pollution within their operations. The tool is being built for companies of all sizes and at all stages in the manufacturing chain, including those who are less familiar with the issue. It will also include potential solutions for identified areas of risk and links to best practice guidance published by other industry-led initiatives, where applicable.

As a first step towards tackling this issue, the risk assessment tool will complement both the ongoing innovation in garment and fabric design and efforts to minimise microplastic fibre loss during washing. The tool is slated to be released publicly in 2023. For more information, please contact info@fauna-flora.org.

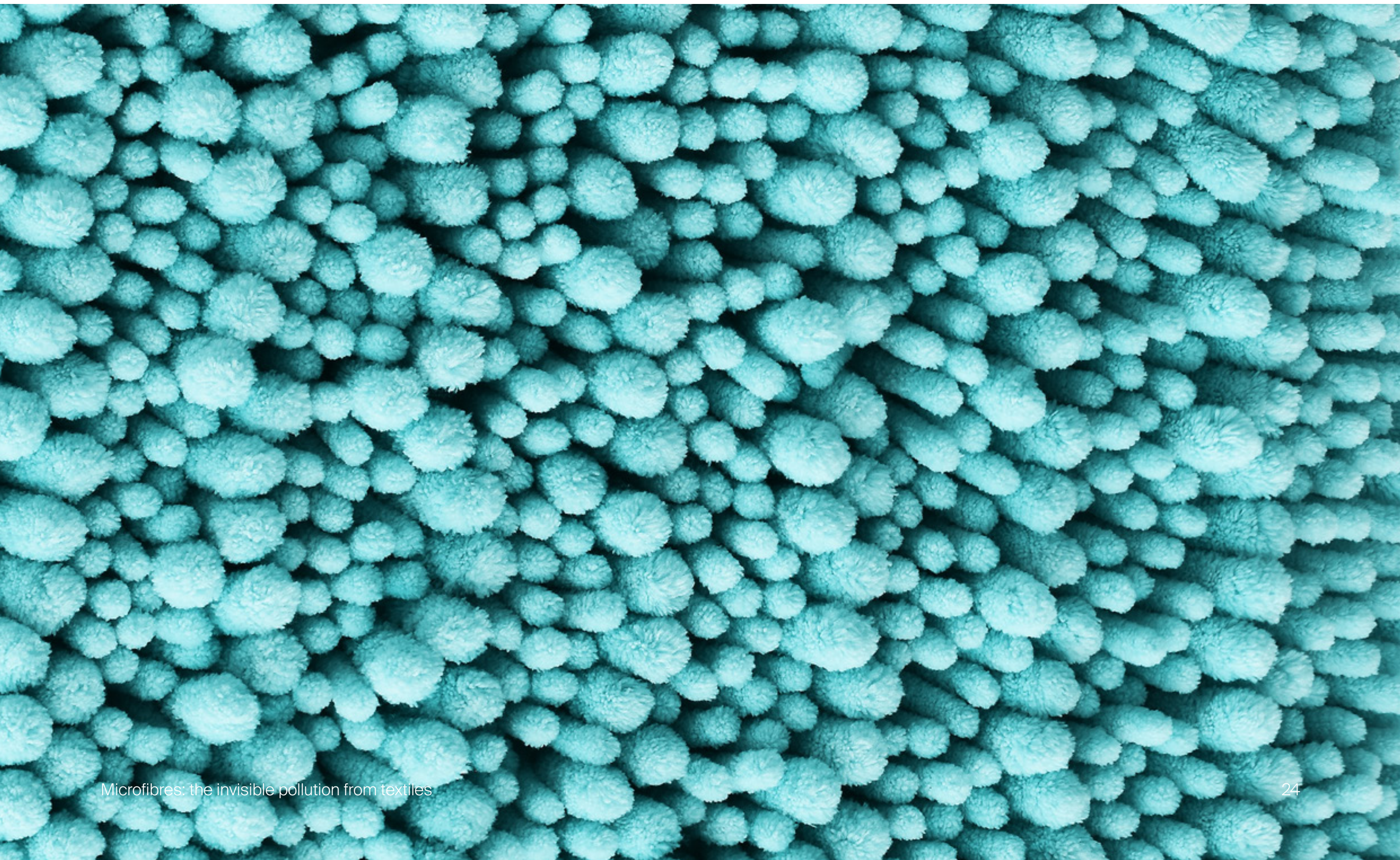
Intervention 4: Improve microfibre retention during wastewater treatment

