FOCUS PAPER

Biodegradability and Compostability

Lenzing
Innovative by nature

Issue August 2026

Executive Summary – End of Product Use

This focus paper explains how regenerated cellulose fibers can support more responsible end-of-use options in selected applications. For customers, this means renewable cellulose-based material choices that may help reduce reliance on persistent fossil-based materials where product design and end-of-use conditions allow.

Cellulose Fibers as Part of the Natural Carbon Cycle

A key differentiator of regenerated cellulose fibers is that they are based on cellulose, one of the most abundant natural polymers in nature. Because cellulose is part of the natural carbon cycle, regenerated cellulose fibers such as viscose, modal, and lyocell are fundamentally different from conventional fossil-based synthetic fibers. These fibers form part of the "cellulose cycle" and therefore offer intrinsic potential for biodegradation under suitable conditions.[1]

Biodegradability and compostability depend on defined conditions and testing

Biodegradability and compostability are important end-of-use properties, but they must be understood in relation to specific environments, timeframes and testing conditions. LENZING™ TÜV certified biodegradable and compostable fibers have been tested by independent laboratories according to recognized standards covering biodegradation, disintegration, ecotoxicity and chemical characteristics. At the same time, claims for finished products depend on the full product composition and must be verified in the final product form.

Scientific studies confirm the biodegradability of regenerated cellulose

Scientific literature and research collaborations show that regenerated cellulose fibers biodegrade in a range of relevant environments, including soil, freshwater, marine conditions, compost, and wastewater treatment settings. In 2025, it was reconfirmed by a study from HYDRA Marine Sciences institute[Fehler! Textmarke nicht definiert.] that regenerated cellulose fibers biodegrade just as readily as natural cellulose fibers (e.g. cotton).

Certified Fiber Solutions for Applications Where Biodegradability Matters

Biodegradability is particularly relevant in product areas where items are short-lived, difficult to collect, or at risk of environmental leakage — such as wipes, hygiene products, packaging, and selected agricultural and aquaculture uses.

Multiple End-of-Use Pathways

A hierarchy of options for end of use is also depending on the application: recycling where feasible, natural recycling through biodegradation or composting where appropriate, and energy recovery by incineration where no better alternative exists. Landfilling remains the least preferred outcome. Responsible end-of-use depends not only on the fiber itself, but also on product construction, local waste systems, and the intended application.

Circularity Also Includes Recycling and System Change

Lenzing contributes to circularity through its REFIBRA™ technology, which enables cellulose fibers to be made with recycled textile content. Partnerships and industry collaborations support innovation, research, and broader transition away from fossil-based materials. It can only be done together: better end-of-use outcomes require not only better fibers, but also product redesign, waste infrastructure, and cooperation along the value-chain.

What Customers customers can take away for Product Design

For customers, the main takeaway is that end-of-product use should be considered already at the product design and material selection stages. Cellulosic fibers can support applications where biodegradability, compostability, recyclability, or reduced risk of persistent pollution are relevant.

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Cellulose fibers in the natural cycle

Cellulose is a major component of plant biomass and one of the most abundant polymers produced in nature. Natural recycling by biodegradation is indispensable to natural material cycles. Natural polymers are thus inherently biodegradable.

The cellulose cycle forms the basis for Lenzing's business model and provides opportunities to address some of the most challenging societal topics.

Regenerated cellulose fibers, like fibers from Lenzing, are produced from natural cellulose in an industrial process. Figure 1 shows that two groups of fibers consist of unmodified natural polymers: natural fibers and regenerated cellulose fibers. Both groups of fibers are inherently biodegradable. Other fiber types can be difficult to biodegrade, such as the conventional fossil-based synthetics like PET (polyethylene terephthalate), some biosynthetic fibers like bio-based polypropylene (PP) and bio-based polyester (PET), and some semi-synthetic fibers made from chemically modified natural polymers like cellulose acetate. For a systematic overview of fiber biodegradation, see the compilation of "Biodegradable Polymers in Various Environments" collated by the Nova-Institute[2].

