FORUM FOR THE FUTURE

Tackling Microfibres at Source

Investigating opportunities to reduce microfibre pollution from the fashion industry through textile design and manufacturing innovation.

Contents

Acknowledgments

This project brings together a group of stakeholders with an interest to better understand the impact of textile manufacturing on the microfibre pollution problem. The project team is led by Forum for the Future ("Forum"), with Ramatex Group as the industry partner, and the Nanyang Environment & Water Resources Institute (NEWRI) as research partner. We were supported by VDE Consultancy in our technical analysis and review, the Universiti Teknologi Malaysia (UTM) as a supporting research partner, and Kim van der Weerd, co-founder and host of Manufactured Podcast, as our impacts and recommendations reviewer. We are very grateful for the hard work and efforts of everyone involved and the perseverance in overcoming the challenges posed by the COVID-19 pandemic over the course of the project.

As part of our primary research, we conducted interviews with selected industry stakeholders (brands and suppliers) and held discussions with many industry experts over the course of the project. We are grateful for their invaluable insights to the analysis and report.

Finally, we acknowledge the support of the UNDP OIC for this opportunity to break new ground in this important topic, and the guidance of the OIC team.

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Foreword

Congratulations Forum for the Future and partners.

We are equally very proud to share the results of the 21-month game-changing research and commitment to catalyze the need to address the microplastics challenge at the source, by preventing microfibre shedding at textile production.

Financed by Sida and Norad, through the Ocean Innovation Challenge incubator and mentoring programme of the United Nations Development Programme (UNDP), Forum for the Future is one of UNDP's first-ever cohort of eight chosen innovators launched in 2021, and selected in 2020 from more than 600 innovative proposals from around the globe to accelerate progress on SDG 14.1 Marine Pollution Reduction and #BeatPlasticPollution.

We have witnessed Forum and the project partners' perseverance in overcoming challenges to deliver the expected outputs during the global pandemic and severe lockdown restrictions in Southeast Asia. They managed to promote the importance of tackling microfibre shedding at source and engaged with textile manufacturers, emphasizing their power to reduce microplastic pollution. Forum also elevated their advocacy of tackling the microplastics pollution and other sustainability challenges facing the textile industry with leading global fashion brands.

Through these seeds planted by Forum and the continuous support from their partners and collaborators, we hope to see transformative change and a more inclusive engagement in the coming days within the various levels in the fashion industry's value chain, towards a more earth-conscious and sustainable fashion.

Mary M. Matthews
Manager, Ocean Innovation Challenge, and
interim Head of Water and Ocean
UNDP

A Note from Ramatex Group

The world is reopening its borders and the fashion industry is in a state of recovery from the many obstacles thrown up by the COVID-19 pandemic. Our project, *Tackling Microfibres at Source*, was carried out under challenging conditions during the pandemic, from national lockdowns to border closures. We are proud to have worked with Forum for the Future and our project partners in driving this exciting and innovative research forward, contributing to a greater understanding of microfibre shed from textile manufacturing processes.

Since we began work on this project in early 2021, climate change has accelerated, biodiversity loss is critical and ocean health continues to decline. This has reinforced the urgency of innovating for more circular solutions, and in the fashion and textiles industry, the important role that suppliers can play in leading a shift to a more sustainable industry.

In our industry, technical solutions appear to offer the most attractive and convenient answers. What this project has shown is that complex problems require collective action and collaboration between multiple stakeholders. The challenge of microfibre pollution cannot be solved by one stakeholder alone – brands and suppliers must work together in undertaking innovative solutions. We hope that the insights and findings from this project can serve as a starting point for further industry and scientific research, and to generate conversations between brands and suppliers as they begin to understand and tackle this emerging challenge together.

There is much we do not yet understand about this problem, for example how different materials and yarns have an impact on microfibre shed, or about the health impacts of microfibre ingestion. This is an opportunity for the industry to come together to develop collective learning, and for brands and suppliers to strengthen trust and equitable partnerships so that when the technical solutions are available, they have the best chance of success. We urge fellow suppliers, brands and retailers, and other stakeholders to make use of the learnings from *Tackling Microfibres at Source* to enable greater innovation in textile manufacturing and a more sustainable fashion industry.

Keith Ma
Strategic Director, Ramatex Group

About the Ocean Innovation Challenge

The ocean faces unprecedented threats to the ecosystem goods and services it provides to humanity -from climate regulation to food security to coastal tourism. Despite some progress, many ocean challenges - from nutrient pollution to illegal, unregulated and unreported (IUU) fishing to ocean acidification - continue to worsen.

For most sectors that rely on the ocean such as fisheries, aquaculture, and industrial agriculture, the `business as usual` scenario will not deliver the kinds of transformational change needed to move towards truly sustainable ocean use.

A combination of technical innovation and cutting-edge policy, financial and economic incentives are needed to transform ocean-related sectors, both sea-based and land-based. At present, while there are a handful of relevant initiatives, these are limited in their sectoral scope. Solutions that cut across the unique innovation needs of each SDG14 target are required, whether it be reduction of plastics pollution, eliminating overfishing, or enhancing access for small scale fishers.

The UNDP Ocean Innovation Challenge (OIC) seeks to identify and provide support to scale-up these solutions to achieve maximum catalytic impact. With funding support from SIDA and NORAD, the OIC is a unique new mechanism designed to accelerate progress on SDG14 by identifying, financing, advising and mentoring truly innovative, entrepreneurial and creative approaches to ocean and coastal restoration and protection that sustains livelihoods and advances the 'blue economy'.

UNDP aims to support 100 ocean innovations by 2030 through the UNDP Ocean Promise, which was launched at the UN Ocean Conference in Lisbon. Currently, the OIC supports two cohorts of 17 diverse organizations to pilot ocean innovations, engaging with 17 developing and least-developed countries, including six small island developing states (SIDS), with the third cohort underway.

Profiles

Forum for the Future (Programme Lead)

Forum for the Future is a leading international sustainability non-profit. For more than 25 years we've been working in partnership with business, governments and civil society to accelerate the shift towards a just and regenerative future in which both people and the planet thrive.

As our environmental, social and economic crises intensify, the world is rapidly changing, with multiple transitions already reshaping how we all live and work. But will we go far enough, and fast enough? Forum is focused on enabling deep transformation in three game-changing areas: how we think about, produce, consume and value both food and energy, and the role of business in society and the economy. We're working with ambitious and diverse change-makers to shift how they feel, think, act and collaborate to drive systemic change for sustainability.

Ramatex Group (Industry Partner)

Established in 1976, Ramatex Group is a Tier-1 manufacturer of apparel products headquartered in Singapore, serving some of the world's leading global sportswear and fashion brands. With operations across Malaysia, Cambodia, China, Jordan, and Vietnam, Ramatex drives innovation from its vertically integrated textile parks in Malaysia and China.

Ramatex has a strong track record in environmental and social sustainability performance. Through a long-term strategic planning process facilitated by Forum for the Future, Ramatex identified transitioning to a circular economy for fashion as an opportunity to apply its manufacturing expertise to regional environmental challenges.Ramatex is well positioned to drive a positive impact on water-related challenges, leveraging the company's technical capabilities in industry-leading wastewater treatment systems and closed-loop water recycling systems. Currently, Ramatex recycles more than half of the water used in its Malaysia and China textile parks.

As a vertically integrated manufacturer (fibre, yarn, fabric and garment), Ramatex directly controls processes across garment manufacturing, fabric production, yarn spinning and fibre processing. This places Ramatex in the unique position to study how design and manufacturing processes across all stages impact microfibre shedding of final products.

Profiles

Nanyang Environment and Water Resources Institute (NEWRI) (Research Lead)

NEWRI is a research and technology organisation in the environment and water domain. It strives to translate the innovations in its labs to engineered solutions for the water and environmental markets. NEWRI bridges deep research with cutting-edge innovation, robust engineering coupled with industry-level translation, to field applications, piloting and deployment at full scale in real-life settings. Through industrial and CSR projects with commercial and social impact, NEWRI continuously strives to make a difference towards developing a true circular economy through efficient reuse innovations and harnessing the value in waste. NEWRI has a strong track record in research relating to contaminants in water supplies and has recently conducted research studying the release of microplastics from toys and food packaging materials.

VDE Consultancy (Technical consultant)

Founder Nicole van der Elst Desai has 20 years of experience working in the fashion industry, working with brands and retailers as well as their manufacturing partners. She is a valued expert in the field of textile innovation, technology and sustainability, and has experience in chemical dyes and water, and in a materials lab. A graduate of the Amsterdam Fashion Institute in the Netherlands, she is passionate about creating better products and processes that leave behind a better planet.

Universiti Teknologi Malaysia (UTM) (Research support)

University of Technology Malaysia (UTM) is one of the five universities in Malaysia well-known in the field of engineering, science and technology. UTM houses more than 10 research alliances comprising 28 research centres of excellence in total. This earned UTM a reputation for cutting-edge research undertakings and innovative education. The reputation is further enhanced by receiving the National Intellectual Property Award for consecutively two years. In keeping with its mission of contributing to the creation of national wealth, UTM has led in the development of creative and innovative human capital as well as advanced technologies.

Acronyms and keywords

AATCC	American Association of Textile Chemists and Colourists
CLA	Circular Leap Asia
CVC	Chief Value Cotton (cotton-polyester blend fabric)
CO	Cotton
EU	European Union
ITMA	Textile and Garment Technology Exhibition
NEWRI	Nanyang Environment and Water Resources Institute
OIC	Ocean Innovation Challenge
PET	Polyethylene terephthalate
rPET	Recycled polyethylene terephthalate
SAC	Sustainable Apparel Coalition
ToC	Theory of Change
TMC	The Microfibre Consortium
TMAS	Tackling Microfibres at Source
UNDP	United Nations Development Programme
U.S.	United States
UTM	Universiti Teknologi Malaysia
ZDHC	Zero Discharge of Hazardous Chemicals (certification group)

Wastewater management facility at the Ramatex factory in Johor, Malaysia

Introduction

Project objectives

1. To contribute to the understanding of the impacts of textile manufacturing on the microfibre pollution problem. While global attention to the problem is increasing—for example, we now know that microfibres from textiles are a major source of microplastic pollution in the oceans—there is still little knowledge in the public domain about how microfibres are shed from the fabrics that are turned into the clothes we wear. Which production processes contribute the most to microfibre shed, and why? Do material types make a difference? What innovations are available today that could help us reduce shedding in production processes? This project hopes to contribute to a deeper understanding of these questions and more.

This study provides a methodology that suppliers can use to better understand where microfibre emissions are occurring in their manufacturing process and insights gained from applying the methodology to the manufacturing processes of a supplier (Ramatex) in the facility in Malaysia. Ultimately, the project hopes to contribute to tackling microfibre pollution by minimising the microfibre shed within production processes (at source), so as to significantly reduce shedding at the consumer stage.The research and findings from this project are made available publicly as an open source to accelerate change in the industry.

2. To identify and understand the driving forces behind the microfibre pollution problem linked to the textile industry. Why is it challenging to bring about change in the industry? What is preventing suppliers from undertaking more sustainable processes? What role do brands and retailers play in driving change? The project identifies where opportunities for intervention lie in the production process, and how it is broadly different for the various tiers of suppliers within the supply chain, as well as for brands and retailers.

3. To create momentum and catalyse action for stakeholders to adopt transformative solutions that can lead to long-term meaningful changes that not only significantly reduce microfibre pollution in the environment, but also shift the industry to one that is more just and regenerative for all. Although we all want straightforward solutions that solve the problem, like climate change, the microfibre problem is one that is complex; there are major gaps in knowledge on their environmental and human health impacts, and if all fibres (natural or synthetic) cause the same degree of harm and why.

We have taken a systemic approach in the understanding and framing of the microfibre pollution problem. This means while we 'zoom in' to understand what the research numbers say, it is equally important to 'zoom out' to understand how various stakeholders interact with one another in the industry, which has impacts on the processes undertaken in production, and contributes to the complexity of the problem. Similarly, while we aim to understand the impacts of each material type or solution, we do not examine them in isolation but instead place them within larger contexts such as their carbon footprint, water use and social impacts. This allows us to better understand their *overall* impact and avoid jumping to quick solutions that may create new or exacerbate existing problems.

Important notes on our scope

1. Microfibres within this project refer to *both* synthetic and natural fibres. While the general understanding of the term "microfibre" is a fibre from a synthetic source e.g. polyester, we have broadened this term to include natural fibres e.g. cotton. We strongly recommend this broadening of scope as all fibres shed regardless of source, and there is now evidence to indicate that natural fibres might persist in the environment. To keep a narrow definition of microfibres as purely microplastics risks ignoring a large source of microfibre pollution.

2. We have used the term "supplier" as a catch-all for the various tiers of textile manufacturers in the industry. A dyeing mill (Tiers 2 and 3) is a supplier to a cut and sew company (Tier 1), who is in turn a supplier to a brand. The definition of supplier in this report refers to both of these types of suppliers, and a customer is the company that purchases from each of these suppliers.

3. Our technical research and analysis of dyeing solutions is based on work with one supplier, Ramatex Group, and samples were taken from their facility in Johor, Malaysia. Our analysis of dyeing solutions is influenced by their circumstances, context, organisational culture and values unique to them. It should be noted that Ramatex is a vertically integrated supplier that has a strong track record in environmental and social sustainability, e.g. use of a reverse osmosis wastewater management system and solar energy. Given the importance of context in analysis, readers should keep this in mind throughout the report.

4. A geographic focus on South and Southeast Asia. While microfibre pollution is a global problem, much of textile manufacturing takes place in the Global South, mainly in Asia. We have thus chosen to focus on South and Southeast Asia and the bulk of our stakeholder interviews and analysis are based on the textile manufacturing ecosystems there. However, we are confident that the insights will be useful to the manufacturing ecosystem in other geographies.

5. Further research is needed in many areas to draw clear conclusions. This project is intended to serve as a starting point to think about textile manufacturing and its impacts on the microfibre pollution problem. As research progressed, it revealed the gap of knowledge in many areas such as yarn type, yarn construction and the different material types and their impacts on microfibre shed.

The textile manufacturing ecosystem is vast. A typical fashion brand reports between 1,000 and 2,000 suppliers,[1] with numbers reaching 20,000 to 50,000 when including sub-suppliers. Solutions will look different for different tiers of suppliers. While we have provided targeted recommendations for each tier, we are aware that they remain broad and would benefit from further research, which falls outside the scope of this project. We acknowledge that we have primarily engaged progressive suppliers in this study. Finally, there are clear limitations in the existing knowledge on the impacts of microfibre ingestion on human and organism health. These areas of research are also beyond this project.

Aerial view of Ramatex factory in Johor, Malaysia

Executive Summary

Five key takeaways

1. The importance of installing a robust wastewater treatment system. Wastewater treatment systems can reduce or eliminate microfibres from polluting the environment, and can also treat polluted water from textile manufacturing processes. In many jurisdictions, this is already a requirement for the licence to operate though implementation varies from country to country.

2. The textile industry should accelerate the move away from processing in heated baths and tanks filled with water, to machinery that requires very little to no water, and significantly less energy and chemistry.[2] This will entail machine-based technologies and innovations or a range of machine and operations-based innovations that currently exist, which present varying levels of potential for shifting the textile industry away from conventional dyeing and wet processes. Whilst chemistry solutions may be more accessible to suppliers and less disruptive to their existing setup, a shift from wet processes to dry processes involving machine-based innovations in the dyeing mill holds greater potential as a transformational solution.

3. The impetus for suppliers to adopt more sustainable practices is often driven by the need to comply with their customers' low-cost and speed demands rather than through their own agency to contribute to a more sustainable fashion industry. This hinders the shift towards a more just and regenerative industry as suppliers are not able to fully tap on their potential as change agents.

4. One key reason for this apparent lack of supplier agency is the absence of collaboration between brands and their suppliers that would place risk equally between both parties. Collaborations mean that brands work *with* suppliers on solutions, rather than asking them to work on their own and offer a solution. To enable the success of long-term sustainable solutions that tackle microfibres at source, the industry needs to build new ways for brands and suppliers to work together.

5. More research on factors that impact microfibre shed in the production stage such as yarn and material type are urgently needed to accelerate the development of solutions. Similarly, more research to understand the potential implications of microfibre ingestion on human and organism health is also critical and will help to advance greater upstream action. Policy has an important role to play in catalysing funding opportunities in these research areas.

The Microfibre Challenge

"If we don't act now, by 2050 there could be more plastic than fish in the ocean."

This alarming statistic by the Ellen MacArthur Foundation[3] sums up the magnitude of the marine plastic pollution problem the world now faces. Microplastics in particular pose a huge challenge given their small size (less than 5mm), which means they are easily ingested by marine organisms. They are contaminating the earth and can be found in even remote regions of the Arctic and the deep sea floor of the Mariana Trench.[4, 5] Research indicates that microplastics can also be found in our bodies and are bioavailable for uptake into the human bloodstream.[6] However, their exact health impacts have not yet been demonstrated.[7]

Microfibres from textiles contribute significantly to microplastics in the oceans
Microfibres from synthetic sources are a dominant component of microplastics found in the oceans. According to a recent report, synthetic textiles contribute the greatest amount of primary microplastics (35% of annual emission into oceans). In fact, natural fibres also contribute to microfibre pollution, adding to the size of the problem.[8] With the growth of the fashion industry, and in particular the continued popularity of fast fashion, microfibre pollution in the environment is set to grow.

