Textile Exchange

The Sustainability of Biosynthetics

How biosynthetics can be part of the fashion and textile industry's journey towards a regenerative and circular future

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Executive summary

At Textile Exchange, we are on a mission to drive a 45% reduction in the greenhouse gas (GHG) emissions that come from producing fibers and raw materials by 2030. We've landed on this target in line with what is needed from our industry to help limit global warming to 1.5°C.

Currently, virgin, fossil-based synthetic fibers like polyester and nylon account for the majority of global fiber production and related GHG emissions. They are a fundamental focus area for us because if we are to protect the 1.5°C pathway, we need to transition away from the extraction of virgin fossil fuels. This means holistically assessing the alternatives on offer, including existing preferred materials like recycled synthetics, and new areas of innovation, like biosynthetics made from natural, renewable sources such as agricultural waste, food crops, or plants.

With performance and technical properties that allow them to be used as a replacement for traditional synthetics, biosynthetics can be derived from sources like corn, sugar beet, sugarcane, wheat, and more. At Textile Exchange, we see their potential to move the industry away from non-renewable resources and to reduce climate impacts when compared to their fossil-based counterparts.

But, like all materials, we need to treat them with care and nuance. We've got to fully understand the impacts of different crops or residues in their regional contexts and manage them responsibly. This means going beyond greenhouse gas emissions, assessing their impacts on areas like water, soil health, biodiversity, and livelihoods too, as well as conducting further research on microfiber shedding.

To push for progress in this sector, we not only need bold goals, investments, and actions, but a holistic approach to measuring sustainability. With the required knowledge and data we need to do this, we believe that biosynthetics can be part of the industry's broader journey towards a regenerative and circular future.

This guidance document has been developed by Textile Exchange in partnership with the Biosynthetics Round Table, to encourage discussion around the sustainability of biosynthetics and share the interim findings with a wider audience.

Key takeaways

- **Biosynthetics can, and should, be made from different crops.**
  Plants such as corn, sugar beet, sugarcane, wheat, cassava, castor, and agricultural residues can be used to make biosynthetics. But there is no one perfect source. Instead, impacts should be assessed according to the region, production methods, and technology used, and a range of feedstocks is likely to be best.
- **We've got to think beyond GHG emissions when assessing their impacts.**
  Multiple factors influence the overall impact of a biosynthetic material, including land-use changes, circularity potential, social aspects, and impacts on other areas like biodiversity and soil health. That's why it is recommended to look at data beyond the traditional Lifecycle Assessment (LCA) method.
- **Biosynthetic doesn't always mean biodegradable.**
  A biobased material is not necessarily biodegradable: these are two completely different qualities. A biobased material means that the feedstock from which the material is made comes from a renewable, biobased source rather than from fossil-based non-renewable resources. A biodegradable material refers to its circularity properties, where the material has a chemical structure and specific functional groups that enable it to be broken down by micro-organisms into carbon dioxide and biomass.
- **We don't have to choose between biosynthetics or recycled polyester.**
  For the fashion and textile industry to meet its climate targets, we've got to use every tool in our toolkit. When it comes to biosynthetics and recycled polyester, it's not about choosing one or the other. In the future, it's even going to be important to develop recycled biosynthetics, helping to close the loop.
- **Biosynthetics are part of the industry's journey towards a regenerative and circular future**.
  Knowledge development and better data will be required to assess which biosynthetics are best, and in which context. When managed responsibly, we believe that these materials can not only help lead the transition away from the extraction of virgin fossil-based resources but play an active role in a regenerative and circular future for the industry.

Introduction

What are biosynthetics and why do they matter?

Synthetic fibers have dominated the global fiber market since the mid-1990s and are expected to grow significantly if business as usual continues. These fibers are mainly derived from non-renewable, fossil-based resources.

Biosynthetics, synthetic fibers that are wholly or partially derived from biobased resources, represent an alternative to their fossil-based counterparts.[1] Due to their potential to lead the transition away from non-renewable resources and help to mitigate climate change, they are gaining much interest in the textile industry.

An important note to make here is regarding terminology as it relates to biosynthetic materials. A common term used in this space, sometimes interchangeably, is “biobased materials.” In the context of this paper, the term biobased materials refers to those which originate, wholly or partially, from a biobased or renewable source, such as agricultural waste, food crops, or plants.

Biosynthetics can be defined as a category within biobased materials. They are not only derived from a biobased, renewable source but are used as replacements to traditional synthetic materials thanks to their performance and technical properties.

In today’s biosynthetics landscape, many of the materials available come from partially biobased feedstocks. A lot of innovation and development is currently underway to create materials deriving from 100% biobased feedstocks, but there are technical and financial challenges to be overcome before this becomes the standard in this material category.

While biosynthetics have plenty of potential, they must be sourced and managed responsibly to ultimately create positive impacts for people and the planet and avoid negative consequences in other areas. Further work is needed to determine the impact of this category of materials and define the “preferred” options within it. Not all biosynthetic material options will have a low climate impact that allows them to be defined as preferred.

Many companies in the textile industry are still hesitant to use biosynthetics due to concerns regarding the impact on food security, the use of genetically modified organisms (GMOs), deforestation, land use in general, microfiber shedding, and questions around circularity aspects. Low fossil fuel prices and thus prices for fossil-based synthetics create a challenging market environment for biosynthetics too.

To enable the responsible adoption and proliferation of biosynthetics, a collaboration of various stakeholders is required to address these challenges and concerns. Textile Exchange’s Biosynthetics Round Table supports this journey with the aim to accelerate the transition to biosynthetics that not only reduces the negative impacts of this materials category, but ultimately creates positive impacts for people and the planet.

Goal and scope of this report

This report was developed in partnership with Textile Exchange’s Biosynthetics Round Table from 2020 to 2022, in consultation with a wider group of stakeholders. The aim of this informational paper is to facilitate the discussion around the sustainability of biosynthetics and to share the findings with a wider audience. However, it is important to note that further work is needed in this fiber category to support its findings and to continue to move the industry forwards to more preferred material choices.

This report addresses key questions related to the impacts of biosynthetics along their entire lifecycle, including feedstocks, processing, uses, and circularity potentials. It provides an overview of key questions and the status quo of the current discussions. It also provides a starting point for the development of a Climate+ strategy for biosynthetics.

However, this report does not aim to provide a comprehensive and systematic assessment of specific biosynthetics, or the specific definitions of different levels of “preferred” biosynthetics. Tools such as Textile Exchange’s Preferred Fiber and Materials Matrix can, however, build on the work of this paper.

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Image: Bundles of fresh sugarcane

Wider context and vision

Why do we need to limit global warming?

In 2018, the IPCC special report "Global Warming of 1.5°C" revealed how "net zero" emissions must be reached well before 2050 if we are to limit global warming to 1.5°C. This means that global CO_2 emissions need to fall by 45% by 2030 compared to 2010 levels.

Further research published in the IPCC's Sixth Assessment Report "Climate Change 2021: The Physical Science Basis" in 2021 called for immediate, rapid, and far-reaching transitions to limit warming close to 1.5°C, before even 2°C becomes beyond reach.

What is Textile Exchange's Climate+ strategy?

Textile Exchange is a global non-profit driving positive impact on climate change across the fashion and textile industry. We guide a growing community of brands, manufacturers, and farmers towards more purposeful production from the very start of the supply chain.

Our goal is to help the industry to achieve a 45% reduction in the greenhouse gas (GHG) emissions that come from producing fibers and raw materials by 2030, in line with what is needed from the industry to limit global warming to 1.5°C.

This target underpins our Climate+ strategy. We call it Climate+, because it goes beyond accounting for greenhouse emissions. Instead, it is an interconnected approach that swaps siloed solutions for interdependent impact areas like soil health, water, and biodiversity. Climate+ is underpinned by three major areas of impact–and opportunity.

First, we're accelerating the adoption of organic, regenerative, recycled, or other more responsible alternatives to conventional fibers. We want to make these materials the accessible default by providing global certifications and standards as well as industry-wide benchmarking for brands to measure and manage their sourcing strategies.

Next, we need innovation and out-of-the-box thinking. New business models, circular systems, and even innovative materials. This means collecting better data and facilitating information sharing around how we can scale existing solutions, like regenerative agriculture and textile-to-textile recycling. We do this through our industry reports and data-driven tools, while bringing leaders together via our round tables, conference, and other platforms.

Most importantly, we've got to rethink growth. Slowing down, making less, and producing with purpose. Our vision is a new system that works in sync with nature, respecting planetary boundaries while protecting the people that sustain it. To get there, we're keeping our focus holistic and interconnected as we guide our global community in this collective climate strategy.

How can existing preferred materials and innovations work together to limit global warming to 1.5°C?

As part of our Climate+ strategy development, we looked at different scenarios to help the textile industry better understand the extent and scope of materials-related carbon strategies required to meet the 1.5°C target.[2] They showed that even if we assume substantial material substitution with existing preferred solutions, a significant innovation gap remains in order to limit global warming to 1.5°C. Closing this innovation gap requires scaling up areas including regenerative practices, carbon sequestration, and circular solutions.

As synthetics have such a high market share and are expected to continue to do so, innovations in this area are particularly important. Biosynthetics have the potential to contribute to the Climate+ goal if they are responsibly sourced and managed. Regenerative practices, carbon sequestration, and circular solutions as well as the use of renewable energy in the context of biosynthetics can be important levers to meet the Climate+ goal.

Why is it important to replace fossil-based carbon with non-fossil carbon?

Several studies have shown that we have to phase-out fossil-based resources and that substantial amounts of fossil resources have to remain in the ground to limit global warming to 1.5°C. While this is referred to as "decarbonization", or increasingly "defossilization" in the energy sector, the equivalent related to materials is the transition to fossil-free carbon.

The nova-Institute uses the term "renewable carbon" for "fossil-free carbon" that may come from biomass, from recycling, or from direct CO_2[3]. Fossil-free or renewable carbon can thus be from the biosphere, the technosphere, or the atmosphere but, unlike fossil carbon, not from the geosphere.[4]

Carbon itself is not bad. It is a very important part of fiber and materials (and organic matter and organic chemistry in general). So, it is more about closing the carbon loops and shifting from fossil-based to renewable carbon. "Turning off the Tap", as reads the title of a nova-Institute publication from 2021, should be the common aim.

The work of the Renewable Carbon Initiative (RCI) further highlights the importance of transitioning from fossil-based carbon to non-fossil carbon[5] as does the work of the Science Based Targets initiative and the Science Based Targets Network.[6] Here the focus is on a zero-carbon, nature-positive future and to accelerate decarbonization.

What role can the bioeconomy play to limit global warming?

Nature provides a very powerful solution to limit global warming: plants. Plants convert CO$_2$ from the atmosphere into biomass through photosynthesis, powered by solar energy.[7] In other words, plants capture and sequester CO$_2$ and transform it into long-chain sugar molecules that can be used for multiple purposes including biosynthetics.[8]

On the other hand, agriculture is also a key emitter of greenhouse gas (GHG) emissions.[9] Deforestation for agricultural land, conversion of high-carbon storage areas to croplands, and the use of large amounts of pesticides and fertilizers are contributing to GHG emissions. Also, the use of large amounts of non-renewable energy for the conversion of biomass into final products leads to GHG emissions.

While the conversion from fossil-based to renewable carbon materials is important, it is also vital to reduce GHG emissions related to the production of biosynthetics along their whole life cycle. In the life cycle of many biobased products, the fossil inputs in the growing stage, along with the energy use during production, are the biggest drivers of climate impacts.

To move away from fossil fuels, eliminating or reducing traditional agricultural inputs and switching to renewable energy use is just as important as using renewable carbon feedstocks. Beyond this, a holistic approach is needed based on the priorities defined by the waste hierarchy: "Reduce, reuse, recycle–and use biobased or CO$_2$-based feedstock as virgin input when 100% recycling rates are not possible which is almost always given."

What is our vision for the future of (bio)synthetics?

Textile Exchange, in partnership with the Biosynthetics Round Table, developed a vision for the future of the (bio)synthetics industry in 2020. It is based on and aligned with our new Climate+ strategy, that launched in 2019.