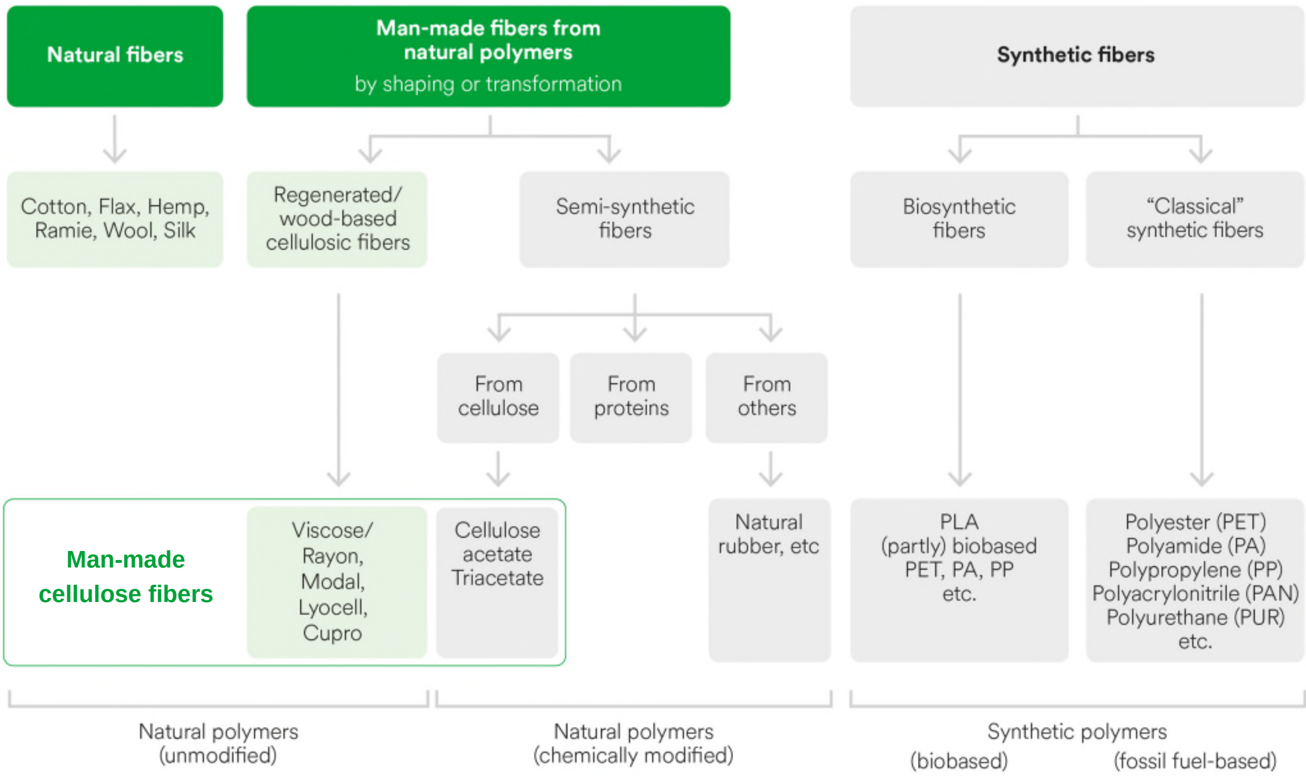

Figure 1: Fibers on the world market

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The cellulose cycle forms the basis for the regenerated cellulose fiber industry and in particular for Lenzing's business model. It provides opportunities to address some of the most challenging issues that society is currently facing, such as climate change or emerging circular economy options. Regenerated cellulose fibers like LENZING™ fibers (viscose (CV), modal (CMD) and lyocell (CLY)) form part of a closed natural material cycle called the "cellulose cycle". Cellulose has been part of the ecosystem since plants exist, and hence our planet is used to dealing with it.

The cellulose cycle has also the potential to provide products with a low carbon footprint for industry, provided that the wood comes from sustainably managed forests. Sustainable forest management can make[3] sure that the amount of wood harvested is always less or equal to the amount of wood growing. In this way, the amount of carbon removed from the forest is at least always balanced out by the same amount of carbon uptake from the atmosphere.

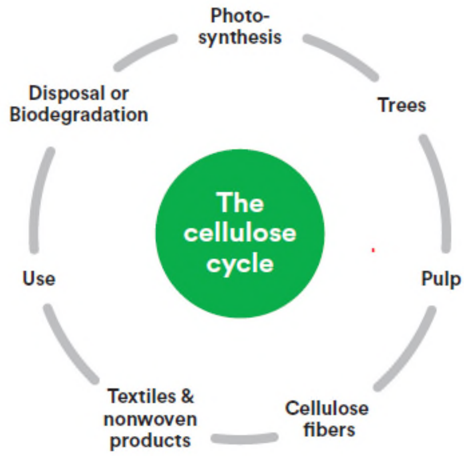

Figure 2: The cellulose cycle

Biodegradability and compostability

It has been recognized in various reports that the increased use of biodegradable fibers would help to reduce emissions of microplastics[36, 4, 5]. Government initiatives, such as the EU Plastics strategy, are addressing the issues of plastic consumption and pollution.

These government initiatives include options for substitution with renewable, biobased and biodegradable polymers[6]. Fibers and other materials made from cellulose fulfill this requirement. If produced without using or retaining any substances of concern, cellulose-based fibers can be safely biodegraded[36]. The transition from non-biodegradable plastics to biodegradable materials will require a change in waste management, with new systems for collection, sorting and treatment installed in order to enable a circular flow via innovative (bio-) materials[36, 6]. Cellulose is the polymer from which all LENZING™ fibers are manufactured[1]. As such, nature is well equipped to break it down, as the material has to be biodegradable in order to maintain the biological cycles. As cellulose fibers derived from the basic raw material of wood, LENZING™ fibers form part of this natural material cycle[1].

[1] LENZING™ fibers which are TÜV certified as biodegradable (soil, fresh water & marine) and compostable (home & industrial) include the following products: LENZING™ Viscose Standard textile/nonwovens, LENZING™ Lyocell Standard textile/nonwovens, LENZING™ Modal Standard textile, LENZING™ Lyocell Filament, LENZING™ Lyocell Dry and LENZING™ Nonwoven Technology. An exception in certification exists for the LENZING™ Lyocell Filament fiber, for which the necessary tests to confirm biodegradability within a marine environment have not been conducted.

A contribution to the solution – biodegradable and compostable fibers from Lenzing

The main raw material for LENZING™ fibers is wood. In 2016 and 2018, a range of LENZING™ fibers were tested for biodegradability at the independent research laboratory Normec OWS in Belgium, one of the world's leading biodegradability and compostability testing companies. The assessment was performed in accordance with existing and applicable international standards, reflecting all relevant natural and artificial environments where biodegradation can take place (Figure 3: Biodegradation of fibers in various environments).

