Toward eliminating pre-consumer emissions of microplastics from the textile industry

Photo credit: Mark Godfrey

The Nature Conservancy

BAIN & COMPANY

Abstract

There is growing global awareness that microplastics are a potentially harmful pollutant in oceans, freshwater, soil and air. While there are many important sources of microplastic pollution, we now know the textile lifecycle of manufacturing, use and disposal is a major emission pathway of microplastics. Microplastics emitted during a textile's lifecycle are referred to as microfibers or 'fiber fragments.' To date, much of the attention has focused on the shedding, washing and disposal of synthetic textiles by consumers.

However, this is only part of the picture and ignores microfiber leakage during the manufacturing and processing of these materials. We estimate that pre-consumer textile manufacturing releases 0.12 million metric tons (MT) per year of synthetic microfibers into the environment – a similar order of magnitude to that of the consumer use phase (laundering). That would mean for every ~500 t-shirts manufactured; one is lost as microfiber pollution.

While we don't yet know how harmful microfibers are, we know enough to take action now to reduce the flows of these materials into natural systems like rivers and oceans. The elimination of pre-consumer microfiber pollution will require changes along all stages of the textile supply chain. These changes include:

1. Better understanding the relative emissions of microfibers at each manufacturing step (from fiber to yarn to fabric to garment).
2. Developing microfiber control technologies and codifying best practices.
3. Scaling these solutions to Tier 1, 2 and 3 suppliers via a combination of regulatory and brand or retailer-led action.
4. Continuing to raise industry, government and consumer awareness of the topic.

Taken together, we estimate these actions could address up to 90% of pre-consumer microfiber emissions.

Introduction

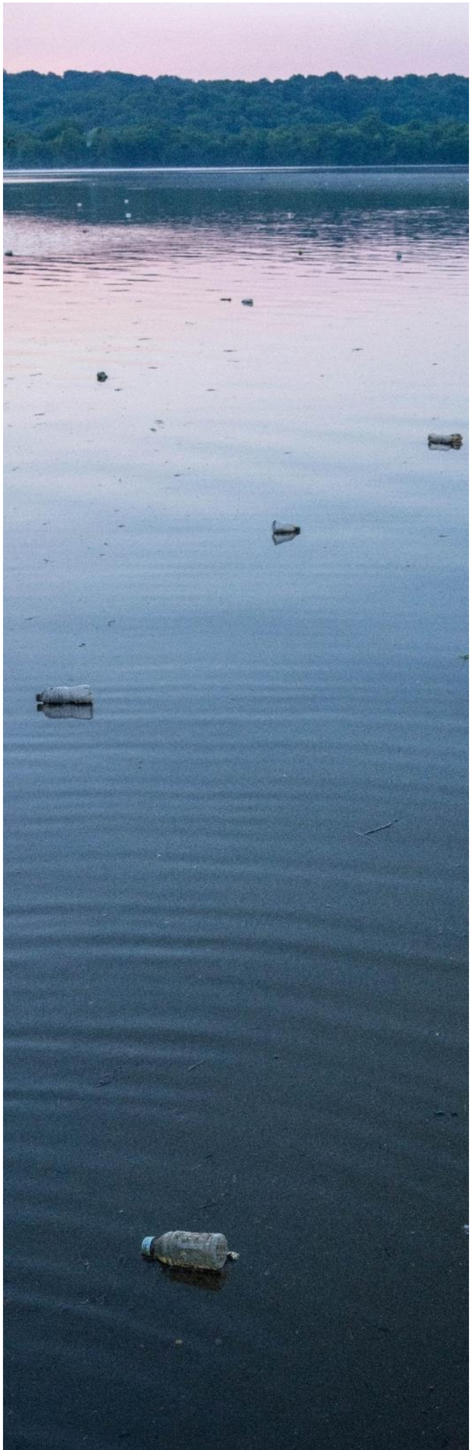


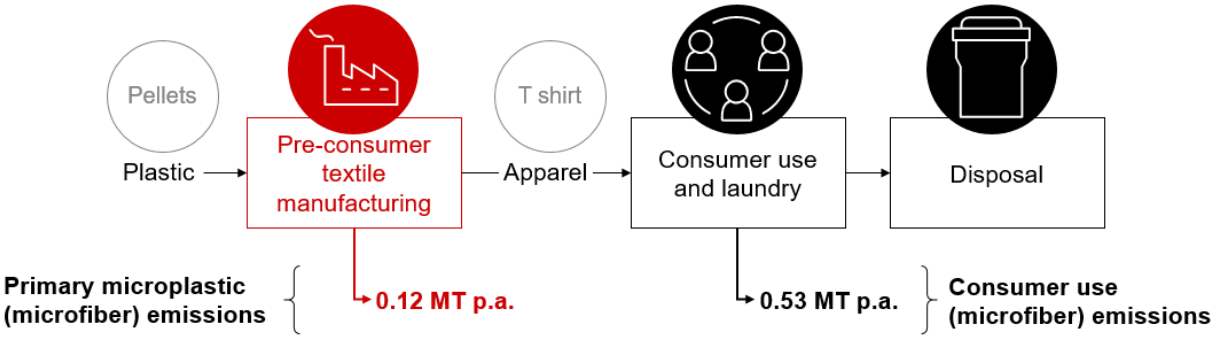
Photo credit: Greg Kahn

Microplastics are fragments of plastic which are less than 5 mm in diameter. As a pollutant with potentially harmful effects, they are attracting increasing attention from scientific circles, industry, media and consumers. Their effects on organisms, the marine environment and humans are still being understood, but early research has already identified microplastics in seafood, tap water and bottled water. One study estimates humans ingest up to "one credit card per week" of plastic via consumption and inhalation (WWF, 2019).