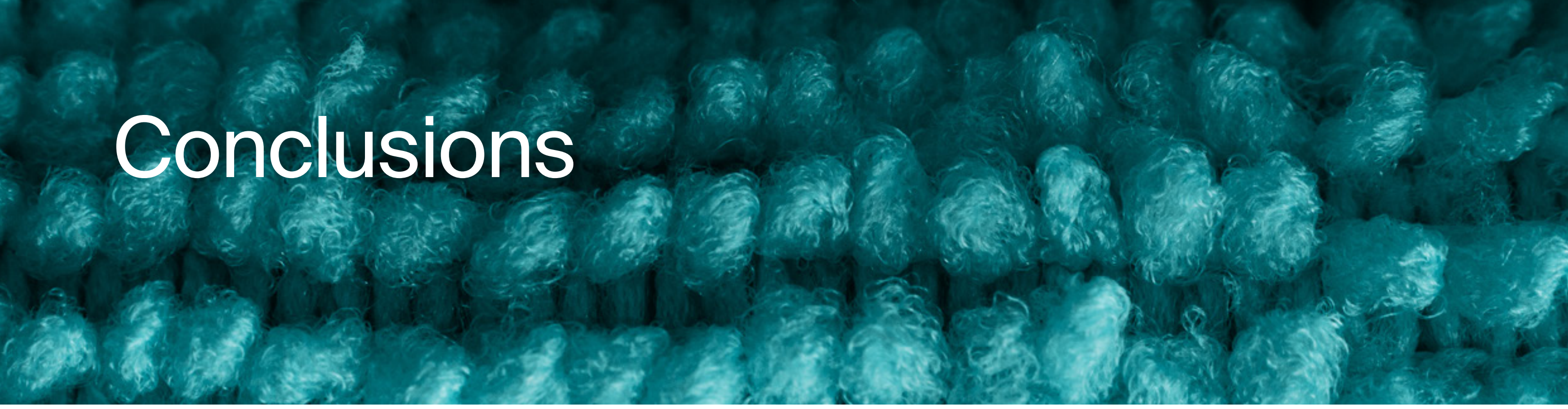
Expansion or improvement of wastewater treatment infrastructure is another potential approach for reducing microfibre pollution, although it could be the least effective solution due to a number of considerations:

- Large-scale infrastructure solutions are typically very expensive;
- The incremental benefit in microfibre capture rate could be minimal, given the already high effectiveness of existing infrastructure (often over 90%);
- Captured pollutants are still reintroduced to agricultural soils via sludge, as this is still a valuable circular economy product and so will likely continue to be so.

All of those considerations create additional incentives to address microfibre loss further up the value chain. Nonetheless, we note that expanding wastewater treatment connectivity would have much wider environmental and health benefits due to the fact that approximately the two thirds of the global population currently does not have access to such infrastructure.

Given the size of capital investment costs for infrastructure expansion and renewal, such initiatives and decisions are largely in the remit of government and regulatory bodies, and investors may have limited ability to influence and contribute.





Conclusions

The vast and growing problem of microfibre pollution has been gaining attention over the past decade. Even though research on the implications of microfibre pollution and exposure is still in its infancy, the available findings to date indicate negative repercussions for both humans and ecosystems.

Ultimately, there is no silver bullet solution for addressing microfibre pollution, as there will likely never be a zero-shed fabric and no existing solution has 100% effectiveness or a strong likelihood of large-scale adoption in the absence of regulation. Even with regulation, it is likely to be some time before substantial reduction is seen in the volume of microfibres entering the environment. Therefore, it will take a combination of approaches that are deployed simultaneously, with actors from all sides pushing for change, to adequately address the issue of microfibre pollution.

Therefore, there are important roles for industry, policymakers and investors in driving forward change on this issue. Some of the most important first steps include:

- **Developing a measurement standard:** A critical first step is the creation of a government and industry-approved standard for measuring the microfibre shedding rates of textiles. From here, companies and policymakers alike can consistently measure shedding rates, paving the way for a common understanding of what fabrics and processes contribute the most to microfibre pollution.

- **Taking policy action:** Policymakers are encouraged to set national action plans for tackling microfibre pollution to provide direction and timelines for industry regarding regulatory action.

- **Setting commitments:** Industry members and associations are encouraged to set commitments and targets relating to microfibre pollution, especially with regard to adopting best practices and gathering data to better understand microfibre hotspots in their supply chains.

- **Conducting research:** Policymakers and industry alike are encouraged to participate in ongoing research efforts directed at understanding how microfibres interact with and affect human health and the planet, especially with regard to their persistence in the environment, their ability to leach contaminants, and the physical affects they have on our bodies.

- **Engaging with industry:** Investors can engage and influence corporate responses to microfibre pollution. Where regulatory response is lacking, investor influence could help speed up the efforts required to effect large-scale change.

Appendix 1: Internally derived estimates

Due to the limited data on microfibre release through the textiles lifecycle, this paper has made an attempt to consolidate and further develop the available estimates. The input sources and calculations are presented below. This work should be considered only as an attempt to provide context. We note that it uses a variety of input sources, which may not be fully complementary or aligned to each other, as well as a number of simplifying assumptions. Due to the data gaps, the variety of sources and the varying degree of overlap and coverage, the internally derived estimates could not be considered complete. Hence, these calculations should be considered in the context of their limitations.

Summary of input data

Available estimates on microfibre release

- 0.52MMT, through entire lifecycle, synthetic microfibres only[22]
- 0.18MMT, during laundry, synthetic microfibres only[70]
- 0.36MMT, during laundry, synthetic microfibres only[1]
- 0.5MMT, during laundry, synthetic microfibres only[38]
- Microfibre release during manufacturing could be higher than that during the use phase,[16] assumed to relate to both synthetic and natural microfibres.
- 10-15% of textile mass could be shed during manufacturing phase.[1] We understand this estimate to relate to both synthetic and natural microfibres.
- 0.5-1.3g of microfibre release per wash cycle.[19] We understand this estimate to relate to both synthetic and natural microfibres.
- Microfiber release during wear could be as high as during washing.[20] We understand this estimate to relate to both synthetic and natural microfibres.