Evidence points to textile-based fibres released via household laundry and municipal wastewater as a significant source, and research shows that textile properties such as yarn type and construction, chemical and mechanical treatment influence the degree of microfibre shedding during domestic laundry. Yet, most recent research has focused on the consumer end-product, including testing and exploring solutions for consumers to reduce microfibre shed.[9]

"We estimate that pre-consumer textile manufacturing releases 0.12 million metric tons (MT) per year of synthetic microfibres 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 microfibre pollution."
— *Toward eliminating pre-consumer emissions of microplastics from the textile industry*, The Nature Conservancy.[10]

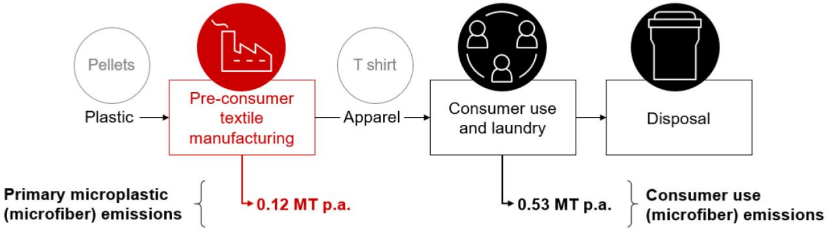


Image 1: from *Toward eliminating pre-consumer emissions of microplastics from the textile industry*, The Nature Conservancy

The industry is not yet focusing on the problem

There is limited research on how upstream manufacturing processes contribute to microfibre pollution, and at the start of this project, we were unaware of research being undertaken to understand exactly why and how microfibres are shed from textiles in their production stage. This presents a gap in knowledge that hinders the fashion industry from taking action to tackle the growing problem of microfibre pollution. In a report[11] by the Carbon Disclosure Project (CDP), it confirmed that fashion and textile companies were generally not aware of and not accounting for their water pollution risks, including the release of microfibres at the production stages. Textile guides widely used by the industry such as the annual Textile Exchange's Preferred Fibre and Markets Report do not yet include microfibre shed as an important component.

Regulations are on the horizon

Despite the industry's limited response towards the microfibre pollution problem, the first regulations targeting microfibre pollution are on the horizon.

The EU Strategy for Sustainable and Circular Textiles launched in 2022[12] has made clear that by 2030 textile products placed on the EU market should be long-lived and recyclable, to a great extent made of recycled fibres, free of hazardous substances and produced in respect of social rights and the environment. As part of the strategy, regulations are likely to include ecodesign requirements, tackling microplastic pollution measures that are set to be released in 2022/2023, and a digital passport that makes information on the product's sustainability transparent.

By minimising the microfibre shed within production processes (at source), our understanding is that this should also significantly reduce shedding at the consumer stage, thus resulting in the overall reduction of the problem from the textile industry. We hope for this project to serve as a starting point that ignites action from the industry to rise to the challenge of tackling microfibre pollution and preserving healthy oceans for all.

Impact on the environment	Impact on human health	Research gaps	Factors driving change
Limited understanding mostly focused on microplastics rather than microfibres: • Microplastics can cause tissue damage, oxidative stress and changes in immune-related gene expression, and antioxidant status in fish • Neurotoxicity, retardation in growth in fish • Behavioural abnormalities observed	**Limited understanding:** • Microplastics can be detected in human body parts and in the human bloodstream[13] • Inhaled plastic microfibres may persist in the lungs and could cause respiratory problems[14] • Microplastics might cause oxidative stress, cytotoxicity, and translocation to other tissues[15] • Microplastics act as vectors for microorganisms and toxic chemicals posing further health risks[16]	1. Impacts on human health when ingested or inhaled, and via skin contact (toxicity) 2. Impacts on the environment - especially in the oceans and waterways (biodegradability, impacting on ability to persist in the environment) 3. Impacts on marine life and organism health ultimately contributing to human health 4. Impacts on livelihoods affected due to contaminated seafood	1. Regulations - regional, global e.g. EU; United Nations Treaty on Plastic Pollution 2. Growing climate and ecological crisis 3. Increased understanding of the health impacts of (synthetic and natural) microfibre ingestion 4. Growing consumer awareness about plastic pollution; demands for more sustainable products 5. Industry actors using sustainability as a differentiating factor

Table 1: At a glance: what we understand about microfibre impacts and the many gaps today

Yarn packing area in the Ramatex polyester mill

Theory of Change

For this project, Forum partnered with a vertically integrated supplier, Ramatex Group, and research lab NEWRI to develop and test a methodology for identifying what manufacturing processes most contribute to microfibre shedding. We sought to understand:

1. How might suppliers contribute to reducing microfibre shedding in their manufacturing process?
2. How might suppliers be provided with the means to test their own manufacturing processes to reduce microfibre shedding?
3. How can we better understand the systemic barriers to upstream solutions that tackle the microfibre pollution problem?

Combined, these actions contribute to protecting and conserving the marine ecosystems for sustainable development.

Background

The goals of the fast fashion business model incentivise suppliers to compete on their ability to reduce cost and to deliver at speed, with little to no regard to the negative environmental and social impacts on the environment and workers. In this context the mindset of suppliers, when asked to lead innovation to reduce microfibre shedding might be, *"if a brand isn't asking for it, there's no value in investing in it"* and *"not if it adds to costs."*

Yet, given how typical fashion brands' have over a thousand suppliers and almost 20,000–50,000 sub-suppliers,[17] and that upstream microfibre shedding makes up almost half of overall microfibre shedding, we know that suppliers need to be considered an active, critical part of the solution to reduce shedding at the levels needed.

We will not successfully tackle the microfibre pollution problem without suppliers being an equal driver to the solution. However, the structure of current business models limit the potential for supplier-driven innovation and, ultimately, industry transformation. This project aims to indicate what actions a supplier might take and the systemic barriers they face in implementing solutions that reduce microfibre shedding.

Theory of Change

Current challenge	Target Group	Activities	Near-term outcomes	Long-term outcomes
• Suppliers are not incentivised nor have the agency to reduce microfibre shedding in upstream manufacturing processes • There is minimal insight into what upstream processes contribute to microfibre shedding	*Primary*: • Suppliers (all tiers), particularly mid-to-large sized progressive suppliers with most of their operations in Asia • Brands and retailers, in particular those with supply chains in Asia • Trade associations of the textile industry and fashion industry *Secondary*: • Interest and Research groups	1. Partner to develop a research methodology to test in what ways we might reduce microfibre shedding in the manufacturing process 2. Baseline research into what processes contribute most to shedding and investigative research into how to reduce microfibre shedding 3. Engagement with suppliers in the region and the industry at large, to better understand the barriers to adopting new practices	• A methodology for testing microfibre shedding that can be replicated with other suppliers • Insights on potential intervention points in the manufacturing process to reduce shedding • We gain better insights on how to address systemic barriers to upstream innovation	• Suppliers have more agency to address the microfibre challenge in their manufacturing plants • Suppliers invest in and adopt new practices to reduce microfibre shedding • The power dynamic between brands and suppliers has begun to shift to a more equitable partnership to address the microfibre challenge
Goal: Oceans are healthier due to the reduction of microfibre emissions from upstream manufacturing processes				

Table 2: TMAS Theory of Change

PET chips being processed at the Ramatex polyester mill

Methodology

This section summarises the research scope, approach and process. The full technical report is available for download on [Forum's website](#).

Textile manufacturing generally involves turning raw material (fibre) into finished clothing products. The research in TMAS focuses on the **upstream steps** that involve turning raw material into polyester or cotton yarn, which is then made into fabric and undergoes different treatment, colouration and finishing processes.

The image below illustrates, in the top half, a general representation of the textile manufacturing process, and in the bottom half highlights the specific process steps that take place in the Ramatex factory where samples for testing were collected. An explanation of each process step can be found in Appendix A, table 9.

Image 2: General process of textile manufacturing

Different types of samples (water or dry) were collected from each process step, as seen in the images from Ramatex's facilities below:

Image 3: A Ramatex worker conducting quality checks on spools of polyester yarn

Image 4: Cotton in the process of being spun

Image 5: Ramatex dyeing mill

In dyeing, water is used as part of the process and released after completion. Therefore, a water sample was collected for testing as part of our research.

Research operating principle and context

The **overarching purpose** is to investigate opportunities to reduce microfibre shedding in the fashion industry through textile design and manufacturing innovation. In the course of the research, the COVID-19 pandemic and lockdowns in Singapore and Malaysia disrupted our ability to collect water samples and transport them across borders, and in this period we collaborated with Malaysian research lab UTM to ensure the continuation of the research.

The **operating principle** of the overall research is to analyse textiles that are produced and purchased in the highest volumes, or are of importance to the industry so as to create the greatest impact through their study.

Overview of the baseline research and investigative research

The objective of the **baseline research** is to understand the textile fibre being shed at the textile manufacturing process, and to establish which step contributes most to shedding within the scope of the chosen textiles and textile colours (Appendix A, table 10). Guided by the research operating principle, the baseline research collected samples from the most prevalent processing steps and the most high-volume fabrics and colours at the Ramatex facilities in Malaysia. The sample types and quantities collected for the baseline research can be found in Appendix A, table 11. From these samples we measured four main types of results - fibre mass, fibre quantity, fibre length and length distribution - and in addition, for the samples from the cotton and polyester blend textiles, we tested for fibre type to understand the raw material from which the shedded fibre was made of (see Appendix A, table 12).

The findings from the baseline research inform the scope of the **investigative research**, which sets out to develop interventions that can be potentially applied to the textile manufacturing process to reduce microfibre shedding. The types of interventions were developed with Ramatex, and were informed by what could be achieved in the lab by NEWRI. In the investigative research phase we focused on measuring fibre mass, as the baseline research showed that this was a useful indicator to standardise the measurements for practical, industry-wide application.

Throughout this process, the input from Ramatex and NEWRI was integral to defining the research scope. The scope of testing in the baseline research differed from the investigative research as it took into account different practical and operational considerations, and relied on the expertise of our partners in their respective fields.

The testing methodology in our baseline research is developed with cost effectiveness and high levels of replicability in mind. Suppliers, in particular progressive ones with the ability to leverage their resources and relationships with brands and/or retailers, are encouraged to consider adopting and developing this methodology to start measuring microfibre shedding in their manufacturing processes.

This report provides a summary of the scope and methodology. Full details may be found in the technical research report ~~linked to~~ on our webpage.

Image 6 summarises the different components of our baseline research, including the manufacturing process steps from which water and dry samples were collected, a brief overview of the flow of testing, and the types of results and selected textiles and colours within the scope of the baseline research.

For the testing we developed a methodology to understand the profile of the microfibres in the samples collected for this project. Image 7 illustrates the flow of the *testing* methodology and an outline of key points to note about this process can be found in Appendix A, table 12.

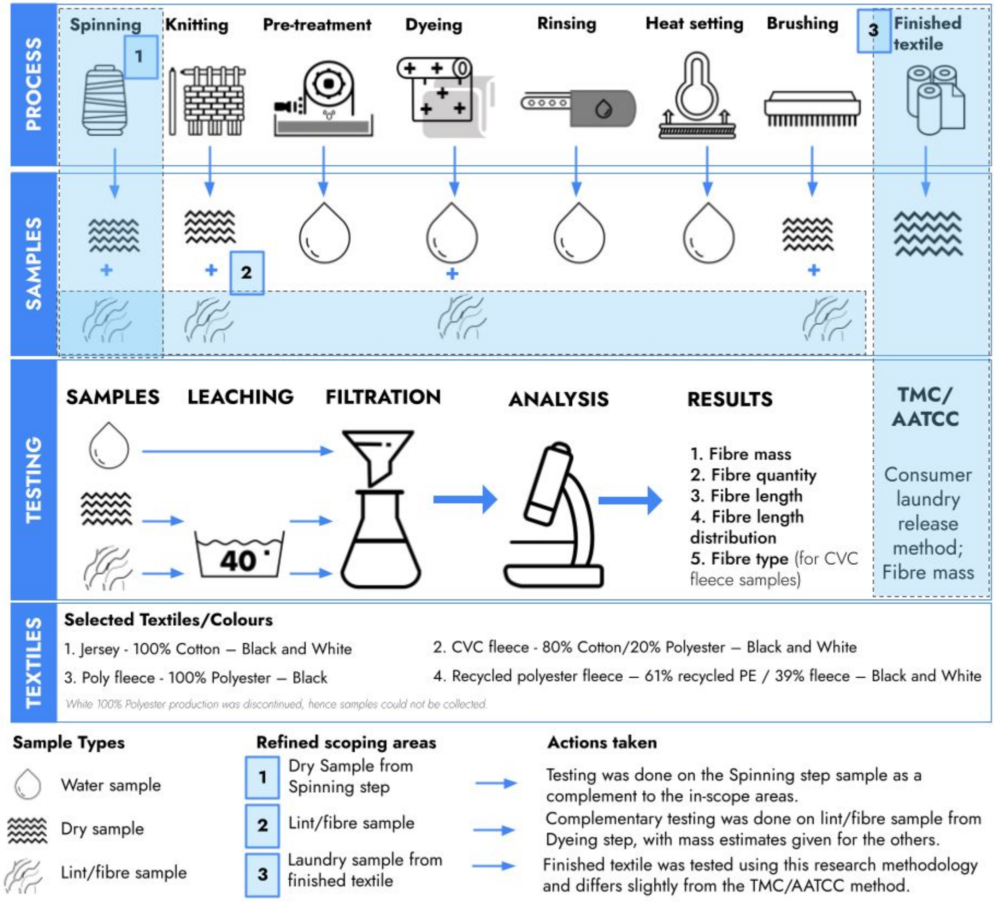


Image 6: Summary of baseline research scope and methodology

Leaching

A dry sample will be taken to leach the microfibre content in liquid; an ***assisted water sample.***

- 40rpm
- 40℃
- 40 min
- 50 stainless steel balls

Filtration

Both leached sample and discharge-water sample will be filtered; ***fibre sample.***

- Glass filter -> **fibre mass of sample**

After chemical separation for cotton rich only!
- Cellulose and glass fibre -> polyester fibre mass

Chemical separation

To dissolve cellulosic fibres the filtered water will be treated with H_2SO_4 for cotton rich only!

After chemical separation, repeat filtration

Analysis and results

Through different ***analytical equipment*** *the different fibre samples will be analysed.*

- Keyence microscope:***fibre quantity*** and ***fibre size distribution***
- FITR:***fibre type*** i.e. PE or PET
- Analytical balance: **fibre mass**
- Empirical formula: **fibre mass (blends)**

Image 7: Flow of baseline testing methodology

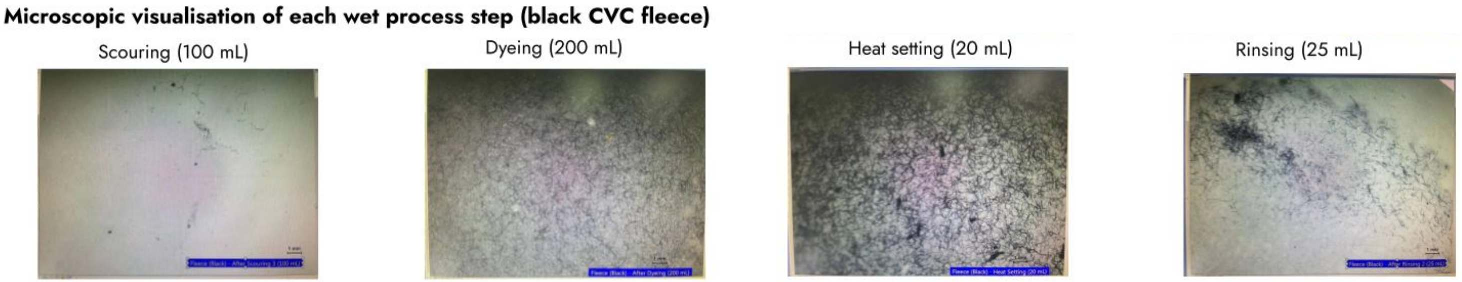
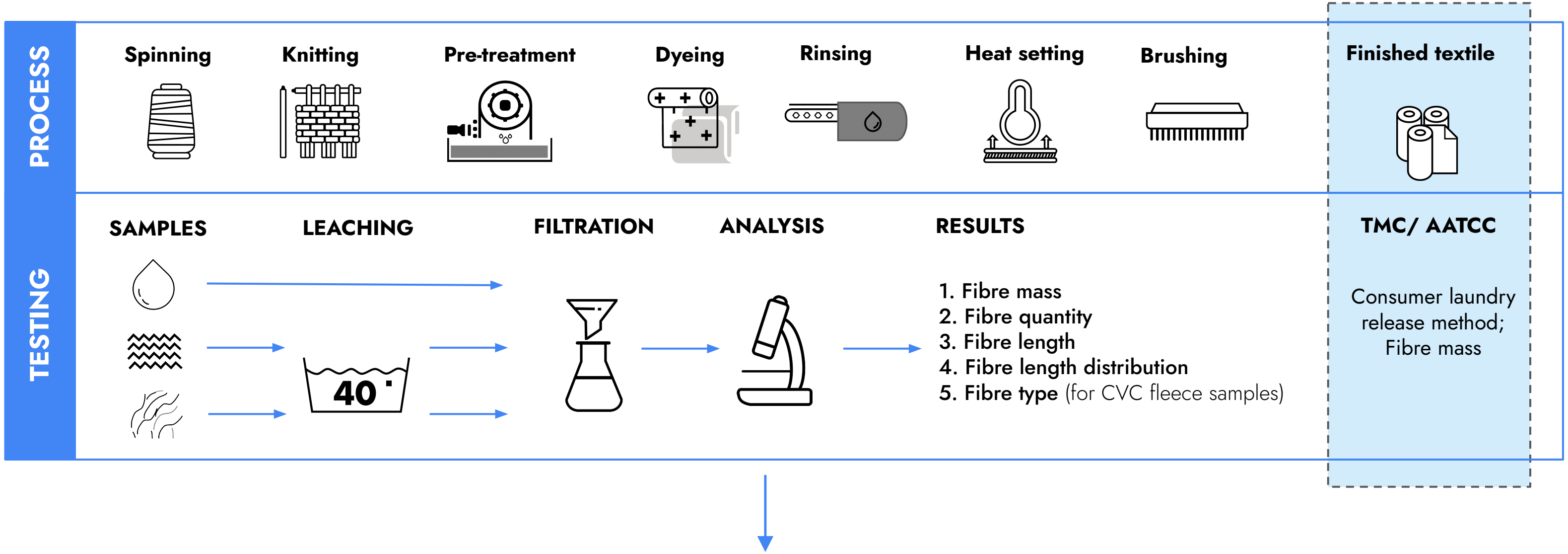
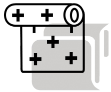
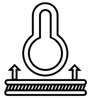


Image 8: Microscopic images of textile fibres taken by UTM

The **baseline research** seeks to establish which step in the textile manufacturing process at the Ramatex facilities contributes most to shedding within the scope of the chosen textiles and textile colours.