Speed of biodegradation (+ to –)

Environment	Temperature conditions	Biodegradability of TÜV certified LENZING™ fibers[b]	Reference
Industrial composting		✓	EN 13432, ISO 14855
Home composting		✓	EN 13432, ISO 14855
Soil		✓	EN 13432, ISO 14855
Freshwater		✓	EN ISO 14851
Marine water		✓	ASTM D6691

a) Modified from: EMAF, 2017, after B. de Wilde, 2013. industrial composting and home composting are controlled environments designed for waste management. The tests in soil, freshwater and marine water environments simulate the fate of litter in respective environments.

b) LENZING™ fibers which are TÜV certified biodegradable (soil, fresh water & marine) and compostable (home & industrial) include the following products: LENZING™ Viscose Standard textile/nonwovens, LENZING™ Lyocell Standard textile/nonwovens, LENZING™ Modal Standard textile, LENZING™ Lyocell Filament, LENZING™ Lyocell Dry and LENZING™ Nonwoven Technology. An exception in certification exists for the LENZING™ Lyocell Filament fiber, for which the necessary tests to confirm biodegradability within a marine environment have not been conducted.

Figure 3: Biodegradation of fibers in various environments (graphics after de Wilde 2013)

Certificates from the international certification organization TÜV AUSTRIA indicate that LENZING™ TÜV certified biodegradable and compostable fibers quickly biodegrade within the time limits of the standards and in all of their test environments (soil, freshwater, marine, home and industrial compost[2]).

Figure 4: Certificates TÜV AUSTRIA

[2] LENZING™ fibers which are TÜV certified as biodegradable (soil, fresh water & marine) and compostable (home & industrial) include the following products: LENZING™ Viscose Standard textile/nonwovens, LENZING™ Lyocell Standard textile/nonwovens, LENZING™ Modal Standard textile, LENZING™ Lyocell Filament, LENZING™ Lyocell Dry and LENZING™ Nonwoven Technology. An exception in certification exists for the LENZING™ Lyocell Filament fiber, for which the necessary tests to confirm biodegradability within a marine environment have not been conducted.

A list of tests which are carried out for obtaining TÜV certificates can be found in this table. More information on the tests can be found in the annex under "How are tests for biodegradation and compostability carried out?".

Table 1: List of tests carried out to obtain TÜV certificates

Chemical characteristics - Heavy metals, fluorine, volatile solids and ash content analyses
Biodegradation (chemical degradation) • Compost (ISO 14855, EN 13432) • Water (fresh: ISO 14851 & marine: ASTM D6691)
Disintegration (physical degradation) • Compost (ISO 20200) • Water (fresh: ISO 14851 & marine: ASTM D6691)
Ecotoxicity (effects on model organisms that are representative for the respective environment) • Compost (ISO 13432) • Water (fresh & marine: OPPTS 850.1010 & OECD 202)
Landfill (ISO 15985 & ASTM D5511)

Example OK Compost

TÜV certified fibers from Lenzing for textile applications (viscose, modal, lyocell) and nonwoven applications (viscose, lyocell) have earned OK Compost certification from TÜV AUSTRIA.
The OK Compost certificate requires the following tests:

- biodegradation
- disintegration
- ecotoxicity
- chemical characterization / heavy metals content

Apart from biodegradability and compostability standards, however, there is no standardized test available for the performance of materials in landfill, as the conditions in landfills can vary significantly between extremes of factors such as temperature, humidity and oxygen availability. As a result, laboratory tests are not representative of real situations. Moreover, in terms of recognized waste hierarchy, landfill is the least preferred waste management option.

Example OK biodegradable Marine

Table 2 shows the components of the testing process for obtaining the certification OK biodegradable Marine.

Table 2: Test components for obtaining the certification OK biodegradable Marine

Test	**Norm/s**	**Testing requirement**	**TÜV certified biodegradable and compostable LENZING™ fibers**
Marine Aerobic Biodegradation	ASTM DD6691 (2009)	90% of testing material must be biodegraded within 6 months in seawater under laboratory conditions.	✓
Marine Aerobic Disintegration	ASTM D6691 (2009)	90% of testing material must be disintegrated within 12 weeks (=84 days) according to TÜV AUSTRIA Standard and pass through a 2mm sieve.	✓
Ecotoxicity: Aquatic invertebrate acute toxicity test with Daphnia magna	OPPTS 850.1010 (1996) OECD 202 (20049)	Less than 10% of an aquatic organism (Daphnia) should be affected when they are put in water containing the tested material in a 0.1% concentration.	✓
Chemical Characterization (heavy metals including cobalt) and fluorine, volatile solids and ash content)	EN 13432 (2000) EN 13432, ISO 17088 and ISO 18606	Heavy metals content in ppm Zn ≤ 150 CU ≤ 50 Ni ≤ 25 Cd ≤ 0.5 Pb ≤ 50 Hg ≤ 0.5 Cr ≤ 50 Mo ≤ 1 Se≤ 0.75 As ≤ 5 Co ≤ 38 Fluorine ≤ 100 Volatile solids content must be >50% on total solids content	✓ Compliant with EN 13432

Scientific studies confirm the biodegradability of regenerated cellulose

Regenerated cellulose fibers, biodegradability and microplastics

A literature review by Pasterk et al., (2024; Wood K Plus Vienna) gives an overview of the discourse about microplastics, marine pollution, and the position of regenerated cellulose fibers. It clarifies the terminology and polymer composition of common textile and nonwoven fibers, especially the distinction between natural fibers, man-made fibers from natural polymers, and synthetic fibers. The review of studies on biodegradation of regenerated cellulose materials reveals about man-made / regenerated cellulose fibers the "consensus […] that these fibers are biodegradable in all natural environments and suitable industrial settings." in a time range between a few weeks to 6 months. Synthetic fibers hardly degrade at all in this time frame but take decades to centuries.