Other data used

- 840 million washing machines in use globally[17]
- 130 loads per household per year[93]
- Natural fibre production as a percentage of synthetic fibres production in 2020 = 61% (2020 global fibre production from natural sources, including plant-based sources, of 41MMT as a share of global fibre production from synthetic sources of 68MMT → 41MMT/68MMT = 61%[3])
- Natural fibre production as a percentage of synthetic fibres production cumulative for the period 1975-2020 = 114% (cumulative global fibre production from natural sources, including plant-based sources, for the period 1975-2020 as a share of global fibre production from synthetic sources for the same period, estimated based on 5-yearly data, assuming equal CAGR for the years where annual data is not available[3])
- 109MMT global fibre production in 2020[3]

Assumptions and calculations

1. All synthetic-only estimates are converted into totals, synthetic and natural, following:
    a. Estimate shedding from natural textiles – multiply the synthetic-only number by 61% and 114% (the proportion of natural fibre production as a share of synthetic fibre production). Neither number – 61% annual for 2020 or 114% cumulative for 1975-2020 – is ideal, as many textiles would likely remain in use for over a single year, but equally few would be in use for over 30 years. Nonetheless, using both approaches could give an approximate range.
    b. Sum available numbers for synthetic-only microfibre release and estimated range for natural microfibre release.
    c. Limitation: For simplicity, the above calculation assumes that shedding rates between synthetic and natural textiles are similar. However, there is some evidence that the dominant natural fibre – cotton, could shed almost 50% more than polyester.[69,75] Hence, our assumption could produce an underestimate.
2. Microfibre release during the wear phase is assumed to equal the estimated release from washing.[20]

Appendix 1: Internally derived estimates

3. Estimated microfibre release during the use phase is assumed to equal the estimated release from laundry and wear.

4. Estimated microfibre release during manufacturing is estimated as follows:

    a. Assumed to equal the estimated release from use phase. This assumption could produce an underestimate, as some work suggests that release during manufacturing could be underestimated compared to release during the use phase.[16]

    b. 10-15%[1] x 109MMT global fibre production for 2020[3] = approximately 11-16MMT. This approach is very likely an overestimate, as the source acknowledges that a portion of microfibres shed during this phase are captured and not released into the environment. However, this portion is not known.

5. Microfibre release from residential washing machines is estimated as: 0.5-1.3g of microfibres released per wash[19] x 130 washing cycles a year[94] x 840 million washing machines globally[17] = 0.06-0.14MMT a year.

6. Relative frequency of handwashing and commercial washing of textiles: No information on microfibre release from these processes were found. For simplicity, we assume that the release from these sources equal release from the residential washing machines. It is unclear to what extent this assumption could produce an under or overestimate, but it only impacts the interpretation of the range calculated under point 5 above.

7. No estimates for the release of microfibres from tumble dryers and from textiles incorrectly disposed of in the environment were found. As a result, our estimates exclude these potential sources of microfibres. This is likely to result in an overall underestimate for total microfibre release into the environment.

Estimation outcomes

Overall, the majority of our estimates for the total release of microfibres (including both synthetic and natural materials), fall in the range of 0.48-4.28MMT. That range excludes a single double-digit estimate in the range of 11-18MMT.

- A range of 1.16-4.28MMT was derived from 3 sources providing estimates for release of synthetic microfibres during laundry.[1,38,70]. The top end of the range is driven by the estimate by the Ellen MacArthur Foundation.

- A range of 0.84-1.11MMT was derived from the single sources providing an estimate for microfibre release from all stages within the textile lifecycle, but for synthetic fibres only.[22]

- A range of 0.48-1.12MMT was derived based on internal calculations using microfibre release estimates per wash cycle.[19] The low end of this estimate determines the low end of our overall internally determined range.

- A range of approximately 11-18MMT is obtained by using the information that as much as 10-15% of textile mass could be lost during the manufacturing process.[1] This approach results in a significantly higher estimate than the other five sources. Due to the lack of clarity as to what share of those microfibres is not captured during manufacturing and as a result released into the environment, this estimate is excluded from our overall estimation range.