This vision is a global 100% fossil-free synthetic textile industry that protects and restores the environment while enhancing lives. In this vision, all fossil-based synthetics are substituted with biobased, recycled, and potentially CO$_2$-based synthetics, powered by 100% renewable energy.[10] The vision is a net-positive (bio)synthetics industry that contributes to carbon sequestration in the soil through regenerative agriculture, increasing biodiversity, and clean water. In this future vision, biosynthetics are part of a broader circular economy (see chapter on circularity).[11]

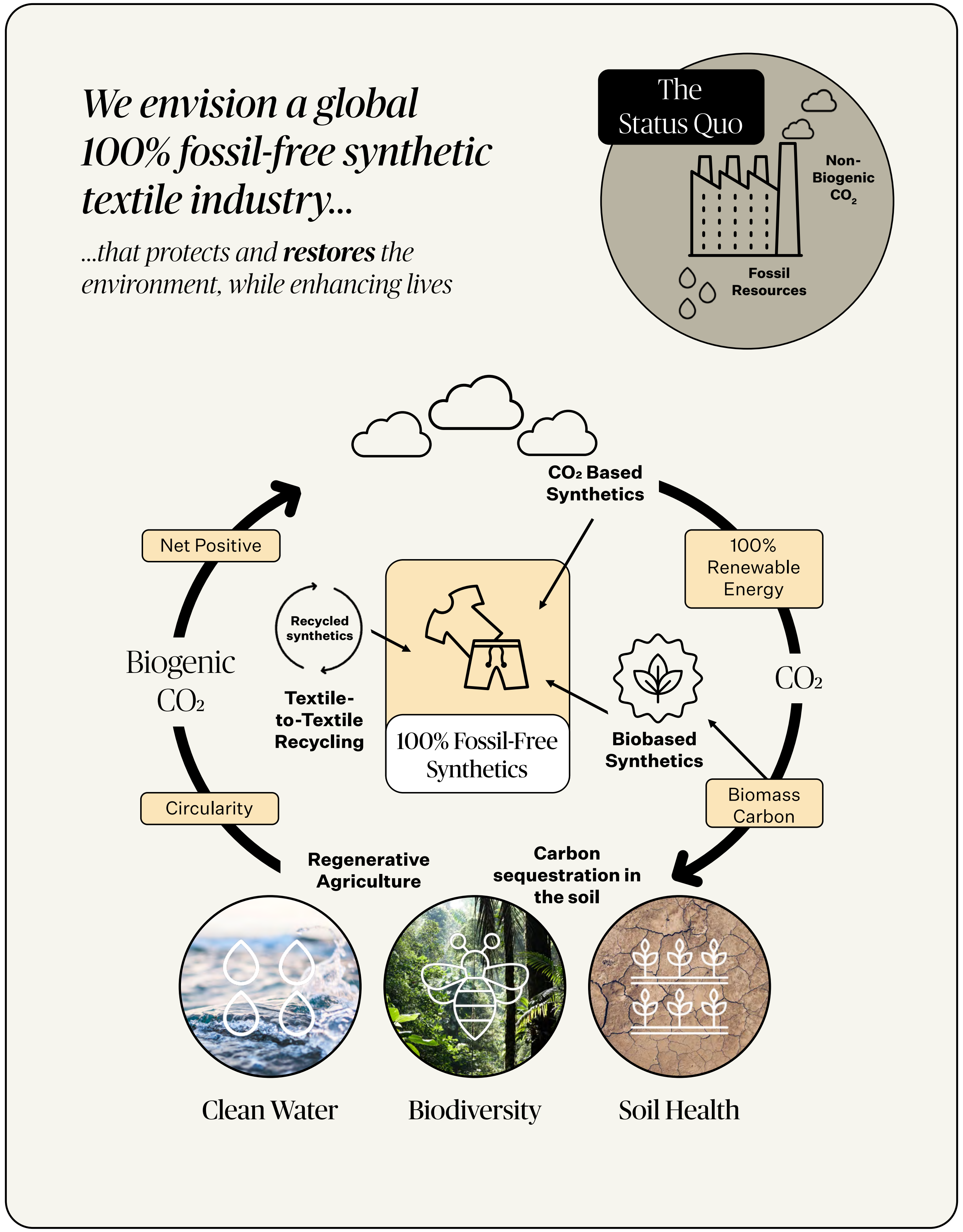


Figure 1: The Biosynthetics Round Table vision for a fossil free synthetic textile industry.

Why do synthetics have such a high market share?

With around 68 million tonnes of synthetic fibers, this fiber category made up around 62% of global fiber production in 2020. Polyester alone had a market share of around 52% of total global fiber production. Approximately 57 million tonnes of polyester fiber were produced in 2020. Polyamide, the second most used synthetic fiber, accounted for 5.4 million tonnes and approximately 5% of the global fiber market in 2020. The production volume and market share of synthetic fibers is expected to increase further.[12]

Reasons for this high market share and growth rate of synthetics are–aside from the comparatively low price for fossil-based synthetics and limited expansion capabilities in natural fiber production–also the quality characteristics of synthetics. Fabrics made from these fibers can be waterproof, durable, crease-proof, and have higher elasticity. While a few people and organizations argue to phase out synthetic fibers in general, this is not only improbable, but due to the benefits of synthetic materials, it is also considered undesirable by most.[12]

What is the market situation of biosynthetics?

The market share of biosynthetics is currently still very low. Biobased polyester had a market share of 0.03% of all polyester fiber produced globally in 2020. Biobased polyamide, also called nylon, had a market share of 0.4%.[13] Following an estimated value in the biobased polymer market in 2018 of 14.2 billion USD, growth is expected in the global biobased polymer market at a compound annual growth rate (CAGR) of over 10% looking out to 2026.[14]

Almost all biosynthetics currently commercially available are only partially biobased. Further work is needed in supporting the transition to 100% biobased feedstocks for biosynthetic materials in the future. Crops such as corn, sugar beet, sugarcane, and castor are the key feedstocks for biosynthetics at the moment.

Image: Castor beans (courtesy of Arkema)

Feedstocks

Biosynthetics can be made from a variety of biomass feedstocks. As it is hard to find one perfect feedstock, the important thing is to choose the best feedstock for a specific context. The aim of this chapter is to discuss main questions around feedstocks for biosynthetics, including questions around land use and productivity, food security, the use of GMOs, the potentials of agricultural residues and future feedstocks, as well as sustainability standards and certification schemes.

What feedstocks are currently used for biosynthetics and why?

The main feedstocks currently used for biosynthetics are high sugar or starch-containing agricultural crops such as **corn, sugar beet, sugarcane,** and–to a minor extent–also **wheat** and **cassava**, as well as oil crops such as **castor**. These crops are the main feedstocks currently used because they are commercially available in large quantities, provide consistent quality, are the most economical, and do not face the difficulties associated with the use of alternative feedstocks such as agricultural waste (see chapter on future feedstocks).

Industrial corn: Industrial corn is currently the most used feedstock for biosynthetics. This is because corn has a high productivity per land area (see table below), it has high availability, and the technology needed to use corn as feedstock is commercially available. Grain from industrial corn plants is used to provide carbohydrate starch.[15] In general, dextrose from corn in the U.S. has been the cheapest sugar available globally. Beet sugar and cane sugar are generally more expensive, although both markets move around.

Economics has been the major driver for the selection of corn-based dextrose. With an increasing consumer awareness around the consumption of too much sugar, and as the demand for high fructose corn syrups and ethanol declines while demand for corn-based protein for animal feed increases, it is likely that starch/dextrose from corn will remain inexpensive.

Corn production is highly concentrated, with the U.S. and China growing over 50% of the world's corn.[16] One other difference is that beet sugar in Europe is from hybrid, non-GM beets, while essentially all the corn in the U.S. is now GM. The majority of corn produced is used as animal feed, and another substantial proportion for ethanol production. The share of corn used for biosynthetics is very low.

The use of certified feedstock, such as corn produced and certified according to at least one sustainability standard, is currently limited in the context of biosynthetics. An example is ISCC Plus certified corn, which was used by NatureWorks for its PLA.

Sugar beet: Sugar beet also has a very high productivity of sugar per hectare (see table below). Sugar beet is mainly cultivated in Russia, France, the U.S., and Germany. Enzymes manufactured in Europe, like at the DuPont enzyme plants in Belgium and Finland, often use beet sugar as a feedstock because it is cheaper to deliver to those locations than corn-based dextrose.

Sugar beet cultivated in Europe is from hybrid, non-GMO beets. This makes it a preferred alternative for companies that want to avoid GM corn as feedstock. Several biomass sustainability standards can be used for sugar beet such as Roundtable on Sustainable Biomaterials Standard (RSB) and International Sustainability & Carbon Certification (ISCC).

Sugarcane: Sugarcane has the highest productivity per hectare among the common crops (see table). Sugarcane is mainly produced in Brazil, India, China, and Thailand. A major sustainability certification for sugarcane is Bonsucro. Around 5.8% of the global sugarcane land is currently Bonsucro certified.[17] The market shares of organic and Fairtrade certified sugarcane are low.

Wheat: Wheat has a high starch content. Wheat flour is generally a mix of sugar and proteins. Typically, wheat is a food staple crop with its sugar being used for human food consumption in bread, pasta, and baked goods. However, sugar extraction from wheat is becoming increasingly common in Eastern Europe and Central Asia. Wheat milling produces protein and fiber co-products. Enzymes manufactured in Europe sometimes use wheat-based dextrose as wheat is more abundant in Europe than corn due to climate.

For more information about the use of "food-crops," see the chapter on food security.

Castor oil is another feedstock used for biosynthetics. This oil is manufactured from the crushing of castor beans, the global production of which is predominantly located in India (85%) in the Gujarat region.[18] The castor plant is cultivated mainly in semi-arid and drought-prone territories as the plant is more drought-resistant than many other crops. It can also be grown on more marginal soils, allowing farmers to keep the more fertile soils for food crops. The productivity per hectare is lower than corn, sugar beet or sugarcane (see table). It is currently mainly used as feedstock for biobased polyamides like Rilsan® PA11 (Arkema). SuCCESS certified castor beans have been available for crops in India since 2018 with 4,500+ farmers being trained so far. The availability of certified feedstock is still rather low but growing. Fair for Life certified castor oil is currently only available in very small units and used in the cosmetic industry.