The recycling of cellulose in nature via biodegradation is therefore indispensable for the carbon cycle. It is known that cellulose in both natural (such as in trees and leaves) and regenerated (such as in viscose and lyocell fibers) forms is degradable via the same enzyme systems of microorganisms[7]. As a result, materials of both origins are biodegradable due to their cellulosic backbone. The biodegradation of regenerated cellulose materials from various producers has been investigated and presented by numerous scientific groups and has been demonstrated in different environments such as wastewater treatment plants[8,9], anaerobic digestors[10], soil[11], compost[12], landfill[13], freshwater[14] and sea water[15].
For a recent review of regenerated cellulose biodegradability, with special focus on marine pollution, see the box, and Reference [16].

Research cooperations supported by Lenzing show that regenerated cellulose biodegrades similarly to natural cellulose, while marine studies highlight the clear difference between cellulose-based materials and plastics[17], [18], [19].
For more information on the conducted studies, please see the chapter "Research cooperations on biodegradation" below.

Applications of LENZING™ fibers where biodegradability plays a role

Let us take a look at a few of the main categories in which biodegradability is essential. This is a topic of relevance for many other applications.

Flushable moist toilet tissues

Flushable wipes require appropriate product design and dispersibility

The improper disposal of materials such as wipes and menstrual products in toilets causes considerable damage to sewer systems every year. Pumping stations become blocked and plastic elements in the wastewater cannot biodegrade. A comprehensive study by Water UK65 shows that the majority of recovered sewer blockage material comprises non-flushable wipes that were not designed to be flushed and should not have been disposed of via the toilet.

Thanks to the right fabric forming and binding technologies, wipes consisting of LENZING™ Lyocell Shortcut fibers with Disperse technology combine both features: high strength during usage, and high dispersibility and biodegradability after flushing down the toilet.[3]

LENZING™ for Hygiene Products

Regenerated cellulose fibers can support hygiene applications with demanding end-of-use needs

Currently the majority of single-use menstrual products and diapers consist of a high percentage of synthetic fibers, aside from their packaging which very often is also fossil-based. Unfortunately, a significant portion of these products ultimately finds its way into landfills after a few hours of use. To put this into perspective, conventional menstrual pads can take anywhere from 500 to 800 years to fully decompose, and it is projected that an individual will use between 5,000 to 15,000 pads and tampons throughout their menstruating years.[20] While reusable alternatives exist for both menstrual products and diapers, accessibility may be hindered by factors such as limited access to running water, a high upfront cost, cultural taboos around menstruation or others. For these cases it is necessary to develop alternatives from natural fibers which have the same properties for their use but additionally are also biodegradable or compostable. The lack of legal consensus regarding the composting of these products in municipal composting facilities poses an additional barrier. This uncertainty stems from concerns over potential contamination with human pathogens and associated hygiene risks, making biodegradability currently the most viable solution to address this issue.

In 2023 the Korean brand Yejimiin offered menstrual products with low carbon VEOCEL™ fibers[4]. Lenzing is collaborating with the French diaper brand Mundao, which have created a fully compostable diaper and also work together with day cares to collect the used diapers and transform them into organic fertilizer, adding extra benefit for a future circular economy.

LENZING™ for Packaging

Regenerated cellulose fibers can support selected packaging applications

The packaging concept employing LENZING™ Modal fibers for fruit and vegetables is an innovative solution available for avoiding plastic. 100 percent LENZING™ Modal fibers are used to produce knitted nets, which

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[3] Wipes composed of wood pulp combined with LENZING™ Lyocell Shortcut fibers and / or LENZING™ Lyocell Fine Shortcut fibers, produced by Lenzing AG in a demo room center and converted in machine supplier; have been tested by SGS laboratory in Wisconsin under the IWSFG protocol, confirming that the fabrics and the fibers are compatible to be used in flushable products and are safe for the wastewater infrastructure they arrive at.

[4] VEOCEL™ collaborates with beauty and feminine care brands to launch carbon neutral products in Asia Pacific

decompose within eight weeks and can be disposed of quite easily with other organic waste.[5] Accordingly, onions, potatoes and beetroot are now being packaged in botanic nets, which are currently available in shops in Austria, Switzerland and the UK.

LENZING™ for Agriculture –solutions for agriculture and aquaculture

Agriculture and aquaculture applications need materials suited to environmental exposure

Enabling eco-responsible consumption and avoiding plastic waste: #ItsInOurHands campaign for biodegradable wet wipes

The eco-responsible initiative #ItsInOurHands celebrated its first anniversary in 2020. The initiative, launched by the VEOCEL™ brand in cooperation with eco-pioneers such as Plastic Free World, succeeded in driving awareness and facilitating debate about the presence of fossil-based plastics in hygiene products. It has taken a leadership role in promoting sustainable solutions and responsibility in the nonwovens industry. The movement invites brands, organizations, influencers, consumers, experts and public figures to share facts and discuss solutions to make our daily lifestyle sustainable in the future at www.ItsInOurHands.com and on social media.