Appendices

Appendix 2: Summary of existing and proposed legislation on microfibres

Intervention	Title of regulation	Status of regulation	Potential implications for companies
Use microfibre filters on washing machines	**Circular Economy Law (France)** Requires that by 2025, new washing machines will be able to filter microplastics	Passed (2020)	All washing machine manufacturers and retailers would be required to produce and sell products fitted with integrated filters
	National Plastics Plan[4] Work with the textile and whitegoods sectors on an industry-led phase-in of microfibre filters on new residential and commercial washing machines by 1 July 2030	Implemented (2021)	
	Assembly Bill 802 (California State Assembly) Would require effective microfibre filtration in laundry facilities	In committee (as of January 2022)	
Regulate textile shedding rates	**Bill A10599 (New York State Assembly)** Would have required additional labels on clothing composed of more than fifty percent synthetic material to notify consumers such clothing sheds plastic microfibers when washed	Not passed; died in committee (2018)	
	Assembly Bill 2379 (California State Assembly) Would have required clothing made of fabric containing more than 50% polyester to have a conspicuous label that warns of plastic microfibre shedding	Not passed; died at 3rd reading (2018)	Potential for decreased consumer demand for clothing garments containing >50% polyester in California and all locations that California brands ship to
Other	**H.B. 5360 (FKA Raised Bill No. 341) (Connecticut General Assembly)** Requires the state Commissioner of Energy and Environmental Protection to convene a working group of representatives of the apparel industry and the environmental community	Passed (2018)	None yet
	Article L-541-10-3 of the Code de l'Environnement Extended Producer Responsibility (EPR) scheme that requires all legal entities producing new textiles and clothing in the French market to take responsibility for the recycling/proper disposal of their products	Passed (2007)	Cost of engaging with recyclers and waste management to address end of life of products
	EU Strategy for Textiles[5] A strategy will help the EU shift to a climate-neutral, circular economy with durable, reusable, repairable, recyclable and energy-efficient textiles. Will include a cost-benefit analysis of policy measures reducing unintentional release of microplastics	Awaiting Commission adoption (scheduled for early 2022)	None yet
Improve microfibre retention during wastewater treatment	None identified	n/a	n/a
Curb microfibre loss during textile manufacturing	None identified	n/a	n/a
Develop and adopt a shedding rate testing methodology	None identified	n/a	n/a

Appendix 3: Non-governmental organisations with activities related to microfibre pollution and sustainable fashion

Organisation Name	Focus/Description
Ellen MacArthur Foundation	A UK registered charity that works to promote a circular economy. It has launched a Circular Fibres Initiative and a New Plastics Economy Initiative.
Plastic Soup Foundation	A non-profit organization that initiated the Ocean Clean Wash campaign focused on microfibres. They work with the Wear off Microfibres Alliance (WOMA), which is a group of research centres that test clothes for microfibre shedding rates.
The Microfibre Consortium	The Microfibre Consortium is a research-led sustainable textiles NGO that convene the global textiles sector through The Microfibre 2030 Commitment to limit fibre fragmentation and microfibre pollution.
Friends of the Earth	A not-for-profit company that has published some communications on microfibres and has an active petition asking the UK government to reduce manufacturers' and retailers' production of plastic waste.
The Outdoor Industry Association (OIA)	An industry association that facilitates efforts among member companies to drive data collection on the sources and causes of microfibre release and to implement solutions. They also provide resources on microfibres, including a microfibre toolkit and a list of key projects.
European Outdoor Group (EOG)	An industry association that represents the outdoor sector across Europe. It includes retailers, national associations and technology providers and engages in market research, CSR, lobbying and more.
Sustainable Apparel Coalition (SAC)	A global multi-stakeholder non-profit alliance for the consumer goods industry made up of 250+ organisations associated with the textile industry to reduce environmental impact and promote social justice throughout the global value chain. They developed the Higg Index, a tool that measures environmental and social labour impacts across the textile value chain. However, the tool is only available to SAC members and it is unclear if it includes microfibre metrics. The environmental criteria it states to cover are: greenhouse gas emissions, water, wastewater, air emissions, waste, and chemicals management.
Fashion for Good	A platform for sustainable fashion innovation. They provide support to innovators through 3 programmes: an Accelerator, a Scaling Programme and a Good Fashion Fund.

Endnotes

1 Gavigan, J., Kefela, T., Macadam-Somer, I., Suh, S. & Geyer, R. Synthetic microfiber emissions to land rival those to waterbodies and are growing. PLoS One 15, 1–13 (2020).

2 OECD. Policies to Reduce Microplastics Pollution in Water: Focus on Textiles and Tyres. Policies to Reduce Microplastics Pollution in Water (2021) doi:10.1787/7ec7e5ef-en.

3 Textile Exchange. Preferred Fiber & Materials Market Report 2021. 1–118 (2021).

4 Lykaki, M. et al. The influence of textile finishing agents on the biodegradability of shed fibres. Green Chem. 23, 5212–5221 (2021).

5 Henry, B., Laitala, K. & Klepp, I. G. Microfibres from apparel and home textiles: Prospects for including microplastics in environmental sustainability assessment. Sci. Total Environ. 652, 483–494 (2019).

6 Viršek, M. K., Lovšin, M. N., Koren, Š., Kržan, A. & Peterlin, M. Microplastics as a vector for the transport of the bacterial fish pathogen species Aeromonas salmonicida. Mar. Pollut. Bull. 125, 301–309 (2017).

7 Hartmann, N. B. et al. Microplastics as vectors for environmental contaminants: Exploring sorption, desorption, and transfer to biota. Integr. Environ. Assess. Manag. 13, 488–493 (2017).