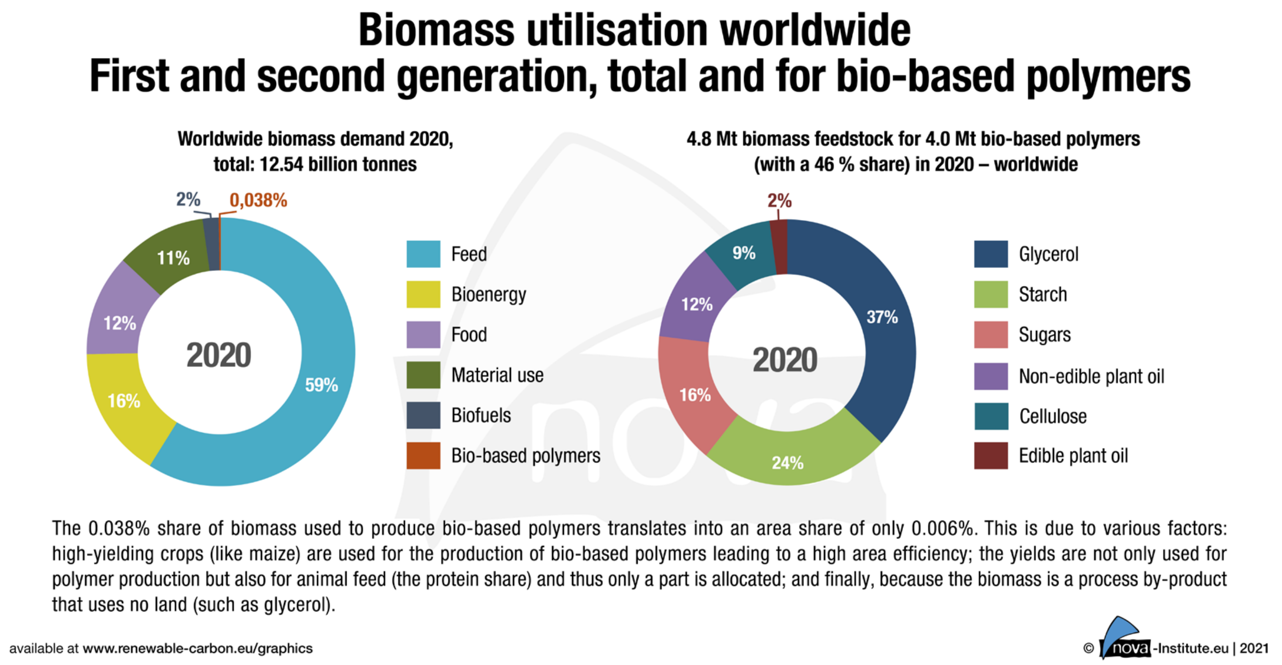
A comparison of the productivity of different biomass feedstocks are shown in the following table:

Crops	**Productivity**
Sugar Cane	9.46 t sugar/ha
Sugar Beet	9.24 t sugar/ha
Corn	4.69 t starch/ha
Wheat	1.72 t starch/ha
Castor	0.51 t oil/ha (given one harvest per year)[19]

Figure 2: IfBB (2020)

It is also important to note here is that some crops can generate additional by-products or co-products which are not necessarily captured in this table and are outside of the scope of this discussion paper. Further information can be found in the nova-Institute 2019 report entitled "Sugar as feedstock for the chemical industry."[20]

The graphic below illustrates the utilization of biomass worldwide as reported by the nova-Institute in 2022:



The 0.038% share of biomass used to produce bio-based polymers translates into an area share of only 0.006%. This is due to various factors: high-yielding crops (like maize) are used for the production of bio-based polymers leading to a high area efficiency; the yields are not only used for polymer production but also for animal feed (the protein share) and thus only a part is allocated; and finally, because the biomass is a process by-product that uses no land (such as glycerol).

available at www.renewable-carbon.eu/graphics

Figure 3: Biomass utilization worldwide: First and second generation, total and for bio-based polymers. nova-Institute., "Bio-based Building Blocks and Polymers - Global Capacities, Production and Trends 2020-2025" January 2021

What feedstocks are currently being explored as "future feedstocks"?

Various companies are exploring the extraction of sugars from lignocellulosic plants (e.g., timber and grasses (e.g., elephant grass, miscanthus and switchgrass) and agricultural and industrial residues (e.g., sugarcane bagasse, wheat straw, corn stover, and the organic fraction of municipal solid waste (OFMSW). Alternative sources for the extraction of oil (e.g., used cooking oil) are also being explored.

These feedstocks require significant processing to extract the relevant components. Its difficulties include being more expensive, and more energy-intensive, to turn larger polysaccharides like agricultural waste into the building blocks of synthetics. The aggregation and pretreatment of these feedstocks does not yet allow for commercially competitive complete bioprocesses. These emerging technologies have thus not yet been demonstrated at commercial scale. As shown in the chapter on agricultural residues, the use of agricultural residues is not always advantageous and has to be managed responsibly.

Research is also being done to directly convert greenhouse gases into synthetics. This is also referred to as direct carbon capture and utilization (CCU).[21] Examples of companies working on this technology are Covestro, Fairbrics, LanzaTech, NatureWorks, and NewLight.[22]

Why is the generation of feedstock not necessarily indicative of the broader sustainability?

Biobased feedstocks are often classified by generation. "First generation" usually includes common agricultural crops, often referred to as "food crops." This could be starch feedstocks (e.g. corn and wheat), sugar feedstocks (e.g., sugar cane and sugar beet), or edible oil feedstocks (e.g., rapeseed and soybean). "Second generation" typically refers to non-food crops such as non-edible oil crops (e.g., castor), lignocellulosic crops (e.g., wood), and agricultural and industrial residues (e.g., sugarcane bagasse, wheat straw, orange peels, waste cooking oil). The term "third generation" is usually used to describe feedstock derived from microalgae.[23]

Several studies have shown that the generation of feedstock is not necessarily indicative of the sustainability of a feedstock.[24 25] "First generation" food crops, for example, often require less land than "second generation" non-food crops and can serve as "emergency food reserves" (see chapter on food security). The use of "second generation" agricultural residues may negatively influence the soil health and stability if it would otherwise have been used as natural fertilizer and crop cover (see chapter on agricultural residues). The crucial factor is the responsible production and management of the feedstock, not its generation classification.

Multiple factors influence the carbon footprint of a material, including land-use changes, circularity potential, social aspects, effects on other impact areas like biodiversity and more (see chapter on agricultural residues).

To avoid that such a maturity pathway is assumed, Textile Exchange's Biosynthetics Round Table is considering moving away from the categorization of feedstocks by generation.

Why should we not look for the perfect feedstock?

In the debate about the sustainability of biosynthetics, one question often comes up: "What is the best feedstock?" Several organizations including the World Wildlife Fund (WWF) acknowledge that all feedstocks have advantages and disadvantages. There is no "best" feedstock because the impacts depend on various factors such as the region, production methods, and technology used. **The focus should not be on finding the perfect feedstock but rather on continuously improving the best available option for a specific application in a local context.**[26] In general, a diversity of feedstocks is likely to lead to the best overall impact results. References (working list).

Key takeaways

- There is no "perfect" or "best" feedstock in general.
- All feedstocks have advantages and disadvantages, and it depends on the specific local context, production practices, and application what the "best" feedstock in a certain context is.
- For example, "non-food" crops are not necessarily better for food security than "food crops" (see chapter on food security) and the use of "agricultural residues" is also not always advantageous but may have serious negative environmental impacts if not managed well (see chapter on agricultural residues).
- The categorization into 1st, 2nd, 3rd generation is not necessarily indicative of the sustainability performance of the feedstock.
- Minimum should be to avoid major negative impacts (e.g., ensure it is sourced legally, deforestation-free, avoid land use change).
- The aim should be to move from "degrading" to "regenerating ".
- Standards and certification systems can help to make sure certain criteria are met (see chapter on sustainability standards).

Why is using agricultural and forest residues not always advantageous?

Using agricultural and forest residues is gaining popularity in the textile industry and is also promoted by several organizations as an opportunity to reduce impacts. While the use of agricultural residues has the potential to reduce land use and associated impacts, **it is important to ensure that the waste residues are truly waste, and not being displaced from another use.**[27]

Using cellulosic and agricultural harvest residues for biobased products rather than as natural fertilizer and ground cover, for example, can have serious impacts on soil health and stability.[28] If residues are used that would otherwise have been used for other purposes such as fuel, animal feed, or pulp and paper, this can also have significant negative impacts as material substitutes will be required for the original use and their impacts must also be taken into account.

The Roundtable on Sustainable Biomaterials (RSB) standard includes requirements around a responsible use of agricultural and forestry residues.[29] Several organizations including WWF and Canopy recommend the use of the RSB standard (see chapter on feedstock sustainability standards).

The report "Spinning Future Threads: The Potential of Agricultural Residues as Textile Fibre Feedstock" funded by the Laudes Foundation and published in 2021, explores the potential of agricultural residues as textile fiber feedstock.[30] The report also acknowledges that existing or potential alternative competing uses–broadly classified by the "Five Fs" (fodder, fertilizers, fiber, feedstock, and fuel)–must be taken into account in assessing the feasibility and commercial viability of any given agricultural residue. Overall, the report found that large quantities of agricultural residues are currently unused or underused, including rice husk and straw, wheat husk and straw, empty fruit bunches (EFBs) from oil palm, sugarcane bagasse, and banana plantains.

It is, however, worth noting that maximizing the crop residue retention rate is an important part of systems like regenerative agriculture. In such a system, the availability of agricultural residues would be limited. For further information on regenerative agriculture, please refer to the Regenerative Agriculture Landscape Analysis report, published by Textile Exchange in 2022.

Why are genetically modified (GM) crops as feedstocks so controversially discussed?

Genetically modified organisms (GMOs) can be used on the feedstock production level as well as on the processing level for biosynthetics.[31] On the feedstock production level, GM seeds are used to produce a variety of commercially available crops including GM corn and sugar beet.

Regulations and consumer attitudes towards GM crops vary widely by region and country. Europe has the strictest regulations on GM crops, and European consumers are the most skeptical of products produced using GM organisms. In the U.S., GM crops are widely used with over 90% of U.S. corn and soybeans based on GM seeds. GM seeds are also used for sugar beet production in the U.S. U.S. consumers are generally less sensitive to GMO use, though there is a segment that prefers non-GMO products. Attitudes in the rest of the world vary. Sugarcane, another source of sugars for biobased products that is produced mainly in Brazil, India, and Thailand, is primarily non-GM. European sugar beet is also non-GM.

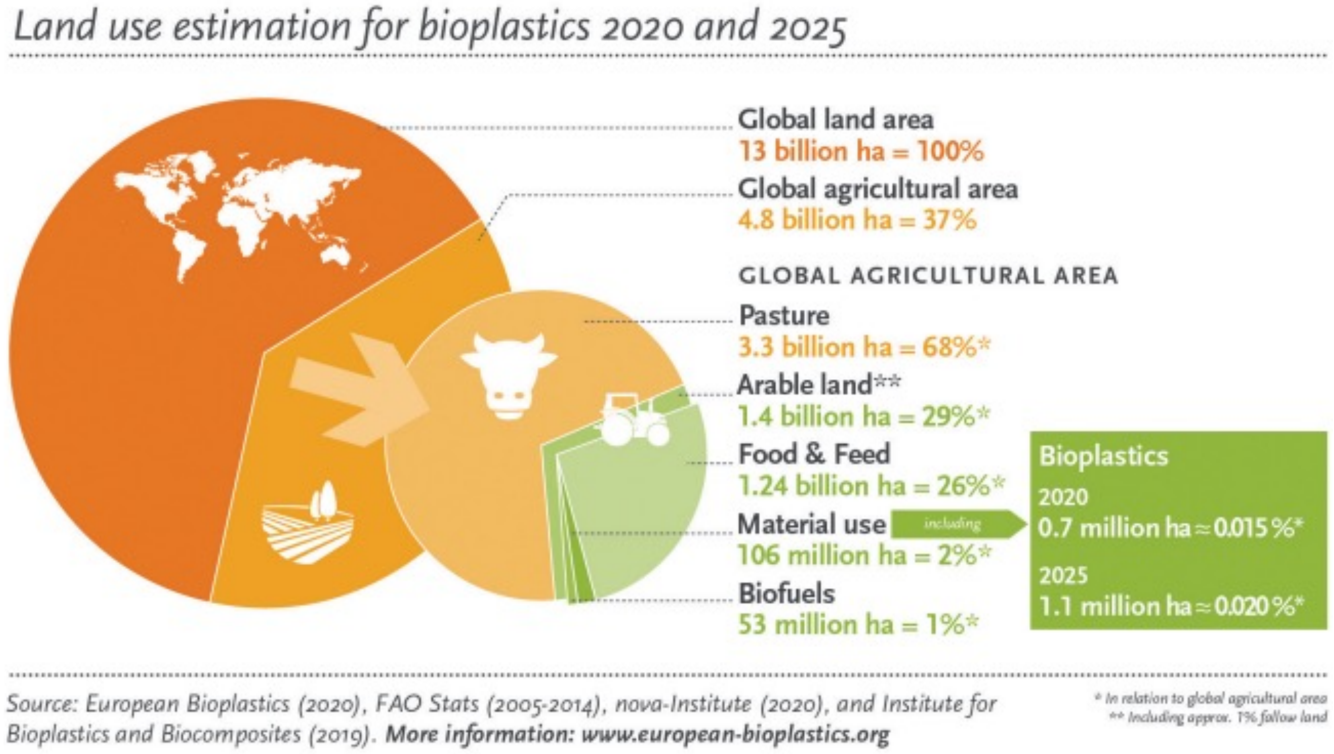
There have been many studies looking at the pros and cons of GM crops and the debate is still raging. Concerns about GM crops relate, for example, to higher herbicide use, risks related to contamination of non-GM crops or natural species, and centralizing power with GM seed and agrochemical suppliers. Supporters of GM crops point to features such as greater crop herbicide and insect resistance, higher yields, and better economics. For example, in the U.S., non-GM corn is available, but is more expensive than GM corn.

