Textile
Exchange

The Future of Synthetics

April 2024

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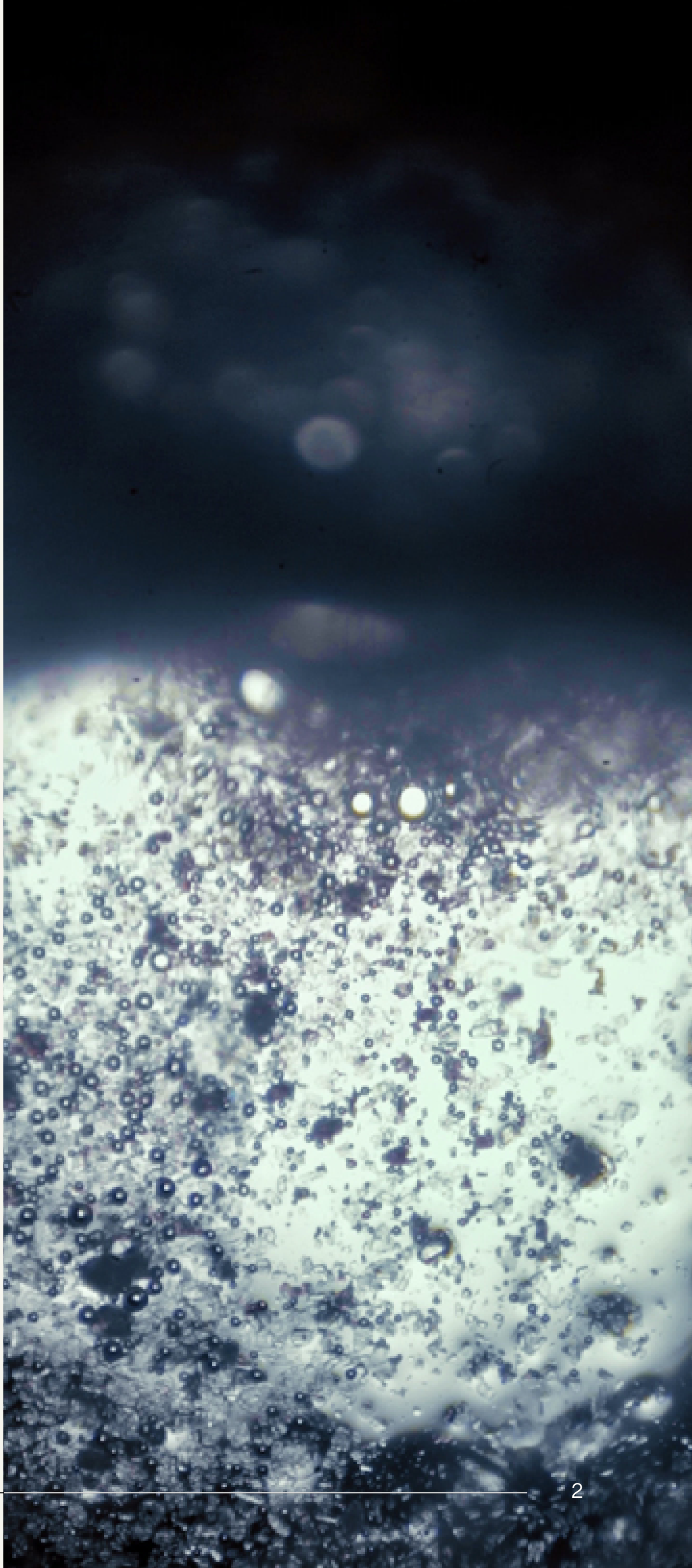

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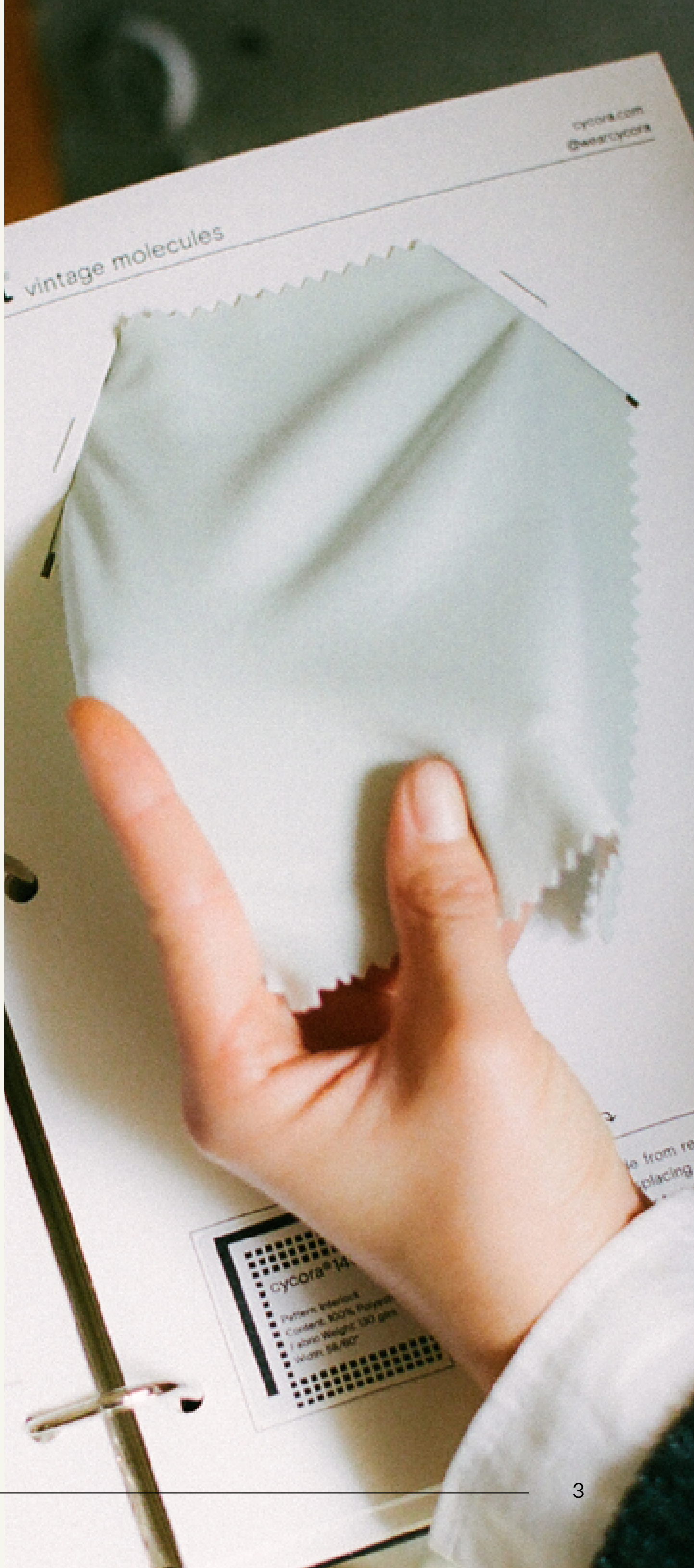


Abbreviations

ACTR	Alliance of Chemical Textile Recycling
BHET	Bis(hydroxyethylene) terephthalate
CCUS	Carbon capture utilization and storage
CO_2	Carbon dioxide
DAC	Direct air capture
DMT	Dimethyl terephthalate
DPP	Digital product passport
EG	Ethylene glycol
ESPR	Ecodesign for Sustainable Products Regulation
EU	European Union
GHG	Greenhouse gas
GRS	Global Recycled Standard
H	Hydrogen
H_2O	Water
IPCC	Intergovernmental Panel on Climate Change
LCA	Life cycle assessment
MEG	Monoethylene glycol
MMR	Materials Market Report
PBS	Polybutylene succinate
PET	Polyester
PHA	Polyhydroxyalkanoate
PHB	Polyhydroxybutyrate
PLA	Polylactic acid
PTA	Purified terephthalic acid
PU	Polyeurathane
RCS	Recycled Claim Standard
rPET	Recycled polyester
SCIRT	System Circularity and Innovative Recycling of Textiles
SDG	Sustainable Development Goal
SWITCH	Switch to Circular Economy Value Chains
TPA	Terephthalic acid
T-Rex	Textile Recycling Excellence
UKFT	UK Fashion and Textile Association
UNDP	United Nations Development Programme
UNFCCC	United Nations Fashion Industry Charter for Climate Change
UNIDO	United Nations Industrial Development Organization
US	United States

INTRODUCTION

Introduction

Synthetics are some of the most widely used materials in the fashion, apparel, and textile industry today. Inclusive of polyester, nylon, acrylic, and elastane, among others, materials in this category are conventionally made from fossil-fuel-derived resources including petroleum-based chemicals. The primary raw material used in their production is crude oil.

In order to end the fashion and textile industry's reliance on virgin fossil fuel-derived synthetic materials and reduce the associated impacts, we need to identify and scale more responsible alternatives. This shift will be necessary if we are to collectively achieve a 45% reduction in greenhouse gas (GHG) emissions related to fiber and raw material production by 2030 – the goal set by Textile Exchange as part of its "Climate+" strategy.

Is the solution for the industry to eliminate its use of synthetic materials altogether? Not necessarily.

First, we face the reality that vast amounts of synthetic materials and products have already been produced. The industry must take responsibility for its textile waste, recognizing the energy and emissions already spent making these materials and finding ways to continue using them as long as possible rather than sending them to landfills around the world.

We must also be aware of the potential unintended consequences associated with solely relying on natural fibers for apparel and textiles. At current production rates, simply shifting from one material category to another would likely lead to the accelerated depletion of natural ecosystems.

Lastly, we recognize that synthetic materials bring inherent performance characteristics – particularly relevant to athletic and outdoor products - that are often difficult to achieve with other material categories today.

Textile Exchange believes that two key actions must be prioritized as we move toward an evolved approach to the use of synthetics and work to achieve the industry's impact reduction goals: the elimination of new, virgin fossil fuels as feedstocks, along with a reduction in the volume of new materials and products produced overall.

While this report focuses on the opportunities for materials substitution, it is important to note that the industry must also find ways to think differently about growth rates and the continuous extraction of new resources to make new products. It should not be assumed that the volume of replacement can or should match our industry's current year-on-year growth trajectory.

> "The industry must take responsibility for the textile waste it has created and must do its part to build a truly circular system into the future. To do this, we will need to reduce the overall volume of new materials being extracted and produced, and where synthetic materials are used, ensure that feedstocks from new fossil fuel extraction are not entering the supply chain."
>
> *– Beth Jensen,*
> *Senior Director, Climate and Nature Impact,*
> *Textile Exchange*

This report aims to establish a future vision for synthetic materials by promoting a greater understanding of the opportunities to replace the use of new virgin synthetics and reduce the industry's reliance on fossil fuel extraction. It covers three key areas of opportunity for material substitution: textile-to-textile recycling, biosynthetics, and carbon capture technologies.