8 Rochman, C. M., Hentschel, B. T. & The, S. J. Long-term sorption of metals is similar among plastic types: Implications for plastic debris in aquatic environments. PLoS One 9, (2014).

9 Vassilenko, P. K., Watkins, M., Chastain, S., Posacka, A. & Ross, P. S. Me, My Clothes and the Ocean: The role of textiles in microfiber pollution. https://assets.ctfassets.net/fsquhe7zbn68/4MQ9y89yx4KeyHv9Svynyq/8434de64585e9d2cfbcd3c46627c7a4a/Research_MicrofibersReport_191004-e.pdf (2019).

10 Jemec, A., Horvat, P., Kunej, U., Bele, M. & Kržan, A. Uptake and effects of microplastic textile fibers on freshwater crustacean Daphnia magna. Environ. Pollut. 219, 201–209 (2016).

11 Ziajahromi, S., Kumar, A., Neale, P. A. & Leusch, F. D. L. Impact of Microplastic Beads and Fibers on Waterflea (Ceriodaphnia dubia) Survival, Growth, and Reproduction: Implications of Single and Mixture Exposures. Environ. Sci. Technol. 51, 13397–13406 (2017).

12 Zhao, Y., Qiao, R., Zhang, S. & Wang, G. Metabolomic profiling reveals the intestinal toxicity of different length of microplastic fibers on zebrafish (Danio rerio). J. Hazard. Mater. 403, 123663 (2021).

13 Lai, P. S. & Christiani, D. C. Long term respiratory health effects in textile workers. Curr. Opin. Pulm. Med. 19, 152–157 (2013).

14 Carney Almroth, B. & Eggert, H. Marine plastic pollution: Sources, impacts, and policy issues. Rev. Environ. Econ. Policy 13, 317–326 (2019).

15 The Nature Conservancy & Bain & Company. Toward eliminating pre-consumer emissions of microplastics from the textile industry. (2021).

16 Liu, J., Yang, Y., Ding, J., Zhu, B. & Gao, W. Microfibers: a preliminary discussion on their definition and sources. Environ. Sci. Pollut. Res. 26, 29497–29501 (2019).

17 De Falco, F., Di Pace, E., Cocca, M. & Avella, M. The contribution of washing processes of synthetic clothes to microplastic pollution. Sci. Rep. 9, 6633 (2019).

18 Napper, I. E. & Thompson, R. C. Release of synthetic microplastic plastic fibres from domestic washing machines: Effects of fabric type and washing conditions. Mar. Pollut. Bull. 112, 39–45 (2016).

19 Eunomia and ICF. Investigating options for reducing releases in the aquatic environment of microplastics emitted by (but not intentionally added in) products. (2018).

20 De Falco, F., Cocca, M., Avella, M. & Thompson, R. C. Microfiber Release to Water, Via Laundering, and to Air, via Everyday Use: A Comparison between Polyester Clothing with Differing Textile Parameters. Environ. Sci. Technol. 54, 3288–3296 (2020).

21 Carney Almroth, B. M. et al. Quantifying shedding of synthetic fibers from textiles; a source of microplastics released into the environment. Environ. Sci. Pollut. Res. 25, 1191–1199 (2018).

Endnotes

22 Boucher, J. & Friot, D. Primary Microplastics in the Oceans: A Global Evaluation of Sources. https://www.iucn.org/content/primary-microplastics-oceans (2017) doi:dx.doi.org/10.2305/IUCN.CH.2017.01.en.

23 UNESCO & UN-Water. United Nations World Water Development Report 2020:Water and Climate Change. (2020).

24 Prata, J. C. Microplastics in wastewater: State of the knowledge on sources, fate and solutions. Mar. Pollut. Bull. 129, 262–265 (2018).

25 Xu, X., Hou, Q., Xue, Y., Jian, Y. & Wang, L. P. Pollution characteristics and fate of microfibers in the wastewater from textile dyeing wastewater treatment plant. Water Sci. Technol. 78, 2046–2054 (2018).

26 Nizzetto, L., Futter, M. & Langaas, S. Are Agricultural Soils Dumps for Microplastics of Urban Origin? Environ. Sci. Technol. 50, 10777–10779 (2016).

27 Horton, A. A., Walton, A., Spurgeon, D. J., Lahive, E. & Svendsen, C. Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. Sci. Total Environ. 586, 127–141 (2017).

28 De Falco, F., Di Pace, E., Cocca, M. & Avella, M. The contribution of washing processes of synthetic clothes to microplastic pollution. Nature 9, 6633 (2019).

29 FAO. Wastewater treatment and use in agriculture - FAO irrigation and drainage paper 47. http://www.fao.org/3/t0551e/t0551e08.htm (1992).

30 Austin, H. P. et al. Characterization and engineering of a plastic-degrading aromatic polyesterase. Proc. Natl. Acad. Sci. U. S. A. 115, E4350–E4357 (2018).

31 Browne, M. A. et al. Accumulation of microplastic on shorelines woldwide: Sources and sinks. Environ. Sci. Technol. 45, 9175–9179 (2011).