Even before the implementation of Directive 2019/904 (EU Single-Use Plastics Directive), the VEOCEL™ brand and the #ItsInOurHands initiative were providing consumers with guidance on making conscious buying decisions.

In 2024, VEOCEL™ marked the four-year anniversary of the #ItsInOurHands initiative on Earth Day, underscoring the company's long-standing commitment to eco-responsible solutions.

Agriculture uses 6.5 million tons of plastic products per year worldwide[21]. Since many of the applications are used only for a short time and are highly exposed to harsh weather conditions, uncontrolled losses of plastic material to the environment are a major issue. Due to their property profile, fibers derived from the natural raw material wood are especially suitable for applications in agriculture and marine environments. For growing vegetables and fruit (support strings, ropes, nets and nonwoven fabrics), LENZING™ for Agriculture fibers offer an ecological alternative. A broad spectrum of applications is possible, including weed-control fabrics. Moreover, mussel nets made of LENZING™ for Agriculture fibers have been developed for application in marine aquacultures.

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[5] LENZING™ fibers which are TÜV certified as biodegradable (soil, fresh water & marine) and compostable (home & industrial) include the following products: LENZING™ Viscose Standard textile/nonwovens, LENZING™ Lyocell Standard textile/nonwovens, LENZING™ Modal Standard textile, LENZING™ Lyocell Filament, LENZING™ Lyocell Dry and LENZING™ Nonwoven Technology. An exception in certification exists for the LENZING™ Lyocell Filament fiber, for which the necessary tests to confirm biodegradability within a marine environment have not been conducted.

End-of-use pathways should be selected according to application and infrastructure

Looking at the end-of-life stage for final products manufactured from Lenzing's fibers including clothing, home textiles, technical products, hygiene products and personal care products, there are several processing options:

- Products made from regenerated cellulose fibers can in principle be recycled and reused for fiber production at Lenzing according to Lenzing's patented processes. In practice, at the moment this is shown by the example of LENZING™ fibers leveraging recycled pre-consumer and post-consumer cotton waste within the REFIBRA™ Technology on a commercial scale.
- If recycling is not possible, some textile and nonwoven applications can be composted if all constituents are biodegradable. The BioSinn report (funded by the German Federal Ministry of Food and Agriculture) from the Nova Institute lists such applications – including wet wipes or binding yarns[22]. A range of LENZING™ fibers has been tested to be compostable, fulfilling the requirements for compostability in terms of biodegradability, disintegration and the absence of ecotoxicity[6].
- Alternatively, for certain products it may be appropriate to use anaerobic digestion with energy recovery (biomethane production) in waste treatment.
- If composting is not an option, final products can be incinerated and the embedded energy recovered. Since the fibers consist of natural polymer originating from sustainably managed forests, only the amount of biogenic carbon that was stored in the plant is released (see Figure 7). Either way, both composted materials and biogenic carbon emissions from waste-to-energy provide input for plant growth, thereby closing the natural carbon cycle.

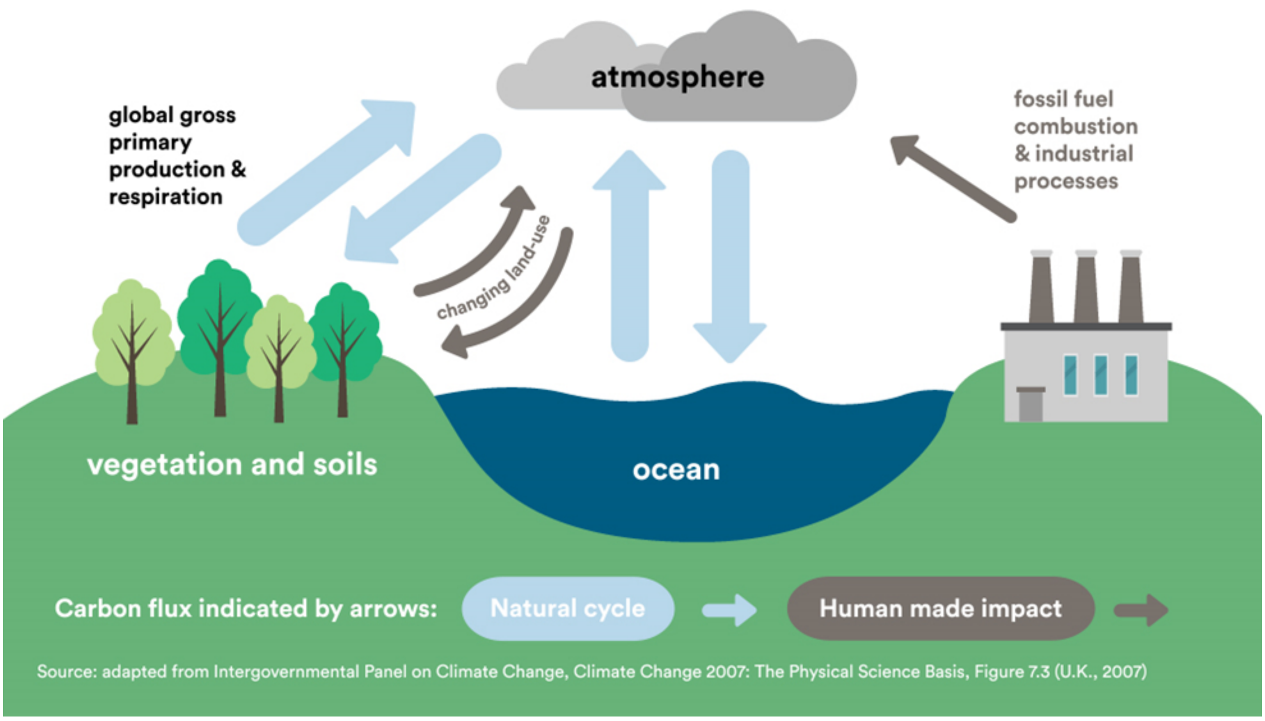

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Figure 5: Natural carbon cycle