Two process steps were identified as contributing the most to microfibre shed:

Dyeing  **Heat setting** 

These findings formed the starting point of our **investigative research phase**.

Image 9: Moving from the baseline research into the investigative research phase

Translating the research into actionable outcomes and recommendations

In the investigative research phase, it was critical to test our baseline results, which had identified dyeing and heat setting as the process steps contributing most to microfibre shed, against primary and secondary research sources. This included interviews, site visits, surveys and desk-based research.

Crucially, on-site interviews with the Ramatex operational staff conducted at their facilities helped streamline the investigative research to focus on the **dyeing process** and determined the scope of testing. This covered the textile types tested and the testing variables to be applied to the test samples in a lab setting. From the dyeing settings provided by Ramatex we studied how changing temperature and duration might impact and reduce microfibre shedding. The purpose of this testing was to develop recommendations for Ramatex to apply in the factory setting and reduce microfibre shedding within the dyeing process. An explanation of the progression of the investigative research is outlined in Appendix A, images 14 to 16.

With the results of the investigative research we again interviewed Ramatex on the feasibility of the recommendations. We learnt that when put in practice, these lab recommended settings would compromise the final quality of the textile product and would likely not be acceptable to the brand customer (Appendix A, table 5).

We took this information into interviews with other suppliers, brands, microfibre innovators and industry interest groups, who echoed the observations made and shared other insights that prompted us to conduct additional desk-based research into other factors in the dyeing process and textile manufacturing in general that also contribute to or influence microfibre shedding. This included various existing dyeing processes, technologies and innovations, different material types, and the crucial first step for any supplier - filtration and wastewater management.

The process we undertook in this final stage is illustrated in Appendix A, images 17 and 18. This phase of the research proved to be critical to sharpening our analysis and recommendations, and was a clear instance of our Theory of Change in action.

There were two important takeaways that shaped the analysis, outcomes and recommendations presented in this report, and that are critical for any industry actor to keep in mind when tackling the microfibre challenge:

1. **Transformational solutions for the microfibre challenge involve a significant level of cost and risk, largely expected to be borne by suppliers. This and other systemic barriers, such as the entrenched ways of working between brands and suppliers, discourage the adoption and scaling of innovations with the potential to eliminate or greatly reduce microfibre shedding upstream.**

2. **We need to address and to allow the complexity of relationships in the supply chain, the power dynamics between suppliers and brands, and the perspectives, motivations and biases of different actors to inform our understanding of the conditions that need to be in place for transformational solutions to take root and scale.**

Summary of baseline research results - most impactful process step

Relating to the Ramatex facilities in Malaysia, the total contribution of the seven identified textiles showed that for each of the different result types - fibre mass, fibre quantity and fibre length - heat setting was the most impactful processing step. This is discussed in detail in the technical research report linked to our webpage.

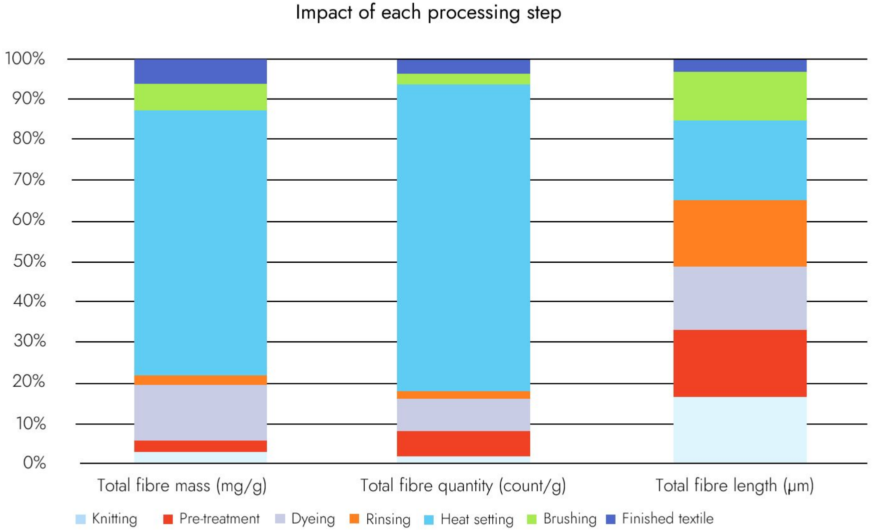


Image 10: Summary of baseline research results

Summary of the investigative research results – impact of interventions in temperature and duration

As a broad comparison the results appeared to show that 100% recycled polyester and 100% polyester shed the most compared to the CVC and 100% cotton greige materials. This was a surprising outcome when compared to the results from the baseline research. It should however be noted that a like-for-like comparison of the materials, especially between cotton and polyester, is difficult to achieve due to the differences in yarn types, spinning methods and so on.

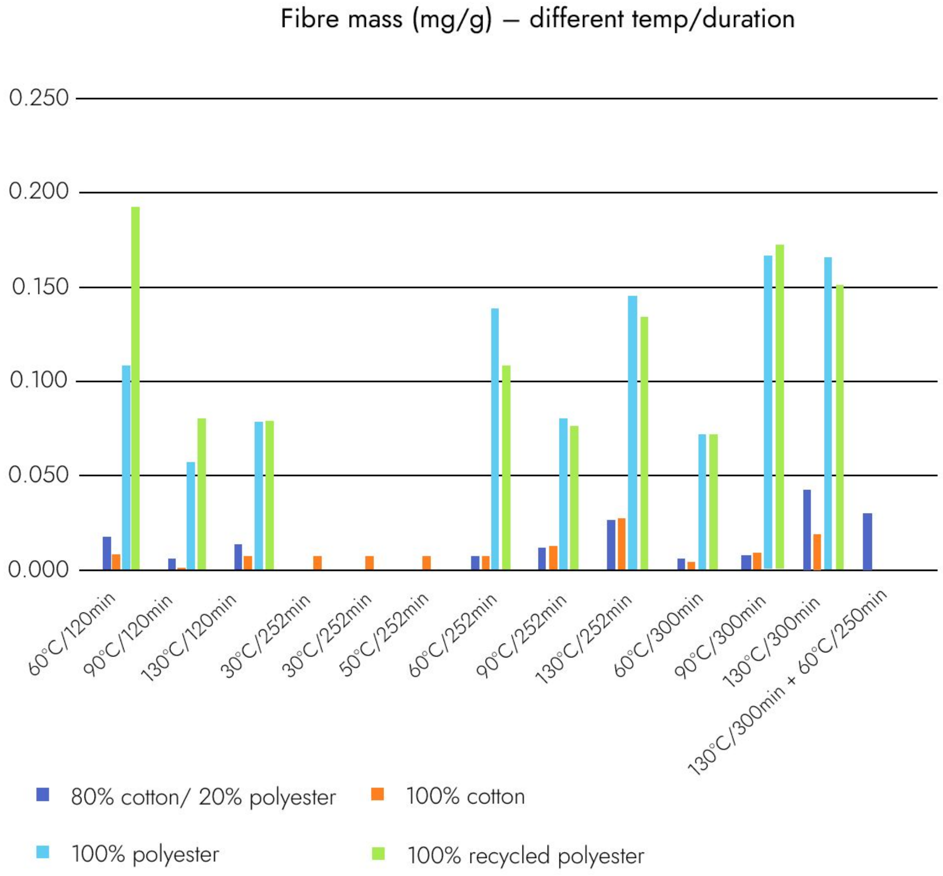


Image 11: Summary of investigative research results

Fabric being dyed at the Ramatex mill

Solutions

Based on our research and industry discussions, at present, changes in wet processes including dyeing hold the clearest pathway for solutions to reduce microfibre shed in textile manufacturing. Please see Appendix B for a more detailed discussion of how materials and yarn options contribute to the challenge.

In assessing solutions that can help reduce microfibre pollution from the textile industry, the first key solution to consider is the installation of a robust wastewater treatment system. Wastewater treatment systems can reduce or eliminate microfibres from polluting the environment, and can also treat polluted water from textile manufacturing processes. In many jurisdictions, this is already a requirement for the licence to operate though implementation varies from country to country.

Wet processes including dyeing

Based on our research findings, we focused on wet processes including dyeing, given that they have the greatest impact on microfibre shed as seen from the results of our testing. However, at present there is limited openly available information on the impact of wet processes, including dyeing, on microfibre shed in textile manufacturing.

Wet processes are the steps that require the input of significant amounts of water and that are required to prepare the fabric for dyeing and to ensure that the dyes are properly set to achieve the desired quality in a product.

Dyeing is the application of colour to a textile material with some level of permanence. Colourants that are applied to the textiles are called dyes.

To dye a textile material and produce the final colour, the dye needs to attach to the chemical molecular structure of the textile fibres. This dye-fibre molecular association is responsible for the degree of fastness or permanence of the colour. Dyes are typically fibre specific.[18]

Chemical products and agents are added during dyeing to allow the dye process to be carried out more effectively.
For dyeing to be considered successful, the following parameters are considered:

- Colour strength (shade) and colour matching
- Colour levelness
- Colour fastness
- Hand feel
- Shrinkage
- Fabric width and weight

Please refer to Appendix C for a more detailed explanation of the dyeing process.

Why is the dyeing process problematic?

Environmental and social impacts of the dyeing process

Textile production is one of the biggest sources of global water pollution, mostly due to the dyeing process. In essence, the dyeing process is problematic because of three main reasons:

1. Water consumption

The dyeing process is a water intensive one. A single fabric mill can use up to 200 tons of fresh water to dye one ton of fabric[19] because almost all dyes, specialty and finishing chemicals are applied to textiles through the use of water baths. The sub-steps that are part of the preparations for the dyeing process such as scouring and bleaching also require water systems. Depending on where the cotton was grown, a pair of denim jeans could require around 2,000 gallons of water to produce a single pair of jeans from growing raw cotton to the finished product.[20]

While water consumption varies among suppliers, Image 12 highlights the water intensity of the dyeing process and the preparations required beforehand, with the exception of some processes that are particularly low in water consumption e.g. cold pad-batch dyeing, which is explored as a potential point of intervention in this report.[21]

The water intensity of the full dyeing process can be mitigated by a closed-loop water system, which ensures minimal freshwater is used by treating and reusing wastewater already in the factory system. This is the case for the Ramatex factory in Malaysia. However, many suppliers, especially those situated in developing countries that do not operate under strict environmental and health regulations, do not yet employ closed-loop systems. As droughts and water scarcity become increasingly intense with global warming, wet processing in the "business as usual" methods will no longer be feasible or acceptable.

2. Water pollution and impacts on human and organism health

The dyeing process is also a major contributor to water pollution and consequently, to negative impacts on human and organism health. To achieve the blue colour in denim jeans, the thread or fabric is repeatedly soaked in large amounts of indigo dye. After dyeing, the denim undergoes more chemical treatments to soften the fabric or give it texture. It is put through more chemical baths to ensure a faded "worn" look. Each time new colours are added to fashion collections, new chemicals and pigments have to be added.

Water Consumption by Unit Process

Processing subcategory	Water consumption, gal/lb of production
Yarn and fabric forming	Nil
Slashing	0.06 to 0.94
Preparation	
Singeing	Nil
Desizing	0.3 to 2.4
Scouring	2.3 to 5.1
Continuous bleaching	0.3 to 14.9
Mercerizing	0.12
Dyeing	
Beam	20
Beck	28
Jet	24
Jig	12
Paddle	35
Skein	30
Stock	20
Pad-batch	2
Package	22
Continuous bleaching	20
Indigo dyeing	1 to 6
Printing	3
Printing afterwashing	13.2
Finishing	
Chemical	0.6
Mechanical	Nil

Image 12: Water consumption for various wet processing steps

These textile dyes and chemicals such as azo dyes can be highly toxic and potentially carcinogenic,[22] and cause environmental degradation as well as diseases in both humans and animals.[23] Again, while many suppliers have methods to reduce or capture this harmful wastewater such as through a closed-loop water system, many factories in developing economies still release wastewater into nearby waterways, eventually flowing into the sea.[24]

The toxicity of textile dyes are also caused by oral ingestion, having contact with reactive dyes, and inhalation of dust[25] that trigger irritations to the skin and eyes.[26] It is important to note that some factories still do not provide adequate protective clothing for workers. There is evidence of the persistence of these chemicals in conventional treatment plants and water systems that eventually lead to public water supplies.[27] Long-term exposures in particular, may have serious impacts on aquatic biota and human health.[28]

3. Energy consumption

According to the Ellen MacArthur Foundation the fashion industry is responsible for 10% of annual global carbon emissions, more than all international flights and maritime shipping combined.[29] Studies suggest that the wet processing and finishing steps account for about 36% to 38% of the energy used in textile manufacturing.[30, 31] This is not surprising as dyeing processes require large amounts of energy to heat big quantities of water. (Because of the diversity and fragmentation of the textile manufacturing industry, it is not always possible to form a clear picture of the carbon footprint of individual suppliers, which is dependent on their energy source, e.g. renewable energy, coal, electricity etc.)

Dyeing solutions and innovations

Due to the limited scope in changing temperature and duration settings within the heat setting step, as well as the current impracticality of measuring these changes alongside other dye settings, we have assessed that it would be more beneficial to focus our analysis on potential solutions that could reduce or eliminate microfibre shed by replacing conventional water based dyeing methods. Some of these technologies and innovations also reduce the environmental harm and impacts on human health from conventional wet processing.

Potential solutions that replace traditional dyeing methods

The ideal solution to addressing the negative impacts that arise from conventional dyeing, including microfibre shed, energy consumption, water use and pollution, and so on, would be to move away from wet processes towards dry processes. In other words, moving away from processing in heated baths and tanks filled with water, to machinery that requires very little to no water, and significantly less energy and chemistry.[32] This will entail machine-based technologies and innovations. It is estimated that this shift could potentially reduce CO_2 emissions by up to 89% and reduce water consumption by between 83% to 95%.[33] In addition, a significant reduction or even elimination of the use of water in the dyeing mill translates to the greatest possible impact in reducing the amount of microfibres that enter waterways and the oceans through the effluent from wet processes.

1. Dope Dyeing

Dope dyeing is a technique used on synthetic fibres in which pigments are added to liquid polymer before synthetic fibres are formed in a process called extrusion. Yarns that can be produced dope dyed include polyester, nylon, polypropylene, polyethylene, viscose, meta-aramid, para-aramid and PET.[34] It produces results of excellent colour fastness and reduces the many impacts of the dyeing process. According to the findings of Swedish brand IKEA, this reduced water consumption by 80%, dyestuff consumption by more than 20%, the use of other chemical agents like alkaline by 80% and electricity usage by 7% compared to traditional dyeing.[35] Since the extrusion process with pigment is almost the same as the production of fibres, it is cost effective.