32 Suaria, G. et al. Microfibers in oceanic surface waters: A global characterization. Sci. Adv. 6, 1–9 (2020).

33 Napper, I. E., Barrett, A. C. & Thompson, R. C. The efficiency of devices intended to reduce microfibre release during clothes washing. Sci. Total Environ. 738, (2020).

34 Kane, I. A. et al. Seafloor microplastic hotspots controlled by deep-sea circulation. Science (80-.). 368, 1140–1145 (2020).

35 First Sentier MUFG Sustainable Investment Institute. Microplastic pollution: the causes, consequences and issues for investors. (2021).

36 Global Fashion Agenda & The Boston Consulting Group. Pulse of the Fashion Industry. http://globalfashionagenda.com/wp-content/uploads/2017/05/Pulse-of-the-Fashion-Industry_2017.pdf (2017).

37 The Nature Conservancy & Bain & Company. Toward eliminating pre-consumer emissions of microplastics from the textile industry. https://www.nature.org/content/dam/tnc/nature/en/documents/210322TNCBain_Pre-ConsumerMicrofiberEmissionsv6.pdf (2021).

38 Ellen MacArthur Foundation. A New Textiles Economy: Redesigning Fashion's Future. https://www.ellenmacarthurfoundation.org/assets/downloads/publications/A-New-Textiles-Economy_Full-Report_Updated_1-12-17.pdf%0Ahttps://www.ellenmacarthurfoundation.org/publications/a-new-textiles-economy-redesigning-fashions-future (2017).

39 Mishra, S., Rath, C. charan & Das, A. P. Marine microfiber pollution: A review on present status and future challenges. Mar. Pollut. Bull. 140, 188–197 (2019).

40 Taylor, M. L., Gwinnett, C., Robinson, L. F. & Woodall, L. C. Plastic microfibre ingestion by deep-sea organisms. Sci. Rep. 6, 1–9 (2016).

41 Devriese, L. I. et al. Microplastic contamination in brown shrimp (Crangon crangon, Linnaeus 1758) from coastal waters of the Southern North Sea and Channel area. Mar. Pollut. Bull. 98, 179–187 (2015).

42 Ross, P. S. et al. Pervasive distribution of polyester fibres in the Arctic Ocean is driven by Atlantic inputs. Nat. Commun. 12, 4–12 (2021).

Endnotes

43 Horton, A., Svensden, C., Williams, R., Spurgeon, D. & Lahive, E. Microplastics in sediments of the low-lying Thames River Basin catchment, UK – abundance, sources 1 and methods for effective quantification. Environ. Pollut. 114, (2017).

44 Wang, W., Ndungu, A. W., Li, Z. & Wang, J. Microplastics pollution in inland freshwaters of China: A case study in urban surface waters of Wuhan, China. Sci. Total Environ. 575, 1369–1374 (2017).

45 Napper, I. E. et al. Reaching New Heights in Plastic Pollution—Preliminary Findings of Microplastics on Mount Everest. One Earth 3, 621–630 (2020).

46 Dris, R., Gasperi, J., Saad, M., Mirande, C. & Tassin, B. Synthetic fibers in atmospheric fallout: A source of microplastics in the environment? Mar. Pollut. Bull. 104, 290–293 (2016).

47 Gasperi, J. et al. Microplastics in air: Are we breathing it in? Curr. Opin. Environ. Sci. Heal. 1, 1–5 (2018).

48 Woodall, L. C. et al. The deep sea is a major sink for microplastic debris. R. Soc. Open Sci. 1, (2014).

49 Ross, P. S. et al. Pervasive distribution of polyester fibres in the Arctic Ocean is driven by Atlantic inputs. Nat. Commun. 12, 4–12 (2021).

50 Gago, J., Carretero, O., Filgueiras, A. V. & Viñas, L. Synthetic microfibers in the marine environment: A review on their occurrence in seawater and sediments. Mar. Pollut. Bull. 127, 365–376 (2018).

51 Sørensen, L. et al. UV degradation of natural and synthetic microfibers causes fragmentation and release of polymer degradation products and chemical additives. Sci. Total Environ. 755, 143170 (2021).

52 Li, L., Frey, M. & Browning, K. J. Biodegradability Study on Cotton and Polyester Fabrics. J. Eng. Fiber. Fabr. 5, (2010).

53 Szostak-Kotowa, J. Biodeterioration of textiles. Int. Biodeterior. Biodegrad. 53, 165–170 (2004).

54 Hurley, R., Woodward, J. & Rothwell, J. J. Microplastic contamination of river beds significantly reduced by catchment-wide flooding. Nat. Geosci. 11, 251–257 (2018).

55 Botterell, Z. L. R. et al. Bioavailability and effects of microplastics on marine zooplankton: A review. Environ. Pollut. 245, 98–110 (2019).

56 Silva-Cavalcanti, J. S., Silva, J. D. B., França, E. J. de, Araújo, M. C. B. de & Gusmão, F. Microplastics ingestion by a common tropical freshwater fishing resource. Environ. Pollut. 221, 218–226 (2017).

57 Kosuth, M., Mason, S. A. & Wattenberg, E. V. Anthropogenic contamination of tap water, beer, and sea salt. PLoS One 13, 1–18 (2018).