Of the three, textile-to-textile recycling can be considered the most "established" solution. While technologies already exist to make this a reality, the demand for textile-based feedstocks currently far outweighs the supply. The investment and collaboration to scale these recycling technologies, as well as the necessary collection and sortation infrastructure, is lacking.

Biobased solutions represent another opportunity for supporting the industry's shift away from virgin fossil fuel-based inputs; however, care must be taken when vetting them. It is fundamental to consider the impacts associated with both feedstocks and processing, including ensuring that biosynthetic options are from sustainably sourced renewable feedstocks and/or true waste byproducts, and that the production of these materials is neither diverting resources from what otherwise would have been a food source, nor is it leading to deforestation or land conversion. End-of-life considerations are also particularly important here; again, we must recognize the energy and emissions that are expended to make these materials. Ideally, where these materials are used, there are channels available to keep them in a closed-loop system as long as possible.

Finally, carbon capture technologies, while the most nascent of the material substitution options covered in this report, are explored as another potential preferred option to enable divestment from new virgin fossil fuels in textiles.

In synthesizing this information, the goal of this report is to facilitate the action needed to drive rapid progress towards reducing the carbon emissions currently associated with synthetic fibers in the fashion, textile, and apparel industry.

A note on microplastics, microfibers, and fiber fragment shedding

While not covered directly in this report, microfiber shedding is another critical issue within the overall category of waste and pollution. It is important to note that all fibers, whether synthetic or natural, may shed, whether in the fiber processing and/or fabric production stages of the supply chain, in the consumer use phase when used and washed, or at the product's end-of-life.

Groups like The Microfibre Consortium are convening the fashion, textile, and apparel industry to take action around this complex issue. As synthetics are the most-used fibers across the industry today, meaningful action should be prioritized to reduce fiber fragment shedding within this category specifically.

The prevalence of synthetic materials

Synthetic fibers and materials make up 64% of the volume of all fibers and materials produced globally across sectors, including fashion, apparel, and textiles, as well as other sectors such as healthcare and automotive.[1]

Within this broad category of synthetics, polyester is the most common, making up 54% of global fiber production in 2022.[2] Based on currently available data, polyester also comprises the largest amount of GHG emissions within the synthetics category and overall across all fiber categories.

Recycled polyester usage has grown somewhat steadily in recent years, and it accounted for around 14% of all polyester produced in 2022.[3] However, between 2021 and 2022, there was a drop of around 1% in recycled polyester's share of the total polyester market.

The second most widely produced synthetic fiber is polyamide, also known as nylon, and accounts for approximately 5% of global fiber production and around 10% of GHG impact. Other synthetic fibers combined make up an additional 5% of global volume.[4] This includes elastane, which although smaller in total volume at around 1.1% of global fiber production, carries outsized importance given that it is often found in a large volume of products, in blended materials to provide properties of stretch and durability.

Within this global production volume data, when looking at the share of production volume that is estimated to be attributed to the fashion and apparel, home textiles, and footwear sectors, polyester remains both the largest volume fiber used as well as the largest contributor to GHG impact. See Figure 2 for the estimated production volumes and associated GHG impact relevant to these specific sectors.

Ultimately, Textile Exchange's goal for synthetic materials is for new virgin fossil-fuel-derived feedstocks to be replaced by preferred materials that reduce carbon emissions, while at the same time slowing down the production of new fibers and raw materials overall.

When thinking about preferred materials, fiber types should not be compared across categories, given the differences in production systems and other variables that contribute to impacts. Textile Exchange's approach is to enable the industry to select options that are lower impact but are also appropriate for given products' specifications and requirements.

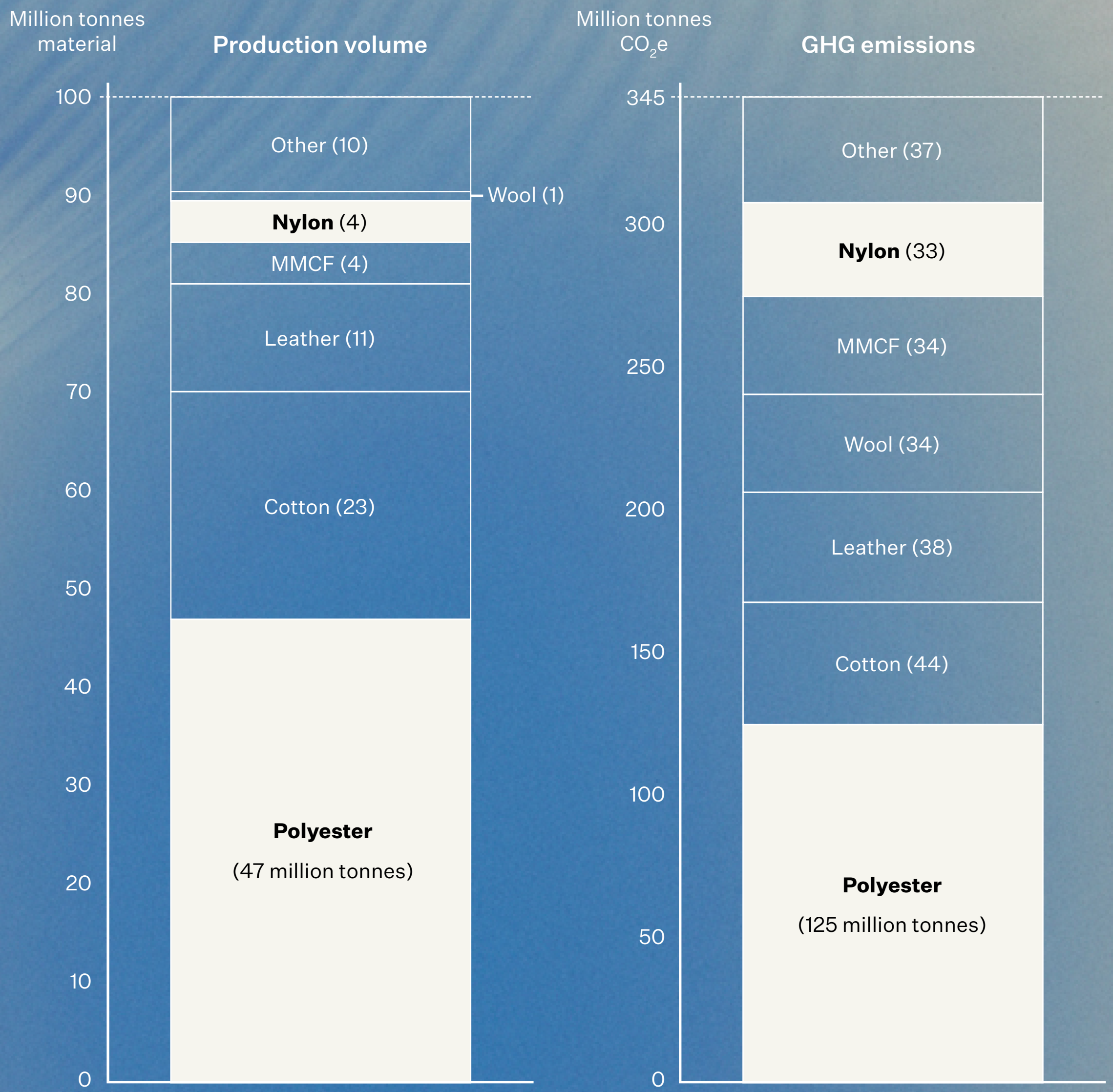


Figure 2: Estimated GHG impact and production volumes for fiber and material categories for 2022. This chart considers the following sectors only: fashion and apparel, home textiles, and footwear. It does not consider total global production (as published in Textile Exchange's Materials Market Report).[5]

Key terms and concepts

Sustainably sourced renewable material

A material that is continually replenished at a rate equal to or greater than the rate of depletion, that delivers consistently reduced impacts and increased benefits for climate, nature, and people.

Sustainably sourced recycled material

A material that is refined and reprocessed from reclaimed material through a manufacturing process and made into a final product or into a component for incorporation into a product, that delivers consistently reduced impacts and increased benefits for climate, nature, and people.

Where "sustainably-sourced" is adapted from UNDP and SDG 12 and is aligned with the concept of "preferred," "recycled material" is adapted from ISO 14009:2020, and "renewable material" is adapted from Ellen MacArthur Foundation.

Textile Exchange aligns with the United Nations and SDG 12 in their use of the term "sustainably-sourced" here, as it is already an accepted policy term. The terms "responsibly-sourced" or "preferred" would be deemed equivalent/aligned to this.

Biodegradability

Biodegradability refers to a material's ability to be broken down by microorganisms into carbon dioxide and biomass in specific conditions. Factors affecting biodegradation include various environmental conditions such as temperature, humidity, and availability of oxygen as well as material properties like crystallinity, fiber structure, and dyes and finishes.[6] [7] Fossil-based synthetic materials do not break down quickly or easily across different environmental conditions.

It is also important to note that biobased synthetic materials are not necessarily biodegradable or result in a reduced/improved environmental footprint. A biobased material is a material that is wholly or partly derived from material of biological origin, excluding materials embedded in geological formations and/or fossilized.[8]