A disadvantage with dope dyeing is that it requires extra cleaning between colours and there are less opportunities to create custom colours.[36] It is a less flexible process commercially and the colour range produced needs to be carefully chosen to avoid large stockholding, but it is viable for certain large volume shades e.g. black.[37]

Dope dyeing has a few means of application. For a supplier like Ramatex with the capacity to process raw material, this can be built in-house within the polyester mill. However, it is not common amongst suppliers to have the in-house capability for dope dyeing application. In-house dope dyeing requires significant investment and commitment from both the supplier and brand customer(s). Alternatively, suppliers can purchase dope dyed yarns from an external vendor such as We aRe sPin Dye®.[38]

At present only a limited number of colours are used or are available, and implementation at scale would entail a number of factors. Firstly, the suppliers of the PET pellets (also known as masterbatch) would have to significantly expand the range of their formulations and potentially overhaul their supply chains to meet the full colour demands of the brand customer.[39]

Secondly, the textile manufacturer would have to build out the operational capacity to be able to meet the demands of production volume and schedules – and in turn justify the cost of ordering certain specific coloured PET chips. The third and most important factor is that this solution hinges on the brand customer's ability to commit to sufficient order volumes that justify the cost and lower of risk of wastage, as suppliers avoid storing the coloured PET chips[40] after they are produced. It is also tied to the suppliers' willingness to bear the attendant risks, such as the lack of flexibility in adjusting the dye proportions, which conventional dyeing machines offer.

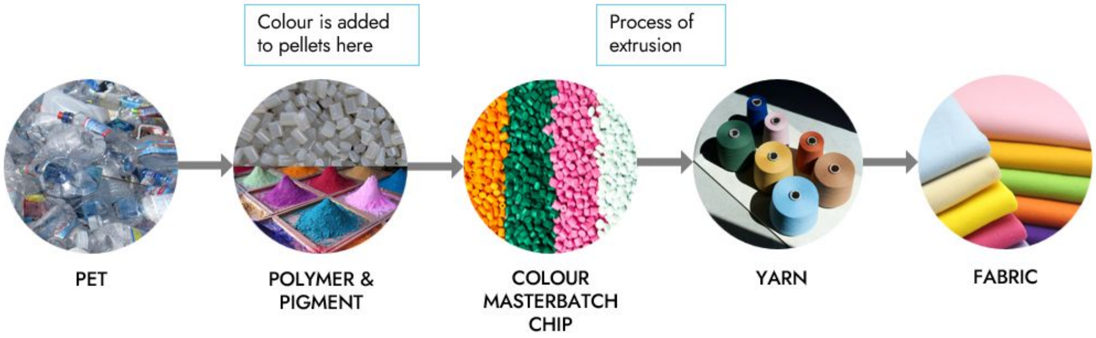


Image 13: Illustration of dope dyeing process

2. Digital Textile Printing

Digital textile printing is a process that has been increasing in popularity particularly in manufacturing regions that specialise in fast fashion. There are primarily two successful digital printing methods: sublimation printing and direct digital printing.[41] Its rise in popularity is due to its high colour fastness, cost effectiveness, and speed in comparison to traditional methods of screen printing. However, digital printing methods are rather limited in use; they are used mostly for prints e.g. batik or repeat prints, and do not work for block dyeing items e.g. a basic coloured hoodie. It does not deeply penetrate fabrics, which makes it more difficult to use on thicker materials like denim[42] or fabrics that require high stretch.[43]

- **Sublimation printing**. Through a two-step dye sublimation process, a printed paper is bonded to polyester using heat and pressure.[44] Using a heat roller, the sublimation ink on the paper evaporates and diffuses as the pores of the polyester fabric open. This allows the ink vapour to penetrate the fabric.[45] It does not use water, and less chemicals are used than in traditional dyeing. However, the dyes can still be toxic, may release fumes from the heat transfer, and release affluent in the washing process. The method cannot be used on cellulosic fibres like cotton and is best used on lighter coloured fabrics.[46]

- **Direct digital printing**. In direct digital printing, fabrics are pre-treated with a stiffening chemical, then passed through an inkjet printer, and then washed to remove any residue. The fabric is coloured by droplets of ink, which are produced by multiple print heads positioned a few millimetres above the substrate.[47] Different inks are best suited to different materials which makes it difficult to print on mixed-fibre materials with high fastness properties.

Operationally, direct digital printing is feasible: printing utilises the same dyestuffs as traditional dyeing, and the printing machines can be installed next to the traditional setup to implement a gradual transition. However, the supplier would have to consider if this would be the best utilisation of their space.[48] Furthermore, with printing currently unable to meet the capacity and production volumes of traditional dyeing[49] as well as producing results that fall short of certain product requirements such as poorer handfeel and aesthetic outcomes,[50] this transition may not be viable in the immediate term.

3. Supercritical carbon dioxide dyeing

A supercritical fluid is a substance above its supercritical temperature and pressure, and has the properties in between a gas and a liquid. Carbon dioxide has been widely studied and used due to its convenient critical point, cheapness, chemical stability, non-flammability, stability in radioactive applications and non-toxicity.[51] Typically, the CO_2 used is a waste product of combustion, fermentation and ammonia synthesis, so it does not have to be specially produced for dyeing, and there are other advantages such as:[52]

- Post-dyeing, it is easy to separate the CO_2 from the unused dye and hence potentially recycle them
- Unlike in water based dyeing, it does require energy-intensive drying after the dyeing step
- It does not require a disperse agent for dyeing polyester, which means simpler dye formulations can be used, and
- it has a higher rate of dyeing compared to conventional processes.

At the time of writing, CO_2 dyeing does not seem to have scaled as expected. From our conversations with the industry, while water use was reduced the energy savings did not match up to expectations.

Further research and testing is still needed to build out knowledge and practical applications on reactive and non-reactive dyeing in supercritical CO_2. The upfront cost of equipment and technological investment is also high, which is a challenge for wide-scale adoption.[53]

4. Ultrasonic assisted wet processing (dyeing and finishing)

Another way is to use ultrasonic energy to clean or homogenise materials, which helps speed up physical and chemical reactions and in turn improve dyeing processes. Ultrasonic technologies can be used to dye both synthetic and cellulosic fibres. Ultrasonic waves are vibrations with frequencies above 17 kHz - outside the auditory range for humans - that require an elastic medium to propagate. In general they can function under low temperatures and reduce the consumption and concentration of auxiliary chemicals, in turn reducing the pollution load in effluent. When used alone or combined with enzymatic treatments they can reduce processing times and potentially cost, minimise fibre damage, and create uniform treatment of the fabric.[54] This in turn can help increase colour strength and fastness.[55]

The trade-off is that ultrasonic waves require high intensities and these are produced by electricity, which represents energy consumption - albeit less costly than the thermal energy which is used in the process. Ultimately, while the technology is not new, testing seems to be at the lab level despite its promise and has not yet been commercially scaled up. Reasons include, the variability of the wave intensity with different-sized production equipment creating unpredictability, and potential inconsistencies in the production process.[56]

Conclusion on technologies and innovations in dyeing and wet processes

There are numerous potential options within the dyeing process involving chemistry and machine-based solutions, all with their advantages and disadvantages. Whilst chemistry solutions may be more accessible to the manufacturer and less disruptive to their existing dyeing setup, a shift from wet processes to dry processes involving machine-based innovations in the dyeing mill holds greater potential as a transformational solution to the microfibre pollution problem.

However, any adoption and scaling of innovations or solutions requires a fair, balanced and committed level of collaboration between suppliers and their brand customers. As mentioned, the industry is up against significant barriers to change: for the majority of suppliers worldwide, the industry continues to unfairly place the burden of cost and risk on the upstream supply chain. In the current landscape, even if the manufacturer does cough up the investment, brands do not necessarily commit to the ensuing outcomes—and with machine technologies estimated to range from USD 150,000 to 20,000,000, this daunting undertaking can put off many suppliers entirely.[57] It should also be noted that operating costs for maintenance and upkeep of machines often outweigh the capital investment, making them a long-term expense for the manufacturer.

Table 3 on the next page compares a selection of dyeing technologies and wastewater treatment based on the level of potential shown in tackling microfibres and how widely considered they are by the industry.

Solution	Strengths	Drawbacks	Potential for positive impact on the environment and worker health	Potential for reducing microfibres	Potential to transform the system
Wastewater treatment	Tackles several environmental problems	Requires significant financial investment (depending on technology)	High	High - already considered a requirement in many countries	Low
Dope dyeing	Proven technology High quality product No water used in the process	Requires significant financial investment Shade limitations Requires prior brand commitment to output Works only with synthetic fibres	High	High	High
Cold pad-batch dyeing	Proven technology Reduced water use Reduced energy use High product quality	Requires some financial investment Works only on cellulosic fibres	Medium	High - Low abrasion on fibres	Medium
Supercritical CO_2 dyeing	No water used in the process Can be used on both synthetic and cotton fibres	Not yet scaled Significant investment required Potentially high energy usage High quality product	Medium - energy use remains high	High	High
Ultrasonic assisted dyeing	Less water used in the process Helps minimise fibre damage High product quality	Not yet scaled Potentially high energy use	Low - energy use potentially high	High	High
Dry digital printing (e.g. sublimation)	Little to no water used in the process	Significant investment required for machine Potentially high energy use Dyes can still be toxic Costly to operate - cost of ink is high Varying quality Fabric requires preparation for printing Only used for specific purposes e.g. repeat prints; not for dyeing full fabrics Works only on polyester fibres or polyester blends Requires consumer acceptance of the look of the products due to print-only style	Medium	High	Low - cannot yet replace conventional wet dyeing

Table 3: Comparison of dye technologies and wastewater treatments

Quality inspection conducted at the Ramatex polyester mill

Systemic Barriers to Change

Considering brand-supplier relationships and the role they play in driving innovation

The textile manufacturing industry has great potential to drive transformation that reduces its contribution to microfibre pollution and build a just and regenerative fashion industry. However, the potential that suppliers hold in this transformation is often overlooked, and change initiatives are mostly led by fashion brands. This is problematic because the solutions in changing wet processes and dyeing will require suppliers' to implement these in their day-to-day manufacturing processes. These solutions, especially those that are potentially transformational, require significant investment upfront. Yet the existing system contains barriers that hinder suppliers from adopting more sustainable practices. The impetus for driving change is often driven by the need to comply with their customers' demands rather than through their own agency to contribute to a more sustainable textile industry.

One key reason for this apparent lack of supplier agency is the lack of collaboration between brands and their suppliers, which would place risk equally between both parties - collaborations that mean brands work *with* suppliers on solutions, rather than asking them to work on their own and offer a solution.

In the absence of such equitable collaborations between brands and suppliers, the industry currently expects suppliers to absorb the costs and risks of implementing solutions at scale or to transform the supply chain. And while brands face a great amount of pressure to drive sustainable practices, they do not always understand the challenges faced by suppliers.

- **The vast majority of suppliers will only take on new solutions if they are viable, that is, if their brand customers are willing to share the cost of upfront capital investments to implement these changes.** However, what typically happens is that brands ask their suppliers to shoulder the investment, costs and risks involved, and will only pay for it if the innovations are proven to work. Most suppliers, especially smaller ones, are reluctant to pull resources away from their livelihoods to do something that might not bear fruit.

Many of the solutions, especially those related to the dyeing process evaluated within this report, require significant investment in the form of new machinery and setup, training for workers, and often an upfront commitment from brands on a minimum order. Even the use of novel materials and yarns require commitments from brands before suppliers would typically invest to adopt or scale these solutions.

> ***"Brands and others (e.g. regulators) have no idea what the real cost of implementing regulations entails."*** - Supplier

> ***"Most suppliers comply [with regulations]. Beyond that it's extra investment and it's a part of your value offering. If the brand does not give recognition to the additional value created, these efforts will not continue."*** - Supplier

- **A sustainable product e.g. one that has gone through a process that resulted in very minimal microfibre shed, is likely to cost more. Is the brand customer, and are consumers willing to pay more for it?**

> ***"What's the point of being innovative if our customers don't want it?"*** - Supplier

> ***"There are various technologies available. What really needs to change is whether the consumer and brand customer can accept the products."*** - Supplier

- **Brands can sometimes have a biased view on what suppliers can or should do.** Even when the supplier tries to propose something different, they are told to focus on their core products and leave the new ideas to others.

- **Most suppliers are not incentivised to lead in innovation around more sustainable products.** (That said, we are aware that there are some - typically - large and progressive suppliers who are leading the way in innovation.) Brands that we spoke to stated their openness for collaboration with their supply chain on innovation projects. However, when they extend these opportunities for innovation, they feel that they are met with disinterest from their suppliers, leading to the conclusion that these suppliers have no interest or ability to collaborate on innovations.

  Brands express frustration at this. However, such reticence could stem from the traditional power dynamic between brands and suppliers that will take time to unravel and shift. As brands and retailers start consolidating their supply chain partners, this could emerge as a window of opportunity for a more just and regenerative dynamic to replace the old, traditional ways of engagement.

- **Transformational change in the supply chain to tackle the microfibre challenge can only begin when *both* these two key sets of stakeholders agree to act collectively to design solutions, and work in true partnership.** Brand-supplier conversations are complex and many factors such as language or cultural barriers, the channel of communication and the level of trust established do influence outcomes. However, suppliers too need to demonstrate proactive efforts to understand the problems (e.g. climate change, microfibre pollution), and be open to considering more sustainable options and discussing how they could be implemented. Willingness on all sides is necessary as a starting ingredient for collaborations to work.

Worker at the Ramatex cotton mill

Overly simplistic comparisons as solutions

In response to the acute sustainability challenges facing the fashion and textile industries, there are calls to move away from synthetic fibres such as polyester, towards using more natural fibres such as cotton. This usually stems from the understanding that synthetic fibres are derived from fossil fuels and contribute to global warming and that they persist in the environment for very long periods of time, causing significant harm to ocean and human health.

On the other end, natural fibres are not derived from fossil fuels, are generally expected to biodegrade quickly in the environment, and thus cause significantly less harm overall. In addition, many brands and retailers use more recycled materials in their products, e.g. recycled polyester, and thus market these products as more environmentally friendly. Consumers therefore assume that products made from natural fibres or recycled materials have a much smaller environmental and social impact. This in turn drives up demand for more of such products.

This is not necessarily accurate as all materials have an environmental and social impact, and the overall understanding of the ecotoxicity or environmental impact of the various types of materials or yarn options are areas that require much more research. Moreover, the risks that processed coloured natural fibres pose, in particular, remain poorly understood. From a microfibre perspective, the gaps in knowledge on the impact of yarn type and construction on microfibre shed is one crucial area that would benefit from further research. It is therefore not presently possible to accurately conclude which materials are "better" or "best".

Examples of overly broad/simplistic comparisons to conclude a "better" or "best" choice:

- Natural fibres versus synthetic fibres
- Cotton versus polyester
- Recycled polyester versus virgin polyester

Example: Comparing cotton versus polyester

Cotton and polyester are the two most popular material types today—in 2021, polyester made up 54% of the global fibre production, and cotton made up 22% of the global fibre market.[58]

There is great interest from the industry to compare these two materials for their contribution to microfibre pollution. While understanding how each material type contributes to the problem is necessary, overly simplistic comparisons are risky and distract us from focusing on the real solutions that are needed to tackle the problem. In short, it would be like comparing "apples and oranges."

- Polyester and cotton have different qualities that make them preferred choices for different products e.g. lightness, moisture management, breathability and so on. For example, a bathing suit is not made from cotton - in this and many cases, it would not make sense to substitute polyester for cotton.

- In comparing the two materials for microfibre shed many different variables need to be considered, including yarn types and spinning methods which play a big role in how much the textile would shed. If we wanted to understand their overall environmental and social impacts, we would also need to understand the unique context of each material—how and where the cotton was grown, how the polyester yarn was spun and the energy source for its production, etc.

To tackle the microfibre pollution problem and enable the industry to shift towards a future that is just and regenerative for both the planet and people, the industry should move away from quick fixes and comparisons. More research is needed to understand specific fibre shedding profiles and work towards improving their overall sustainability profile, not just for cotton and polyester but for all fibres and textiles. Until new materials that have been proven to have a better sustainability profile can be developed, which would entail their shedding profiles and success of scaling for mass production, the industry should move away from employing the lens of strict comparisons in order to make meaningful progress toward sustainability.

Cotton being spun at the Ramatex mill

Recommendations

These recommendations are segmented three ways: the first for mills (Tiers 2-3), the second for cut and sew factories (Tier 1), and third for brands and retailers.

Integrated suppliers should consider recommendations for both groups of suppliers.

For industry

1. **Ensure that manufacturing facilities have a robust wastewater management system. This should be the first step taken *if not already in place*. (See Appendix C for more detailed information on wastewater management systems.)**
   Robust wastewater management systems are a first step in tackling the microfibre pollution problem and many suppliers already have wastewater management systems in place due to requirements from their brand partners, or to fulfil local regulations.

Mills (Tiers 2-3)	Mills that do not yet have a wastewater management system in place should urgently implement such a system as a first step in tackling the microfibre pollution problem. For those with systems in place, they should review existing systems for their efficacy in filtering microfibres, with the goal of moving towards ultrafiltration or a reverse osmosis system.
	Educate your customers about the importance of installing or improving these systems, so they understand the environmental and social benefits of these systems as well as the costs involved.
Cut and sew (Tier 1)	Educate your customers about the importance of installing or improving these systems, so they understand the environmental and social benefits of these systems as well as the costs involved.
	Choose to work with suppliers with robust wastewater management processes. Ask about the wastewater treatment processes of existing suppliers. Consider ways of supporting these suppliers through price premiums or fronting them with brands and retailers.
Brands and retailers	Ask your suppliers about how wastewater is managed in their mills, or the mills of their suppliers, and if they can be optimised. If not in place, work with them towards eventually setting up a robust wastewater system.