58 Rochman, C. M. et al. Anthropogenic debris in seafood: Plastic debris and fibers from textiles in fish and bivalves sold for human consumption. Sci. Rep. 5, 1–10 (2015).

59 Yang, D. et al. Microplastic pollution in table salts from China. Environ. Sci. Technol. 49, 13622–13627 (2015).

60 Elizalde-Velázquez, G. A. & Gómez-Oliván, L. M. Microplastics in aquatic environments: A review on occurrence, distribution, toxic effects, and implications for human health. Sci. Total Environ. 780, 146551 (2021).

61 Sørensen, L. et al. UV degradation of natural and synthetic microfibers causes fragmentation and release of polymer degradation products and chemical additives. Sci. Total Environ. 755, 143170 (2021).

62 Pesticide Action Network UK. Is cotton conquering its chemical addiction? https://issuu.com/pan-uk/docs/cottons_chemical_addiction_-_update?e=28041656/62705601 (2018).

63 Stone, C., Windsor, F. M., Munday, M. & Durance, I. Natural or synthetic – how global trends in textile usage threaten freshwater environments. Sci. Total Environ. 718, 134689 (2020).

64 Zhao, Y., Qiao, R., Zhang, S. & Wang, G. Metabolomic profiling reveals the intestinal toxicity of different length of microplastic fibers on zebrafish (Danio rerio). J. Hazard. Mater. 403, 123663 (2021).

65 Watts, A. J. R., Urbina, M. A., Corr, S., Lewis, C. & Galloway, T. S. Ingestion of Plastic Microfibers by the Crab Carcinus maenas and Its Effect on Food Consumption and Energy Balance. Environ. Sci. Technol. 49, 14597–14604 (2015).

Endnotes

66 Brennecke, D. et al. Ingested microplastics (>100μm) are translocated to organs of the tropical fiddler crab Uca rapax. Mar. Pollut. Bull. 96, 491–495 (2015).

67 Acharya, S., Rumi, S. S., Hu, Y. & Abidi, N. Microfibers from synthetic textiles as a major source of microplastics in the environment: A review. Text. Res. J. 91, 2136–2156 (2021).

68 Schmidt, C., Krauth, T. & Wagner, S. Export of Plastic Debris by Rivers into the Sea. 12246–12253 (2017) doi:10.1021/acs.est.7b02368.

69 Vassilenko, E. et al. Domestic laundry and microfiber pollution: Exploring fiber shedding from consumer apparel textiles. PLoS One 16, 1–17 (2021).

70 Belzagui, F., Crespi, M., Álvarez, A., Gutiérrez-Bouzán, C. & Vilaseca, M. Microplastics' emissions: Microfibers' detachment from textile garments. Environ. Pollut. 248, 1028–1035 (2019).

71 Hernandez, E., Nowack, B. & Mitrano, D. M. Polyester Textiles as a Source of Microplastics from Households: A Mechanistic Study to Understand Microfiber Release during Washing. Environ. Sci. Technol. 51, 7036–7046 (2017).

72 Hartline, N. L. et al. Microfiber Masses Recovered from Conventional Machine Washing of New or Aged Garments. Environ. Sci. Technol. 50, 11532–11538 (2016).

73 Pirc, U., Vidmar, M., Mozer, A. & Kržan, A. Emissions of microplastic fibers from microfiber fleece during domestic washing. Environ. Sci. Pollut. Res. 23, 22206–22211 (2016).

74 Dris, R., Gasperi, J., Saad, M., Mirande, C. & Tassin, B. Synthetic fibers in atmospheric fallout: A source of microplastics in the environment? Mar. Pollut. Bull. 104, 290–293 (2016).

75 Carney Almroth, B. M. et al. Quantifying shedding of synthetic fibers from textiles; a source of microplastics released into the environment. Environ. Sci. Pollut. Res. 25, 1191–1199 (2018).

76 Carr, S. A., Liu, J. & Tesoro, A. G. Transport and fate of microplastic particles in wastewater treatment plants. Water Res. 91, 174–182 (2016).

77 Biosolid Assurance Scheme. About Biosolids. https://assuredbiosolids.co.uk/about-biosolids/ (2021).

78 Costa, A. Microplastic Filters (Washing Machines) Bill. (UK House of Commons, 2021).

79 Cora Ball. WE ARE EATING OUR CLOTHING. https://www.coraball.com (2021).

80 GuppyFriend. GUPPYFRIEND Washing Bag. https://en.guppyfriend.com/products/guppyfriend-waschbeutel#gfdescription (2021).

81 FibreFree. FibreFree. https://www.livefibrefree.com (2021).

82 Xeros Technologies. XFiltraTM Rated Best Microfibre Filter For Laundry. https://www.xerostech.com/updates/xfiltra-rated-best-microfibre-filter-for-laundry (2021).

83 Environmental Enhancements. MicroPlastics LUV-R. https://environmentalenhancements.com/store/index.php/products/products-micro-plastics (2021).

84 PlanetCare. Global Microfiber Pollution Research: People Want Washing Machines to Stop Polluting the Oceans [2021]. (2021).