Accelerating Circularity's Spent Textiles Waste Hierarchy

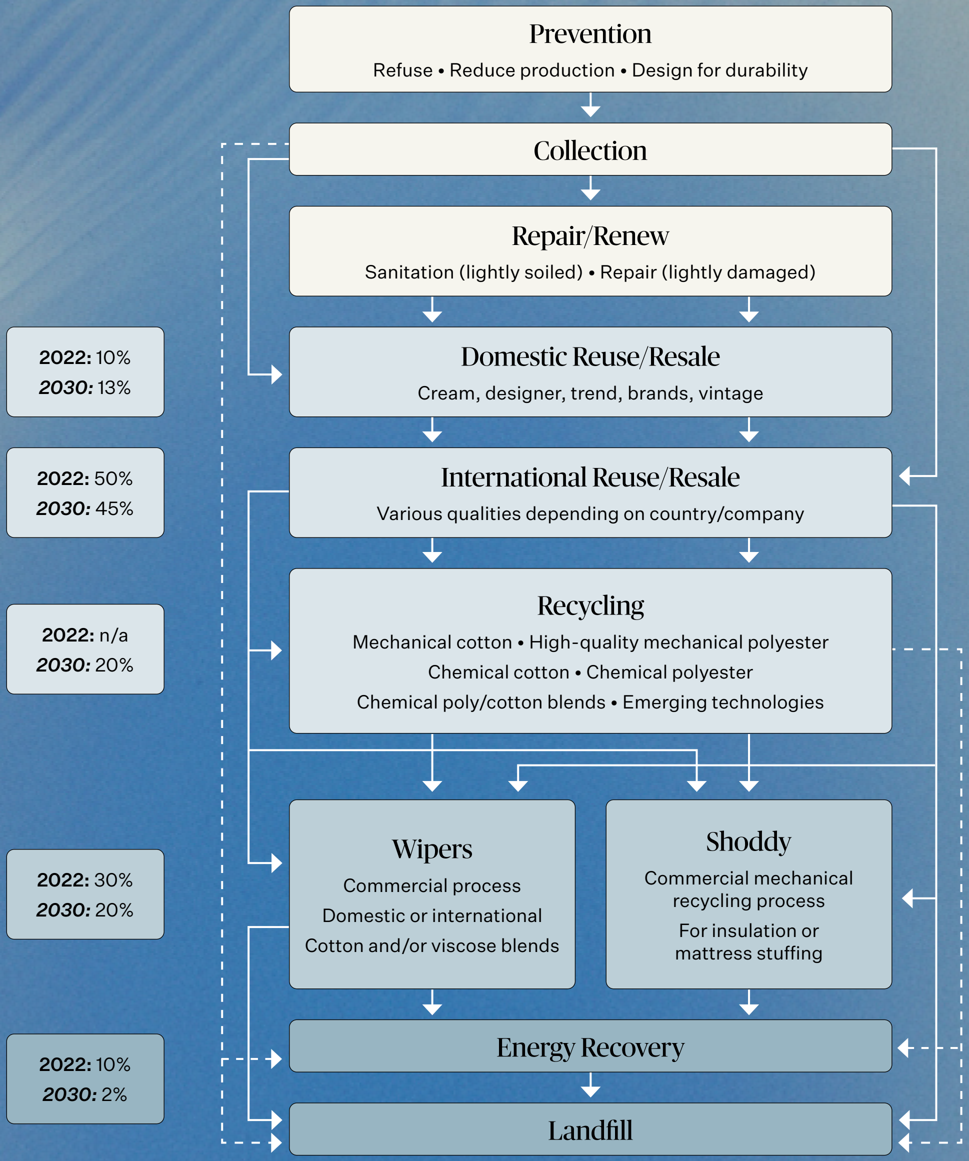


Figure 1. Diagram based on Accelerating Circularity's Spent Textiles Waste Hierarchy

Key focus areas for polyester

Textile Exchange's aim for the industry is that by 2030, no new virgin fossil-based synthetics enter the supply chain and that all materials used (whether synthetic or natural) come from sustainably sourced recycled or renewable feedstocks.

Given the dominance of polyester in the synthetics market, this fiber should be seen as a priority in the shift away from conventional, fossil fuel-based feedstocks. Currently, recycled polyester from plastic bottle-based feedstocks is the most widely used alternative to virgin polyester on the market. However, the fashion, apparel, and textile industry needs to move as rapidly as possible toward other solutions, for several reasons:

- Our industry has a waste problem, with mountains of used textiles going to landfills or being incinerated, often in the global south. We must take responsibility for the textile waste we have created and the embedded energy and GHG emissions that have already been spent on producing these materials and products.
- Bottle-based feedstocks for textiles and apparel are not truly circular, as they are using waste from the food and beverage industry rather than the vast amounts of waste generated by our own industry. By using another industry's waste material, we are actually impeding their circularity efforts, particularly given the fact that current technology can much more easily recycle bottles into new bottles rather than bottle-based textiles into new textiles.
- The recycled content targets set by food and beverage companies have the potential to decrease the supply of inputs available for use by other industries, as targets for recycled plastic content in this industry increased to 25% by 2025 and 30% by 2030 per EU legislation.
- Potential forthcoming regulatory requirements may discourage use – in particular, the EU Commission has indicated that they may no longer consider polyester from bottles as preferable.

The 2025 Recycled Polyester Challenge and beyond

In 2021, Textile Exchange and the UNFCCC set a challenge for the industry related to recycled polyester usage – inclusive of textile-to-textile recycling as well as bottle-based feedstocks - designed for brands to signal demand back to Tier 4 of the supply chain (the stage where the cultivation and extraction of raw materials to be processed into a commodity state takes place).

With a target date of 2025, this initial Recycled Polyester Challenge was intended to encourage a shift from conventional to recycled sources. The program was designed to increase the proportion of recycled polyester within brands' overall polyester usage, not to encourage an increase in total production or uptake of polyester. Explore the Recycled Polyester Challenge dashboard for annual updates.

Three years on, progress toward our goal for recycled polyester is not happening fast enough, and we acknowledge that the primary focus now should be on textile-based feedstocks rather than bottles.

Human rights within synthetics supply chains

People are an integral part of supply chains, and circular supply chains are no exception. Every supply chain has the potential to create negative impacts on human rights, and within each, there will be groups of people who are particularly vulnerable and more severely affected.

To meet their individual responsibility in regards to respecting human rights, companies as well as other relevant actors engaging in recycling or circular supply chains should carry out due diligence as outlined in the UN Guiding Principles on Business and Human Rights. However, there are other resources which may help companies on this journey. While originally developed for the recycled packaging industry, the Fair Circularity Principles can offer a valuable roadmap for other industries to systematically tackle the issues faced by people in the informal waste sector around the world. Other practical resources such as Tearfund's Due Diligence Toolkit can help companies put these actions in place.

Steps needed to scale preferred synthetics

In conjunction with an overall reduction in material production

Step 1

Remove dependence on new virgin fossil fuels, and away from polyester (PET) bottles as feedstocks

The first step is to reduce the reliance the industry has built upon new virgin fossil fuel sources for producing polyester – and synthetic materials at large. In recent years the recycled polyester landscape has been dominated by the use of waste PET bottles as the primary feedstock source, diverting millions of PET bottles from landfill or incineration. However, as described in the section above, recent developments signal that the industry needs to look beyond bottles as inputs and shift to more circular sources of polyester feedstocks - as rapidly as possible.

Step 2

Scale up/increase textile-to-textile capacities and supporting infrastructure

As an industry, we must also recognize our responsibility to address the amount of textile waste that has already been created, and support suppliers and innovators to scale up their processes for accepting textile waste (pre- and post-consumer) as a feedstock for recycled synthetics. There are many promising technologies in development which need to be scaled to both increase the availability of recycled polyester and capabilities to process additional types of feedstocks beyond bottles.

Current challenges in this space include a lack of sorting infrastructure, a lack of access to high quality textile waste feedstocks suitable for each specific type of textile-to-textile recycling, a lack of financing to build at scale facilities, and a lack of supplier partnerships. Solving these systems challenges will require collaboration, strategic supplier partnerships, and consistent support from brands which may include a willingness to pay a price premium.

Step 3

Support and scale new, innovative, lower-impact materials that are direct replacements or alternatives to virgin synthetic options

The third lever to enable a transition away from new virgin fossil fuel-derived synthetics is around "next-generation solutions" - new and innovative materials with the properties of traditional, virgin-based synthetics. While textile-to-textile recycling is being scaled, it is important to continue developing next-generation solutions that result in reduced and/or beneficial impacts compared to virgin materials, while ensuring that we are not simply replacing one problem with another.

We believe that an urgent, coordinated focus on these three areas will enable synthetic fibers and materials to rapidly transition from conventional fossil-fuel-derived sources to preferred materials, reducing the overall impacts of this fiber category toward our industry's overarching environmental targets.

TEXTILE-TO-TEXTILE RECYCLING

Textile-to-Textile Recycling

Between 2010 and 2020, recycled polyester usage increased from 4% to 14% of total polyester, the vast majority coming from PET bottles as feedstocks.[9] Today, bottle-based feedstocks still dominate the recycled polyester market, and therefore the recycled synthetics market at large.

In addition, during the same timeframe, there has been a rise in fiber and materials production, leading to a corresponding increase in textile waste generation.[10]

Given the risks that this presents, the fashion, apparel, and textile industry must not only rapidly transition away from new virgin fossil fuel-based feedstocks for polyester, but also find alternatives to PET bottles. This will mean prioritizing the development of textile-to-textile feedstocks at scale.

In the short term, its priority should be to build out the needed textile-to-textile recycling systems, infrastructure, and technology. In the longer term, we may expect to see mixed recycling solutions that include a mixture of different synthetic waste feedstocks such as textiles, bottles, carpets, and inputs from other industries. Pre-preparation processes and transport systems across geographic regions will need to be built out too.

The following section focuses specifically on textile-to-textile recycling technologies, providing an introductory technical overview of the current landscape of options and how they can be applied. The focus on textile-to-textile recycling technologies is due to it being promising in terms of potential, scalability, and timeline. It is also important to underline that total impact assessment should be completed on a technology-by-technology basis due to the various in manufacturing processes.