Table 4: Recommendations around wastewater management systems

2. **Use dyeing solutions as an opportunity for innovation and new ways of collaboration with industry partners; opt for solutions that have a high potential for transformational versus incremental improvements**

   There are many options to innovate in the dyeing process. Some provide only incremental improvements but may be more feasible as an immediate solution, while others such as waterless dyeing innovations (dope dyeing, dry printing, supercritical carbon dioxide dyeing) may offer greater transformational potential but may be less accessible due to the amount of financial investment required. There are also uncertainties around the quality of dyeing and whether, as a whole, they offer a more sustainable solution with other considerations such as energy use in mind.

   At present, all dyeing innovations entail significant changes with the more transformational solutions requiring an even greater amount of financial investment and risk-taking on the part of suppliers. Given the current power structures within the system, suppliers are likely to opt for incremental solutions that are easier to implement as that avoids disrupting the established dyeing process and guarantees the delivery of customer orders. However, when decisions are made to invest in incremental solutions they become entrenched which makes it harder to invest in disruptive or transformational technologies later on.

If we want to truly tackle the microfibre pollution problem in textile manufacturing, we need to put in place the building blocks that can accelerate the shift towards more transformational solutions. In other words, before these investments are made, we need brand-supplier collaborations that more equitably share the risks of investment and the burden of the risks involved in major process changes, building strong relationships for win-win outcomes.

We strongly encourage all stakeholders to start the conversation on microfibres and dyeing solutions with your customers and suppliers, as an area ripe for innovation and change and a new opportunity for collaboration.

Mills (Tiers 2-3)	Understand microfibre shedding from your own dyeing processes by first undertaking testing using the research methodology developed in this project, followed by considering more sustainable options. (Refer to solutions table on page 40.)
	Educate and share knowledge with your customers and suppliers about dyeing methods and processes. Consider sharing your preferred dye methods or approaches through mutual learning sessions.
	Advocate for more sustainable and transformational dyeing solutions to your customers either directly or through pre-competitive collaboration with peers. Consider collective advocacy with peers to leverage a stronger voice with your brand customers.
Cut and sew (Tier 1)	Understand the processes of your fabric suppliers, especially the dyeing methods and processes that precede your part of the production.
	Support supplier mills that have made investments to transform their dyeing processes, for example, by putting them forward to brands and retailers during the product development stage.
	Advocate for more sustainable and transformational dyeing solutions to your brand customers either directly or through pre-competitive collaboration with peers to leverage a collective voice and consolidate enough orders to create economies of scale for mills to adopt the chosen innovation(s).
Brands and retailers	Invest in understanding the production process for your products. Understand the processes of your suppliers, especially the dyeing methods and processes used in the production of your finished items.
	Discuss current dyeing methods and processes with your suppliers and explore more sustainable options. Support suppliers by exploring ways to de-risk the cost of investment jointly. Support suppliers that have already invested to transform their dyeing processes by paying them a premium for their products.
	Educate consumers on the impact of dyeing processes and the decisions made to shift towards more sustainable options that mean they may cost more, and that some products may have a different look. For example, shifting to more sustainable methods of dyeing might mean consumers accept some margin of unlevel dyeing, or accept fewer colour options (or no colour!).

Table 5: Recommendations around dyeing solutions as an opportunity for innovation, collaboration and transformational improvements

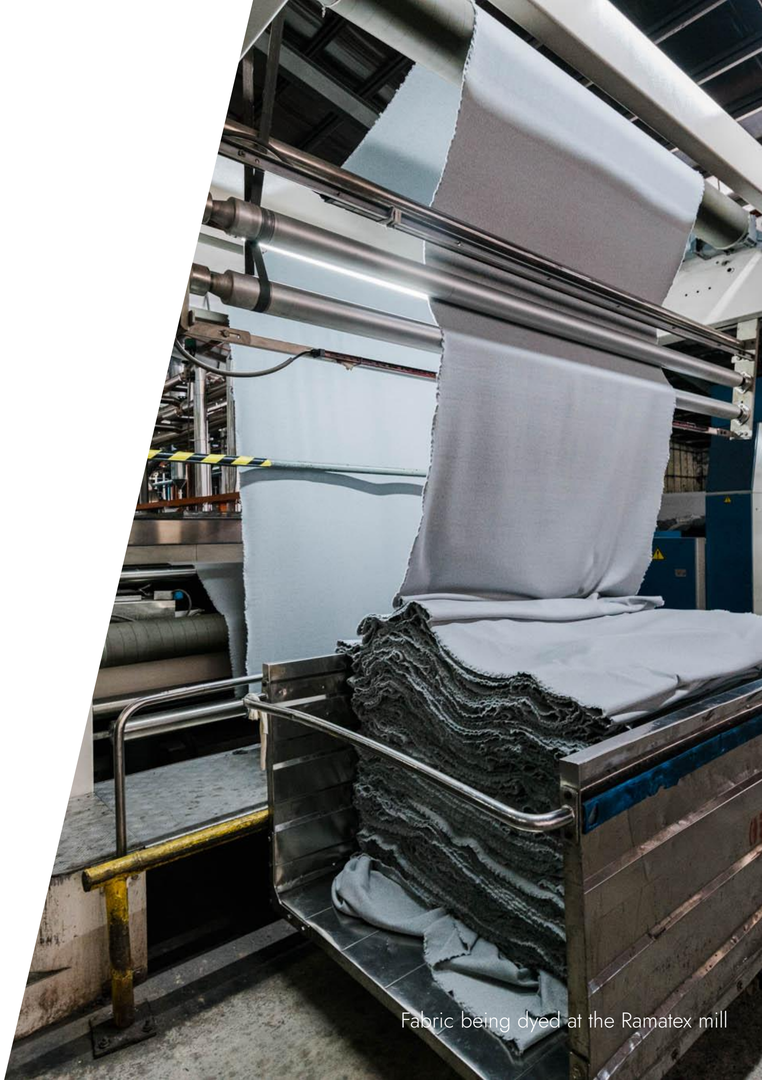
Please refer to the comparison of dyeing technologies based on the level of potential shown in tackling microfibres and how widely considered they are by the industry[59] on page 38.

3. Selection of material and yarn type and construction

Material and yarn types and construction are important factors in microfibre shed in the manufacturing process. Synthetic materials such as polyester are products of fossil fuels and do not biodegrade, staying in the environment for a long time, while driving climate change. However, natural fibres such as cotton also have an impact on the environment and at present, emerging studies indicate they could remain in the environment for longer periods of time than expected. Recycled polyester, while closing the materials loop could, on the other hand, drive demand for even more plastics.

The impact of yarn type and construction on microfibre shed is also an area that requires more research and analysis to draw robust conclusions.

Decisions such as shifting to all natural fibres or only recycled materials could create unintended consequences. Our recommendation is to take a systemic and measured approach in material and yarn selection, recognising that the selection of any material has trade-offs. As more research on materials and yarn types and constructions emerge, better decisions can be made to reduce microfibre shed while reducing energy, water and other harmful chemicals leaching to the environment that affect human health. Focusing on solutions within the dyeing process in the meantime can result in significant reductions in microfibre shed as well as reduce energy, water and the release of harmful chemicals.



Fabric being dyed at the Ramatex mill

Mills (Tiers 2-3)	Invest in understanding the types of materials and yarns you are working with and their environmental (including microfibre shedding) and social impacts. While you may not have a direct influence on the materials and yarns chosen, this helps demonstrate accountability to your customers.
	Discuss and communicate across your company about reducing microfibre shed as a priority consideration for material and yarn choices. Equip your operational staff with the knowledge and capacity to engage with customers and suppliers on this topic.
Cut and sew (Tier 1)	Invest in understanding the types of materials and yarns selected by your brand customers and used by your suppliers, their environmental (including microfibre shedding) and social impacts. Keep up to date about innovations in materials and yarns.
	Discuss and communicate across your company about reducing microfibre shed as a priority consideration for material and yarn choices. Equip your operational staff with the knowledge and capacity to engage with customers and suppliers on this topic.
	Advocate for more sustainable materials and yarns to your brand customers, including what it would take to implement these solutions as experiments or longer-term solutions.
Brands and retailers	Invest in understanding the types of materials and yarns used by your suppliers, what is involved in their production processes, and what their environmental (including microfibre shedding) and social impacts are. Keep up to date about innovations in materials and yarns.
	Advocate for more sustainable materials and yarns to your suppliers and have open discussions on what it would take to implement these solutions as experiments or longer-term solutions. For example, limited edition or test batch collections are often made in small volumes - can brands commit to larger volumes in advance?
	Commission research and testing of microfibre impact within your supply chain by supporting suppliers in their testing. Partner with other peers to commission research and testing to help close the gap of understanding on the impacts of various material and yarn types on human and organism health.

Table 6: Recommendations around materials and yarns selection

4. Demonstrate leadership by taking action now; engage with your industry partners, consumers, and start testing within facilities.
We recommend that brands and suppliers start engaging on the microfibre pollution problem, if they have not yet begun. Although there are currently no industry standards nor regulations on microfibres, this is a good opportunity for industry actors to demonstrate leadership on a new challenge. With regulations on the near horizon, it is prudent to stay ahead of the curve and take action today in preparation. This would stand them in good stead when regulations are implemented.

Suppliers should begin by understanding microfibre shed from their own processes by undertaking testing either using the testing methodology developed in this project, or using the TMC test method on finished products. Suppliers who have not yet installed wastewater management systems should do so as a first step. Brands can also begin to educate consumers on the topic, laying the groundwork for when the solutions implemented may require a new acceptance from consumers of how their products look.

View of the Ramatex wastewater management facility

Mills (Tiers 2-3)	All recommendations in previous sections. Since microfibre shed occurs across the entire manufacturing process, explore ways of measuring fibre shed from other (dry) steps such as knitting and spinning e.g. lint collection.
	Consider pre-competitive collaboration with peers for collective action such as commissioning more research and testing so that it is clear to the industry - especially brands and retailers - what is needed to reduce microfibre pollution from textile manufacturing.
Cut and sew (Tier 1)	All recommendations in previous sections. Understand microfibre shed from the finished garment by undertaking testing on your products e.g. using the TMC method.
	Since microfibre shed occurs across the entire manufacturing process, explore ways of measuring fibre shed from finishing steps e.g. lint collection.
Brands and retailers	All recommendations in previous sections
	Consider pre-competitive collaboration with peers for collective action such as commissioning more research and testing so that it is clear to the industry what is needed to reduce microfibre pollution from textile manufacturing.
	Engage and educate within your company about the microfibre pollution problem, especially departments that have direct interactions with or an impact on suppliers or product design. Ensure all departments are clear on the actions being taken by the company on microfibres.
	Educate and equip your design teams to design with production processes in mind. Designers should have an understanding of how their products are or will be made.
	Engage and educate policymakers about the challenges faced by the industry in understanding and tackling the problem. Include suppliers in these engagements to support policymakers in making a holistic assessment of the challenge and drafting regulations that tackle the root causes of the problem.
	Educate consumers on what it takes for products to be sustainable - from processes to cost and what questions consumers should be asking for truly sustainable fashion. Influence preferences towards more sustainable options and styles. Innovate within sustainable styles to set new trends that promote a deep and meaningful shift to sustainable fashion.

Table 7: Recommendations for engagement and taking action

For policymakers

The first policy commitment to address microfibre pollution was passed in France in 2021 and will require mandatory microfibre filters on washing machines from 2025. We share four recommendations for policymakers considering regulatory actions on microfibre pollution:

1. **Policy to enable more research on upstream emissions and the potential implications on health in manufacturing countries. Provide funding opportunities for urgent research to better understand the impacts of various materials and their impacts on microfibre shed including toxicity studies.** Particularly helpful would be studies that draw out the impacts on ocean and human health and biodegradability (see Table 1 for existing gaps). Deeper and more holistic understanding of these impacts can drive momentum for change in the right direction.

2. **Take a systemic approach and consider the apparel industry and its impacts as a whole.** Beyond microfibres, the industry has a big impact on energy and water use, environmental pollution, human and biodiversity health. **Policymakers need to be careful of any unintended consequences of regulations so that they do not exacerbate existing problems or even create new ones.** For instance, the mandate for recycled content such as rPET could entrench current demands for PET production, or even worse drive up demand in a bid to meet regulations. Policymakers can consult different stakeholder groups beyond brands and retailers, such as suppliers (either directly or via brands and retailers) and researchers who conduct research on textiles.

3. **Provide funding opportunities or incentives for the industry, tailored to SMEs to test and scale promising solutions to de-risk the cost of innovation for first movers.** This encourages industry leaders to opt for proven transformational solutions that may require more capital investment upfront versus incremental solutions. Supply chain voices are often left out of the discussion as they may not sit within the same geographies and jurisdictions as brands and retailers. Policymakers can design incentives in a way that encourages brands and retailers to engage their supply chain and bring supplier representation to the table. Governments with aid agencies in the Global South could play a role in bringing these voices in too.

4. **Provide incentives for industry actors to promote cross-industry pre-competitive collaboration.** Policymakers have the ability to design their funding opportunities in a way that encourages equal participation of industry partners and should do so to encourage systemic changes that are long-term and sustainable.

For other stakeholders

If you are...	Engagement opportunities
Part of a trade association of the textile industry or fashion industry	**Replicability of methodology and adoption of solutions:** Trade associations are important stakeholders that can communicate the recommendations from this report to their members. They can also organise large-scale sharings amongst their members to create more awareness of the problem and share experiences. Stakeholders can then begin their own testing and engagement with their customers/suppliers about the problem.
Part of an interest and/or research group working on microplastics and microfibres	**Replicability and scalability:** Leverage access to research labs through member partners as this can play an important role in encouraging the replication of the research methodology amongst across the network of supplier members. Stakeholders can build on the knowledge of microfibre impacts from production processes, or scale the research by linking up upstream and downstream impacts.
Other suppliers in industry e.g. suppliers of dyestuff, machinery companies	**Scalability:** Progressive suppliers of equipment and dyestuff (vendors) can accelerate the shift to more transformative solutions. Stakeholders can be part of discussions with their customers to explore potential solutions.
Policymakers and government-linked groups	**Scalability**: Policymakers have the potential to strongly influence the direction and pace of change for e.g. incentivising partnerships between stakeholders, further research, and the adoption of transformational solutions.
Financial institutions or investor groups financing the plastics research or the manufacturing and textiles sector	**Scalability**: Financial actors have the potential to strongly influence the direction and pace of change. For eg. incentivise partnerships between stakeholders, further research, and the adoption of transformational solutions.
Other civil society groups looking at microplastics, textiles, sustainable fashion etc.	**Replicability and scalability**: We see these groups as important actors to build on the research we have started, through either the microplastics or microfibres route, or communicating the problem to build awareness with consumers.
Consumers/the general public	**Scalability**: Consumers are critical to the overall shift to a just and regenerative apparel industry. Read up on the microfibre pollution problem and let your favourite brands know you want them to do more in this area. Be open to trying and appreciating new, more sustainable styles, materials and undyed products.

Table 8: Recommendations for engagement opportunities for other stakeholders

Recommended Resources

Understanding pre-consumer microfibre shed

1. The Nature Conservancy: Pre-consumer microfiber emissions from clothing enter oceans at an alarming rate

Research on post-consumer microfibre shed

2. Ocean Wise, Plastics Lab

Understanding brand-supplier dynamics and collaborations

3. Manufactured: a podcast about sustainability and the making of fashion

Understanding the dyeing process and its impacts

4. Fashion Revolution (2019) The true cost of colour: The impact of textile dyes on water systems
5. Fashion for Good (2022) Textile Processing Guide: Pre-Treatment, Colouration & Finishing

Understanding brand-supplier dynamics and collaborations

6. European Environment Agency (2022) Microplastics from textiles: towards a circular economy for textiles in Europe

General industry information

7. The Microfibre Consortium
8. Sustainable Apparel Coalition

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Appendix A – Methodology

Processing step	Description
Spinning	The process of producing yarns from the extracted fibres.
Knitting	First, the yarn is put into the knitting machine creels. After that the yarn is passed through the knitting machine where it is converted into knitted greige and wound in the roll form.
Pre-treatment	The process of removing impurities from greige and bringing it to a stage where it is more suitable for colouration.
Dyeing	The interaction between a dye and a fibre, as well as the movement of dye into the internal part of the fibre.
Rinsing	The removal of any excess dyes and chemicals.
Heat setting	The coloured textile is subjected to the action of high temperature for a short time to make it dimensionally stable so that the garments made from such fabrics retain their shape.
Brushing	A mechanical finishing process used to raise the surface fibres of a coloured textile.
Finished textile	The final stage of the coloured textile which is wound in the roll form.