How may global land use scenarios for food, fiber, fuel, and forests look?

The global land area, particularly fertile agricultural land, is limited, and operating within our planetary boundaries requires sustainable management of limited resources.[14] Land is required for the cultivation and production of food, fiber, fuel, and forests as well as for various ecosystem services including carbon sequestration. This raises questions around the best allocation of land for different purposes.

The Bioplastic Feedstock Alliance/WWF state that "Allocating land use towards a sustainable future is complex and depends on local environmental, social, economic, and policy conditions. There is no silver-bullet solution to land-use optimization. Decision-making around land use must address and balance local needs, potential risks, and potential benefits of incorporating biobased material production into the agricultural and economic system under consideration. Agricultural activity can result in both negative and positive impacts, both of which need to be carefully considered."[32]

In general, the land use for bioplastics including biosynthetics–current as well as predicted–is minor. European Bioplastics estimates that bioplastics used 0.015% of the global agricultural area in 2020 and this share is expected to increase to 0.020% in 2025. Biofuels used 1% of the global agricultural area in 2020. The majority of the global agricultural land is used for pasture at 68%, followed by food and feed at 29%.[33]


Land use estimation for bioplastics 2020 and 2025

Source: European Bioplastics (2020), FAO Stats (2005-2014), nova-Institute (2020), and Institute for Bioplastics and Biocomposites (2019). **More information: www.european-bioplastics.org**

* In relation to global agricultural area
** Including approx. 1% fallow land

Figure 4: Land use estimation for bioplastics 2020 and 2025. European Bioplastics, "Frequently Asked Questions on Bioplastics," February 2021.

The nova-Institute also developed a land use scenario for bioplastics and came to a similar conclusion. Their scenario shows that even if the production of bioplastics (including biosynthetics) grows significantly to more than 10% of the projected 1,200 million tons of total plastic production by 2050, the land use share is estimated to rise to only around 1% of the biomass currently used around the globe in all fields of application.[34]

Due to the increasing land use competition for different purposes – including feeding a growing population, targets to increase the biofuel and packaging rates, and the urgent need for setting land aside for conservation targets – combined with challenges such as loss of fertile soils, it is still very important to decouple growth from land use (see also chapter on circularity) and to responsibly manage the land used for biosynthetics.

How to address land use and land-use change?

Land-use change (LUC) is the conversion of a specific area from one type of utilization to another one, for example:

- Natural area to a human-impacted area (e.g., conversion of natural forest or grassland to a farm).
- Human-impacted area to another human-impacted area (e.g., forest plantation to a farm).
- Human-impacted area to a natural area (e.g., reforestation, set-aside land for conversation).

Land-use change can be classified into direct land-use change (dLUC) and indirect land-use change (iLUC). Direct land-use change is the land-use change that happens if a specific area is made suitable for biomass production and processing. An example here would be arable crops grown on former grasslands.[35] Indirect land-use change refers to the displacement of the original land use to additional land. An example of this would be where forest land area is cleared to cultivate crops for biofuels.

Negative land-use change involves various risks for people and planet such as the loss of ecosystem services, destruction of habitats for wildlife, and the release of carbon contained in the soil or associated vegetation.[36]

Credible standards to address land-use change and define the conditions under which it is acceptable are important. For example, the RSB standard covers a comprehensive set of principles and criteria to address land-use change.[37] It identifies "no-go" areas such as International Union for Conservation of Nature (IUCN) protected areas, wetlands under the Ramsar Convention, UNESCO world heritage sites and biosphere reserves, primary forests, and biodiverse grasslands, as well as "no-conversion" areas like Key Biodiversity Areas, peatlands, and forests.

How may food security be impacted by biosynthetics?

Concerns regarding the competition of biosynthetics with food security are widespread. The public debate mostly focuses on the use of food crops for biosynthetics and how this may negatively impact food security. Several organizations such as the nova-Institute and Bioplastic Feedstock Alliance, convened by the WWF, have shown that this debate does not adequately address the core of the issue.[38] [39]

The nova-Institute has published a paper on this topic called "Food or non-food: Which agricultural feedstocks are best for industrial uses?". It shows that **"the crucial issue is land availability, since the cultivation of non-food crops on arable land would reduce the potential availability of food just as much or even more."**[40]

Food security certainly has to be the top priority when decisions on the allocation of land and biomass are made. Several studies have shown that non-food crops often require more land than food crops such as sugar crops. This land is then not available for food production.[41] However, the share of land currently used for biosynthetics and expected to be used for biosynthetics in the future is very small (see chapter on land use scenarios).

Another aspect to consider is that the world is mainly short of protein, and not of carbohydrates such as sugar and starch. Using sugar, starch, or oil for biosynthetics does not necessarily create competition with food uses, as the plant-based proteins of the same plants can be used for food and animal feed purposes. Beyond this, the nova-Institute argues that cultivation of food crops even has an advantage over non-food crops as they may serve as emergency food reserve in the case of a food crisis.[42] In general, the debate "should not differentiate simply between food and non-food crops, but that criteria such as land availability, resource and land efficiency, valorization of by-products, and emergency food reserves are taken into account."[43]

Last but not least, **climate change is a major threat to food security.** Climate extremes–together with conflict and economy downturns–have already been identified as key drivers for food insecurity in the last decade.[44] Even though fossil-based synthetics do not require much land nor are they derived from "food crops", their impact on food security may be higher than that of biosynthetics depending on their impacts on climate change.

Image: Bundles of wild sugarcane (Saccharum spontaneum)

Key takeaways

- The use of “non-food crops” is not necessarily better for food security than “food crops” (it can even be worse).
- If “non-food crops” are cultivated on a certain land area, the same area is not available for the production of food.
- In cases of emergency, the production of “food crops” may potentially even have advantages as they could be used as “emergency food reserve”.
- Whilst there are concerns of competition with food crops, the primary market for the highest quality outputs will always trend towards the food sector.
- The use of agricultural residues can help to reduce land use but unintended negative effects have to be avoided (see chapter on agricultural residues).
- “Food crops” often have higher productivity than “non-food” crops requiring less land.
- Agricultural systems that combine or rotate the cultivation of food crops with (food or non-food) crops as feedstock for biosynthetics can help to contribute to food security (through food production and cash crop).
- If sugar, starch or oil from plants are used for biosynthetics, the plant-based proteins may still be used for food and animal-feed purposes.
- Food security is a complex issue that needs solutions on multiple levels (incl. poverty reduction, conflict prevention etc.).
- The use of reliable standards and certification schemes can help to ensure that the biomass production does not negatively impact food security (e.g. the RSB standard).
- Fossil-based synthetics do not require much land for their production but their impact on food-security may be significant due to their contribution to climate change and the resulting impacts on food security.

What feedstock sustainability standards can be used?

The use of feedstock-related sustainability standards is still rare for biosynthetics. On the positive side, **a variety of sustainability standards for biomass have already been developed and can be used for biosynthetics.** Various feedstock sustainability standards that are already used by other sectors such as food, biofuels, and bioplastics could also be used for biosynthetics.

Examples:

Figure 5: Examples of standards available for biomass

Different standards address different criteria. Comparing different standards is complex, as multiple dimensions and criteria have to be taken into account. Several organizations have already assessed different sustainability standards for biomass, including the World Wide Fund for Nature (WWF), Umweltbundesamt (UBA), Sustainable Agriculture Initiative (SAI) Food Standards Agency (FSA). A basic meta-comparison of these assessments shows some similarities in the results (see table in the appendix). For details, please have a look at the assessments.

While most standards can be used for all crops (e.g., RSB, ISCC Plus), a few standards have been developed for specific crops (e.g., Bonsucro, Castor Success).

Examples of initiatives already using feedstock sustainability standards include NatureWorks using ISCC Plus for their Ingeo™ PLA, Corbion using Bonsucro for their PLA, and Arkema and BASF driving the spread and adoption of the SuCCESS code in India to increase the part of certified castor oil in their products.[45]

WWF[46], Canopy[47], and the UBA[48] recommend the RSB standard for the certification of agricultural biomass.

Key takeaways

- The use of feedstock-related sustainability standards is still rare for biosynthetics.
- A variety of sustainability standards and certification systems for biomass have already been developed and can be used for biosynthetics.
- Several of these standards are already used and well established for other sectors (e.g. biomass production for bio-fuels or bio-plastic packaging as well as the food sector).
- The ambition level, scope, and robustness of the standards and certification systems varies significantly.
- Several organizations have conducted comparative assessments of these standards (e.g. WWF CAT, UBA, SAI FSA).
- Examples of standards and programs include RSB, ISCC, Bonsucro, Field to Market, ROC, Fair for Life, Fairtrade, and many more.
- From the well-established standards, the RSB is recommended by several organizations (incl. WWF, Canopy and UBA).
- While most standards can be used for all crops (e.g. RSB, ISCC+), a few standards have been developed for specific crops (e.g. Bonsucro, Castor Success).
- Several standards require a chain-of-custody (e.g. Fair for Life), while others use a mass balance approach (e.g. Redcert tbd) or offer both options (e.g. RSB tbc).
- Examples of initiatives already using feedstock sustainability standards include NatureWorks using ISCC Plus for their Ingeo™ PLA, Corbion using Bonsucro for their PLA, and BASF using Castor Success that is used for EVO® by Fulgar.

How can low-cost synthetics and regenerative agriculture be combined?

Fossil-based synthetics are widely used because they are made inexpensively by reaching economies of scale in manufacturing, amongst other reasons. Concerns are raised that the application of this mentality to agriculture will lead to monoculture crops, soil erosion, habitat destruction, and significant losses to biodiversity. Close links exist here between the biosynthetics category and regenerative agricultural practices. A recent Textile Exchange report entitled "Regenerative Agriculture Landscape Analysis" focuses on the current landscape for regenerative agriculture and provides a framework for the industry in this area as well as further guidance on this topic.

Particularly if the aim is to not just "do less harm" (reduce degrading) but have actual "positive impact" (regenerating) through biosynthetics, the question is how this is achievable in a low-cost synthetics market environment.

There are many various and complicated factors to be taken into account when selecting whether to use biosynthetics or recycled synthetic materials. The end use of a product, performance and technical requirements, availability, scale, and price all must be considered before decisions can be made. A portfolio approach is needed to achieve the 1.5°C pathway and therefore the use of biosynthetics, together with recycled synthetics, as well as future innovations in the synthetics space will work towards achieving this goal.

The "Price vs Value Paradigm: Reframing Costs as Investments", a thought-starter paper by Textile Exchange, explains how a holistic view of environmental, social, and financial returns on investment will show the value of preferred fiber and materials.[49] The chapter on "how to accelerate the transition" shows the role that the regulatory framework may play to overcome this challenge.

Image: Glass flasks and beakers

Processing biosynthetic fibers

What are the key processing steps, and do they differ for biosynthetics?

The processing includes various steps from the conversion of the biomass (e.g., corn or sugarcane) into sugar or oil, their conversion into different types of intermediary chemicals, the polymerization, the extrusion of the polymers into fibers, and the production of yarns, fabrics, and final products.

While the steps from the conversion of biomass up to the production of intermediary chemicals differs for biosynthetics compared to fossil-based synthetics, the remaining steps of the supply chain can be the same as for fossil-based synthetics.

This depends on whether a biosynthetic is a "drop-in" material, or a new fiber. A "drop-in" biosynthetic fiber is chemically identical to the same fiber produced from petroleum raw materials, but it is produced from biobased renewable resources instead. For example, a biobased polyester fiber is chemically identical to fossil-based polyester, and can be processed in the same way, on the same equipment, and with the same material properties. If the biosynthetic material is a new fiber and not a "drop-in", then further processing steps differ.