Microplastics released into the environment can be categorized as either primary or secondary. Primary microplastics are emitted directly as small plastic particles (e.g., microbeads in facial scrub); whereas secondary microplastics come from the degradation of larger "macro" plastics. The largest sources of primary microplastics are laundering synthetic textiles (35% of annual emission into oceans), abrasion of tires while driving (28%), city dust (24%) and road markings (7%) (IUCN, 2017).

As laundering synthetic clothing is the largest primary microplastics emission pathway, the textiles industry is under increasing pressure to find solutions to avoid shedding of plastic fibers during wash and dry cycles. Early work has investigated adding filters to laundry units and changing the construction of clothing to reduce shedding of these microfibers (Mitrano & Wohlleben, 2020).

Figure 1: High-level textile value chain investigated in this white paper



However, the textiles industry has yet to comprehensively address emissions of microfibers during manufacturing (termed "pre-consumer"). With synthetic textile production and consumption expected to continue growing (IHS, 2019), this issue will only continue to get larger if unaddressed. Manufacturers today are largely unaware of the issue and rarely test for microfibers in waste streams – meaning there could be substantial emissions across processing steps. In this White Paper, we'll examine this challenge of sources and scale of pre-consumer microfiber emissions from textile manufacturing, and options for resolving the issue.

Photo credit: Aristo Risi

Pre-consumer emission from textile manufacturing


Photo credit: Michael Yamashita

Textile Industry Background

Textile manufacturing involves a series of complex processes and encapsulates a fragmented base of stakeholders largely concentrated in Asia-Pacific (APAC) countries. The textile manufacturing process is made up of three main stages, or tiers:

- Tier 3: Fiber production is the first step in the making of synthetic textiles (Figure 2). Synthetic fibers are manufactured from natural gas, oil and coal through a complex polymerization process.
- Tier 2: Yarn and fabric production involves the production of yarn which is then tufted, woven or knitted to construct fabrics with different qualities. Tier 2 of the manufacturing process involves a number of abrasive and water-based processes. For example, it is at this production stage that yarns and fabrics are dyed.
- Tier 1: Garment production entails garment construction and distribution.

Global textile production, both synthetic and natural, has grown significantly over the past decade. In particular, synthetic fiber production has grown at a compound annual growth rate (CAGR) of 4% from 2010 – 2019 and is projected to grow at similar rates over the next 5 years. In comparison, cotton fiber production has grown at a CAGR of 1% in the same period (IHS, 2019). The shift in production is fueled by increases in the consumption of synthetic fibers for apparel, carpet and automotive interior design applications.

Synthetic fiber production is concentrated in APAC, and China more specifically. Of the 62 MT of synthetic fibers produced in 2019, APAC accounted for 92% and China 70% of the 62 MT total mass (IHS, 2019). Synthetic fiber producers are fragmented across China and APAC. For example - the top 32 polyester fiber producers account for 47% of production, 21 of these are in China (IHS, 2019).

Compared to synthetic fiber production, yarn and fabric production is more globally dispersed and more fragmented. By revenue, China and India account for about 53% of global yarn and fabric production (D&B Hoovers, 2020). Other countries, including Brazil and the United States, are significant contributors to the global yarn and fabric production ecosystem. The fragmentation within this segment is extremely high: for example, there are 190K producers in China (D&B Hoovers, 2020 – for Textile Manufacturing category).