Table 9: Explanation of the manufacturing processing steps that take place at the Ramatex facility

Textile and composition	Weight gsm	Colour
CVC Fleece 80% Cotton / 20% Polyester	250	Black
	280	White
Jersey 100% Cotton	145	Black
	190	White
Poly Fleece 100% Polyester	180	Black
	180	White*
Recycled Poly Fleece 61% Recycled Polyester / 39% Polyester	180	Black
	180	White

Table 10: Baseline focus textiles and colours

Dry samples *As part of the testing methodology, the dry samples are leached to release their fibre content in water* | | **Water samples** *Discharge water samples* | |

Dry samples *As part of the testing methodology, the dry samples are leached to release their fibre content in water*		**Water samples** *Discharge water samples*	
Processing step	**Sample quantity**	**Processing step**	**Sample quantity**
Spinning	Cone – 1 cone per yarn type	Pre-treatment	4 L
Knitting	Greige – 400 gm	Dyeing	4 L
Brushing	400 gm	Rinsing	4 L
Finished sample	400 gm	Heat setting	
Lint/Fibre samples			
Vacuum system; daily averages (generic)		*Built-in auto collection; specific to textile (specific)*	
Spinning	Min. 100 gm	Dyeing	Min. 100 gm
Knitting	Min. 100 gm		
Brushing	Min. 100 gm		

Table 11: The sample types and quantities TMAS collected

**When operations resumed, Ramatex discontinued the production of the white Polyester Fleece due to a lack of demand. This was indicative of an increasing shift away from virgin to recycled polyester.*

It was not possible to source for old stock from other Ramatex factories. There was the option of a small production run for this study, but the resources used and the fibres emitted would run counter to the objectives of this project.

Result type	Measurement unit	Description
Fibre mass	mg fibre / g textile	The average weight of a fibre. This result type facilitates a link to the industry methods used by TMC and AATCC, which both solely report on fibre mass.
Fibre quantity	counts/g	To learn about the number of fibres in the sample
Fibre length	µm	To learn more about the size of the fibres, and its distribution.
Fibre length distribution	%	
Fibre type	N/A	To know the raw material which the shedded fibre is made of, especially the stable polymer used. Note this test was applied only to the samples of the CVC fleece – 80% Cotton / 20% Polyester.
Testing process step	**Key points to highlight**	
1. Leaching	The leaching method is based on the ISO 105-C06 with some modifications. A blank is also processed alongside in the same way to indicate any background contamination, and corrections are made when needed.	
2. Filtration	The liquid samples run through a filtration system with vacuum pump using a glass fibre and cellulose filters. Oven-drying is used as a preparation and final step. Using a Keyence Digital Microscope with a VHX Digital Microscope Multi Scan Lens the research institute analysed the fibre residue. The filter image provided the fibre mass, fibre quantity, fibre length and length distribution results.	
3. Chemical Separation	An extra step performed on textiles that are cotton rich to separate from polyester, or other stable polymer. This chemical separation is based in DIN EN ISO 1833-11.	

Table 12: Explanation of result types and key points to note about the testing methodology

HEAT SETTING | DYEING

PRIMARY RESEARCH

Interviews with the Ramatex operational staff

The baseline results identified heat setting as the greatest contributor to microfibre release, followed by dyeing. This differed from the experience of the Ramatex staff. They had observed that the heat, mechanical and chemical treatments applied in the dye tank during the dyeing process creates more stress on the fabric than the process undertaken in the heat setting padder.

We **hypothesised** that as the waste water drained from under the dye tank, the fibres shed reattached onto the fabric. Hence the fibres collected at the heat setting step were these 'loose' fibres released during dyeing, creating a false positive result.

To test this we conducted a sonication test* in the lab setting, and found that a high degree of microfibre attachment did take place...

SECONDARY RESEARCH

... and referenced existing research on dyeing and wet process steps in textile manufacturing.

INVESTIGATIVE FOCUS:

DYEING

Image 14: Flowchart explaining the primary and secondary research methods applied to derive the focus of our investigative research.

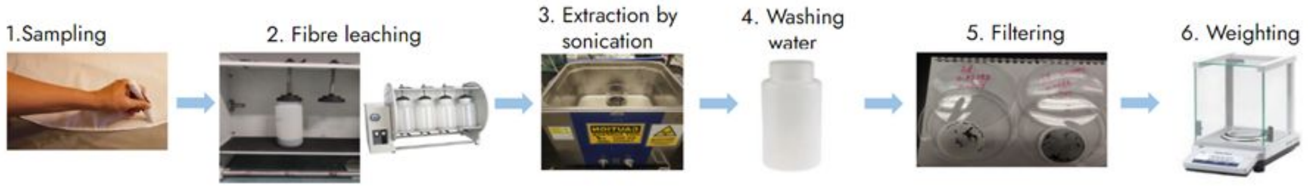

*Image 15: Flowchart illustrating the microfibre reattachment test

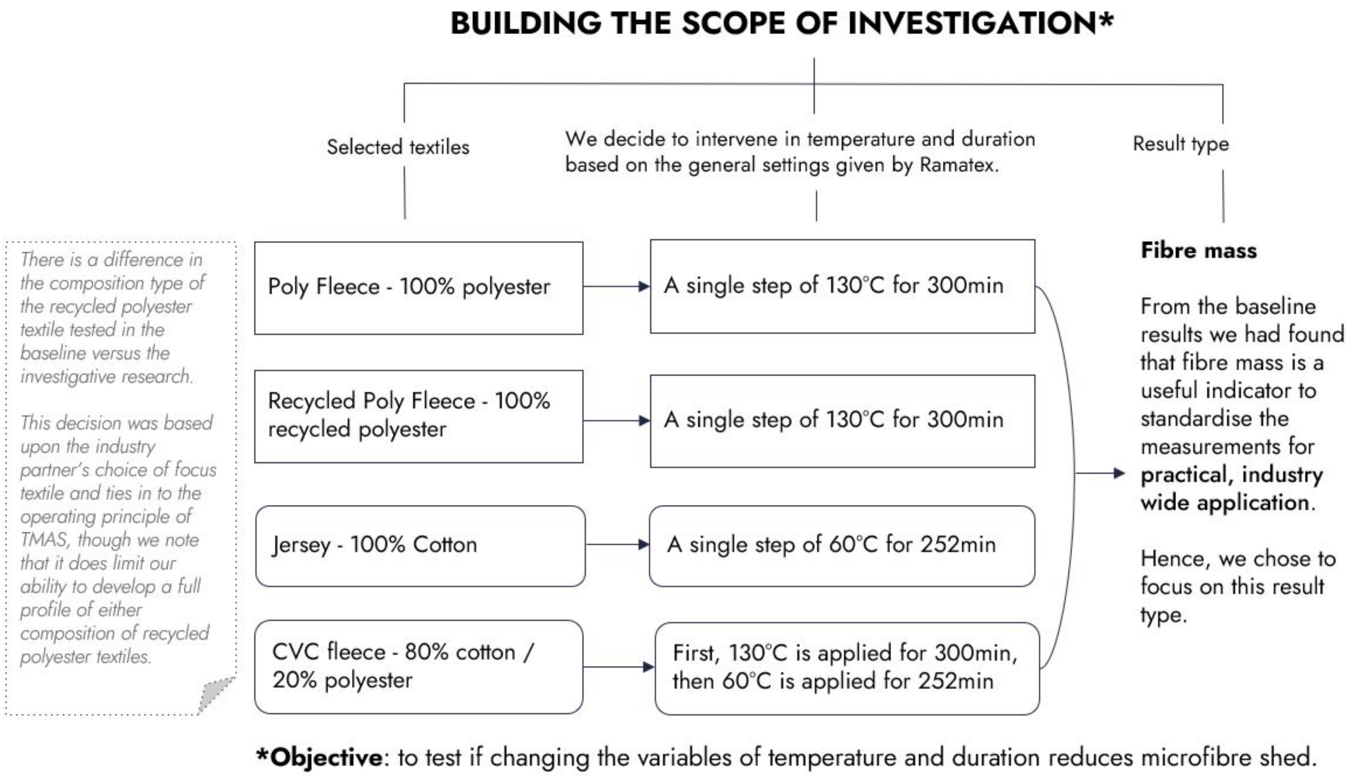

Image 16: Flowchart of scoping the investigative research, with the objective of developing interventions to reduce microfibre shed in the identified process step

***Notes about the investigative research scope**

The investigative research was informed by various practical and operational considerations, and the parameters shaped by the expertise of our partners in their respective fields. A detailed explanation is provided in the technical research report linked to our webpage. We have outlined some of the key parameters below:

1. The textiles selected were based on the operating principle of TMAS, which is to analyse textiles that are produced and purchased in the highest volumes or are of importance to the industry—in this case the industry partner Ramatex—so as to create the greatest impact through this research.

2. The types of interventions were determined by what could be achieved by NEWRI in the lab setting, as well as the general dye settings given to us by Ramatex that are "optimal" in temperature and duration in the duration that the textile spends in the dye tank.

3. Based on the settings provided we set the range for lab testing as follows:

    a. With 130℃ and 60℃ at the upper and low end of the range we selected an approximate midpoint of 90℃ as a wide range would surface the differences in microfibre shed. We applied these three temperatures to all the textiles sampled. In addition, on 100% Cotton we conducted tests at 30℃, 40℃, 50℃ to further observe its impact on microfibre shed from the cotton textile.

    b. Based on the given settings of 252 minutes and 300 minutes we picked 120 minutes as a third point of comparison to see if a shorter duration would reduce microfibre shed. We applied this range to all the textiles sampled.

4. At the end of the baseline and investigative research we engaged an independent consultant, Nicole van der Elst, to conduct a technical review and support the validation of the technical research report. Nicole helped to design the baseline scope and methodology at the start, before stepping off TMAS in August 2021.

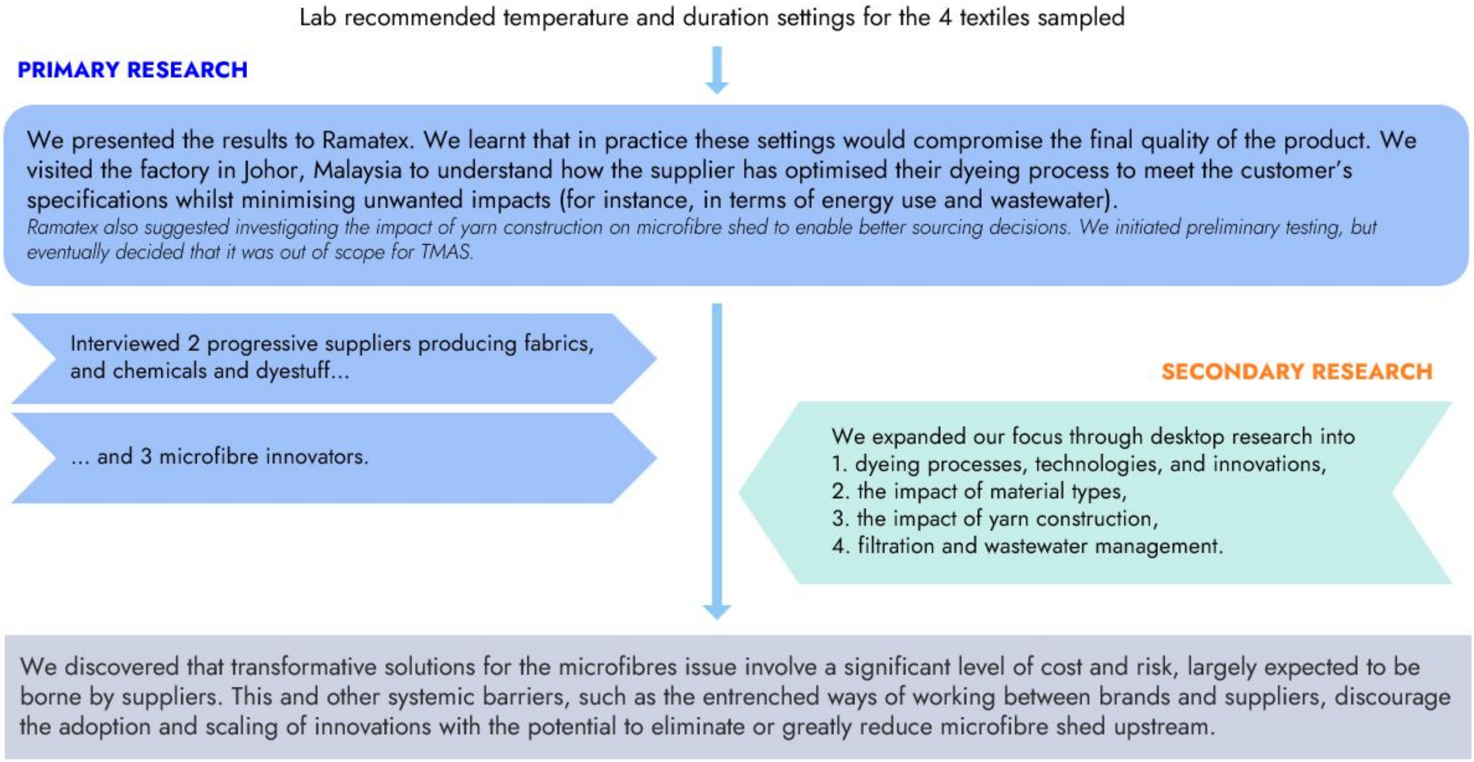

Image 17: Flowchart illustrating the process in the final phase of the investigative research, leading up to the final insights presented in this report.

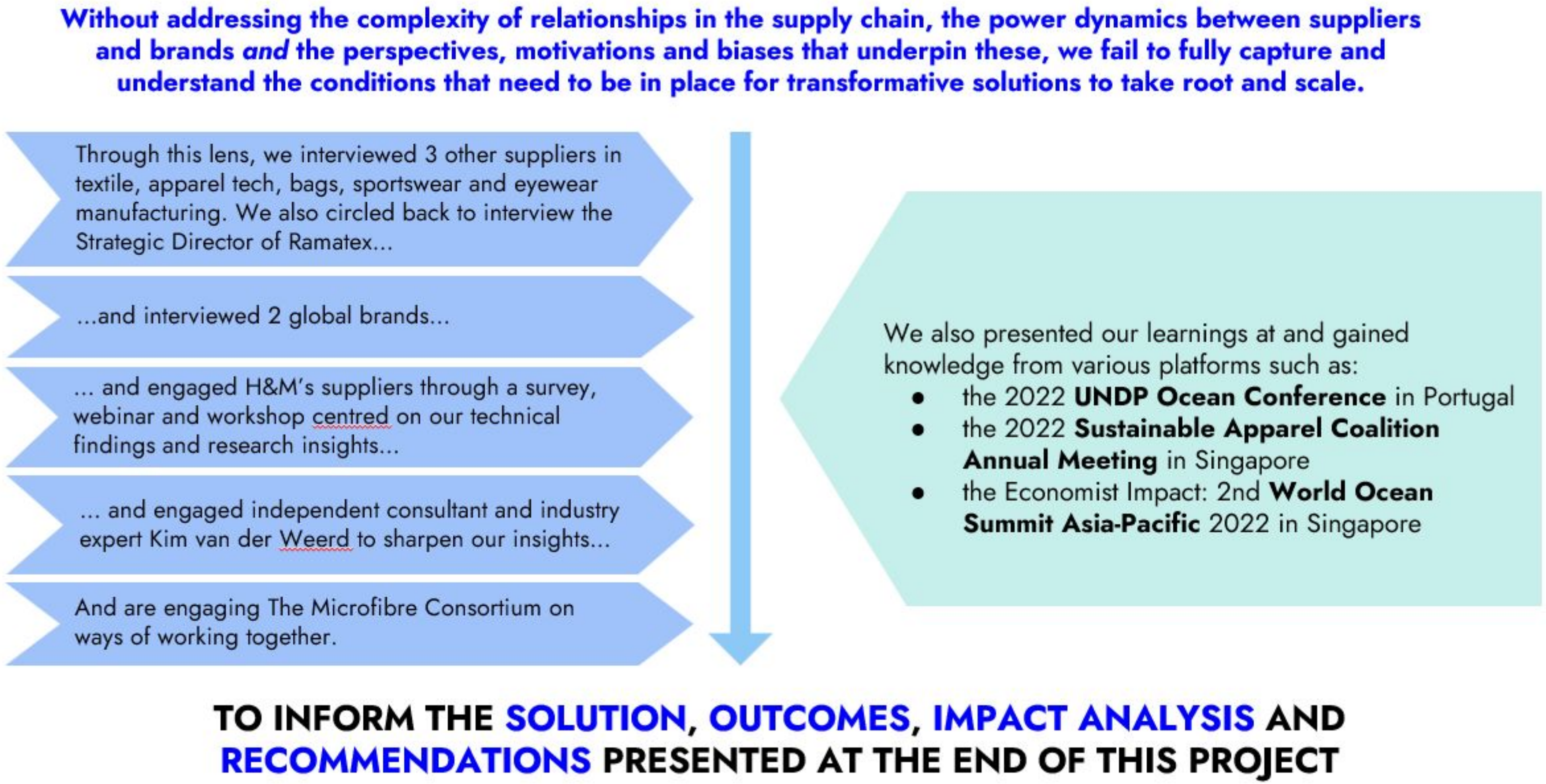

Image 18: Flowchart illustrating the process in the final phase of the investigative research, leading up to the final insights presented in this report.