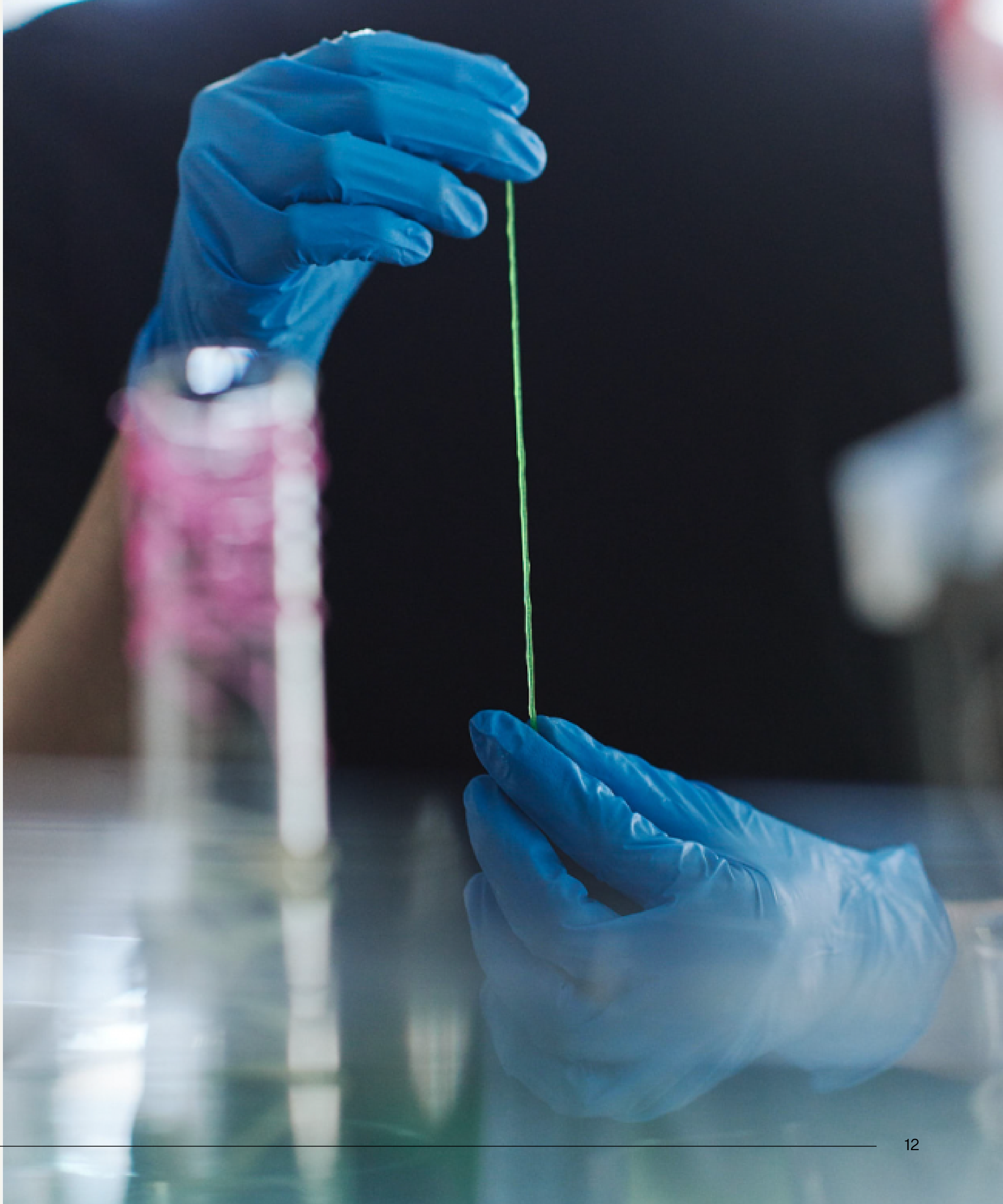


Photo (right): Jon Brown

Current landscape of textile-to-textile recycling technologies

Mechanical recycling for polyester

Approximately 99% of recycled polyester for the textile industry comes from mechanically recycled PET bottles.[11]

While mechanical recycling represents a legacy technology that works well for PET bottles, there are some challenges when it comes to using textile inputs. Mechanical recycling requires clean textile inputs free from contaminants, and it is difficult to process textiles containing more than one material type. Materials containing blends of cotton, polyester, and elastane, for example, require costly and labor-intensive separating.

Mechanical recycling is also an abrasive process which produces a recycled fiber that is weaker and of lower quality than virgin polyester fibers. To keep its original quality and performance, it is common to blend mechanically recycled textiles with virgin materials.

Chemical recycling for polyester

Given the complications associated with mechanical recycling of textiles, alternative recycling technologies, such as chemical recycling, are promising thanks to their capacity to recycle blended textile waste. They are designed to handle colorants, additives, and finishing materials, and are also able to produce recycled textile fibers with performance capabilities substantially equivalent to virgin polyester fibers.

Interest in chemical recycling has increased in the textile industry in recent years and today, many startups and established recyclers are working to develop technologies that can handle the quantities and varieties of recycled polyester currently in use, including blends. The type of recycling technology chosen will depend on a brands end product and overall goal.

Various methods can be used to partially, or fully, depolymerize polyester so that it can be rebuilt to create a polymer with performance properties that are equivalent to conventional virgin polyester. Common chemical recycling methods for textiles include hydrolysis, methanolysis, glycolysis, and enzymolysis.

To increase the efficiency of these processes, as well as to ensure complete depolymerization is achieved, a catalyst chemical is required. These catalysts vary based on the desired characteristics of the final material.

Depending on the chemical recycling method used, polyester can be partially or fully depolymerized into monomers or oligomers which are processed and chemically converted back into PET using conventional manufacturing techniques. These monomers include terephthalic acid (TPA), purified terephthalic acid (PTA), bis(hydroxyethylene) terephthalate (BHET), dimethyl terephthalate (DMT) and other trace amounts of chemical substances.

Different chemical recycling methods

Hydrolysis

When hydrolysis is used, the polyester materials used as feedstocks are reacted with water at high temperature and pressure (115-420°C) under acid or alkaline conditions.[12] Alkaline hydrolysis is carried out most commonly using sodium hydroxide and acid hydrolysis is carried out primarily using sulphuric acid, although other acids can be used.[13] The output of chemical recycling via hydrolysis is TPA terephthalic acid and ethylene glycol (EG).

Methanolysis

During methanolysis, a combination of high temperatures (180-280°C), pressure, and methanol is used to depolymerize the polyester.[14] The output of chemical recycling via hydrolysis is dimethyl terephthalate and ethylene glycol. An 80% yield of DMT can be obtained at a higher temperature of 300°C, but this greatly increases the cost of operation.[15] Due to the higher cost, methanolysis is generally a less popular method of chemical recycling.

Glycolysis

The most common type of chemical recycling for polyester, and the one that has been around the longest, is glycolysis. Different methods include solvent, supercritical, and microwave assisted. Many efforts have been made in optimizing the process itself and it is becoming increasingly popular across the industry. It involves reacting the polyester with glycol, a chemical reactant used in the production of polyester, at temperatures generally between 180-240°C under inert atmosphere conditions.[16] Whilst the most common glycol used in glycolysis recycling is ethylene glycol (EG), it is important to note that there are a range of other glycols that can be used to depolymerize polyester. The output of chemical recycling via glycolysis is bis (hydroxyethylene) terephthalate (BHET).

Enzymatic recycling

Alongside chemical recycling technologies, there is significant research being undertaken into enzymatic recycling, which involves the use of different enzymes to break down and depolymerize polyester found in textiles.[17] Bacteria as well as fungi can be used for enzymatic recycling.

Currently, four enzyme classes are most commonly used, with varying rates of efficiency: Cutinase, Lipase, PETase, and Esterase. These enzymes are selected based on various factors, including but not limited to, their ability to perform under high operating temperatures, compatibility with the chemical composition of polyester, and the total yield of monomer products produced.

Overall, the application of enzymatic recycling technologies to polyester textiles at scale is hugely challenging given the high energy costs to remove dyes, chemical treatments, and other additives generally present in polyester.[18]

Chemical Recycling for Other Synthetics (Nylon/Polyamide)

Nylon 6 and nylon 6,6 are the most commonly used in terms of volume in the fiber industry. Most Nylon 6 is chemically recycled, while most nylon 6,6 is mechanically recycled.[19] Of the previously mentioned chemical recycling processes, Hydrolysis, Glycolysis, and Enzymolysis are proven methods for depolymerizing nylon fibers into their monomer building blocks. However, hydrolysis is the only technique used on a large scale for the depolymerization of post-industrial and pre-consumer nylon to date.

The challenges of textile-to-textile recycling

Beyond the lack of connected infrastructure, it is worth noting some of the other challenges related to scaling textile-to-textile recycling. These include, but are not limited to:

Lack of access to quality feedstock

Recyclers often have limited access to appropriately sorted and pre-processed feedstocks in sufficient quantities to maintain process efficiency. Planning the location of collection and sorting activities, as well as developing the infrastructure to easily access these waste streams, will be critical to make textile-to-textile recycling scalable.

Technical challenges in scaling solutions

There are technical challenges associated with scaling solutions from proof of concept to commercial scale, including purification, integration into large-scale processing, consistency of feedstocks entering the process, and ensuring the efficiency of the process along with a viable business model to support scaling.

Complex material blends and increased cost

The variety and complexity of blends and material types that are combined with polyester create challenges for what can and can't be recycled through different recycling methods. Plus, compared to bottle-based feedstocks, textile waste generally requires additional removal of trims, purification, and cleaning steps (including the removal of zippers, buttons, dyes, and contaminants). These steps generally increase the cost of operations.

Limited impact data

Impact data – and appropriate methodologies - for different recycling processes are limited, hampering the ability to ensure those with reduced environmental impact (compared to conventional polyester production) can be prioritized and that overall impact is not being increased. Impact data should ideally take a holistic view of impacts beyond just carbon/greenhouse gas emissions, including other impact areas such as biodiversity, freshwater, and land use – an approach that is in alignment with Textile Exchange's Climate+ strategy.

More investment needed

The level of investment required to develop and scale from proof of concept to commercial scale is still in development. This includes the financing required to either convert existing infrastructure into new recycling facilities or to build new facilities where they do not currently exist. Building out infrastructure at scale will require collaborative effort across stakeholders to commit the capital, secure the output volume purchase, and policies to enable consistent and cost-effective inputs.

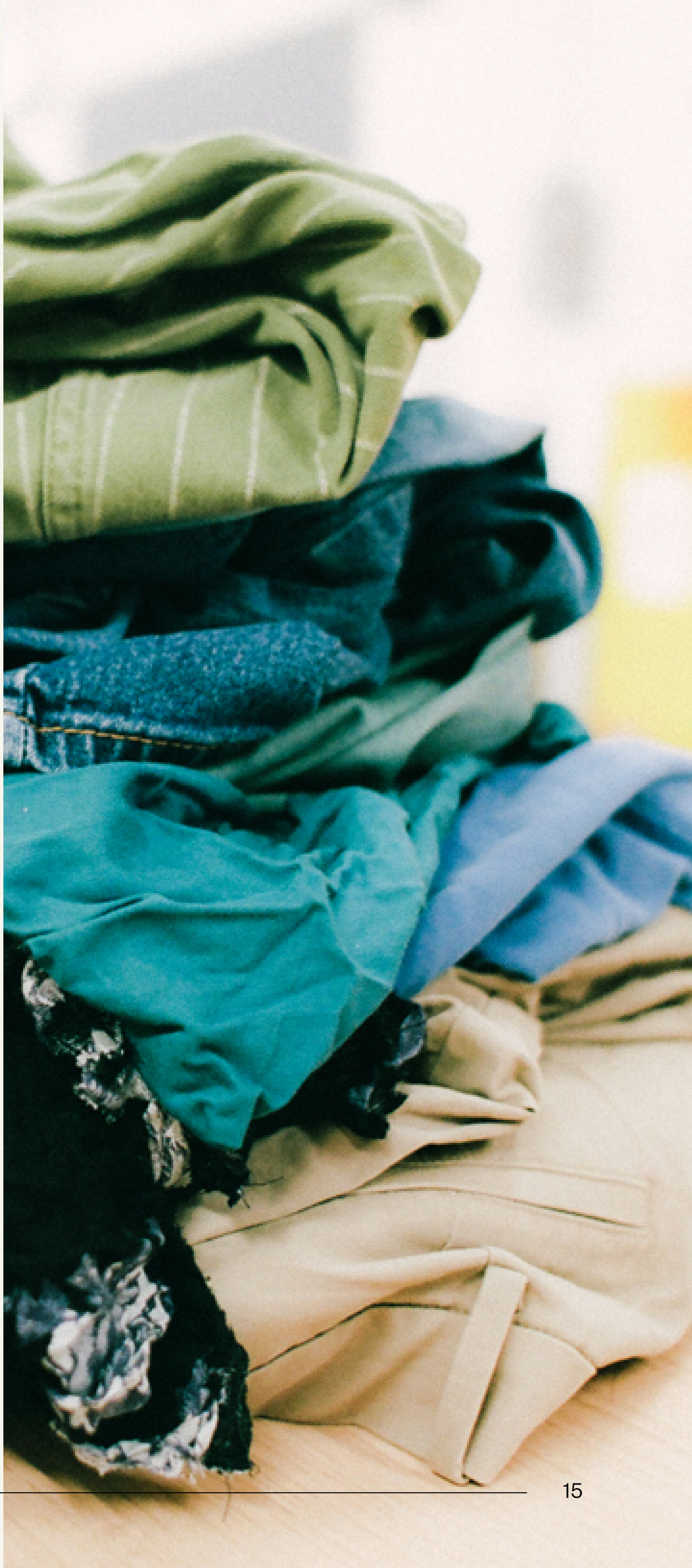
Government policy uncertainty

At the time of this writing, policy requirements that will incentivize textile-to-textile recycling are under discussion, particularly within the EU, but are not yet finalized.