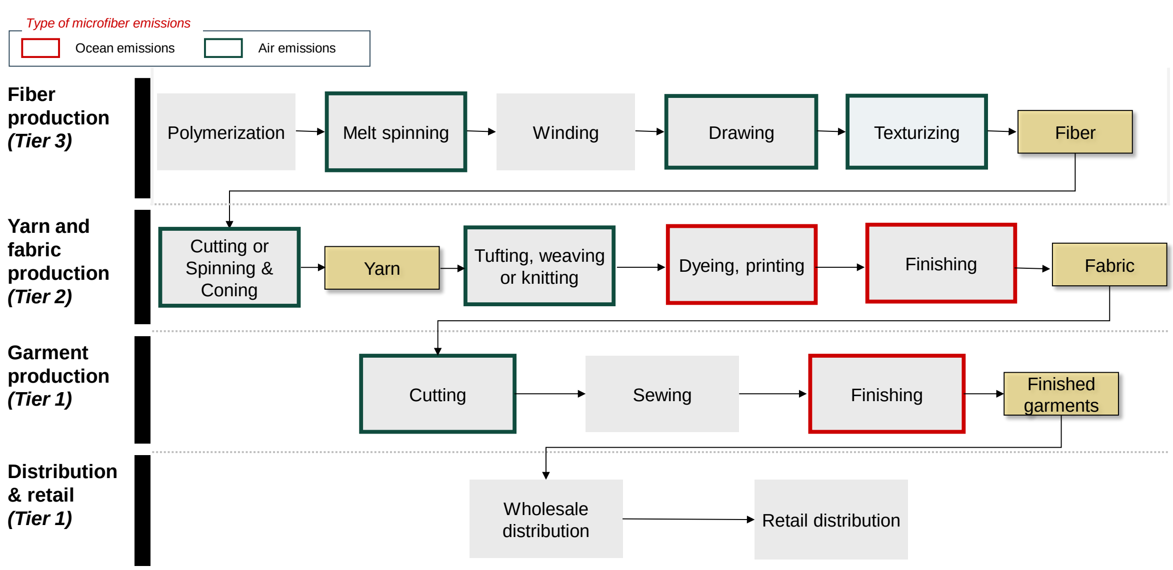
Given the fragmentation within the yarn and fabric industry, many retailers and brands often source their fabric and yarn needs from multiple producers. Despite the fragmentation, brands and retailers have had success influencing the practices of their suppliers. For example, retailers like Primark have had great success in ensuring the cotton used in their products is sustainably sourced. In Primark's case, they partnered with a local organization, CottonConnect, and developed a program to assist cotton farmers adopt sustainable farming practices.

Effluent from Tier 1 and 2 suppliers' wet processes is the key pathway into oceans

Dyeing, printing, finishing and pre-washing of textiles are abrasive processes which cause the fibers to break, releasing microfibers in the wet effluent. The extent to which these fibers are captured depends on what form of effluent treatment is used.

Suppliers can use their own in-plant effluent treatment and/or a common effluent treatment plant (CETP) to increase microfiber capture. Larger and more sophisticated suppliers will typically use their own in-plant treatment – involving primary, secondary and sometimes tertiary steps (Zhou, 2020). This is often mandated by their brand or retailer customers so the effluent will meet the appropriate quality specifications; as set out by the Zero Discharge of Hazardous Chemicals (ZDHC) Roadmap to Zero program. Smaller

Figure 2: Simplified supply chain for textile manufacturing



suppliers or those in industrial parks will send their effluent to a CETP. CETPs ask the suppliers to meet temperature and pH guidelines, but otherwise there are few other quality specifications.

Both in-plant treatment and CETPs can remove microfibers, however their efficiency at doing so depends on the plant technology and operation. A recent study of CETPs in China found that plants removed 85% to 99% of microfibers from influent (for example, using reverse osmosis); however, the plants still released 430 billion microfiber items per day (Zhou et al., 2020). Thus, reducing pre-consumer emissions will require ensuring textile effluent receives the appropriate treatment. Further, the waste sludge can release captured microfibers unless contained in a landfill – signaling that effective disposal practices must be adopted even for sludge.

Pre-consumer emissions could be similar in magnitude to apparel laundering

Most of the scientific research that exists today focuses on understanding the microfiber emissions at the consumer use, or more specifically, the laundering phase. Such studies have helped quantify the level of shedding from different fabrics and the emission differences between washing machines (e.g., from front-load vs. top load). To our knowledge, no scientific research has yet estimated the emissions attributed to the pre-consumer phases like yarn and fabric production.

We estimate synthetic microfiber emissions from the pre-consumer phases to be of similar order of magnitude as the emissions from the consumer phase (0.5 MT per annum: Ellen MacArthur Foundation, 2017). In 2019, the emission from pre-consumer phases was 0.12 MT per annum (Figure 3). This estimate is an average across three different methods used to calculate pre-consumer emissions (see Appendix for additional information):

- Method 1: Connects plastic material loss from textile processing data to microfiber loss to synthetic fiber production volume
- Method 2: Uses textile wastewater effluent data to relate wastewater treatment plant capacity to average treatment efficacy to synthetic fiber production volume
- Method 3: Considers lifecycle emissions of a Sympatex outdoor jacket during production and use and relates that to global primary microfiber emission estimates from IUCN

If left unaddressed, we project by 2030 the emissions could grow by 54% (based on the historical synthetic textile consumption growth over 2010-2019 of 4% p.a. from IHS continuing to 2030). This implies an incremental 0.06 MT per annum of microfibers emitted into the environment in 2030 vs. present levels.

Based on interviews with stakeholders along the textile supply value chain, the biggest process contributors of the pre-consumer phase emissions are dyeing, printing and finishing. During these processes, yarns and fabrics are subject to chemical treatment, washing and drying. In general, these abrasive wet processes cause loosely attached fibers to shed at high rates – resulting in direct emissions to waterways and the natural environment if left untreated.