Appendix B – Material and Yarn options

Yarns, spinning systems and composition – more testing required

Materials

In response to the acute sustainability challenges facing the fashion and textile industries, there are calls to move away from synthetic fibres such as polyester, towards the use of more natural fibres, such as cotton. This usually stems from the understanding that synthetic fibres persist in the environment for very long periods of time and cause significant harm to ocean and human health, whilst natural fibres should biodegrade in the environment and thus cause significantly less harm overall. It is critical to note that the overall understanding of the ecotoxicity or environmental impact of all types of fibres is still an area that requires more research. Moreover, the risks that natural fibres pose remain poorly understood - some recent studies indicate the dominance of natural fibres over synthetic fibres in the environment.[60, 61]

Within the scope of this project we have chosen to focus on two strategic materials, cotton and polyester, as these are both the materials of greatest volume in production for Ramatex and also the top two material types in terms of global fibre production.[62] Critically, as the most widely used material in textile manufacturing and as a synthetic fibre, polyester contributes significantly to marine plastic pollution as microplastics, and reducing its release into the environment would consequently support ocean health. We have also included recycled polyester due to its strategic importance to the industry, as most major brands look to increase their recycled materials content in the move towards circularity.[63] In assessing cotton and polyester, we did not include cotton-polyester blends (CVC 80/20) due to the complexity in comparisons.

While material type impacts the amount of microfibre shed due to their inherent properties, comparing between materials to find a "best in class" is currently not practical nor feasible until much more research has been done to understand the propensity of various types of fibres - natural and synthetic - to shed, their biodegradability, and ecotoxicity.

Polyester (polyethylene terephthalate – PET)

Polyester is a manufactured synthetic fibre derived from petroleum; a type of plastic. It is the most commonly used fibre globally, making up 52% of the global fibre production.[64] As a material, polyester is light, strong, versatile and easily blended with other fibres to possess a mix of desired qualities. It is easy to wash and does not wrinkle easily. Critically, polyester is comparatively easy and cheap to produce. This has fueled its popularity over the past few decades, which has in turn contributed to the growth of fast fashion. Industry projections of polyester in the next few years vary, but on the whole point unanimously to it remaining as the most widely used textile fibre.[65]

Environmental impacts of PET

PET is fossil fuel based, and is derived from coal, petroleum (from crude oil), air and water. To make polyester fibres, PET pellets are melted and extruded through tiny holes called spinnerets to form long threads, which are then cooled to harden into a fibre.

Carbon footprint, water and land use

As polyester is fossil fuel based, the energy required to produce polyester broadly makes it a high-impact process.[66] The bulk of the global warming impact derives from its fossil fuel base, either to create the polymer pellet feedstock or to generate electricity that runs the production machinery. The amount of electricity required depends on the manufacturing processes needed to create a desired effect in the final material - the biggest driver of this difference is whether the fabric is woven or knitted.[67]

If the industry grows as predicted, by 2050 polyester fibre production could use more than 26% of the carbon budget associated with a 2°C global warming pathway.[68]

On the other hand, polyester compares favourably when seen through the lens of water and land use. It is generally considered to have a lower impact compared to the production of natural fibres such as cotton, given that it is not grown on land.[69]

Biodegradability

One of the key reasons for polyester's popularity is its durability since it is essentially plastic. This same quality is also why polyester is generally considered non-biodegradable - or taking up to hundreds of years to biodegrade.[70] In landfills, synthetic materials can release heavy metals and other additives into soil and groundwater. Left in the environment, synthetic fibres such as polyester can contribute to the estimated 640,000 tons of abandoned fishing nets in the world's oceans.[71]

Circularity - recycling polyester

As consumers are increasingly educated about the impacts of the fashion industry on the environment, the momentum for circular fashion is greater than ever. Most major brands have begun to increase the recycled content of their products and many have also increased efforts at take-back schemes for used clothes, some of which might be recycled.

It is possible to fully recycle polyester in its pure form (100% polyester) and recycling centres for textiles can be found in many countries today. However, the recyclability of polyester depends on the material - cotton-polyester blends which are highly popular remain a technical challenge to recycle as the two fibre types need to first be separated. As a result, even when cotton-polyester garments are collected for recycling, they tend to end up in landfills or are incinerated.

Recycled polyester (rPET)

rPET is obtained by melting down existing plastic and re-spinning it into new polyester fibre. From 2010 to 2020, recycled polyester increased from 11% to 15% of total global polyester production. Currently, almost all recycled polyester is mechanically made from PET plastic bottles (an estimated 99%). rPET can also be made from other post-consumer plastics such as ocean waste, discarded polyester textiles, or from pre-consumer processing residue such as fabric scraps.[72]

Due to the climate emergency, more and more brands have moved from virgin to recycled polyester, and incorporate recycled materials as a way of reaching their sustainability targets. These collections of apparel are often marketed as being more sustainable and better for the planet.[73] Regulatory changes such as those to be announced by the EU are set to push brands and retailers for greater recycled and recyclable content within textiles in the near future.[74]

Environmental impacts of rPET

Compared to virgin polyester, rPET does appear to have a lower carbon footprint. According to a Textile Exchange report, rPET has a significantly lower carbon footprint than virgin PET.[75] It is estimated that each kilogram of mechanically recycled polyester represents a reduction in carbon emissions by more than 70% as compared to virgin PET.[76] It also reduces the need for primary extraction of crude oil and cuts the amounts disposed in landfills.

However, there are issues with the use of rPET. They are made from PET bottles mechanically turned into yarn for knitting or weaving into textiles, a process that degrades it so that it might not be recycled another time, let alone multiple times, without a big decline in quality.[77] The base colour of the plastic chips from recycled plastic can make dyeing more difficult, so more dyes and more water are needed – although inconsistent colouration can still occur. The high-temperature plastic recycling process can also release a carcinogenic antimony compound into the atmosphere.[78] Another point to note is that turning PET into rPET takes away feedstock from the bottling industry that has come close to closing the loop of bottle to bottle recycling, hence a more efficient and sustainable process than the process of turning PET into recycled textile fibre.[79]

Critically, although rPET has a smaller carbon footprint it is still a synthetic fibre - non-biodegradable and a contributor to the microfibre pollution problem.

Microfibre shed: virgin polyester versus recycled polyester
Because of the momentum for recycled materials in the industry, the comparison between virgin and recycled polyester was important to include within our research. In discussions with industry stakeholders, we often heard the hypothesis that rPET would shed more due to the additional processing and mechanical actions enacted on the material. However, in our baseline research results, we found that in a like-for-like comparison the rPET samples analysed had higher *fibre mass* and *fibre number* shed values in comparison to the virgin polyester samples.

Recycled Poly Fleece (black)	**Fibre shedding**		
61% Recycled Polyester / 39% Polyester (180gsm) *Processing step*	Total fibre mass, average mg/g - incl. lint/fibre	Total fibre quantity, average count/g	fibre length, average μm
Knitting	0.060	288	167
Pre-treatment	0.022	139	200
Dyeing	0.389	5,108	86
Rinsing	0.035	445	100
Heat setting	0.096	277	337
Brushing*	0.057	1,003	138
Total	0.658	7,259.917	

Poly Fleece (black)	**Fibre shedding**		
100% Polyester (180gsm) *Processing step*	Total fibre mass, average mg/g - incl. lint/fibre	Total fibre quantity, average count/g	fibre length, average μm
Knitting	0.060	188	200
Pre-treatment	0.102	174	320
Dyeing	0.076	764	129
Rinsing	0.032	190	169
Heat setting	0.035	183	226
Brushing*	0.087	707	137
Total	0.391	2,206.009	

Table 13 and 14: Comparison of polyester versus recycled polyester fleece (black, 180gsm) in baseline research

**Note: the final step of the polyester fleece is the brushing, hence this data point represents the finished textile.*

A like-for-like comparison was performed on the recycled polyester fleece and the polyester fleece as the textiles are composed of the same yarn type and weight. It showed that recycled polyester fleece (black) had significantly higher fibre mass shed, and also a significantly higher fibre quantity shed. The poly fleece (black) had an overall less shed - better performance in terms of fibre shedding.

This is an important finding. Cross-referencing available open source data and information, there were studies that found rPET fibres shed more than PET fibres which found that rPET knitted fabrics released almost 2.3 times more fibres than the virgin PET fabrics.[80]

At the same time, we found several sources indicating that the key determinants for microfibre shedding in rPET fabrics and virgin PET fabrics was actually fabric construction, rather than recycled fibre content. In a study that compared the shedding properties of recycled or virgin fibres while keeping fabric construction identical led to a conclusion that using rPET fibres did not significantly increase the shedding propensity during laundering. It also suggested that other factors such as yarn construction (twist, interlacing/interloop patterns etc) could have an impact on microfibre shed.[81] Another study by Mistra Future Fashion that compared shedding between virgin and recycled jersey shedding, and virgin and recycled polyester microfleece did not find that the recycled materials shed more.[82] This aligns well with our discussions with industry stakeholders who have also suggested further investigation into yarn types and construction, to be examined further down.

Conclusion

A critical recommendation to the industry is to include **comparisons of fibre fragmentation** profiles in addition to environmental impact when suggesting preferred materials.

More research that includes strict like-for-like comparisons between rPET and virgin PET in terms of microfibre shed is needed in order for us to derive more conclusive results of whether one type of fabric sheds more than the other.

Cotton

Cotton made up 24% of the global fibre market in 2020, and is the most widely used natural fibre.[83] When woven or knitted, cotton produces a soft, strong fabric that is breathable, absorbent and washable. As a highly versatile fibre, cotton can be turned into a wide range of fabrics such as corduroy, denim, flannel, jersey, velvet and others. It is also easily blended with other fibres such as polyester to improve durability or elastane for instance to make stretchy jeans. Despite its versatility, cotton's share of the market has been declining since the early 2000s, giving way to synthetic fibres.[84]

Environmental impacts of cotton

Many have called for the industry to shift away from synthetic fibres towards natural fibres such as cotton. However, there are major environmental concerns with the production of cotton, as there are in the production of synthetic fibres.

Carbon footprint, water, land, and chemical use

The main bulk of the carbon footprint of cotton comes from the growing of cotton. For natural fibres one looks at field preparation, planting and field operations such as mechanised irrigation, weed control, pest control and fertilisers, harvesting and yields. A 2015 report showed that cotton cultivation accounted for 220 million tonnes of CO_2 per annum.[85] On average, the carbon footprint of one cotton t-shirt is roughly equal to the carbon footprint of driving a passenger car for 10 miles. However, the level of impact depends largely on the region where the cotton was produced and how it was produced. For example, cotton produced in a factory powered by coal will have a higher impact on climate change than cotton produced in a factory using renewable energy.[86]

Cotton is a thirsty crop. The global water footprint of cotton is around 8.2 trillion cubic feet a year, the same as 238 bathtubs of water per person annually.[87] Some major cotton-producing countries like China and India are already experiencing high levels of water stress and scarcity.[88] Organic cotton production however does use far less water than conventional cotton, with 80% of the land used for organic cotton being rain-fed.[89]

In addition, cotton cultivation uses chemicals. It is estimated that cotton cultivation alone uses around 4% of all world pesticides and around 10% of all insecticides.[90] These chemicals can pollute local ecosystems and drinking water.

Biodegradability

As a natural fibre, it is usually expected that cotton fibres would biodegrade quickly in the environment. However, assessing whether natural fibres biodegrade in ocean environments has been particularly tricky; it is still inconclusive if cotton fibres - after manufacturing processes and treatments - would persist in the environment, and what that means for the industry. In particular, it has been suggested that mercerisation, the processing of cotton into textile fibres, transforms cotton from its original cellulosic form into a form that causes it to lose its biodegradability, hence potentially allowing the fibres to persist in the environment for a long time.[91] In other studies, as mentioned, it was found that freshwater and airborne textile fibres populations are dominated by "natural" and not microplastic fibres.[92, 93] Yet some studies have found high biodegradability.[94]

Clearly, more research is needed before the industry can understand the role that manufacturing processes and treatments play in the biodegradability of cotton and other natural fibres in the environment, and especially in ocean environments where numerous other variables would be present.

Circularity - recycling cotton

Recycling cotton is not a simple affair, because the process of recycling lowers the quality of cotton fibres and shortens their staple length. Staple length plays an important role in determining the strength and softness of cotton threads. The longer the staple, the better these characteristics. As a result cotton's recyclability is comparatively low, given that it is unlikely to be recycled more than a single time, or it requires to be blended with other synthetic fibres to strengthen the fabric. This is also the reason why brands have found it difficult to use large amounts of recycled cotton in their products.[95] In 2020, less than 1% of cotton production was recycled cotton.[96]

Social impacts of cotton farming

Cotton growing has long been linked to human rights abuses. Human rights groups have long documented evidence of the ongoing use of child and forced labour in cotton cultivation even today, with children as young as five working in cotton fields in countries such as India, Egypt and Uzbekistan.[97, 98, 99] From 2020 to 2021, the cotton and apparel industry reeled from the reports of forced labour in China by hundreds and thousands of Uyghurs and other minorities into manual labour in the cotton fields of Xinjiang. This led to sanctions by several western countries on China as well as boycotts by some brands.

Overly simplistic comparisons as solutions

In response to the acute sustainability challenges facing the fashion and textile industries, there are calls to move away from synthetic fibres such as polyester, towards using more natural fibres, such as cotton. This usually stems from the understanding that synthetic fibres are derived from fossil fuels and contribute to global warming and that they persist in the environment for very long periods of time, causing significant harm to the ocean and human health. On the other hand, natural fibres are not derived from fossil fuels, are generally expected to biodegrade in the environment, and thus cause significantly less harm overall. In addition, many brands and retailers use more recycled materials in their products, e.g., recycled polyester rather than polyester, and thus market these products as more environmentally friendly. Consumers therefore assume that products made from natural fibres or recycled materials have a much smaller environmental and social impact. This, in turn, drives up demand for more of such products. This is not necessarily accurate as all materials have an environmental and social impact, and the overall understanding of the ecotoxicity or environmental impact of the various types of materials of yarn options are areas that require much more research. Moreover, the risks that processed coloured natural fibres pose, in particular, remain poorly understood.

Comparing cotton vs. polyester

Cotton and polyester are the two most popular material types today—in 2021, polyester made up 54% of the global fibre production, and cotton made up 22% of the global fibre market.[100]

There is great interest from the industry to compare these two materials for their contribution to microfibre pollution. While understanding how each material type contributes to the problem is necessary, comparisons are risky and distract from focusing on the real solutions that are needed to tackle the problem. In short, it would be like comparing "apples to oranges".

- Polyester and cotton have different qualities that make them preferred choices for different products e.g. lightness, moisture management, breathability etc. E.g., a bathing suit is not made from cotton - in this and many case, it would not make sense to substitute polyester for cotton.
- In comparing the two materials for microfibre shed, many different variables need to be considered, including yarn types and spinning methods which play a big role in how much the textile would shed. If we wanted to understand their overall environmental and social impacts, we would also need to understand the unique context of each material - how and where the cotton was grown, how the polyester yarn was spun and the energy source for its production, etc.

To tackle the microfibre pollution problem and enable the industry to shift towards a future that is just and regenerative for both the planet and people, the industry should move away from quick fixes and comparisons. More research is needed to understand specific fibre shedding profiles and work towards improving their overall sustainability profile, not just for cotton and polyester but for all fibres and textiles. Until new materials that have been proven to have a better sustainability profile can be developed, which would entail their shedding profiles and successful scaling for mass production, the industry should move away from employing the lens of strict comparisons to make meaningful progress toward sustainability.

Conclusion

The comparison in microfibre shed rate between cotton and polyester is one that is not straightforward. While many industry stakeholders want to know which is the "better" choice, the picture is a complex one that needs to include additional considerations such as chemical treatments, the overall environmental impact of both material types including carbon footprint, water use and biodegradability.

Yarn options

A textile yarn is a long fine fibre strand. There are two main categories of yarns - staple or spun yarn and filament yarn. The yarn can be twisted with one or more yarns to create added value or aesthetics. Filament yarns tend to be smoother, more lustrous, more uniform, harsher, and less absorbent. They consist of long continuous fibres either twisted or grouped together, and tend to be manmade or synthetic. Staple yarns have a hairy surface, are more uneven in appearance, have lower luster, are softer, and more absorbent. Traditionally, yarns have been constructed of fibres of finite length called staple fibres.[101] With the exception of silk, all natural fibres including cotton, are staple fibres. Today, filament yarns can also be used to construct yarns. Synthetic fibres can be either filament or staple yarns.

The impact of yarn types on microfibre shed

It is widely acknowledged within the textile industry that yarn construction and type impact the amount of shedding due to the length of the yarns and the method of spinning or constructing the yarns. Staple yarns tend to be shorter in length.

During the course of the investigative research Ramatex suggested testing the microfibre shed from yarns constructed using different spinning systems and different compositions of yarn. We conducted preliminary testing on a range of seven textiles in greige form and have included the results in this report as a starting point of reference. This is what we have considered complementary testing.