- The least preferable option for materials' end-of-life is landfill, which is still a regular practice in many countries. While this option has to be phased out as soon as possible, Lenzing's cellulose fibers which are TÜV certified for biodegradability can biodegrade without releasing microplastic or toxic substances if conditions in the landfill favor biodegradation.
- The disposal of materials made of TÜV-certified LENZING™ fibers[6] after use does not contribute to persistent environmental pollution, unlike fossil-based plastics. LENZING™ TÜV certified fibers[6] can be recycled, composted via home and industrial composting, biodegraded in soil, fresh water and marine environments (natural recycling) or incinerated for energy recovery without releasing toxic substances.

Recycling of materials

REFIBRA™ technology supports circularity through recycled cellulose content

Lenzing takes the progress of the circular economy – and specifically recycling – very seriously. Its proprietary REFIBRA™ technology is an essential step towards creating a circular economy for cellulose fibers on an industrial scale as it allows the manufacturing with recycled content. At this stage, the main sources are cotton scraps from the textile industry, although post-consumer textiles are being increasingly used and there is potential to use nonwoven materials as well.

In addition, LENZING™ fibers themselves can be recycled into fibers through the REFIBRA™ technology. For details and more context relating to the concept of a circular economy, please refer to the "Resource use and circular economy" chapters in the Lenzing Sustainability Report 2024.

Energy recovery (incineration)

Energy recovery may be an option where higher-value pathways are not available

In western European countries such as Germany, Austria or Belgium, household waste (including textiles and wet wipes) is incinerated using energy recovery and state-of-the-art emission control systems. The use of fossil-based carbon sources for burning materials such as fibers contributes to the increase of CO_2 in the atmosphere. Materials made from renewable sources such as cellulose also release CO_2 when burned, but this carbon is part of the natural carbon cycle as utilized by a sustainable circular bioeconomy, which is based on the carbon removal by plants like trees (see Figure 6 and Figure 7). Bio-based fibers from sustainable sources therefore do not release additional carbon into the atmosphere as they are part of a larger natural carbon cycle – because they are made from carbon that is not extracted from fossil sources.

[6] LENZING™ fibers which are TÜV certified as biodegradable (soil, fresh water & marine) and compostable (home & industrial) include the following products: LENZING™ Viscose Standard textile/nonwovens, LENZING™ Lyocell Standard textile/nonwovens, LENZING™ Modal Standard textile, LENZING™ Lyocell Filament, LENZING™ Lyocell Dry and LENZING™ Nonwoven Technology. An exception in certification exists for the LENZING™ Lyocell Filament fiber, for which the necessary tests to confirm biodegradability within a marine environment have not been conducted.

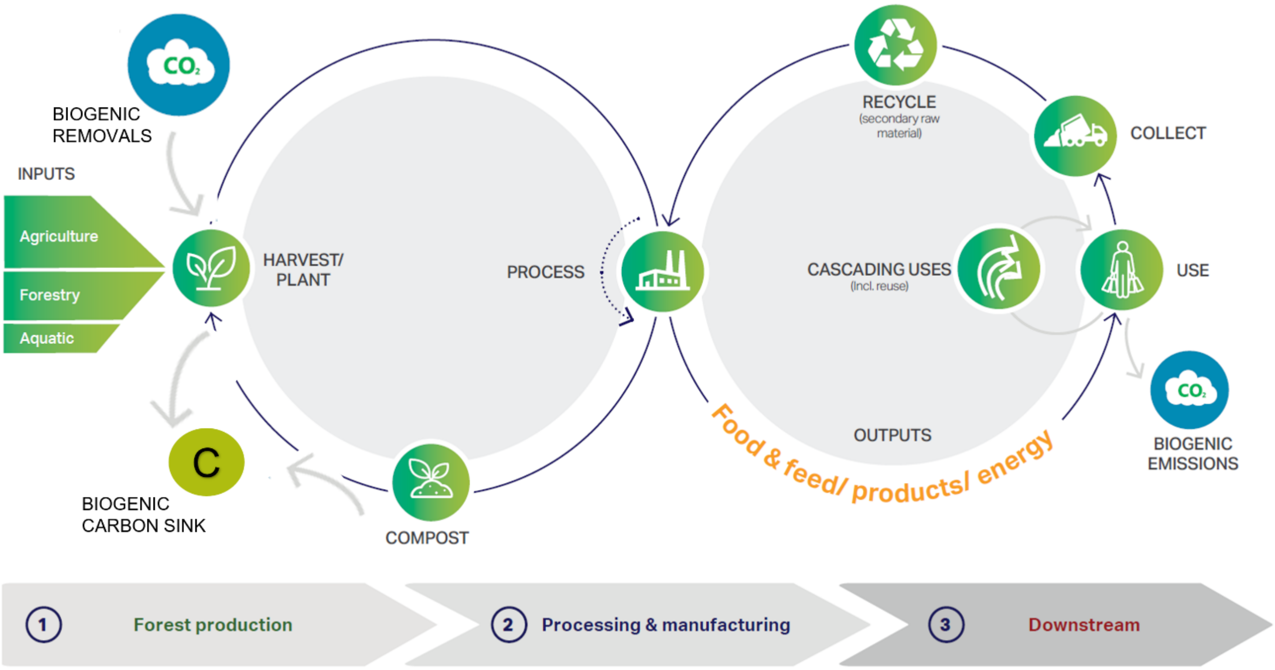

Figure 6: Material flows in a circular bioeconomy.
Modified after: WBCSD. (2020). The Circular Bioeconomy: A Business Opportunity Contributing to a Sustainable World. A business opportunity contributing to a sustainable world | WBCSD