A critical next step in subsequent research is to measure the microfiber emissions from each of the pre-consumer phases with a particular focus on the emissions from suppliers who do not have on-site effluent treatment capabilities.

Limited supplier knowledge of the issue is a barrier

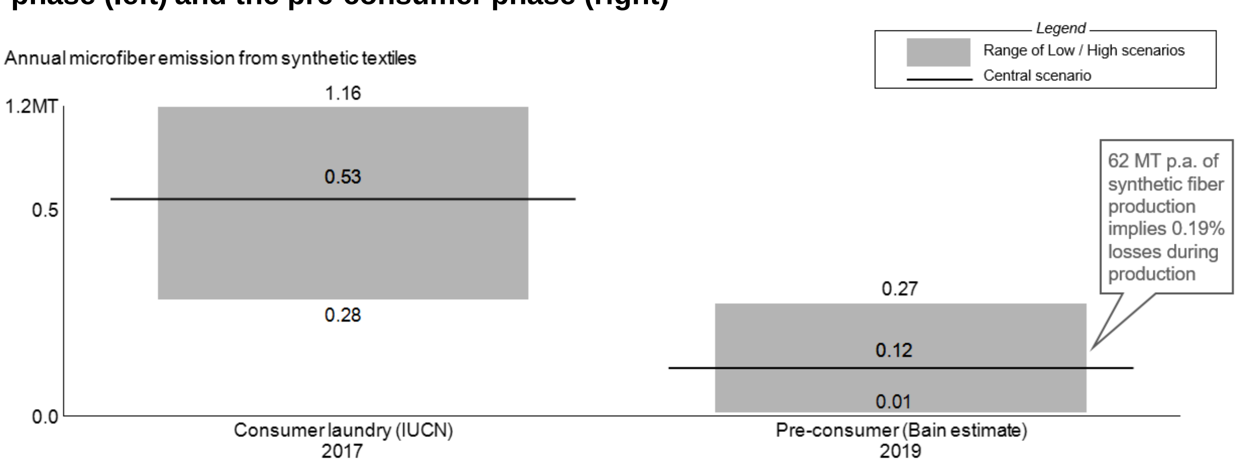
Textile suppliers have limited awareness of microfibers as an environmental issue. Those who are aware of microfibers as an issue cite three key challenges with addressing it:

1. There is no standardized methodology or equipment to test for microfibers (across all fiber size classes),
2. Suppliers do not know which specific process steps are the biggest emitters, and
3. Suppliers are unsure what technological solutions are available.

Suppliers are typically made aware of environmental issues via their customer brand or retailers. The extent to which they align their environmental agenda to their customers is dependent on their tier and their share of revenue attributable to environmentally-oriented customers. Brands are less able to influence higher tiers – for example, some brands may be completely unaware of the original fiber or fabric supplier for their apparel.

Given that textile effluent is a substantial microfiber emission pathway, knowledge of best practices regarding effluent and wastewater treatment is critical to address the above barriers. For many suppliers, this would require installation of effluent treatment technology, as well as education on how to operate it effectively. This also applies to operators of CETPs.

Figure 3: Annual microfiber emissions from synthetic textiles from the consumer phase (left) and the pre-consumer phase (right)



US consumer awareness of microplastics


Photo credit: Tim Calver

Opportunity to increase consumer awareness

A key lever to drive the action of brands and their supplier is pressure from consumers. For example, Greenpeace's "Dirty Laundry" reports in 2011-12 prompted a wave of action by brands and suppliers leading to the ZDHC agreement.

In the US, consumer awareness on the topic of microplastics is relatively low. In a representative sample of US consumers in July 2020, 57% of surveyed adults had not heard of microplastics before (Bain survey, N = 500). Of those who had, about 50% learned of them in the past year.

Although awareness is low, those who have heard of the issue are willing to act. A third of respondents believed microplastics emissions needed to be "addressed urgently", and of those who did not, about 50% believed climate change and about 50% believed ecosystem destruction were issues more important than microplastics (Figure 4). Microplastics directly relate to both of these issues, and part of an increased consumer awareness campaign could connect these issues to motivate the consumer to act.

Consumers want to help

When asked how they would consider helping with the microplastics issue, about 50% of consumers indicated they would recycle more and avoid using single-use plastics (Figure 5). Encouragingly, roughly one third said they would consider buying a filter for their washer or dryer and a quarter would replace their entire laundry unit – an opportunity for laundry unit manufacturers. Finally, one third also said they would "vote with their wallet" and actively choose brands who reduce microplastic pollution, which suggests an opportunity for apparel brands or retailers.