From a sustainability perspective, the same questions that are relevant for the processing of fossil-based synthetics are also relevant for biosynthetics, such as health and safety, energy, and water use. Beyond these generic questions, certain specific questions may be asked for individual biosynthetics (e.g. if GMOs are used in the processing–see chapter on GMOs in processing).

What is Textile Exchange's role regarding the processing?

Textile Exchange focuses on the raw material phase of fashion and textile production. This includes all pre-spinning (or equivalent) activities. Textile Exchange acknowledges that a holistic assessment including all steps of the supply chain is important and thus builds partnerships to leverage the work of organizations focusing on the processing.

What sustainability standards and certifications exist for processing?

Several sustainability standards and certifications exist for processing, including RSB, bluesign®, EU Ecolabel, and MADE IN GREEN by OEKO-TEX®.

Different standards address different criteria. The comparison of different standards is complex as multiple dimensions and criteria have to be taken into account. Several organizations have developed benchmarks and assessed different sustainability standards for the supply chain, such as ZDHC Accepted Certification Standard, ISEAL, and Siegelklarheit. These standards may cover parts or the whole supply chain.

Why is the use of renewable energy so important?

The production of synthetic fibers requires large amounts of energy. The use of renewable energy is very important in order to limit global warming, and this is the case for fossil-based synthetics as well as biosynthetics. Phasing out fossil-based energy is an important component in order to phase out fossil inputs.

What should we know about the use of GMOs on processing level?

GMOs may not only be used on the feedstock level (see chapter on GM feedstocks). A second way that GMOs can impact biosynthetic fibers is the use of GMOs such as yeasts, enzymes, and bacteria in reactions to produce a biobased material. The GMO is used in a closed bioreactor, so the issues are different than in the use of GM crops. Concerns about GMOs used in processing relate to issues such as the disposal of genetically engineered microorganisms.[50]

Attitudes and regulation towards the use of GMOs in industrial production processes can vary from attitudes towards the use of GMOs in crops. While several companies have restrictions regarding the use of GMOs in open agricultural systems, the same companies may accept GMOs if used in closed systems.

Image: Algae in a petri dish

Use of biosynthetic fibers

How can biosynthetics be used?

Replacing fossil-based with biobased feedstock does not generally alter the chemical structure of a material. Even though there are a few biosynthetics with new quality properties, the majority equals fossil-based synthetics in terms of their product properties.

Biosynthetics are used for a variety of applications including outdoor wear, apparel, home textiles, and many more.

What are the key impact areas related to the use phase?

The sustainability impacts related to the use phase of biosynthetics are, in general, not widely different from fossil-based synthetics. A key measure to reduce the overall impacts is to use (and reuse) biosynthetics products as long as possible (see chapter on circularity potentials).

Specific impacts related to the use phase are water and energy use for cleaning and drying. Microfiber shedding–while not limited to the use phase–is another key impact here (see chapter on microfiber shedding) in the microfiber-related part.

Why do we need biosynthetics if recycled synthetics can be used?

In many debates, we hear questions as to why biosynthetics are needed if recycled synthetics can be used. We regularly also hear that biosynthetics are not required because recycled synthetics are the future. But in order to phase out fossil-based synthetics, we need to use every tool in our toolkit, including both recycled synthetics and responsibly produced biosynthetics (as well as recycled biosynthetics and potentially CO_2 based synthetics).

The uptake of 100% recycled synthetic fibers is unlikely if not impossible for various reasons, including feedstock availability and technological challenges.[51] Biosynthetics and (fossil-based) recycled synthetics can complement each other and help to phase out the use of virgin fossil-based synthetics. A portfolio approach will be needed to ensure the ambitious targets being set by the industry can be met, with growth, scale, and capacity playing important roles in this. In a biobased circular economy, fossil-based synthetics will be completely phased out and biobased synthetics will be recycled into new recycled biosynthetics again and again.

Key takeaways

- Current market data show the huge need and potential for all types of renewable carbon-based synthetics to replace fossil-based synthetics.
- If recycled synthetics can be used, use them.
- If recycled synthetics can't be used, use responsibly produced biosynthetics (or potentially CO_2 based synthetics) rather than fossil-based synthetics.
- Biosynthetics can complement recycled and CO_2 based synthetics.
- In fact, biosynthetics and recycled synthetics are not mutually exclusive: recycled biosynthetics can be an important part of a circular textile system in future.
- The overall aim should be to phase out fossil-based synthetics.
- 100% recycled synthetic fibers is unlikely if not impossible for various reasons (incl. material leakage, feedstock availability, and technological challenges).
- It is also important to note that almost all recycled polyester is currently still based on feedstock from non-textile sources (recycled plastic bottles). Textile-to-textile recycling is still emerging.
- Biosynthetics may also have attractive quality attributes that may differ from recycled synthetics.
- CO_2 based synthetics are in very early development. Their production is currently energy-intense. The use of 100% renewable energy for their production is important.

Should we stop using synthetics due to microfiber shedding?

Microfiber shedding relates to fibers that are unintentionally shed from materials during use and laundering. It can also be referred to as "fiber fragmentation" and is relevant for all fibers, both synthetic and non-synthetic.

It is a complex topic that is not yet fully understood, but the issue is about more than the number of fibers that are unintentionally shed from materials. However, it can also be relevant in discussions around cross-cutting topics including biodegradability, the toxicity of chemicals carried on the fibers, and the environmental impact of those fibers.

The microfiber shedding rate is influenced by various factors. In order to minimize microfiber shedding, multiple approaches are required and more work needs to be done in this area. For more information, we recommend getting in touch with The Microfiber Consortium.

Image: Sugarcane bagasse

What are the circularity potentials of biosynthetics?

As with synthetic fibers from fossil-based materials, there are multiple circularity scenarios for biosynthetic fibers. The specific options will depend on the properties of the material, as well as the local conditions (for example, infrastructure for collection and recycling, or for composting) which could vary significantly by location and geography. In general, the aim should be to avoid "end-of-life" pathways (e.g., landfilling, incineration) and leverage the circularity potentials of biosynthetics.

What should be the priorities in a circular bioeconomy?

A circular bioeconomy approach is complementary to a circular economy approach and the two can co-exist well together. In general, both approaches call for the first priority being to ask whether a product is necessary at all.[52 53]

A circular bioeconomy approach relies first and foremost upon healthy, biodiverse, and resilient ecosystems.[54] The three circular economy principles, outlined by the Ellen MacArthur Foundation,[55] are as follows:

- Eliminate waste and pollution
- Circulate products and materials (at their highest value)
- Regenerate nature

The theoretical concept behind this is the waste hierarchy or circularity hierarchy (see figure 6 below). Depending on the model, it includes up to 10 Rs: refuse, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, rot, and recover.

Most Preferred
↑
Circular Economy Hierachy
↓
Least Preferred

REFUSE: Prevent the use of resources
REDUCE: Decrease the use of resources
REUSE: Find new product use
REPAIR: Maintain and repair
REFURBISH: Improve product
REMANUFACTURE: Create new product from second hand
RE-PURPOSE: Reuse product for different purpose
RECYCLE: Reuse raw materials of product
ROT: Biodegrade or compost materials of product
RECOVER: Recover energy from waste

Figure 6: Textile Exchange's Biosynthetics Round Table based on WRI 2019

The WWF says: "There are clear applications where plastics (or alternative options) are necessary, but we must recognize that our current global consumption patterns are unsustainable and must therefore **first ask whether a product or packaging is necessary at all, before asking whether we can find a more environmentally friendly alternative. While the first priority is to reduce unnecessary plastic,** WWF does not advocate for elimination of all plastic because when one material is reduced or eliminated from the global material system, environmental costs can be transferred to another part of the system. Material substitution can cause its own trade-offs and the benefits of plastic may be lost (for example plastic packaging can keep food fresh, protected and safe, and therefore minimize food waste). Prioritizing reduction is key, but we must take a careful and holistic approach."

Why aren't all biosynthetics biodegradable?

One important point to understand is that a biosynthetic or biobased material does not mean that the material is biodegradable.[56] A biobased material means that the feedstock from which the material is made comes from a renewable, biobased source rather than from fossil-based non-renewable resources. A biodegradable material refers to its circularity properties, where the material has a chemical structure and specific functional groups that enable it to be broken down by microorganisms into carbon dioxide and biomass. A biobased material is not necessarily biodegradable: these are two completely different qualities.

Image: Corn husks

Key takeaways

- Only a few biobased synthetics are biodegradable.
- Generic statements around the biodegradability (e.g. “all biobased PLA is biodegradable”) should be avoided.
- A reference to the specific material and specific standard and testing method should always be given.
- Biodegradability alone is not sufficient, eco- and human-toxicological impacts have to be considered.
- Several standards used for biodegradability exist (e.g. OK Biodegradable).
- Biodegradability at the fiber level does not mean that the final product made with fiber or material is biodegradable.
- Oxo-biodegradability is a mis-leading term that should be avoided.
- Oxo-fragmentability should be avoided.
- The advantages of biodegradability are controversially discussed. The key advantage of biodegradability is likely related to fiber and material leakage into the environment (e.g. microfibers in the ocean). In most other cases, design for durability and recyclability should likely be the first choice.

What are the recycling options for biosynthetics?

The specific recycling options depend on the physical characteristics of biosynthetics as well as the infrastructure available. The key outcomes of our discussion with regard to recycling options for biosynthetics are summarized below:

- “Drop-in” biosynthetic materials with the same characteristics as fossil-based synthetics can be recycled in the same infrastructure (e.g. biobased PET in fossil-based PET recycling streams).
- New types of biosynthetic materials with innovative characteristics can in general not be recycled in existing recycling infrastructure. In this case, investments in new recycling technologies and infrastructure should be considered.
- Recyclability at the fiber and material level does not mean that the final product is recyclable as well. The composition at the material level determines the recyclability of a product.
- Overall, the waste hierarchy should always be considered (Reduce, Reuse, Recycle).

How should we deal with new biosynthetic types that cannot be recycled in existing streams?

One question that regularly comes up is how the vision to create biosynthetic materials with new properties and the vision to recycle biosynthetics can be combined into a coherent picture, given that materials with new product characteristics typically cannot be recycled in existing recycling streams.

Some companies have decided to reduce the number of different materials used and avoid materials that do not have any existing recycling infrastructure in place. In general, investments should be made to develop recycling systems for all materials that are sold (including those that are biodegradable). So, biosynthetics that can be recycled in existing infrastructure are a big plus.

Image: Test tubes

LCA and other impact assessments

What is a Life Cycle Assessment (LCA)?

A Life-Cycle Assessment (LCA) is a method to account for the environmental impacts associated with a product or service. LCAs are a useful tool, but it is also important to understand what they can and cannot do.

In general, LCAs cover environmental, but not social, aspects.[57] A major use of LCAs is to understand the greenhouse gas emissions profile of a given material, measured as an amount of carbon dioxide emitted per unit of material. LCAs can also provide information on topics such as energy consumption, water, and chemical uses at various stages of a production process.

What they do not cover is topics like social issues, or the use of GMOs. LCAs always model certain indicators but can never fully cover all aspects of very complex ecological and social systems. While LCAs can theoretically look at the whole life cycle(s) of a material, they usually focus on a specific part of the lifecycle only, such as feedstock to fiber gate. LCAs are also always based on assumptions (e.g., data from a specific supply chain or generic global average data) as it is too expensive to conduct LCAs for all individual supply chains.

As WWF states: “Life Cycle Assessments can be used as a preliminary method of evaluating a feedstock, but these tools do not capture land-use change effects or provide a complete picture of the full range of impacts, especially at a landscape scale. There is no “whitelist” of feedstocks that are considered sustainable. WWF supports the use of metric-based decision making (for example through the Supply Risk Inquiry methodology) to thoroughly evaluate the environmental and social risks, impacts, and opportunities of biomass sourcing.”[58]

For processes that produce more than one product, the environmental burden must be properly accounted for. The International Organization for Standardization (ISO)’s ISO 14044 states that where allocation cannot be avoided, the input and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them (e.g., mass, energy).[59] Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way that reflects other relationships between them, such as economic value.