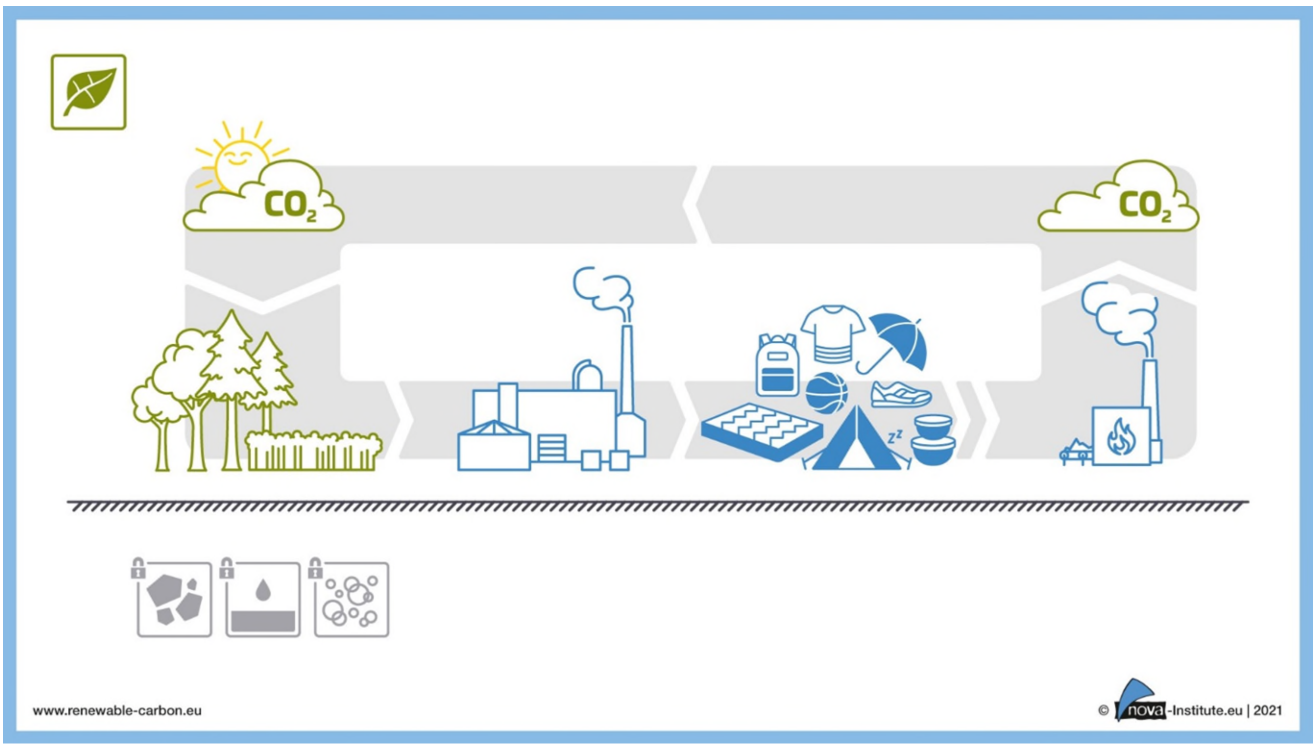

Figure 7: Biogenic waste treatment with energy recovery by incineration as part of the natural cycle – source: nova-institute.eu

Regulatory context and partnerships

European Union Single Use Plastics Directive

EU rules create opportunities for non-plastic cellulosic materials

According to the Directive (EU) 2019/904 (SUPD – single use plastics directive), which aims to reduce the impact of plastic products on the environment, natural polymers that have not been chemically modified are not regarded as "plastic" according to the definition. The Commission guidelines on single-use plastic products in accordance with Directive (EU) 2019/904 clearly state that viscose and lyocell are not considered to be chemically modified and are therefore not classified as plastic. Also, the proven biodegradability of LENZING™ TÜV certified biodegradable and compostable fibers shares the same aim of this Directive, i.e. avoiding plastic pollution. Consequently, the SUPD is a potential catalyst for nonwoven applications of LENZING™ fibers.

Mundao

Mundao shows how compostable diaper concepts can work in practice

In 2023, Lenzing has intensified its cooperation and development with Mundao, a French eco-conscious start-up company, which has developed an industrially compostable diaper. Lenzing has supported the French company with its expertise in biodegradable materials and use of cellulosic fibers. As a result, the diapers, marketed under the brand Popotine, include a range of VEOCEL™ fibers in different components of the diapers. "Popotine" compostable diapers, the first of its kind in the European diaper market, are currently commercialized to child daycare facilities and kindergardens, collected after use by city-bike associations, and repurposed in industrial composting. This end-of life concept offers a sustainable solution for disposable diapers as feedstock for farming compost and for biomass industrial equipment. However, this solution is dependent on national laws and regulations.