Figure 4: US consumer awareness of microplastics based on results from a Bain-conducted survey

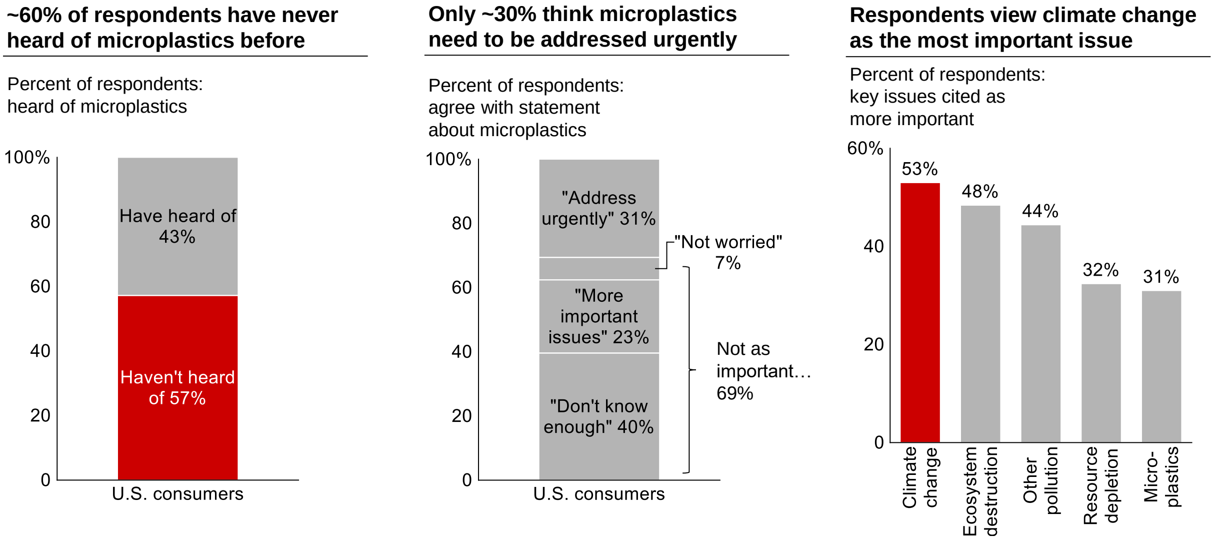
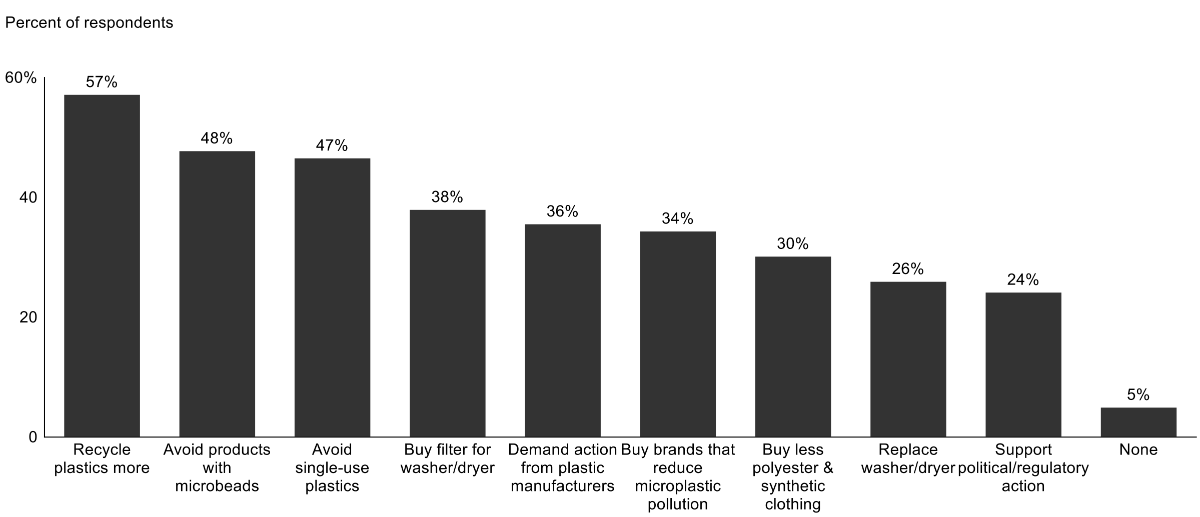


Figure 5: Actions US consumers would be willing to take to reduce emissions of microplastics; results from a Bain-conducted survey (methodology described in the appendix)



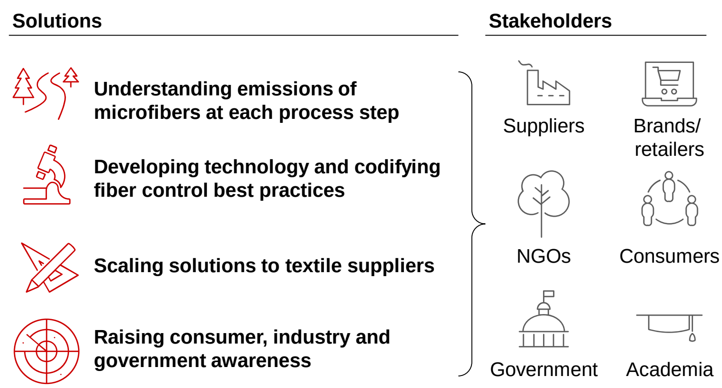
Solutions and next steps


Photo credit: Mark Godfrey

With consumption of synthetic fibers likely to increase for the foreseeable future (IHS, 2019), the solutions recommended here focus on how to control the emission of microfibers from pre-consumer manufacturing rather than on reducing the demand for synthetic fibers.