It is also good practice to utilize a sensitivity analysis to illustrate the consequences of various allocation methods. For example, the process that produces starch and sugars from corn also produces other co-products such as protein, animal feeds and corn oil. In developing an LCA for a corn sugar-based product, these co-products must be considered in allocating the environmental impacts.

Another issue to look at is comparing virgin materials to recycled materials. In developing LCAs for recycled materials, the question remains as to how to allocate the environmental burden associated with the source of the original material. One view is that for materials that are recycled, environmental burdens associated with mining must be allocated among primary and recycled materials.

Data should also be reviewed for time-based and spatial differentiation where applicable. One time-based example is the changing impact of grid-based electricity as the electricity production mix changes over time. One spatial example is that while greenhouse gases emissions impact the whole planet, water use and scarcity are more local issues and can differ greatly by geography.

What approaches to biogenic carbon accounting exist?

A key concept to understand related to LCAs and GHG emissions for biosynthetics is biogenic carbon as compared to fossil-based carbon. Biogenic carbon is carbon contained in biomass that accumulates during plant growth. As a result, many natural materials store, or "sequester" atmospheric CO_2 in the short term.[60]

The leading comparative LCA tool used in the textile industry is the Higg Material Sustainability Index (Higg MSI). In the Higg MSI 3.1, launched in December 2020, **biogenic carbon was added as a new separate metric. Biogenic carbon is not part of the actual Higg MSI scores.**

The Higg MSI FAQ explains: "In the Higg MSI, this is not subtracted from the global warming results but displayed as a separate inventory metric. This is consistent with many standards for communicating LCA results and is because there is no way of knowing that the carbon is sequestered for 100+ years in a cradle-to-gate LCA, since the end of life is not included."

This approach is aligned with the biogenic carbon storage reporting requirements of three common product carbon footprinting standards/guidance documents for cradle-to-gate scope: the ISO 14067: 2018, EU PEFv6.3 and PAS 2050.

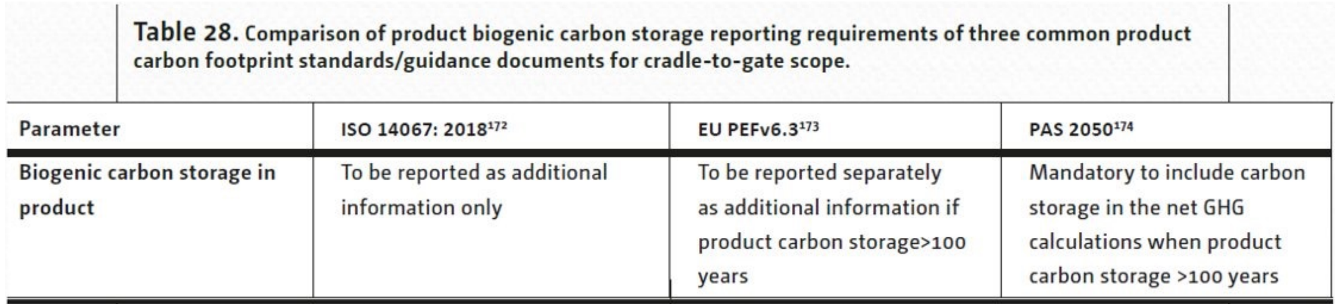


Table 28. **Comparison of product biogenic carbon storage reporting requirements of three common product carbon footprint standards/guidance documents for cradle-to-gate scope.**

Parameter	ISO 14067: 2018[172]	EU PEFv6.3[173]	PAS 2050[174]
Biogenic carbon storage in product	To be reported as additional information only	To be reported separately as additional information if product carbon storage>100 years	Mandatory to include carbon storage in the net GHG calculations when product carbon storage >100 years

Figure 7: Comparison of biogenic carbon storage reporting requirements. UN Fashion Industry Charter for Climate Action (FICCA), "Identifying Low Carbon Sources of Cotton and Polyester Fibers" April 2021.

The UN Fashion Industry Charter for Climate Action report on low carbon sources for cotton and polyester also recommends reporting the biogenic carbon content of a product at the factory gate separately, as additional information, in line with ISO 14067 and EU PEF.[61]

Many suppliers, in contrast, include biogenic carbon in LCA figures reported at the factory gate. This explains some of the differences related to GHG emissions reported by suppliers versus the ones included in tools and publications where biogenic carbon is a separate value.[62]

It is also important to note that biogenic carbon in the Higg MSI is measured in kilograms of carbon, not CO_2. One kilogram of biogenic carbon is equivalent to 3.67 kilograms of CO_2 (based on stoichiometric ratios). So, a material that has 0.39kg of biogenic carbon has incorporated the equivalent of $0.39\text{kg} * 3.67\text{kg } CO_2/\text{kg C} = 1.43\text{kg of } CO_2$.[63]

If biogenic carbon were included in the Higg MSI scores, the relative performance of biosynthetics compared to fossil-based synthetics would be better.

The UN FICCA report 2020 concludes: "There is a need to improve the data collection effort and harmonize GHG measurement practices for PET production in order to draw fair comparisons between the GHG profile of biobased PET with virgin and recycled PET fibers."[64]

What can we learn from the Higg MSI for biosynthetics?

The Higg Materials Sustainability Index (Higg MSI) is a leading tool used in the fashion and textile industry to measure the environmental sustainability impacts of materials based on Life Cycle Assessments (LCAs). It is a cradle-to-gate assessment tool covering all steps up from the raw material source to the fabric level, with a breakdown by the following phases: Raw Material Source, Yarn Formation, Textile Formation, Preparation, Coloration, Additional Coloration and Finishing. Environmental impacts covered include: Global Warming, Eutrophication, Water Scarcity, Resource Depletion, Fossil Fuels, and Chemistry. In addition, Biogenic Carbon Content and Water Consumption are disclosed as well, however as separate values and not included in the Higg MSI scores.

Since the launch of the Higg MSI 3.1 in December 2020, the following six biobased or partially biobased materials were included in the Higg MSI:

- Two partially biobased polyesters (partially biobased PET from Toray, Lycra T400 EcoMade Fiber)
- One partially biobased nylon (biobased nylon 4.10)[65]
- One partially biobased PTT (partially biobased PTT Sorona from Dupont)
- One partially biobased elastane (Creora® biobased spandex from Hyosung)
- One biobased PLA (PLA from NatureWorks)

Beyond this, one biomass-balance based material, Ultramid B BMB (biomass balance) from BASF was covered as well.[66] Further data on wholly or partially derived biosynthetics is needed to support decision-making and understanding.

Notes (Figure 8, opposite):

A lower Higg MSI score shows lower negative environmental impacts within the assessment scope; however, the functional units in the "Raw Material Source" table for the listed materials differ and are thus not all comparable. Biogenic carbon is not included in the scores.

*ND = not disclosed

** 18% biobased and 50% recycled

*** For recycled fibers, several supplier-specific materials are part of the Higg MSI as well. As this is not the focus of this paper, only a generic mechanically and chemically recycled polyester are included here.

**** For synthetics, where the stage / functional unit is not specified, it refers to the plastic pellet/chip stage (input into a yarn extrusion machine), as per info received from SAC by mail on October 1, 2021.

	Functional Unit	% Biobased	Global Warming	Eutrophication	Water Scarcity	Resource Depletion, Fossil Fuels	Chemistry	Last publication or review date
Polyester (PET)								
Polyethylene terephthalate (PET), fossil fuel based	Pellet/chip	0%	2.73	0.46	0.406	5.13	1.90	2019
PET Toray, partially biobased 🍃	Pellet/chip	ND*	3.2	4.16	0.252	4.91	2.84	2014
LYCRA(r) T400 EcoMade Fiber {The LYCRA Company}, (includes yarn formation 🍃	Yarn	18%**	5.52	5.19	0.639	7.26	2.84	2020
Polyethylene terephthalate (PET), mechanically recycled, for textiles****	Pellet/chip	0%	0.642	0.280	0.406	5.13	0.948	2016
Polyethylene terephthalate (PET), chemically (methanolysis) recycled, for textiles***	Pellet/chip	0%	1.75	2.12	1.03	2.07	1.90	2010
Nylon/Polyamide (PA)								
Nylon 6, fossil fuel based, for textile production	Pellet/chip	0%	7.38	1.61	0.089	9.81	1.90	2018
Nylon 6.6, fossil fuel based, for textile production	Pellet/chip	0%	7.08	1.92	0.022	9.76	1.90	2019
Nylon 4.10, biobased, for textile production[68] 🍃	Pellet/chip	ND*	7.04	33.5	55.9	7.21	1.90	2018
Ultramid B {BASF}	Pellet/chip	ND	4.02	0.569	0.006	6.95	1.90	2019
Nylon, mechanically recycled, for textile	Pellet/chip	0%	0.598	0.563	0.218	0.495	0.948	2018
Polytrimethylene terephthalate (PTT)								
Sorona polymer {DuPont}, biobased 🍃	Polymer	37%	3.88	7.86	0.678	5.56	2.84	2016
Elastane / Spandex								
Spandex fiber {The LYCRA Company}, contains data for yarn formation/ spinning	Yarn	0%	7.71	6.11	5.18	8.30	1.90	2014
Creora® biobased spandex {Hyosung}, contains data for yarn formation/ spinning 🍃	Yarn	ND	6.97	4.92	2.50	8.50	1.90	2020
Polylactic Acid (PLA)								
Polylactic acid (PLA), biobased, for textiles 🍃	Pellet/chip	ND	2.23	3.47	0.768	2.18	1.90	2019

Figure 8: Higg MSI 3.1 Raw Material Source scores for fossil-based, biobased, and recycled synthetics [67]

A commonly asked question is why biosynthetics score worse than fossil-based synthetics in the Higg MSI. The Higg MSI Raw Material Source score is often referenced in a way implicating that biosynthetics score worse than fossil-based synthetics.

Textile Exchange's Biosynthetics Round Table had a closer look at the Higg MSI for biosynthetics. When using the Higg MSI or LCAs in general, it is important to look at the specific scope, assumptions, and indicators covered as well as the age of the data.

To illustrate a couple of important aspects, the Higg MSI for different types of polyester is given here as example. At the time of the launch of the White Paper Discussion Draft, the Higg MSI included two partially biobased polyesters. One of them (Lycra T400 EcoMade) includes the yarn formation phase and is thus not directly comparable to the fossil-based polyester provided in pellet/chip form in the Higg MSI Raw Material Source.[69] The other one is a partially biobased PET (from Toray) which is based on data from 2014, while the data for the fossil-based PET are from 2019 as reported in the Higg MSI database. As both the technology and the energy supply may have changed significantly over time, the data are of limited comparability. It is also important to note that biogenic carbon is listed separately and not accounted for in the Higg MSI Raw Material Source score. In general, the assessment of a specific supplier's biosynthetic should not be used as a general assessment of all biosynthetics of this type given the huge variances in biosynthetics. A comparison of fossil-based and biobased PET is thus very limited given the current LCA data.

This finding is also aligned with the conclusion from the "UN Fashion Industry Charter for Climate Action (FICCA): Identifying Low Carbon Sources of Cotton and Polyester Fibers" report launched in April 2021 with SCS Global Services as technical lead, that assessed virgin, fossil-based, and biobased polyester against each other. The report "excludes biobased PET from the comparison due to limited availability of LCA data."

Key takeaways

- Biogenic carbon is listed separately (included since the Higg MSI 3.1 launched in December 2020) – and not taken into account for the Higg MSI scores.
- The entities assessed in the "Raw Material Source" table differ (e.g. sometimes it refers to resins, sometimes to extruded fibers). Like for like comparisons are only possible if the same entities are compared and data from the "Yarn Formation Method" may have to be included as well.
- The timeliness of the data differs with some data being rather old.
- The Higg MSI of a specific supplier's biosynthetic should not be used as a general assessment of all biosynthetics of this type (e.g. partially biobased PET from Toray based on 2014 data for all biobased polyester).
- Not all biobased % are disclosed. For the disclosed ones, they are rather low (18-37%).
- It matters what is compared to what (e.g. Dupont Sorona PTT to nylon or polyester).