85 Collective, G. The Microfiber Filter. https://girlfriend.com/products/water-filter (2021).

86 Filtrol. The Filtrol Solution. https://filtrol.net/about/ (2021).

87 Grundig. World's 1st Integrated Microfibre Filter. https://www.grundig.co.uk/fiber-catcher (2021).

88 Environmental Enhancements. Lint LUV-R. https://environmentalenhancements.com/store/index.php/products/products-lint-filter (2021).

89 Beat the Microbead. Global Impact. (2021).

Endnotes

90 OECD. Workshop on Microplastics from Synthetic Textiles: Knowledge, Mitigation, and Policy. 1–11 (2020).

91 Operation Clean Sweep. Operation Clean Sweep Best Management Practices. (2021).

92 Best Management Practices (BMP). Thompson Reuters Practical Law, (2021).

93 National Federation of Women's Institutes. In a Spin: How our laundry is contributing to plastic pollution. (2018)..

95 Suaria, G. et al. Microfibers in oceanic surface waters: A global characterization. Sci. Adv. 6, eaay8493 (2020).

96. Belzagui, F., Buscio, V., Gutiérrez-Bouzán, C. & Vilaseca, M. Cigarette butts as a microfiber source with a microplastic level of concern. Sci. Total Environ. 762, 144165 (2021).

97. FSI. Responsible Investment Report 2020. https://www.firstsentierinvestors.com.au/content/dam/web/global/responsible-investment/documentation/global-documents/first-sentier-investors-2020-responsible-investment-report.pdf (2020).

98. Fibre2Fashion. Textile industry alliance moves closer to microfibre shedding standard. (2021)

99. Environmental Audit Committee, Fixing Fashion: Clothing Consumption and Sustainability. Sixteenth Report Session 2017-19 (2019).

100. Australian Government: Department of Agriculture Water and Environment. National Plastics Plan 2021. (2021).

Important Information

This material is for general information purposes only. It does not constitute investment or financial advice and does not take into account any specific investment objectives, financial situation or needs. This is not an offer to provide asset management services, is not a recommendation or an offer or solicitation to buy, hold or sell any security or to execute any agreement for portfolio management or investment advisory services and this material has not been prepared in connection with any such offer. Before making any investment decision you should consider, with the assistance of a financial advisor, your individual investment needs, objectives and financial situation.

We have taken reasonable care to ensure that this material is accurate, current, and complete and fit for its intended purpose and audience as at the date of publication. No assurance is given or liability accepted regarding the accuracy, validity or completeness of this material and we do not undertake to update it in future if circumstances change.

To the extent this material contains any expression of opinion or forward-looking statements, such opinions and statements are based on assumptions, matters and sources believed to be true and reliable at the time of publication only. This material reflects the views of the individual writers only. Those views may change, may not prove to be valid and may not reflect the views of everyone at First Sentier Investors.

About First Sentier Investors

References to 'we', 'us' or 'our' are references to First Sentier Investors, a global asset management business which is ultimately owned by Mitsubishi UFJ Financial Group. Certain of our investment teams operate under the trading names FSSA Investment Managers, Stewart Investors and Realindex Investments, all of which are part of the First Sentier Investors group.

We communicate and conduct business through different legal entities in different locations. This material is communicated in:

- Australia and New Zealand by First Sentier Investors (Australia) IM Limited, authorised and regulated in Australia by the Australian Securities and Investments Commission (AFSL 289017; ABN 89 114 194311)
- European Economic Area by First Sentier Investors (Ireland) Limited, authorised and regulated in Ireland by the Central Bank of Ireland (CBI reg no. C182306; reg office 70 Sir John Rogerson's Quay, Dublin 2, Ireland; reg company no. 629188)
- Hong Kong by First Sentier Investors (Hong Kong) Limited and has not been reviewed by the Securities & Futures Commission in Hong Kong
- Singapore by First Sentier Investors (Singapore) (reg company no. 196900420D) and has not been reviewed by the Monetary Authority of Singapore. First Sentier Investors (registration number 53236800B) is a business division of First Sentier Investors (Singapore).
- United Kingdom by First Sentier Investors (UK) Funds Limited, authorised and regulated by the Financial Conduct Authority (reg. no. 2294743; reg office Finsbury Circus House, 15 Finsbury Circus, London EC2M 7EB)
- United States by First Sentier Investors (US) LLC, authorised and regulated by the Securities Exchange Commission (RIA 801-93167)

This material is neither directed at nor intended to be accessed by persons resident in, or citizens of any country, or types or categories of individual where to allow such access would require any registration, filing, application for any licence or approval or other steps to be taken by First Sentier Investors in order to comply with local laws or regulatory requirements in such country.

To the extent permitted by law, MUFG and its subsidiaries are not liable for any loss or damage as a result of reliance on any statement or information contained in this document. Neither MUFG nor any of its subsidiaries guarantee the performance of any investment products referred to in this document or the repayment of capital. Any investments referred to are not deposits or other liabilities of MUFG or its subsidiaries, and are subject to investment risk, including loss of income and capital invested.