There are number of barriers today preventing suppliers from effectively removing microfibers from their waste streams including: awareness of the issue, lack of the right technology or the ineffective operation of technology, limited pressure from their customer brands, no regulation on microfiber emissions and/or inability to afford the technology. These barriers could be addressed by the following actions (Figure 6).

Figure 6: Summary of solutions to address pre-consumer emissions of microplastics from textile manufacturing



- **Understanding emissions of microfibers at each process step**: In order to most effectively target solutions, brands and manufacturers should understand which steps in the textile manufacturing process are more polluting and why. This should include understanding microfiber emissions to air and sludge, as well as wastewater. The type of emissions may also differ from country to country depending on what type of textile product is made and the waste management infrastructure. Success here will require partnerships with interested suppliers who would “open up” their manufacturing process to third parties.

- **Developing technology and codifying fiber control best practices**: Technical solutions for fiber control have already been developed. For example, in conversations with sustainability representatives at leading retailers, both mentioned they were trialing technology to address fiber emissions. For water, conventional wastewater treatment practices such as reverse osmosis are already effective at removing most fibers. Removal of fibers from air and sludge is less well-understood. In all these cases, further work needs to be done to improve the efficacy of the technology and codify the knowledge on how to operate the technology consistently. A consistent standard to test for microfibers (currently under development) will support this.

- **Scaling solutions to suppliers**: Brands, retailers and regulatory bodies can play a role in driving adoption of microfiber control practices. Establishing policy on microfiber limits (e.g., via the ZDHC guidelines or through local government regulations) that requires suppliers to regularly measure and report microfiber concentrations in effluent will drive uptake of best practices and technology. Brands and retailers should ask their suppliers to conform to these relevant microfiber regulations, proactively engage them on discussions regarding microfibers, and offer to share industry best practices on control. Finally, where cost of upgrading technology is a barrier, there is the opportunity to educate suppliers on the benefits of water sustainability best practices to both control microfibers and save water, chemicals and energy costs. A study by Ozturk et al. (2016) indicated payback periods up to 26 months for textile mills adopting water sustainability best practices (including nanofiltration and reverse osmosis, which can remove microfibers).

- **Raising awareness:** Brands, retailers and governments will be more strongly compelled to act if consumers ask for action. Fundamental research into the effects of microfibers on the environment and humans should continue. The textile industry should also develop and adopt a standardized approach to measure and report pre-consumer emissions, such as the Higg Index, a holistic measure of a company’s sustainability performance which includes metrics for textile wastewater effluent. This would enable brands to set emissions targets and can be tracked against them.

Taken together, the actions described here could address up to 90% of pre-consumer microfiber emissions (of those not already captured by effluent treatment). This would require the majority of the ZDHC signatories agree to act on microfiber mitigation in partnership with their textile suppliers and local industrial park or governmental CETP operators.

All the above actions will require a coordinated intervention across NGOs, brands, retailers, suppliers, academia, governments and consumers.

An urgent need for coordinated action

Ocean plastic pollution, including global microfiber emissions, represents a global threat to both nature and people that requires urgent, coordinated action and innovative solutions. Given the significant scale and rapid growth of microfibers flows into our environment, we cannot delay urgent action. Fortunately, scalable, practical, cost-effective solutions already exist to significantly reduce these flows during the manufacturing phase. These interventions must be implemented across the textile supply chain while innovations aimed at identifying new materials, alternative fabrics and scaling cost-effective recycling are developed. Through bold, focused and coordinated action, the textile industry can proactively address an increasingly important issue for consumers and build a sustainable future for our oceans, delivering benefits for both people and nature.

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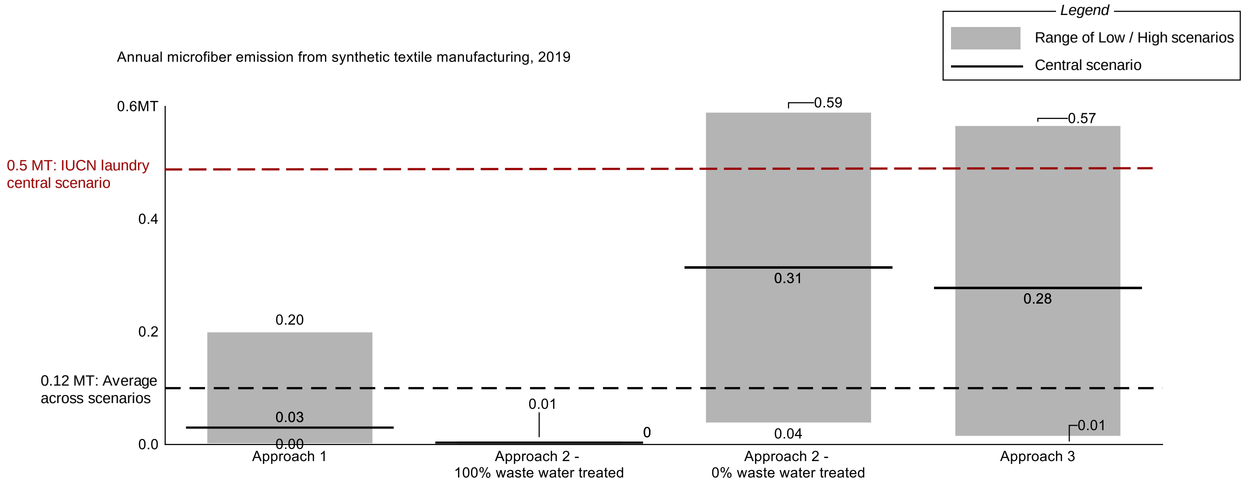
Appendix