In general:

- The environmental impacts associated with biosynthetics vary significantly based on the specific feedstock, local context, production practices, and assessment scope.
- The comparability of the biobased vs. fossil-based vs. recycled on the "Raw Material Source" level is limited.
- The LCA data availability and quality for biosynthetics is limited.
- Improvement of data collection efforts and harmonization of GHG measurement practices are required to draw fair comparisons between the GHG profile of biosynthetics with fossil-based synthetics.

What is LCA+ and how will the Preferred Fiber and Materials Matrix assess biosynthetics?

At Textile Exchange, we advocate for the use of LCA+ assessments. LCA+ assessments are a combination of LCA assessments and further metrics that cannot be captured through LCAs.

Our Preferred Fiber and Materials Matrix uses this LCA+ approach to assess fibers and materials.[70] It builds on several existing tools, including the Preferred Fibers Toolkit developed by Gap Inc, and was given to Textile Exchange to make it publicly available. The tool is designed to capture a broad set of impact indicators like climate and GHG, biodiversity, water use and pollution, chemicals and toxicity, soil health, land management, human rights, animal welfare, and program robustness.

In 2020, Textile Exchange launched the draft Preferred Fiber and Materials Matrix methodology. The consultation phase was completed by January 20, 2021. The feedback is being reviewed and incorporated into the tool now.

In the first phase of this tool, biosynthetics will not be included. This decision was made due to prioritization needs (focusing on large volume materials) and challenges regarding impact assessment for biosynthetics compared to fossil-based and recycled synthetics.

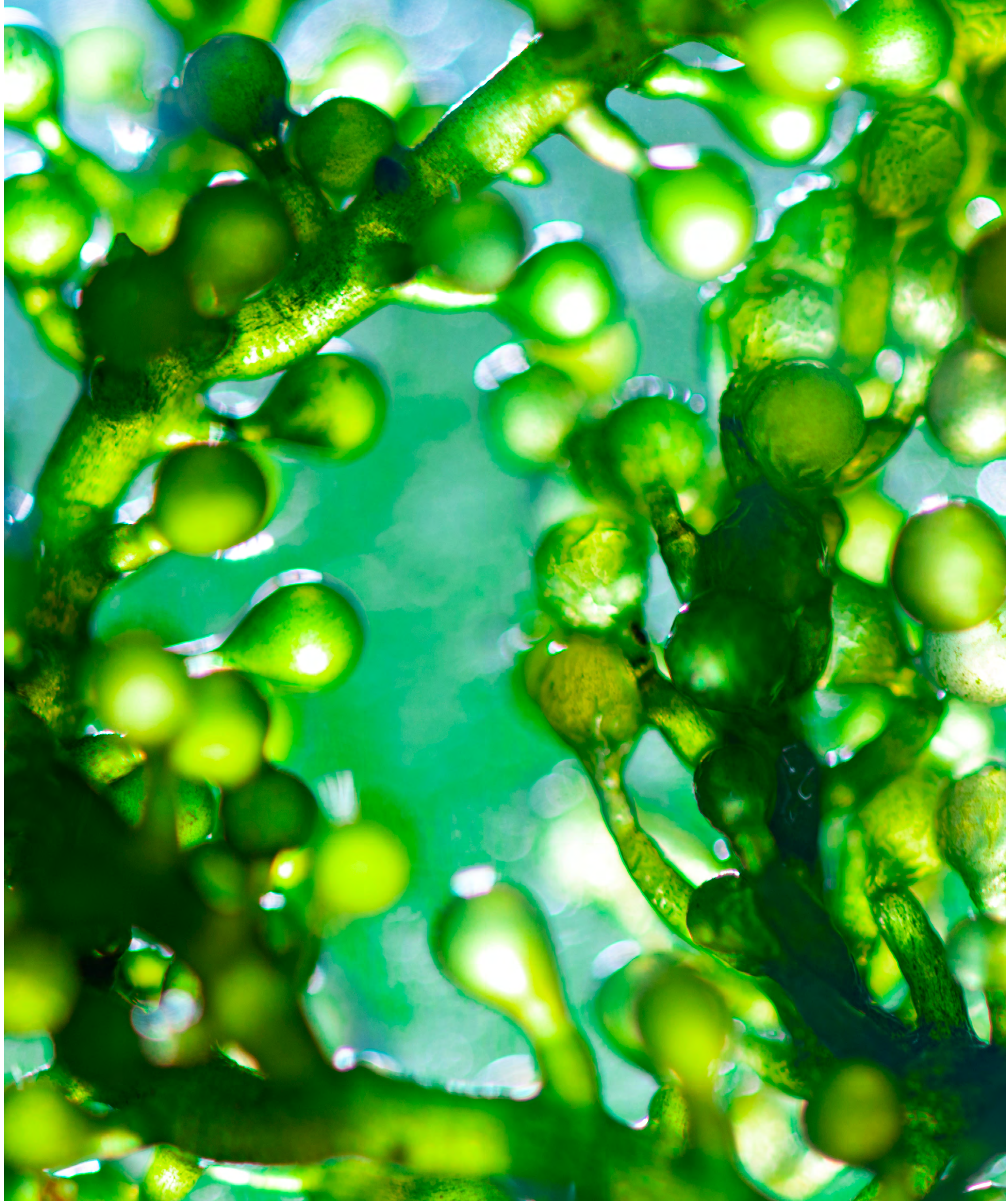


Image: Seaweed

Roadmap to the future of biosynthetics

How may a roadmap towards preferred biosynthetics look?

The nova-Institute has developed a scenario for the carbon feedstocks of the overall plastics industry.[71] It models a scenario where around 1,200 million tons of total plastic will be produced in 2050, with around 70% recycled synthetics, 20% CO_2 based synthetics, and 10% biobased synthetics. In this scenario, the total amount of biomass required would equal around 1% of all biomass currently used in total for all applications. Currently, around 60% of all biomass is used for the production of animal feed to produce meat and milk.

It is important to note that the best mix of renewable carbon options (e.g., biosynthetics, recycled synthetics, and synthetics from direct CO_2 utilization) is needed.

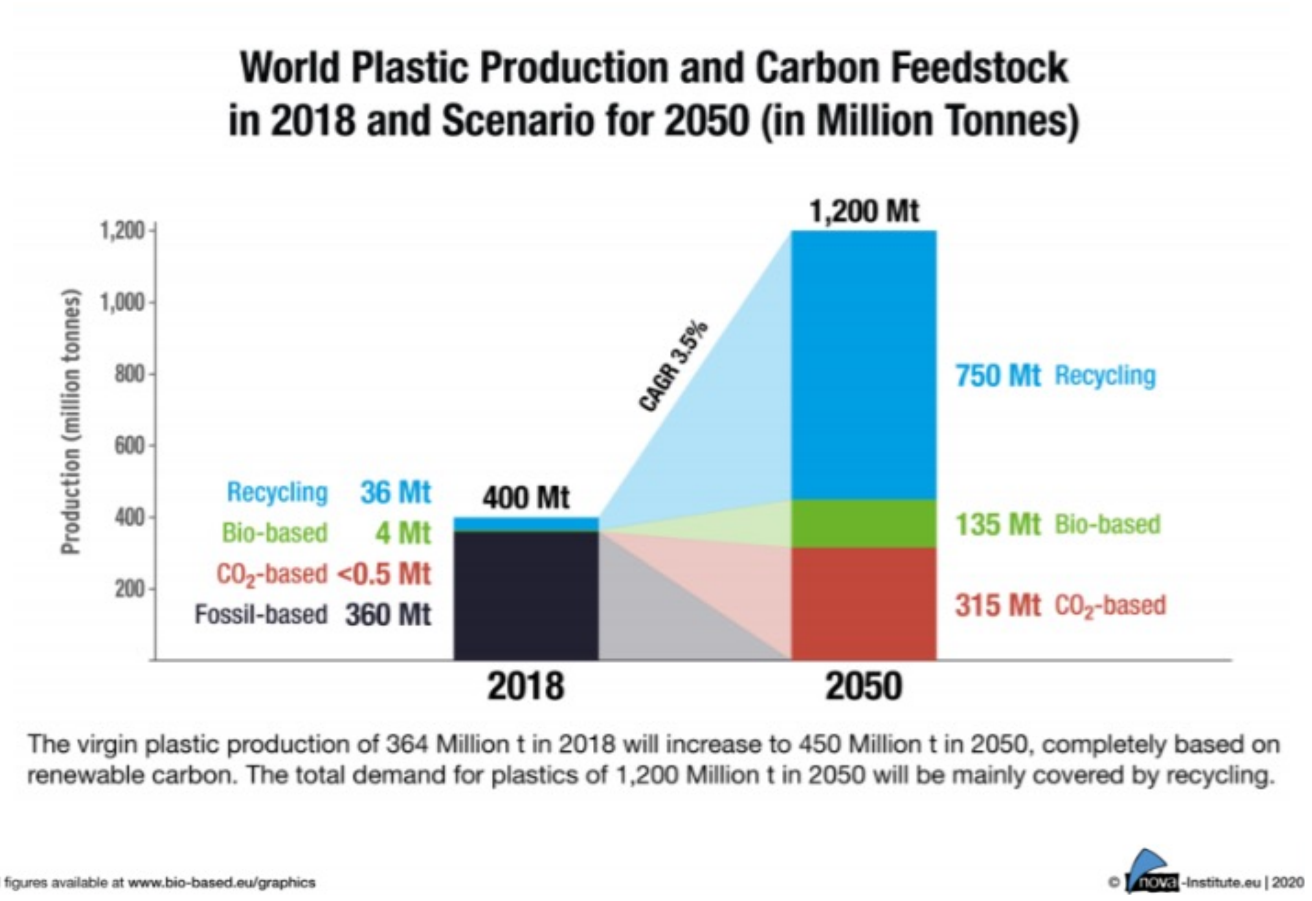


Figure 9: World Plastic Production and Carbon Feedstock Volumes. nova-Institute, ”Renewable Carbon – Key to a Sustainable and Future-Oriented Chemical and Plastic Industry”, September 2020.

What are the minimum criteria that biosynthetics should meet?

The Bioplastic Feedstock Alliance (BFA) / WWF defines a “responsibly sourced bio-content” as one that **“at a minimum must be legally sourced; derived from renewable biomass; pose no adverse impacts on food security; have no negative impact on land conversion, deforestation, or critical ecosystems; and provide environmental benefits - including near-term climate benefits compared with fossil-based plastic.”** [72]

In order to meet science-based targets for climate and nature, every company should accelerate the transition from fossil-based to responsible biobased, recycled, and potentially CO_2 based synthetics and continuously improve the impacts across the whole portfolio of fibers and materials used.

How can we accelerate the transition to preferred biosynthetics?

In order to limit global warming to 1.5°, we need to accelerate the transition from fossil-based synthetics to renewable-carbon based synthetics including responsibly produced and managed biosynthetics, recycled synthetics, and potentially synthetics produced through direct CO_2 utilization.

Shifting relevant amounts of the synthetic fiber market towards the use of renewable carbon will require significant efforts by the industry, policymakers, and society as a whole.[73] While major investments are required, the right political measures (see list below) and economies of scale through increased production can reduce the costs for biosynthetics.

Together we can achieve much more than what we can achieve as individuals. Multi-stakeholder initiatives such as Textile Exchange’s Biosynthetics Round Table, nova-Institute’s Renewable Carbon Initiative, and Fashion for Good can play an important role in accelerating the transition. Organizations and individuals have to set ambitious targets and investments into preferred biosynthetics.

As mentioned in the beginning of this paper, many companies in the textile industry are still hesitant to use biosynthetics due to concerns regarding the competition with food production, the use of GMOs, deforestation, microplastic, and end-of-use options. **Supply chain transparency and the use of sustainability standards such as the ones mentioned in this paper can help to address these concerns.**

Another barrier to the growth of the biosynthetics market are low fossil fuel prices and thus prices for fossil-based synthetics, creating a challenging market environment for biosynthetics. While upscaling the biosynthetics market will also contribute to lower prices due to economy of scale, a broader debate about price and value, as well as political measures, is required.