Challenges in nylon recycling

Nylon is a lower-volume fiber and therefore has lower availability of textile feedstocks for recycling processes. In addition, the two primary types of nylon (nylon 6 and nylon 6,6) must be separated for recycling due to differences in how their chemical bonds must be broken down.

To overcome these challenges, the industry needs a range of solutions in a range of locations. Only in this way will it be able to recycle both the textile products that exist on the market today as well as those that will be on the market in years to come. Circular hubs and systems will also be needed to support regional collection, sorting, and fiber recycling.



Current industry-wide research projects to support textile-to-textile recycling

There are numerous companies actively engaged in working across geographic regions to advance textile-to-textile recycling technology innovations, which can be a starting point for building regional capacity.

Partnership-based organizations that already exist to enable the build-out of regional recycling systems include:

- Accelerating Circularity
- Circle-8
- Fashion for Good
- Global Fashion Agenda
- The Global Circular Fashion Forum
- The UK Fashion and Textile Association (UKFT)
- United Nations Industrial Development Organization (UNIDO)

Spotlight: GANNI and Ambercycle

Ambercycle is an innovation company that uses novel molecular regeneration technology to convert end-of-life textiles into decarbonized, circular materials for brands. In collaboration with Danish womenswear brand GANNI, the two companies worked together to bring cycora® to market – Ambercycle's first commercially viable regenerated alternative to virgin polyester. In this case study, we hear how the two companies came together to overcome the challenges of integrating innovative materials into the supply chain.

Read the full case study here.

Several examples of relevant research projects have occurred in recent years. Projects have included:

- Alliance of Chemical Textile Recyclers (ACTR) by Accelerating Circularity
- Textile Ecosystems by Circle-8
- Circular Fashion Partnerships by Global Fashion Agenda
- Sorting for Circularity by Fashion for Good
- Full Circle Textiles Project by Fashion for Good
- Fibersort technology® by Fibersort
- Resyntex by Prospex Institute
- Scaling Circularity Report by Global Fashion Agenda and McKinsey & Company
- System Circularity and Innovative Recycling of Textiles (SCIRT)
- Textile Recycling Excellence project (T-Rex)
- Circular Innovation Network by The UK Fashion and Textile Association (UKFT)
- Switch to Circular Economy Value Chains by UNIDO

In addition to industry partnerships, there is an important place for academia and industry to collaborate on research to scale textile-to-textile recycling. This can enable the discovery and advancement of new technologies (such as the refinement of chemical recycling methods) – starting with pilot projects and ultimately proving commercial scale viability.

Actions to scale recycled textile feedstocks

Set public targets

Continue to set and work towards ambitious targets to convert from virgin fossil-fuel-derived polyester to textile feedstocks, reducing reliance on PET bottles.

B

Share the financial responsibility

Work with the rest of the supply chain on investment opportunities and share the responsibility to create the infrastructure needed.

B

Design for recycling

Bring in relevant experts across the organization to design the end product with recycling in mind. This includes selecting materials, chemicals, components and additives which are compatible with recycling processes.

B

Offtake agreements

Commit to offtake agreements with suppliers to use and implement recycled outputs in large scale collections, not only niche product lines where both volume and impact are limited. This could also include exploring opportunities around providing feedstocks for recycling, in conjunction with using the recycled outputs.

B R

Strive for certification and traceability

Ensure appropriate certification is in place for recycled synthetic materials, and work to improve traceability too.

B S

Invest in reverse logistics

To support the infrastructure development of collection and sortation systems and build the business case to demonstrate that it is financially beneficial to have improved capabilities.

B I

Invest in improving feedstocks

Prioritize investment in the development of sorting and fiber identification technologies for recycled feedstock inputs, including fiber traceability solutions throughout the supply chain to improve the data quality around textile waste inputs (e.g. digital product passports or physical tracers).

I

Participate in policy creation

Engage with consortiums and the Policy Hub to inform upcoming policy.

B R S

Begin trials

Bring in relevant teams across the organization (such as designers and product development) to trial and test different material options and integrate across existing products. This includes understanding the specifications and limitations of various recycling processes, validating technology, and determining the most suitable options.

B R S

Prioritize partnership

Enable partnerships across the industry to support the above investments.

B I R S W

Support the scaling of infrastructure

Scaling of innovative recycling technologies as well as collection and sortation infrastructure.

I

Educate about end-of-use

Recyclers to engage with the brands, retailers, and supply chain stakeholders to provide relevant end-of-use expertise to those designing for circularity.

R

Share specifications

Recyclers to provide publicly available feedstock specifications to brands and the wider industry to inform them of any relevant limitations, and provide the opportunity to collaborate on solutions.

R

Improve sorting and separation

Strive to improve the sorting and separation of recycled feedstocks with quality control mechanisms for both inputs and outputs that help to achieve high-quality feedstocks.

W

Note: All actions should be underpinned by respect for human rights.

B Brands
I Investors
R Recyclers
S Suppliers
W Waste aggregators

The future of textile-to-textile recycling technologies

In the coming years, Textile Exchange will further support the industry to decrease its reliance on bottles as a feedstock and bring textile-to-textile recycling technologies and infrastructure to scale.

Overall, there is a need to diversify feedstocks used to produce synthetics as we shift away from new virgin fossil fuel-based feedstocks. The Textile Exchange Recycled Polyester Round Table has been conducting research into market realities with a variety of industry experts and supply chain actors to document and report on the barriers, challenges and opportunities that currently exist. This work will include actionable steps which the industry can take. In the meantime, some high-level recommendations for the industry collaboration (brands and retailers, suppliers, innovators, waste aggregators, recyclers) are outlined on the left.

Use the Materials Directory to find textile-to-textile recyclers

Textile Exchange's Materials Directory is a filterable online repository for raw material suppliers, production units, and branded materials, and can be used to identify textile-to-textile recyclers.

BIOSYNTHETICS

Biosynthetics

Biosynthetics are fibers that are wholly or partially derived from biobased resources and represent an alternative to their fossil fuel-based synthetic counterparts. Released in 2022, Textile Exchange's "The Sustainability of Biosynthetics" report provides an initial view of feedstocks, processing, circularity potential, and impact data considerations for biosynthetic materials.

Biosynthetics hold potential as part of the overall portfolio of preferred materials that will be needed to replace the use of new virgin fossil fuel-based synthetics. However, as always, we must ensure that potential unintended consequences are considered; just because a fiber is from a biobased source does not necessarily mean its impact is favorable. Was the feedstock grown regeneratively or organically? Was the production of the feedstock detracting from what otherwise could or should have been a food source? If the feedstock is claimed to be waste, is there proof that this is really the case? What are the impacts related to the processing of the feedstock into a fiber? Is the biobased material or blend recyclable or biodegradable at the end of its useful life? These are just a few of the questions that should be asked when exploring biosynthetic options.

In the ideal state, biosynthetic fibers and materials should continue to circulate in a closed loop recycling system for as long as possible in order to utilize the energy and resources expended to produce these materials in the first place. Biodegradability and composability should be considered a last resort and only if the materials are no longer able to be recycled into new uses.

In general, biosynthetic materials still require a significant amount of development and scaling to be considered widely viable options. For example, most biosynthetic solutions currently in development are only partially biobased. The insights presented here focus on opportunities currently being researched. Understanding preferred options is dependent on impact data, including appropriate methodologies for solutions that are not yet at commercial scale – representing a challenge in this category today.

As the industry works to eliminate all virgin fossil fuel-based feedstocks, identifying and scaling biosynthetic solutions with proven lower or beneficial impacts – ideally those containing 100% biobased content, those that are blended with recycled content where blending is required, and those which can be recycled or become biological nutrients at end of life – will be a critical component.

Current landscape of biosynthetic innovations

When discussing the biosynthetic choices currently available and/or under development, we can separate them into two main categories:

- “Direct replacements” are biobased feedstocks that are chemically identical to their virgin counterparts and can be used as like-for-like “drop-in” solutions within existing technologies.
- “Alternatives” are biobased feedstocks that are chemically different from their virgin counterparts and therefore cannot be used as “drop-in” solutions.

Some biosynthetic innovations have received early-stage investments with limited production capacities, while more mature companies have already entered the market.

Biosynthetic direct replacements

Biobased polyester

Biobased polyester (PET) is a direct replacement for petroleum-based polyester fibers. The market share of biobased polyester is estimated at around 0.01% of total polyester production.[20] Low volumes are primarily due to price, availability, and questions about the sustainability of biobased polyester. Biobased polyester has the potential to reduce greenhouse gas emissions, but materials must be sourced and managed responsibly to achieve this. More sustainable feedstocks need to be developed to provide the industry with innovative solutions to drive the uptake of biobased polyester.[21]

Currently, at commercial scale, biobased PET is predominantly made from partially biobased feedstocks (30% renewable and 70% petroleum-based raw materials) into the future, we must seek to develop and scale fully biobased solutions. Biobased PET can seamlessly integrate into products, and can be chemically recycled at the end of life.