Calculation methodology – pre-consumer emission estimates

Synthetic pre-consumer microfiber emissions were estimated using 3 different approaches, resulting in an average of 0.12 MT of microfibers emitted in 2019 from textile manufacturing. Given the 62 MT of synthetic fibers produced in 2019, this suggests a pre-consumer microfiber loss rate of 0.19%.

Figure S1: Comparison of methodologies for estimating pre-consumer emissions of microfibers



Approach 1: Connect plastic material loss to microfiber loss during synthetic fiber production

Emissions: Pessimistic/Optimistic: 0.01/0.2 MT of microfibers in 2019

Approach 1 calculation: Estimates microfiber emissions by connecting plastic material loss from textile processing data to microfiber loss to global synthetic fiber production volume. Pessimistic and optimistic views were informed by ranges in inputs from multiple different reputable sources.

Quantity	Low	Central	High	Units	Assumptions & Comments	Source
Synthetic fiber production, 2019		61.8		MT	Includes all uses of fiber – apparel, carpets, medical supplies etc.	IHS Fabric Overview
x						
% raw material loss from fiber to garment	12%	19%	25%	%	12% because 12% of fibers are lost during textile production processes From Quantis, 420g of macroplastic are used to create a Sympatex jacket that weighs 360g e.g., Implies material loss of (420-360)/420 = 14% 25% because research suggests that in some developing countries volumes of different types of leftovers from fabric mills and garment factories is at least 25% of resources used by factories	Ellen MacArthur Foundation, 2017 Runnel et al., 2017 Quantis, *Tackling Plastic Pollution*, 2020
x						
% plastic loss which is microfibers	1%	3%	5%	%	Implied shed rate from Sympatex jacket during production (0.6g/60g = 1%); 0.6g of microfibers are estimated to be released from production	Quantis, *PLP Methodological Guide,* 2020
x						
% of loss which is released into oceans	8%	10%	20%	%	Study found 6% of leaked plastic ends up and in the oceans and 2% in Freshwater sediments and ~92% ends up in other terrestrial environments	Quantis, *Tackling Plastic Pollution*, 2020
=						
Mass of synthetic microfibers released into water via textile manufacturing	0.01	0.03	0.2	MT microfiber		Calculation

Approach 2: Uses textile waste effluent data to relate WWTP capacity to average treatment efficiency to synthetic fiber production volume

Losses: Optimistic/Pessimistic: 7.4 x 10^-5/0.038 MT of microfibers in 2019

Approach 2 calculation: Estimates microfiber emissions through the efficacy and capacity of wastewater treatment plants. Optimistic and pessimistic views are based on ranges in the inputs.

	100% of effluent treated		**0% of effluent treated**				
Quantity	**Xu, 2018**	**Zhou, 2020**	**Zhou, 2020**	**Zhou, 2020**	**Units**	**Assumptions & Comments**	**Source**
Synthetic microfiber concentration per L of treated wastewater effluent	16	600	8.4K	54.1K	# / L	16 (Xu) and 600 (Zhou) are treated effluent concentrations reported from textile ETPs 8.4K is the lowest microfiber concentration found in WWTP influent; 54.1K uses the highest concentration of microfibers from textile mill effluent	Xu et al., 2018 Zhou et al., 2020
x							
Avg mass of synthetic microfiber	2.92 x 10^-7	2.92 x 10^-7	2.92 x 10^-7	2.92 x 10^-7	g / fiber	Average mass calculated from research findings on size, mass, and density of microfibers	De Falco et al., 2019 Zhou et al., 2020 Rochman et al., 2019
x							
Ton wastewater per ton of textile produced	250	600	250	600	ton / ton	250 from 3000 ton WW / 12 ton textile Assumes microfibers captured by treatment plants are disposed of in non-leaking landfills	Xu et al., 2018 Business for Social Responsibility, 2008
x							
Tonne synthetic fiber produced p.a.	61.8	61.8	61.8	61.8	MT	Includes all uses of synthetic fiber – apparel, carpets, medical supplies, etc., from 2019	IHS Fabrics Overview
=							
Total mass of synthetic microfibers released into water via textile manufacturing	7.4 x 10^-5	6.5 x 10^-3	0.038	0.59	MT microfibers		Calculation

Approach 3: Considers lifecycle emissions of a Sympatex outdoor jacket during production and use and relates that to global primary microfiber emission estimates from IUCN

Losses: Optimistic/Pessimistic: 0.014/0.57 MT of microfiber released in 2019

Approach 3 calculation: Calculates microfibers emitted by considering the lifecycle emissions of a Sympatex outdoor jacket during use and production, and relates that to potential global emissions across garments. Optimistic and pessimistic calculations stem from ranges in assumptions from industry sources.