However, this falls outside of the immediate research scope of TMAS as it will require additional scoping and investigation of the different elements, factors and variables in yarn spinning systems and composition that also influence microfibre shed.

We therefore recommended further research in this area, which is invaluable to informing brands and suppliers' sourcing decisions prior to the manufacturing process. As part of the scope, it will be important for researchers to ensure that they have the full profile of the textile yarn type, its construction, weight, and so on. This will allow the pinpointing of a single variable to undergo testing, with all other elements being the same.

Within this set of complementary testing, the useful insights are obtained from:

1. A comparison of three spinning systems used in 100% Cotton: vortex, open-end and ring,

2. The amount of fibre shedding mass from two types of cellulosic fibre blends, and

3. The fibre mass shed from two types of polyester jersey, one made of rPET, and the other virgin PET.

Some of the research questions that arise from our preliminary results include: why does the open-end spun yarn shed the least and the vortex yarn shed the most? Why do the filament yarns shed more than the staple yarns contrary to existing literature/research?

	Yarn type	Description[102, 103]
1.	Ring spun	Ring yarn is the most widely used method of staple fibre yarn production. The fibres are twisted around each other to give strength to the yarn. Advantages: Strongest, finest, softest Disadvantages: Uneven, expensive, low productivity, hairy
2.	Vortex	A new method of air jet spinning - vortex yarn has a different yarn structure compared to the conventional yarn structures. Vortex spun yarn consists of a two-segmented structure which includes core and wrapper fibres which covers the core part of the fibre grouping the yarn body. Advantages: Less hairy, good handfeel, dyes darker, high productivity, less expensive, less labour intensive Disadvantages: More waste in spinning (greatest microfibre shed - this corroborates with our research results), limited count range, lower elongation
3.	Open-end (rotor spun)	Open-end spun yarn is produced with fewer processes and more automation compared to ring spinning. It is less labour intensive. Generally shorter fibres. Advantages: More even, high-strength uniformity, high production rate, fewer processes, lower costs, fewer imperfections, least amount of microfibre shed (in our research) Disadvantages: Harsher handfeel, not as strong, limited count range, more abrasive, more hairy

Table 15: Comparison of different yarn spinning systems

Conclusion

Yarn options are a major factor in microfibre shedding due to their different properties. It is clear that the decisions made even before the manufacturing process such as the choice of yarn can decisively determine the amount of microfibres that will be shed. Much more research is needed on the shed rates of the various yarn options. We recommend that industry fibre and material guides include fibre profiles as a standard criteria for fibre selection in addition to water use/consumption, carbon emissions and other environmental and social impacts.

Appendix C – The dyeing process

Yarns, spinning systems and composition – more testing required

The chemistry of dyeing

Dyeing is the application of colour to a textile material with some level of permanence. Colourants that are applied to the textiles are called dyes.

Historically the primary source of dye has been nature, with the dyes being extracted from animals or plants. Since the mid-19th century artificial dyes have been used to achieve a wider range of colours and to render the dyes more stable to washing and general use. Different classes of dyes are used for different types of fibres and at different stages of the textile production process, from loose fibres through yarn and cloth to complete garments.

To dye a textile material and produce the final colour, the dye needs to attach to the chemical molecular structure of the textile fibres. This dye-fibre molecular association is responsible for the degree of fastness or permanence of the colour. Dyes are typically fibre specific.[104]

Chemical products and agents are added during dyeing that allow the dye process to be carried out more effectively.

Desired outcomes of dyeing

For dyeing to be considered successful, the following parameters are considered:

1. Colour strength (shade) and colour matching

Within dyeing, a key goal for textile manufacturers is to get it "right first time."[105] Broadly, this refers to getting the fabric dyed to the right shade in the first attempt, therefore avoiding the need to re-shade. Colour strength is the key parameter in measuring the quality of the fabric in terms of its depth of colour.

Different fabrics can be dyed the same colour, but appear differently under different lighting conditions e.g. daylight versus artificial factory lighting. If the dyeing process is compromised and the end product is not of the desired shade, it is by definition "off-quality."

2. Colour levelness

Colour levelness refers to a uniformity of shade in different parts of the fabric. Un-levelness is generally not accepted in commercial dyeing. Instances where it is accepted would be when it is created as a deliberate effect e.g. acid-wash or stone-wash.

3. Colour fastness

Colour fastness is the extent to which a fabric loses colour under certain conditions – this can include laundering, sunlight exposure, perspiration and daily wear and tear. Good colour fastness minimises the amount of colour bleeding or fading when the consumer launders the garment.

4. Handfeel
Handfeel generally refers to the "feel" of the fabric e.g. softness, silkiness or crispness. Handfeel depends on the type of fibres used, knitting structure (for knitted fabrics), and the treatment and finishing processes. In the dye machine, pre-treatment (or scouring) of the fabric occurs – how well and effectively this is done can have an impact on handfeel.[106]

5. Shrinkage
Shrinkage entails any negative change in the dimensions of the product. It also relates to changes such as seam puckering (a waviness of the fabric along the seam line), skew, and any changes in relationship between the body cloth and trim components, and changes in fit. Forces applied during the dyeing and finishing processes can cause shrinkage. Product shrinkage is affected by both the application and removal of stresses.[107]

6. Fabric width
Relevant to the end product, this takes into account the loss that occurs during garment production and ensuring that the fabric is accurately sized to fit the factory machinery.

7. Fabric weight (measured as g/m2)
Fabric weight is part of the specifications in the customer's order - usually with a 5% margin of tolerance. Certain dyeing methods lower the fabric weight, which deviates from the desired specifications.

Steps within the dyeing process
We consider the pre-treatment, rinsing and heat setting steps part of the dyeing process, as these steps together culminate in the completion of the textile colouring stage. The process can be broken down broadly as follows:

1. **Pre-treatment** (also called scouring): The pre-treatment step is where water and chemicals such as hydrogen peroxide and caustic liquid are added. This is necessary to remove oil and wax from the fabric and maximise the fastness of the dye. A neutralising agent is then added, and the water is drained from the dye tank.

2. **Dyeing**: Water, chemical agents and dyestuffs are introduced to the fabric based on the customer's specifications. A heated temperature is applied to the process at different durations depending on the type of fabric. In the dye tank, high temperature, chemicals and mechanical agitation are applied to the fabric over a period of time.

3. **Rinsing**: This comes after the dyeing wastewater is drained. Water, neutralising and soaping agents are introduced to adjust the pH. For polyester, an acidic solution is introduced and for cotton an alkaline solution is introduced. Finally, a fixing agent is added, which helps to clear any unsettled dyes. This prevents colour run-off during consumer laundering.

4. **Heat setting**: This occurs when the fabric exits the dye tank. It is passed through a padder where functional chemicals and softeners are added depending on the customer's requirements. This is also where agents are added to fulfil specific unique properties such as water-repellency, quick-drying, anti-microbial functions, etc. These steps are also known as part of the finishing step.[108]

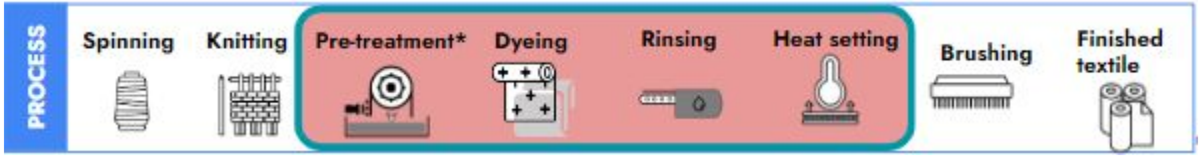

Image 19: The dyeing process

Appendix D – Filtration and Wastewater Management

A large majority of microfibres are released into the environment through effluent from the dyeing and washing process in manufacturing facilities. This makes water treatment and filtration a key line of defence against their spread into marine ecosystems. Municipal wastewater treatment facilities have not been found to be 100% efficient at microfibre removal since smaller microfibres have been found downstream from wastewater treatment facilities.[109, 110] Therefore, a robust filtration system at a facility level can help ensure that microfibres are responsibly captured and removed prior to flowing into the wider wastewater system. Although most facilities have regulatory standards for total suspended solids (TSS), it is anticipated that more stringent standards will emerge as zero-discharge filtration technologies scale.[111]

It should be noted that wastewater management is not enough to address the full extent of the microfibre pollution problem. The conventional dyeing process emits microfibres that are not fully captured in wastewater, such as by air, and has other impacts such as intensive energy use and implications for worker health and well-being. Additionally, these systems are capital intensive which may be a barrier for manufacturers in lower and middle-income countries.[112] Hence, there is also a need for suppliers to look upstream, at their dyeing processes, or their material and yarn choices, as we have outlined in this report.

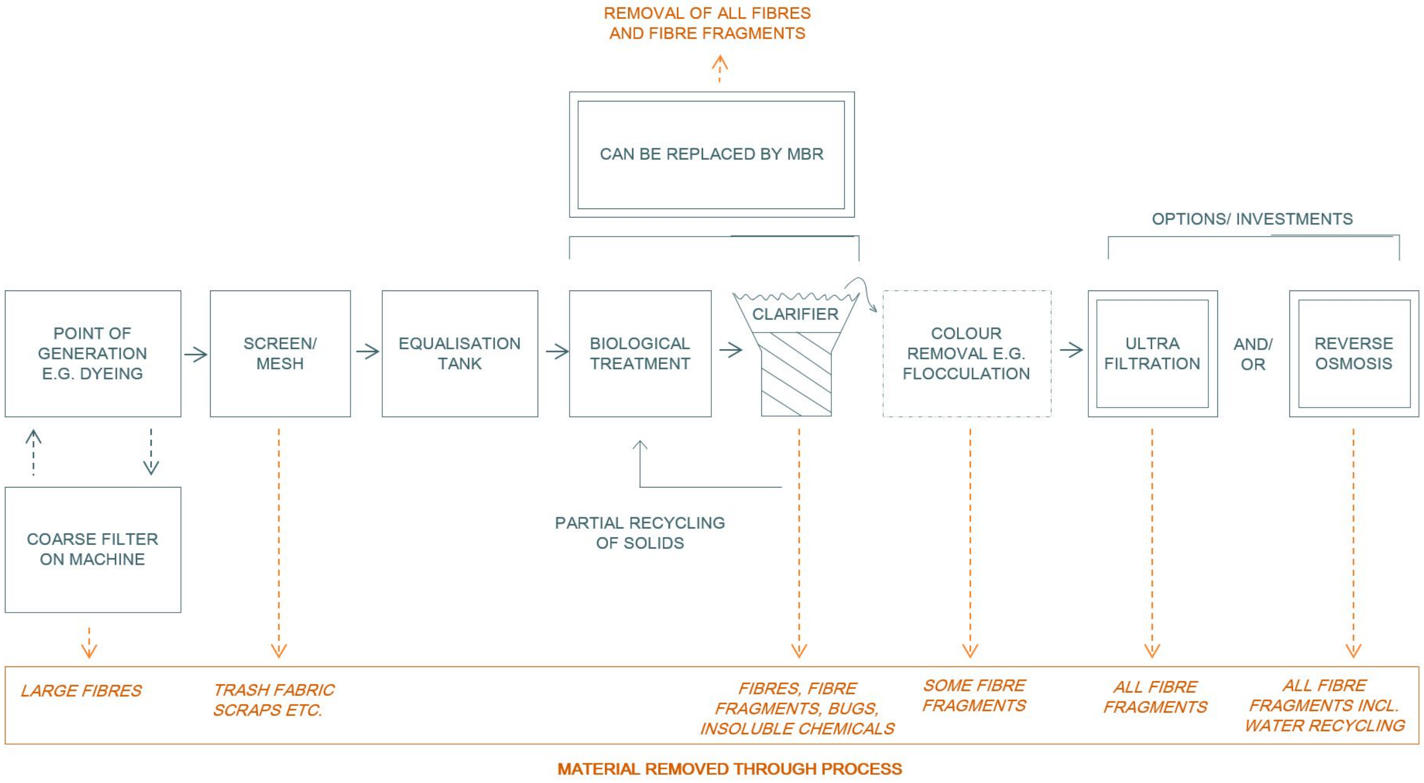

Image 20: *Credit: The Microfibre Consortium - Preliminary Guidelines: Control of Microfibres in Wastewater. Available on request from* https://www.microfibreconsortium.com/preliminary-manufacturing-guidelines

There are a number of filtration systems designed to capture microfibres throughout the wastewater disposal processes. The recommended practice suggests that filtration systems will need to get finer as you move further from the point of microfibre generation.

Low-efficiency microfibre removal

The use of coarse or fine filters at the point of generation and the use of screens and strainers throughout textile processing are recommended as a preliminary treatment in order to capture large microfibres before they degenerate and flow downstream.[113] The use of fine knit filters can help to improve existing filtration systems. However, they are not effective enough for capturing smaller microfibres that may emerge throughout wet processes.[114]

Another method, clarification, is commonly used to separate liquids from solids in textile wastewater treatment plants. It relies on the use of gravity to sink heavier sediments and particles to the bottom of the clarifier. Similar to screens and strainers, this method is best for filtering out larger particles. However, decreasing the flow rate and the amount of turbulence in the water will improve its efficiency.[115]

High-efficiency microfibre removal

The use of fine membranes in ultrafiltration or reverse osmosis are recommended for capturing the smallest microfibres. They are often compatible and used with one another which can improve efficiency, prolong the life of the membranes, and enable full water-recycling systems.[116]

Membrane bioreactors (MBRs) are a relatively new technology and becoming more common in wastewater treatment facilities as a tertiary filtration system.[117] MBRs combine a separation process (typically microfiltration or ultrafiltration) with biological catalysis into a treatment process that has been found to filter out up to 99% of microfibres. MBRs offer significant improvement over other classical activated sludge treatments because they have higher sludge ages and densities.[118] This system can also replace traditional clarifiers and allows for the wastewater system to take up less space. It is recommended that these systems are built into modern wet processing facilities and in upgrades to all wastewater treatment facilities.[119] However, the cost of conversion or renovation may be a barrier at existing facilities.

Ultrafiltration systems use a fine membrane to remove particles as small as 0.1–0.01 μm. The effluent is typically directed to a crossflow module or dead-end module. In the crossflow module, the concentrated effluent flows perpendicular to the filtering direction. This often preserves the filter from fouling especially if ultrafiltration is happening downstream of a biological wastewater treatment system. It is also typically associated with wastewater recycling systems which would enable a facility to have a more closed-loop system.[120]

While this may use more energy and is more complex than a dead-end module, it is typically what is recommended for longevity and efficiency if the solid content in the wastewater is higher than 0.5%.[121]

Reverse osmosis uses an even finer membrane than ultra filtration (0.001 μm) and can yield fresh water that can then be reused at a facility. It is able to capture all particles and chemicals by forcing treated water through a highly pressurised filtration system.[122] Ramatex has invested RM250 million into a reverse osmosis system that collects or harvests water from the Industrial

Effluent Treatment System, rainwater, and domestic wastewater.[123] The challenge of reverse osmosis systems is that the high pressurisation exposes the membranes to a high fouling rate which reduces their reliability. It is recommended that other filtration systems such as ultrafiltration or MBRs are used alongside reverse osmosis in order to improve overall efficiency.[124]

Emergent technologies for microfibre removal in wastewater

Beyond process improvement, the Hong Kong Research Institute of Textiles and Apparels (HKRITA) has extended the use of the ultrasonic technology, or acoustic waves, to capture and remove microplastic fibres from wastewater. This method is touted as an eco-alternative to conventional filtering treatments that employ membrane type filters to capture the fibres, as these fibres can block the pores of the filters and reduce their efficiency, and need regular replacement. Membrane-type filters are typically made of polypropylene (PP) and nylon and cannot be reused, turning into solid waste that adds to the plastic pollution problem.[125]

Acousweep: An Innovative Microplastic Fibre Separation System Developed by HKRITA Using Sweeping Acoustic Waves

Utilising acoustic waves and a specially shaped chamber, the Acousweep system enables continuous water treatment and easy collection of microplastic fibres. HKRITA indicates that the Acousweep can separate microplastic fibres longer than 20 μm, which is 250 times smaller than the typical size of a microplastic (5mm in diameter) as defined by the United Nations Environment Programme.[126] The component parts of the acoustic chambers and its sensory system are key elements in the trapping and collection of the microplastics in water. The technology allows the microplastic fibres to drip into a collection tank. A high temperature is then applied to remove the water, leaving the fibres as an easily removable and compact mass. No chemicals, solvents nor biological additives are added, nor are membrane filters required to be installed, hence the water treatment is continuous as there is no need to reset and replace filters.

HKRITA has developed a lab-scale treatment system with potential to be upscaled in industrial plants. From our understanding as at March 2022, the institute is continuing to work on the prototype and seeking opportunities to scale up.

Credits

This report was written by Ariel Muller, Jael Chew and Karen Sim, with support from Fern Yu, Natasha Mehta and Sangam Paudel at Forum for the Future. Photos on page 10, 12, 14, 20, 23, 25, 33, 41, 44, 46, 50, 52 and the top and bottom left photos on the coverwere taken by Ahmad Iskandar Photography. For more information on the project, please contact Karen Sim k.sim@forumfortheufuture.org.