Biobased nylon

Biobased nylon 6 and nylon 6,6 are direct replacements for petroleum-based nylon 6 and nylon 6,6 fibers. The market share of biobased nylon fibers in 2022 remained low, at around 0.4% of the global nylon fiber market.[22] Similar to the reasons for the low uptake of biobased polyester, price, availability, and questions about the sustainability of biobased polyamide dampened growth in the market.[23]

Biobased nylon 6 and nylon 6,6 are made either in part or completely from renewable resources. Like biobased polyester, biobased nylon seamlessly integrates into products and can be processed through existing recycling streams. Embracing biobased nylon empowers brands across the textile industry to offer plant-derived alternatives while reducing their dependence on new virgin fossil fuel-based nylon.

While nylon 6 and 6,6 are the largest in terms of volume, there are other nylon types such as Nylon 11 and Nylon 5,6 which are also derived from biobased feedstocks.

Biosynthetic alternatives

Polyhydroxyalkanoates (PHAs)

PHAs are a category of thermoplastic polyesters that can be synthetized using many forms of bacteria and microorganisms.[24] Unlike synthetic polyesters, which rely on fossil fuel-based inputs, PHA feedstocks are either from greenhouse gases, such as CO_2, methane, or from biomass derived sources such as sugars, starches, glycerin, and triglycerides. The opportunities in PHA-based materials mean that they could be used as replacements for both conventional polyester and nylon materials, making them an interesting category for future development.

PHAs have naturally been produced for millions of years by bacteria that fabricate them when placed in the right fermentation environments. PHA is not an entirely new solution; initial attempts to commercialize the technology began in the 1990s. Attempts at the time fell short due to high costs.

In new commercial cases, PHA/polyhydroxybutyrate (PHB) is produced using a gaseous input which is metabolized using organisms such as microalgae using a fermentation tank. Other similar fermentation technologies utilize methanotrophs, which particularly metabolize methane, a hydrocarbon formed from natural gas which is 25 times as potent as CO_2.[25]

Another approach to PHA production is sourcing organic/cellulosic waste. This is becoming an increasingly popular feedstock for biomaterial innovation.

Properties and shortcomings of PHAs

Adaptable properties

There are a variety of processing techniques for PHA-based materials and innovators use different methods. This range of techniques has led to over 150 PHAs being discovered which could help produce biobased polyesters with varying properties to help replace traditional polyester fibers. Variations can vary from high strength and stiffness to low strength with high elasticity.[26] However, the number of grades and variabilities could make standardization somewhat difficult and inhibit a particular method from reaching commercial availability and economies of scale.

Potential to scale

Innovators must not only think about how to scale their technologies but consider the variety of feedstocks available for PHA production and the impact associated with scaling these new supply chains. Depending on the feedstock, it has been helpful for innovators to establish pilot facilities in locations shared with their input source: i.e., waste streams, or methane production facilities.

Current landscape of biosynthetic innovations

Proteins

Proteins enable many natural organisms to have properties such as stretch, water resistance, and unique colors. They can be found in a great deal of places in natural ecosystems such as in plants, kelp, and even insect nests.

These proteins can be extracted from natural sources and then regenerated in a lab into fibers that brands can use for a variety of applications. While the industry is most familiar with natural protein-based materials such as wool, silk, and feathers, synthetic proteins are increasingly being used to make a variety of fiber types, including some that have the potential to replace traditional synthetic materials including polyester, nylon, and elastane.

A notable recent use of proteins in textiles has been the continual pursuit of synthetic spider silk using silk proteins. Spider silk is a very strong material, which has driven innovators to investigate ways of developing fermentation processes that end in a viable, scalable textile fiber. In recent years there have also been a handful of startups utilizing proteins from unique sources to replace polyester, nylon, and even to reduce the waste generated from dyeing.

Properties and shortcomings of proteins

Potential to suit different needs

Proteins can possess unique properties depending on their genetic sequence – giving them the potential to be used as a platform for customizable fibers. With almost eight million known protein sequences, proteins can be coded to behave like synthetic fibers without needing a fossil-fuel precursor. This is thanks to their tunable nature and ability to manipulate and change a material’s properties to suit different needs and applications, making them interesting to consider in this field.

Challenging to scale

Synthetic biology, as a method of manufacturing, was traditionally reserved for pharmaceuticals and drug discovery, such as when Genetech first introduced synthetic insulin in 1978. Products in these markets are typically manufactured at low volumes and high margins. Fermentation processes and DNA sequencing must reach critical scales, while still meeting the cost requirements of a commodity industry if these materials are to become one viable replacement for traditional synthetic materials in the future.

Traditional setup to produce these materials is likely to consist of large and costly bio reactors that require fermentation media while still only being able to produce relatively low volumes. The use of fermentation media is important to obtain a good output from the fermentation process. Media used to aid fermentation can be liquid or solid state. Although many innovators in the space have turned to fermentation processes to produce their materials, proteins have unique challenges due to the extensive gene editing that must be done to create ideal properties typically found in traditional synthetic textiles. However, if this can be solved, they provide an interesting replacement option.

Polylactic acid (PLA) and polybutylene succinate (PBS)

Biobased PLA and PBS are potential alternatives to traditional polyester materials. Polylactic acid (PLA) is a polyester-like fiber material traditionally made from starch-rich plant sources such as corn, wheat, and sugar beets. Ideally, these feedstocks are grown regeneratively or organically, and are from a waste source to ensure that the food supply is not being impacted.

Polybutylene succinate (PBS) made from sugar as a feedstock is also being explored as a potential replacement to synthetic fibers. There has been an increasing amount of innovation using sources such as sugarcane, cassava, and corn as a feedstock. PBS is a somewhat newer innovation area and is often brought into conversations as a material that can blended with PLA to increase its flexibility.[27]

Properties and shortcomings of polylactic acid (PLA)

Potential to work in existing processes

PLA has the advantage of being a thermoplastic, meaning it holds promise of dropping into traditional melt-spinning processes used to make synthetic fibers today. PLA also shows excellent wicking ability making it an excellent candidate to replace some synthetic fibers without compromising on key performance specifications.

Lower melting temperature than conventional polyester

Although similar in feel to polyester, PLA has lower melting temperatures than fossil fuel-based polyester. This means existing melt-spinning manufacturers may be required to conduct spinning studies to better understand what processing parameters are needed to produce PLA. Additionally, PLA fibers are much harder to dye in conventional dyeing processes.

Lower tenacity

In addition to lower melting temperatures, PLA has lower tenacity than polyester which could make PLA problematic as a standalone fiber (depending on the application and end use), but could still be highly functional as a blend in natural fiber fabrics.

Current challenges to the commercialization of biosynthetic materials

Many challenges exist around the scaling and further commercialization of biosynthetic materials, and further information on these can be found in Textile Exchange's 2022 report "The Sustainability of Biosynthetics". A short summary of the most critical challenges the market has faced recently can be found below, with key next steps that the industry can take.

Limited impact data

There is still a lack of understanding and available data around the environmental impact of biosynthetic materials and different feedstocks. In general, early-stage innovative materials are not usually well-suited for Life Cycle Assessment studies given the amount of assumptions that need to be made and the high cost of conducting such studies.

Content labeling

As some of the material innovations in this space are new, there can be complexities in how to label, classify, and communicate these materials, both within the supply chain as well as to the consumer on a final product.

Blended composition

Most biosynthetic materials available on the market today are comprised of partially, not fully, biobased content and may require the addition of petroleum-based additives to make material performance robust enough for textile applications. This requires additional quality control measures to be taken.

Different production processes

Production processes may need to be adapted from those of traditional synthetic materials due to differences in physical properties (such as melting point, strength, and tenacity). This can cause challenges for suppliers seeking to process biosynthetics alongside other synthetic materials using the same machinery and equipment.

No guaranteed biodegradability

Biodegradability cannot be assumed just because a material is biobased. There are biodegradability considerations at every stage of the supply chain..

Additional investment needed

Additional investments in research and development and infrastructure for processing and manufacturing is needed to make these materials more broadly commercially available – particularly at a cost which can be absorbed by the supply chain.

Spotlight: Geno and Lululemon

Geno is an innovation company that combines bioengineering, computer modeling, and industrial engineering to create more sustainable materials. In recent years, the company has teamed up with Canadian athletic apparel brand lululemon to move toward biobased solutions for nylon, which would otherwise be derived from fossil fuels. Here, Textile Exchange speaks with the two companies to uncover the importance of their partnership in bringing plant-based nylon to a commercial scale.

Read the full case study here.

The future of biosynthetics

While biosynthetic materials have numerous challenges, stakeholders across the supply chain, from raw material producers to brands and retailers, can take actions to work towards scalability. These include:

- Working together to invest in and research ways to convert partially biobased solutions to fully biobased solutions. This includes building test laboratories and pilot plants to support scale-up efforts.
- Coordinating across raw material producers, growers, data providers, and brands to align on and collect comparable impact data on promising biobased materials to be able to establish their overall environmental impact.
- Educating stakeholders on the production processes, the benefits of biosynthetic materials, and overall material performance compared to their petroleum derived materials.

Use the Materials Directory to find biosynthetic suppliers

Textile Exchange's Materials Directory is a filterable online repository for raw material suppliers, production units, and branded materials, and can be used to identify biosynthetic suppliers.