Quantity	Low	Central	High	Units	Comment	Source
Microfibers lost during production		0.048		grams	Emission measured from a Sympatex Technologies jacket which indicated 0.6g of microplastic emissions were recorded in the garment production process of which 6% was lost to the Oceans and 2% to Freshwater sediments	Quantis, *Tackling Plastic Pollution*, 2020
÷						
Microfibers lost during textile use**	0.95	0.091	0.074	grams	Calculation methodology on the next table, where the lowest microfiber shed rate is used in the high estimate	Bain analysis
=						
Ratio of microfibers emissions during production vs use	0.051	0.53	0.65			Calculation
x						
IUCN estimates of microfibers emissions	0.8	1.5	2.5	MT		IUCN Primary Microplastics in the Oceans, 2017
x						
% of microplastics attributed to use of synthetic textiles		35%		%	Study found 35% of primary microplastic emissions are the result of domestic washing of synthetic textiles	IUCN Primary Microplastics in the Oceans, 2017
=						
Mass of synthetic microfibers released into water via textile production	0.014	0.28	0.57	MT micro-fibers	Calculation	Calculation

**Microfibers lost during textile use calculation:

Quantity	Low	Central	High	Units	Comment	Source
Range of shedding synthetic textile shedding rate	2.9 x 10^-04	3.5 x 10^-04	3.6 x 10^-03	gram/gram	Microfiber shedding rates for polyester products from three studies	Low shed rate: Piro et al Central shed rate: De Falco et al High shed rate: Napper and Thompson
÷						
Shed rates from Quantis study		8.33 x 10^-5		gram/gram	Computed shed rate from Sympatex jacket: 0.03g/360g = 8.3x10^-5 gram/gram	Quantis, *Tackling Plastic Pollution*, 2020
=						
Scaling factor	3.4	4.2	44		Scaling factor	
x						
Microfibers lost during use		0.03		grams	Sympatex jacket loses 0.03g of microfibers during use	Quantis, *Tackling Plastic Pollution*, 2020
x						
% of microfibers lost to Oceans and freshwater sediments		72%		%	% of microfibers lost to the Oceans and Freshwater sediments	Quantis, *Tackling Plastic Pollution*, 2020
=						
Microfibers lost during textile use	.074	0.091	.95	grams microfiber	Total microfibers lost to the ocean	Calculation

Research methodology – US consumer awareness survey

The Bain microfiber consumer awareness poll surveyed 500 US consumers through Poll Fish (online polling and panel software), fielded on 2 July 2020. The purpose of the survey was to understand to what extent US consumers are aware of the issue, and whether they would be willing to make changes to address them.

(Initial introduction to topic of microplastics)

Q1. Microplastics are small pieces of plastic less than 5 mm wide (0.2 inches).

Q2. Microplastics come from large plastics (e.g., single-use bags) breaking down into smaller pieces and can be released directly into the environment in many ways, including by washing polyester and other synthetic clothes.

Q3. We inhale microplastics in the air, consume them in food, and drink them in water. One study estimates this amounts to a "credit card's worth of microplastic per week".

(Body of survey)

Q4. When was the first time you heard about this issue of microplastics?

1. Never heard about it before – this is the first time
2. In the last year
3. 2-3 years ago
4. 4 or more years ago

Q5. Which of the statements about microplastics do you most strongly agree with? (Select one only)

1. I don’t know enough/ need to learn more about microplastics
2. I am not so worried about microplastics
3. I believe microplastics are a serious issue but there are more important environmental issues to address
4. I believe microplastics are a serious environmental issue and we need to address them urgently

Q6. Which of the following environmental issues are more important to you today than microplastics? (select all that apply)

1. Climate change / global warming
2. Resource depletion (e.g., deforestation or overfishing)
3. Ecosystem destruction (e.g., loss of habitats, animal extinction, wildfires)
4. Other forms of water, air, soil pollution (e.g., by waste, chemicals, or larger plastics)
5. Other
6. None / microplastics are the most important environmental issue to me

Q7. Which of these actions, if any, would you be willing to take to reduce microplastic pollution? (select all which apply)

1. Replace my washer/ dryer with one which filters microplastics from wastewater
2. Buy a device which captures microplastics to use with my existing washer/ dryer
3. Avoid using products that contain plastic “microbeads” (e.g., shower gel or face wash)
4. Demand manufacturers of plastic products to take action on microplastics
5. Preferentially buy from brands who are reducing microplastic pollution
6. Avoid single-use plastics (e.g., straws or grocery bags)
7. Recycle plastics more
8. Stop buying (or buy less) polyester & synthetic clothing
9. Support political or regulatory action against microplastic pollution
10. None / I wouldn’t take action

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