Political measures to support and accelerate this transition could include:

- Taxation of fossil carbon
- Discontinuation of any funding programs in the fossil domain
- Higher costs for fossil CO_2 emissions in the emissions trading system (ETS)
- Quotas of renewable carbon in “drop in” products
- Reporting requirements for the percentage of renewable carbon used in production processes
- Tax credits for sequestration
- Storage and utilization of CO_2
- Tightening of environmental requirements for chemicals

Image: Corn after harvesting

Call to action

Biosynthetics are part of the broader sustainability journey towards a regenerative and circular future. Replacing fossil-based synthetics with biosynthetics has the potential to limit global warming, but they must be sourced and managed responsibly to realize this potential and to avoid negative effects on other impact areas.

We need to use every tool in our toolkit to reduce the impacts associated with the use of synthetic materials in the fashion and textile industry, support the transition from fossil-based to renewable carbon-based synthetics including recycled, biobased, and potentially CO_2 based synthetics in a responsible way. For biosynthetics, this means assessing options holistically and developing comprehensive impact data, such as an LCA+ approach that uses LCA data alongside additional metrics. In this way, we can work to define what preferred biosynthetics are and support the scaling of preferred solutions, as well as identifying risks and opportunities for biosynthetics, together with best practice examples and mitigation strategies to overcome identified risks.

- We encourage companies to set bold science-based goals, invest in emerging innovations, and work on continuous improvement. This can be done by actioning any of the following:
- Moving from partially biobased to 100% biobased materials
- Continuously advancing the use of sustainability standards
- Increasing the share of renewable energy
- Increasing transparency
- Transitioning to regenerative and circular net positive systems
- Understanding supply chains and barriers to uptake.
- Supporting further research into fiber fragmentation to support the adoption and implementation of The Microfibre Consortium's 2030 roadmap as well as establish reduction pathways for fiber fragmentation

For those looking to further their understanding in this area, we recommend joining Textile Exchange's Biosynthetics Round Table. The Biosynthetics Round Table is a collaborative, pre-competitive, multi-stakeholder community for people to connect, share knowledge, and drive collective action with a focus on biobased synthetics.

Acronyms

BfA	Bioplastic Feedstock Alliance
CAGR	Compound Annual Growth Rate
CAT	Certification Assessment Tool
CO_2	Carbon Dioxide
FSA	Farm Sustainability Assessment
GHG	Greenhouse Gas
GMO	Genetically Modified Organisms
IPCC	Intergovernmental Panel on Climate Change
ISBWG	International Sustainable Bioeconomy Working Group
ISCC	International Sustainability & Carbon Certification
LCA	Life Cycle Assessment
MSI	Materials Sustainability Index
PA11	Polyamide 11 (a.k.a. nylon)
PE	Polyethylene
PET	Polyethylene Terephthalate (a.k.a. polyester)
PLA	Polylactic Acid
PTT	Polytrimethylene Terephthalate
RCI	Renewable Carbon Initiative
RSB	Roundtable on Sustainable Biomaterials
SAC	Sustainable Apparel Coalition
SAI	Sustainable Agriculture Initiative
UBA	Umweltbundesamt (Germany's central environmental authority)
WWF	World Wildlife Fund

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Appendix

Comparison of feedstock sustainability standard assessments

	Feedstock	**WWF 2013**[74]	**UBA 2019**[75]	**UBA 2019**	**SAI FSA 2021**[76]	**Certified Operators**
Description		Share of completely fulfilled criteria	Mean of environmental aspects	Mean of social aspects assessment	Equivalence level	
Scale		0-100 (worst to best)	0 – 100 (worst to best)	0 – 100 (worst to best)	Partially Bronze Silver Gold	
Aspects Covered:		Biodiversity, water, soil, agrochemicals and fertilizers, greenhouse gases, waste management, social: labor, spraying of pesticides and health protection, social: surrounding communities + scheme requirements	Biodiversity, soil quality and fertility, soil erosion, water withdrawal, water pollution, air emissions, waste management	Human rights, labor rights, land use rights and land use change, water use rights, food security		
RSB	All	76%	94	97	Silver (gold if with FSA Cert Prot)	Link
ISCC Plus	All	64%	67	84	Silver (gold if with SAI Gold)	Link
SAN	All	n.a.	76	61	Silver	
Bonsucro	Sugar	48%	63	60	Gold eq.	Link
Fair for Life	All	n.a.	n.a.	n.a.	Silver (gold if combi with Global GAP)	Link
Redcert	All	28%	60	69	All levels depending on country	
Fairtrade	All	n.a.	n.a.	n.a.	Silver	Link
Castor Success	Castor	n.a.	n.a.	n.a.	n.a.	Link
Organic	All	n.a	n.a	n.a.	n.a	National databases
Regenerative Organic Certified™ (ROC)	All	n.a.	n.a.	n.a.	n.a.	Link

Figure 10: Textile Exchange's Biosynthetics Round Table based on UBA 2019, WWF 2013, and SAI FSA 2021.

List of key questions

At a minimum, the following impact-related questions for biosynthetics should be asked:

Feedstock:

- What is the biobased % and from what feedstock (e.g., corn, castor, wheat straw) is it derived? Does the product currently hold any certification for the biobased content (e.g., USDA BioPreferred®)?[77]
- Does the product currently hold any sustainability certification for the feedstock (e.g., RSB, ISCC, Fair for Life)? If yes, what sustainability aspects are covered by the standard and how robust is the certification scheme according to third-party assessments (e.g., ISEAL, WWF CAT, SAI FSA)[78]? Have genetically modified crops been used (yes/no)?
- If no sustainability certification is available for the feedstock (e.g., in the case of early-stage innovators or if other measures are used), what measures are implemented to assess and manage key sustainability impacts related to the feedstock (e.g., BFA Assessment / Scorecard, RSB Screening Tool, FSA Self-Assessment or remote sensing of land use change risks)?

Processing / supply chain:

- What is the share of renewable energy used?
- Does the product currently hold any sustainability certifications for the processing (e.g., RSB, bluesign®, EU Ecolabel, OEKO-TEX Made in Green)? If yes, what sustainability aspects are covered by the standard and how robust is the certification scheme according to third-party assessments (e.g., ZDHC Accepted Certification Standard, ISEAL, Siegelklarheit)? If the whole supply chain is not covered by the standard, which steps of the supply chain are covered?
- If no sustainability certification is available for the processing (e.g., in case of early-stage innovators or if other measures are used), what measures are implemented to assess and manage key sustainability impacts related to the processing (e.g., use of ZDHC MRSL without certification)?

Circularity potential/end-of-life:

- Is the "product" recyclable and if yes, which entity (e.g., fiber, yarn, fabric, final product) in which recycling stream (e.g., 50% biobased PES in thermomechanical recycling stream for fossil-based PET / i.e., melting)? How widely available is this recycling stream already? What measures and investments are needed to move from a "theoretical recyclability" to actually closing the loop?
- Is the "product" biodegradable and if yes, which entity (e.g., fiber, yarn, fabric, final product), in which environment (e.g., marine, soil, water, industrial, home) and according to which standard (e.g., OK biodegradable by TÜV Austria)? How are ecotoxicological aspects covered in the biodegradability standard?
- How can material leakage on the different steps along the supply chain be prevented or at least minimized (e.g., microfiber fragment leakage)?

Life Cycle Assessments (LCA):

- Is a Life Cycle Assessment (LCA) for the "product" available? If yes, what functional entity has been assessed (e.g., fiber, fabric, garment), what indicators were included (e.g., GHG emissions, water scarcity), and what assumptions were made (e.g., biogenic carbon included or excluded)? Is a normalized LCA comparison available (e.g., is the LCA included in the Higg MSI)? How old are the underlying data?
- What impact areas are not covered by the LCA?

Endnotes

1 To verify the biobased content, standards such as ASTM D6866 (used by the USDA BioPreferred® Program), CEN/TS 16295, EN 16785, ISO 16620 can be used. If mass-balance is used and thus no biobased content in the final material, the term “biosynthetic” or “biobased synthetic” should not be used. Textile Exchange’s detailed technical definition of “biosynthetics” is currently under review.

2 Based on volume data from the Preferred Fiber and Materials Market Report 2020 and the Higg MSI GHG emission factors

3 This is also called “Carbon Capture and Utilization” (CCU) – see also the chapter on future feedstocks.

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10 This vision is also inspired by nova-Institute‘s Renewable Carbon Concept and Initiative. Recycled synthetics would have the largest market share, followed by CO_2-based and (virgin) biobased synthetics. Recycled synthetics will also include recycled biosynthetic and recycled CO_2-based synthetics in future.

11 Aspirational principles and criteria for a sustainable bioeconomy have also been defined by the International Sustainable Bioeconomy Working Group (ISBWG). They may be used as a reference for further principles and criteria.

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21 Not to be confused with Carbon Capture and Storage (CCS)

22 “Renewable Carbon” is defined by the nova-Institute as “all carbon sources that avoid or substitute the use of any additional fossil carbon from the geosphere. Renewable carbon can come from the biosphere, atmosphere or technosphere – but not from the geosphere. Renewable carbon circulates between biosphere, atmosphere or technosphere, creating a carbon circular economy” (RCI, 2022). For more information on CO_2-based fibers, see also Textile Exchange’s Preferred Fiber and Materials Market Report 2021

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41 Dammer, L., Carus, M., Piotrowski, S., 2019. “Sugar as Feedstock for the Chemical Industry.” nova-institute. https://renewable-carbon.eu/publications/product/sugar-as-feedstock-for-the-chemical-industry-%E2%88%92-full-version/

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51 Mechanical recycling of synthetics reduces the quality of the synthetics and chemical recycling is still very limited at the moment.

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57 Social LCAs also exist but they are not wide spread. LCA thus refers to environmental LCAs here.

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60 Higg, 2021. “Higg MSI FAQ.” https://howtohigg.org/higg-msi/faq/

61 UN Fashion Industry Charter for Climate Action, 2020. “Identifying Low Carbon Sources of Cotton and Polyester Fibers.” https://unfccc.int/sites/default/files/resource/UCC_Cotton_Pet_report.pdf

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65 The Higg MSI does not mention any specific supplier. However, DSM seems to be the only supplier of polyamide 4.10. Thus, we assume the figures refer to their polyamide 4.10.

66 The Biosynthetics RT decided to cover it in its work but it is important to note that it shouldn't be called a "biobased synthetic", as the material does not contain any biobased content.

67 The total „Single Score" that combined the Global Warming, Eutrophication, Water Scarcity, and Resource Depletion scores was abandoned in early 2021 (SAC PR, November 2, 2020 – Link).

68 The Higg MSI does not mention any specific supplier. However, DSM seems to be the only supplier of polyamide 4.10. Thus, we assume the figures refer to their polyamide 4.10.

69 A comparability in terms of the functional unit seems possible if further steps are included (i.e. at the fabric level).

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74 The WWF published a Comparative Analysis of Certification Schemes for Biomass used for the Production of Biofuels in 2013. It compares 13 certification schemes based on the Certification Assessment Tool (CAT) developed by WWF. The CAT is a formal tool for analysing and comparing voluntary standards and certification schemes. Using a detailed set of questions and criteria, the tool uses a point system to assess the strategic, structural, social and ecological strengths and weaknesses of standards and certification schemes against WWF's requirements for a sustainable environmental and social standard. The percentage given in the table refers to the share of completely fulfilled CAT criteria. (PDF).

75 The German Environment Agency (UBA) published a study in the context of the research project "Implementation of sustainability criteria for the material use of biomass in the context of the Blue Angel" that compared nine different labels based on various environmental, social, and systemic sustainability criteria defined in ISO 13065 (ISO/PC 248). For each dimension (e.g. environmental aspects) up to 100 points were allocated. More information in their assessment report. In German (PDF).

76 SAI Platform FSA has assessed around 450 standards against a large set of environmental and social content criteria as well as assurance and governance criteria. The results are presented in a categorized way, e.g. bronze, silver, gold. (excel).

77 To verify the biobased content, standards such as ASTM D6866 (used by the USDA BioPreferred® Program), CEN/TS 16295, EN 16785, ISO 16620 can be used.

78 See also the comparison of biomass feedstock sustainability standards assessments here