CARBON CAPTURE

Carbon Capture

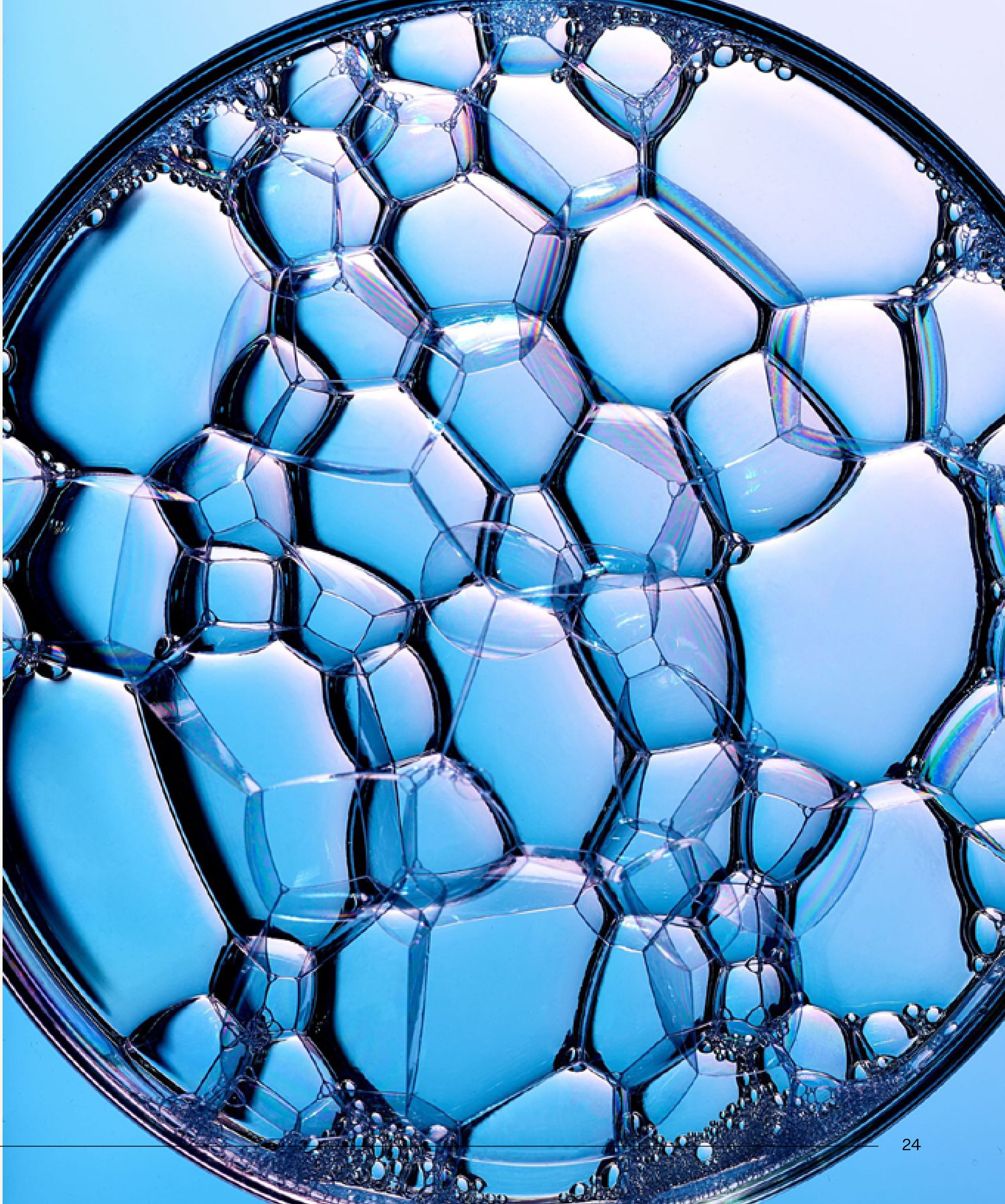
The use of CO_2 emissions as a feedstock in place of virgin fossil fuels has gained momentum in recent years and is becoming an emerging area of interest across industries. As outlined by the most recent Intergovernmental Panel on Climate Change (IPCC) report, technologies removing CO_2 emissions from the atmosphere are critical in the path towards achieving the goals of the Paris Agreement.[28]

There are a few innovators and key players that are already developing textiles from captured carbon, and as the fashion, apparel, and textile industry looks to shift away from virgin fossil-based inputs, the option of using waste CO_2 as a feedstock to create the chemical building blocks for new materials is worth investigating.

One of the key opportunities is the potential to offer an identical monomer to virgin while avoiding the input of new virgin fossil-fuels into the production of synthetics. Alongside recycled and biobased feedstocks, carbon capture can help replace crude oil with alternative feedstocks (in this case, renewable carbon which refers to carbon sources that avoid fossil-carbon derived from the geosphere).[29] However, further clarity is needed on the ability of these technologies to produce synthetic materials that reduce greenhouse gas emissions and align with Textile Exchange's Climate+ strategy, and would eventually be scalable too.

This section of the report is intended to provide an informational overview of the current landscape of carbon dioxide (CO_2) derived synthetics, so that the industry can work together on defining the role of these materials in the future. It highlights key opportunities, challenges, and areas for further exploration.

While using CO_2 as a feedstock is particularly interesting in the context of synthetic fiber and material production, which is the focus of this report, it is important to note that carbon capture can also be used as a feedstock across other fibers and materials (such as cotton, viscose, and lyocell).



Current landscape of carbon capture technologies

To provide a holistic overview of what CO_2-derived materials cover and to begin exploring their suitability for use and textile applications, it is important to understand the different technologies that currently exist and are being developed.

During carbon capture, waste carbon emissions are captured, and the CO_2 is separated from other gases through various methods (including the use of chemical solvents, membranes, and absorbents) to either be stored in geological formations or utilized as a resource to produce products such as chemicals, materials, plastics, packaging, and fuels, or power generation.

CO_2 can be captured from various sources. Carbon Capture Utilization and Storage (CCUS) typically refers to the capture of CO_2 from point sources (such as industrial facilities, power plants, bioethanol plants, fermentation plants, or breweries) while Direct Air Capture (DAC) refers to emissions that are extracted directly from the atmosphere. Today, CCUS is more common due to the high concentrations of CO_2 in the flue gas of factories, in comparison to DAC which is more diluted, and therefore more energy-intensive and costly.

The most used technologies to capture carbon today include **post-combustion carbon capture**, **pre-combustion carbon capture**, **oxy-fuel carbon capture**, and **direct air capture**.

Post-combustion carbon capture

During post-combustion carbon capture, the CO_2 is captured from the flue gases as they are emitted from a point source such as an industrial facility. The CO_2 is separated from other gases with the use of solvents or adsorbents to create a solvent CO_2 solution. The CO_2 then gets separated from the solvent using heat. Post-combustion carbon capture is the primary method used for carbon capture today because it can be retrofitted into existing industrial facilities and power plants.[30]

Pre-combustion carbon capture

During pre-combustion carbon capture, fuel is converted into syngas through gasification. The CO_2 is then separated from the syngas through heat and chemical absorption before combustion. Pre-combustion carbon capture is not as commonly used for carbon capture today because it cannot be retrofitted into existing facilities and is limited to being used in electricity and syngas production.[31]

Oxy-fuel combustion carbon capture

During oxy-fuel combustion carbon capture, fuel is burned in pure oxygen (instead of air) which creates a flue gas composed of mainly CO_2 and water vapor. The CO_2 is separated from the water vapor by condensation. Oxy-fuel combustion carbon capture is not commonly used today because there are challenges with retrofitting into existing facilities and the process of separating oxygen from air is energy intensive and costly.[32]

Direct air capture

During DAC, CO_2 is captured directly from the atmosphere. Air is drawn through a system resembling a fan and the CO_2 is separated, producing a more concentrated stream of CO_2 using sorbents, chemical reactions, or membranes.[33]

Storage and use

Once the CO_2 is separated and collected, it then gets compressed and stored in a liquid form to be transported (by road, ship, or pipeline) for either storage and/ or utilization. CO_2 for storage gets injected in underground geological rock formations or gets directly mineralized by binding chemically to the surrounding rock. CO_2 for utilization is further processed to convert the CO_2 into chemicals and products.

There are multiple technologies and methods for converting CO_2 into the desired chemical pre-cursors used in the production of synthetic textiles such as polyester. Most commonly, this conversion takes place through a catalytic process. There are also innovative technologies in development working to directly convert the CO_2. It is important to note that these technologies are in their infancy.

Gas fermentation

During gas fermentation, a specialized microorganism or biocatalyst is used in a fermentation process that feeds off waste gases, converting the CO_2 into valuable chemicals such as ethanol which can be converted to monoethylene glycol (MEG). Gas fermentation processes also offer the opportunity to switch out the microorganism/ biocatalyst used to produce different chemicals.[34] Gas fermentation is one of the most scaled technologies today due to its ability to produce both chemicals and fuels, serving multiple sectors. Some of the key challenges associated with a gas fermentation process include achieving conversion efficiencies and resource intensity.

Electrochemical

During electrochemical conversion, a catalyst (typically an electrode) together with a solvent is used to carry out electrochemical reactions to convert the CO_2 into ethylene to produce polyester. Electrochemical technologies offer the opportunity to directly convert the CO_2 and avoid the need for multiple processing steps. These technologies also offer benefits such as the potential to utilize renewable energy sources such as solar and wind power. However, electrochemical conversion is currently small scale and in the development stages.

Biological processes

During a biological process, microorganisms (such as bacteria, enzymes, and algae) are reacted with carbon or methane gasses to create polymer chains. These methods are typically being developed to be used for PHAs as well as cellulose-based materials which have the potential to mimic synthetic properties in future. Biological processes can offer benefits such as low energy and achieve high specificity but remain at a small scale with efforts focused on scaling and determining appropriate conditions.

Chemical synthesis

During chemical synthesis, CO_2 is converted using chemical means and a catalyst. Due to existing infrastructure, the process is relatively straightforward and can be used to produce a large variety of chemicals. However, the process is energy-intensive and requires the use of many chemicals. Chemical synthesis may be used in combination with other technologies in a hybrid approach to maximize efficiency and output.

Spotlight: LanzaTech and On

LanzaTech is a technology company that harnesses biology to transform carbon emissions into raw materials for the next generation of circular products. In collaboration with On, a forward-thinking sportswear brand, the companies have worked together to incorporate commercially viable polyester products from carbon capture technology into their supply chain. In this case study, Textile Exchange speaks with the two companies about how their partnership opened the door to scaling an apparel collection made using this carbon capture technology.

Read the full case study here.

Uses, applications and commercial viability of carbon capture technologies

There are several carbon capture innovations emerging within the fashion, apparel, and textile industry, the majority of which are at the lab or research stage except a few examples entering the commercial market, showcased in pilot collections. Some of the current developments focus on polyester, PHA, PBS, and polyurethane for uses and applications such as apparel and sportswear, footwear, and accessories.

Developments are currently focused on partially carbon-captured solutions. Typical carbon captured content ranges on average between 10 to 30%. Some examples include CO_2-derived ethylene glycol for the production of PET and CO_2-derived polyols to produce polyurethane. The role that carbon captured synthetics may play in the future will be largely dependent on finding a solution for the remaining fossil-based component.

One of the largest opportunities to scale and develop carbon capture within the textile industry is the ability for it to be used as a drop-in solution using existing infrastructure. The ability to scale will also depend on brands' willingness to pay price premiums, the building of carbon capture infrastructure, and potential policy intervention to support scaling and increased capacity for these types of materials.

Key challenges and areas for further exploration

There are many challenges in developing, scaling, adopting and implementing carbon capture technologies; several of these are highlighted here.

Lack of impact data

Data gaps need to be filled and it may not always be the case that these technologies result in reduced CO_2 emissions. This depends on the product the CO_2 is replacing, how carbon-intensive the process is, and how long the CO_2 is retained in the product. Robust LCA data is essential to back this up to form a more holistic view across key impact indicators such as carbon emissions, energy, water, and chemicals.

The role of hydrogen

Due to the high energy intensity of the process, renewable energy will need to play an important role in the future to move the process away from fossil fuel energy. Access to renewable hydrogen may be a bottleneck in the future due to availability and competition for energy supply.

Clear communication

Both consumers and the industry need to understand these technologies, how they work and their role in reducing environmental impact, to avoid greenwashing.

Lack of certification

There are currently no certifications that include chain of custody traceability specifically for materials created using carbon capture technologies. Further work is needed to determine the appropriate criteria and how to manage the auditing and certifying of these processes.

The fossil-based component

Most solutions in development today are only partially CO_2-derived. The MEG (representing 30% of PET by weight) is CO_2-derived, while the TPA (representing 70% of PET by weight) remains fossil fuel-derived. Solutions for the remaining TPA are lagging due to high costs and dependency on scaling chemical recycling technologies.

Costs of equipment

Whether retrofitting onto an existing plant or building alongside a new facility, the associated costs can be high and capital investment will be needed.

Price premiums for brands

Supporting the development of new and innovative technologies will always attract higher prices to offset the costs associated with development and scaling. The question is whether the supply chain will support by uptaking these materials or not. Coupled with the low cost of traditional fossil fuel-derived materials, this could be a significant challenge to overcome in promoting and upscaling carbon capture technologies.

Competition from other industries

Textiles currently represent a small portion of the carbon capture industry, and demand from other industries such as aviation fuels, plastics, packaging and building materials continues to grow. In the future there are expected to be substantial quotas, subsidies, and investment from the aviation industry.

Further links to fossil fuels

The majority of innovations in development source their CO_2 from fossil fuel-based practices and the capturing, separating, and conversion process requires fossil-fuel energy inputs.

An additional criticism of carbon capture technologies is that they may discourage the industry from trying to reduce its overall CO_2 levels. Textile Exchange is focused on achieving its Climate+ goal of reducing GHG emissions by 45% by 2030, and one of the ways we see this goal being achieved is through the slowing of growth overall.

While we do not want to focus on solutions that would promote an overall growth in emissions, meeting the goals set for 2030 will require a diversified approach and currently we are considering all potential solutions.

The future of carbon capture

While slowing growth and reducing GHG emissions is the immediate priority, for emissions that cannot be reduced or removed, additional research is needed to identify the impact of solutions such as carbon capture.

These technologies hold potential as part of a portfolio of solutions to enable the industry to achieve its impact goals, however, the opportunities are not yet fully understood. To further this development, actions and points of consideration for the industry are:

- Exploring options to innovate on the 70% TPA, for example by replacing the virgin fossil fuel-based polyester with recycled polyester from textile feedstocks.
- Prioritizing approaches that permanently sequester CO_2 where possible.
- Implementing Renewable Carbon Initiative's key policy recommendations.
- Exploring the retrofitting of carbon capture technologies on existing manufacturing/processing plants.
- Defining high-quality standards and certifications for CO_2 removal and how these technologies can be categorized alongside recycled and biobased, as well as how standards can be implemented to support the scaling and uptake of CO_2-derived materials.

Use the Materials Directory to find carbon capture suppliers

Textile Exchange's Materials Directory is a filterable online repository for raw material suppliers, production units, and branded materials, and can be used to identify carbon capture suppliers.

KEY TAKEAWAYS AND ACTIONS

Key takeaways and actions

We hope that this report has provided a helpful view of insights into the landscape of opportunities to support a transition away from virgin fossil fuels as a feedstock for materials used by the fashion, apparel, and textile industry.

There is much work to be done in this category, requiring bolder, faster action than the industry has seen before if we are to collectively meet our impact targets and reduce GHG emissions by 45% by 2030. For this reason, we encourage readers of this report to take at least one of the following actions towards a more sustainable future for synthetic fibers and materials:

Ways to take action:

- Create a material strategy and commitment to transition synthetic fiber usage to those from recycled or sustainably-sourced renewable sources by 2030, prioritizing textile-to-textile recycled.
- Reduce overall consumption of new materials and fibers.
- Proactively seek partnerships and collaboration across and beyond the industry to scale technology and infrastructure needs.
- Commit to offtake agreements with innovators and supply chain partners.
- Prioritize scaling recycling solutions that promote textile feedstocks as inputs.
- Ensure synthetic materials and products are designed with recycling and circularity as a priority.
- Support research and impact data collection for textile-to-textile recycling, biosynthetics, and carbon capture in the context of synthetics.
- Monitor and continue to understand the evolving landscape around carbon capture technologies, as well as the role of different industry stakeholders.
- Partner with organizations such as Fashion for Good and Accelerating Circularity that are supporting the piloting and scaling of promising technologies.
- Continued training and education on preferred synthetics for brands and suppliers, across each level of the organization.
- Ensure supply transparency of material and waste flows throughout your value chain supported using digital mapping technologies to accurately trace waste and connect the necessary stakeholders for recycling.

Relevant areas to get involved in:

- Sign up to Textile Exchange's 2025 Recycled Polyester Challenge at the highest possible commitment bracket.
- Join Textile Exchange's Recycled Polyester and/or Biosynthetics Round Tables, contribute to our conversations and join our growing community taking collective action.
- Inform and actively engage in policy through The Policy Hub.

Useful Textile Exchange tools:

- Preferred Fibers and Materials: Definitions Initial Guidance
- Materials Impact Explorer
- Preferred Fiber and Materials Matrix
- Textile Exchange Standards
- Materials Benchmark
- Materials Directory

Textile Exchange's journey towards a unified standard system

As of the writing of this report, Textile Exchange is in the process of bringing together its existing standards under one more unified framework. The main aim of this transition is to more clearly embed climate and nature outcomes, including those that contribute to our Climate+ goal of a 45% reduction in GHG emissions within the "pre-spin" phase of the supply chain by 2030. Additional objectives are to harmonize systems across the full scope of the current standards and to enable clearer communication at the consumer-facing level. More information on the development of Textile Exchange's unified standard can be found here.

While the Recycled Claim Standard (RCS) and Global Recycled Standard (GRS) currently start at recycling, Textile Exchange's draft unified standard looks to extend the chain of custody to the reclaimed material concentrators, as well as mechanical/chemical/molecular recyclers. This addition broadens the traceability scope.

Additional areas of consideration for synthetic fibers and materials

The role of policy

In recent years, particularly in the European Union (EU), new regulatory requirements relevant to the fashion, apparel, and textile industry are being introduced on topics ranging from claims and labeling to recycled content requirements to corporate reporting and due diligence. If new policies strike a balance between aspirational and realistic, they have the potential to catalyze more rapid achievement of the industry's collective goals and targets.

As of the writing of this report, the EU Commission is working on numerous policy initiatives relevant to synthetic fiber production and usage in the fashion, apparel, and textile industry. Examples include the Waste Framework Directive and Extended Producer Responsibility, and the Ecodesign for Sustainable Products Regulation (ESPR) and Digital Product Passport (DPP).

The role of certification and standards

Standards and certifications are important tools to set voluntary input requirements for organizations to meet. Standards with chain of custody requirements support tracking products and volumes through the supply chain, and verify sustainability claims communicated to the consumer.

Key standards for recycled synthetic fibers and materials include Textile Exchange's Global Recycled Standard (GRS) and Recycled Claim Standard (RCS). Additionally, the Ocean Bound Plastic certification exists to address certifying "Abandoned Plastic Waste" which includes microplastics, mid-size plastics and macroplastics located within 50km from shores where waste management is inexistent or inefficient.[35]

It will be important to continue evolving what is considered a "recycled input" within the standards system, in order to incentivize the recycling of existing fibers and materials and keeping them in use as long as possible in closed-loop systems.

When it comes to biobased materials, there are standards for biomass which can be used for various biosynthetic materials and feedstock types. Additional standards used for biobased feedstocks can be found in Textile Exchange's 2022 report "The Sustainability of Biosynthetics."[36]

Textile Exchange primarily uses the chain of custody associated with its RCS and GRS standards to track recycled materials. This system is based on a segregated model, which ensures that third-party certified materials are kept separate from non-certified materials at every stage of the supply chain. This separation allows for the assurance that the claimed material within a particular product originates from certified sources.

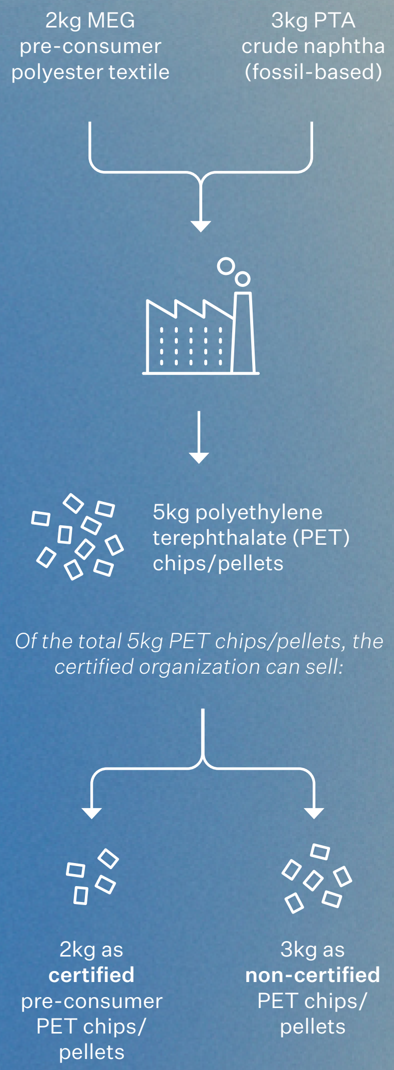
In chemical recycling and pulp making, where continuous production is the prevailing process, the Policy for Alternative Volume Reconciliation for RCS and GRS allows for a mass balance approach between certified and non-certified materials on a rolling three-month basis. This system provides assurance that the volume of certified recycling input matches the volume of recycled output where the calculation of material content is disruptive or incompatible with operations, and is not intended to verify the presence of claimed material in a specific product. Mass-balanced recycled materials bear unique raw material codes and are tracked separately from segregated materials from the first process across the supply chain using the standing chain of custody. On the right is a simple example of how the process may work.

Textile Exchange's Trackit traceability program centralizes site-level verification and offers two alternatives to transaction verification for materials certified to RCS and GRS. Digital Trackit (dTrackit) traces certified materials by digitalizing transaction certificates, and Electronic Trackit (eTrackit) traces certified materials online via eTransactions.

Physical verification can add another layer of assurance, though on its own does not provide chain of custody or adequate traceability. Textile Exchange's collaborative analysis with Fashion for Good The Textile Tracer Assessment offers a guide on physical tracer technologies that can help suppliers and brands choose the right solution to boost their traceability and sustainability models.

How a mass balance approach works

Within a 3-month period:



2kg MEG pre-consumer polyester textile

3kg PTA crude naphtha (fossil-based)

5kg polyethylene terephthalate (PET) chips/pellets

Of the total 5kg PET chips/pellets, the certified organization can sell:

2kg as **certified** pre-consumer PET chips/pellets

3kg as **non-certified** PET chips/pellets

Endnotes

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