NAÏF BABY WIPES

Naïf baby wipes show a plastic-free wet wipe application

In 2024, Lenzing collaborated with Naïf and introduced baby wet wipes made from VEOCEL™ branded lyocell fibers. In comparison to most other wet wipes, Naïf baby wipes are plastic-free, made from cellulose VEOCEL™ fibers using wood as a raw material, and contain only nurturing natural ingredients with no addition of alcohol or per-fume. With this move, LENZING™ and Naïf aim to encourage a change in the industry from fossil-based synthetic fibers to environ-mentally friendly methods, while keeping sensitive baby skin at the forefront.

Glacier protection

Cellulosic geotextiles can help reduce microplastic risks in glacier protection

Glaciers are at risk due to global warming, but an innovative circular concept to protect the ice and snow while minimizing environmental harm has emerged. Traditional methods of glacier protection use synthetic fiber-based geotextiles to help limit ice-melting but contribute to microplastic pollution.

In collaboration with the University of Innsbruck's Institute of Ecology, Austrian glacier tourism, and the Chamber of Commerce (WKO Tirol), a new approach utilized cellulose LENZING™ fiber-based geotextiles, free from synthetic fibers. In a 2023 field trial on Stubai Glacier (Tyrol, Austria), a small area was covered with the new material containing cellulose LENZING™ fibers, saving four meters of ice from melting. The project expanded to other Austrian glaciers and won the first place in the Swiss BIO TOP Award 2023 for wood and material innovations and received the Biodiversity and Water Award at the CNMI Sustainable Fashion Awards 2024.

In 2024, the sheets that covered the glaciers for the summer season were dismantled. After rigorous testing, the material underwent a three-step process of cleaning, drying, and tearing. Lenzing is collaborating with a network of partners like Marchi & Fildi Spa (a specialist in the field of mechanical recycling), Candiani Denim (a denim fabric manufacturer), and Blue of a Kind (an avant-garde fashion studio) to process geotextiles into new fibers. This creates a more sustainable and recyclable approach, as these geotextiles are typically disposed of after two years. In the pilot project's first phase, recycling was successfully tested, resulting and in the production of the "Glacier Jacket".

Research cooperations on biodegradation

Research cooperations strengthen the scientific basis for biodegradation claims

Research cooperations supported by Lenzing show that regenerated cellulose biodegrades similarly to natural cellulose, while marine studies highlight the clear difference between cellulose-based materials and plastics[23], [24], [25]. Find more details in this chapter. In addition, it should be noted that for the biodegradability of a final product such as a piece of garment or wipe, the intrinsic properties of the fiber material used are highly important but are not fully representative of the product itself. Processed products have to be tested and certified in their final form in order to make any claims on biodegradability.

HYDRA Marine Sciences institute

Regenerated cellulose biodegrades like natural cellulose

In 2025, it was reconfirmed by a study from HYDRA Marine Sciences institute[17] that regenerated cellulose fibers biodegrade just as readily as natural cellulose fibers (e.g. cotton). The study combined a total of 122 scenarios across standardized laboratory tests, mesocosm and field experiments, spanning cold-temperate to tropical

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regions as well as temperatures between 0 and 30 °C. All cellulosic fibers exhibited inherent biodegradability, with biodegradation half-lives typically ranging from weeks to months. Regenerated cellulose degraded at rates comparable to native cellulose, indicating no scientifically justified distinction in environmental behavior.

Scripps Institution of Oceanography

Marine studies show a clear difference between cellulose and plastics

Bilateral research is important to Lenzing's approach to scientific collaboration. Noteworthy examples include its collaboration with the Scripps Institution of Oceanography, University of California San Diego, USA, on the biodegradability of cellulose-based materials in a maritime environment since 2019.

Scripps Institution of Oceanography at UC San Diego

"… works to understand and protect our planet, and investigate the oceans, earth, and atmosphere to find solutions to our greatest environmental challenges."

Scripps BIOLOGY, EARTH, OCEANS & Atmospheric sciences

- Climate change impacts and adaptation
- Human health and the ocean
- Resilience to hazards
- Innovative technology to observe the planet

In **2023**, results of a new study conducted by this institute, showed "that polylactic acid, a so-called biodegradable plastic, does not degrade in the marine environment for over 428 days. This was also observed for the oil-based polypropylene and polyester, including their portions in cellulose/oil-based plastic blend textiles. In contrast, natural and regenerated cellulose fibers undergo complete biodegradation within approximately 35 days. The results indicate that polylactic acid resists marine degradation for at least a year, and suggest that oil-based plastic/cellulose blends are a poor solution to mitigate plastic pollution. The results on polylactic acid further stress that compostability does not imply environmental degradation and that appropriate disposal management is crucial also for compostable plastics. Referring to compostable plastics as biodegradable plastics is misleading as it may convey the perception of a material that degrades in the environment."**Fehler! Textmarke nicht definiert.**

A study in **2021** showed that "fabrics containing polyester remained relatively intact with a limited biofilm after more than 200 days in seawater off the Scripps Oceanography pier, in contrast to wood-based cellulose fabrics that fell apart within 30 days."**Fehler! Textmarke nicht definiert.**. In addition, via SEM (scanning electron microscopy) and diameter analysis biodegradation of the wood-based / regenerated cellulose fibers could be proven.

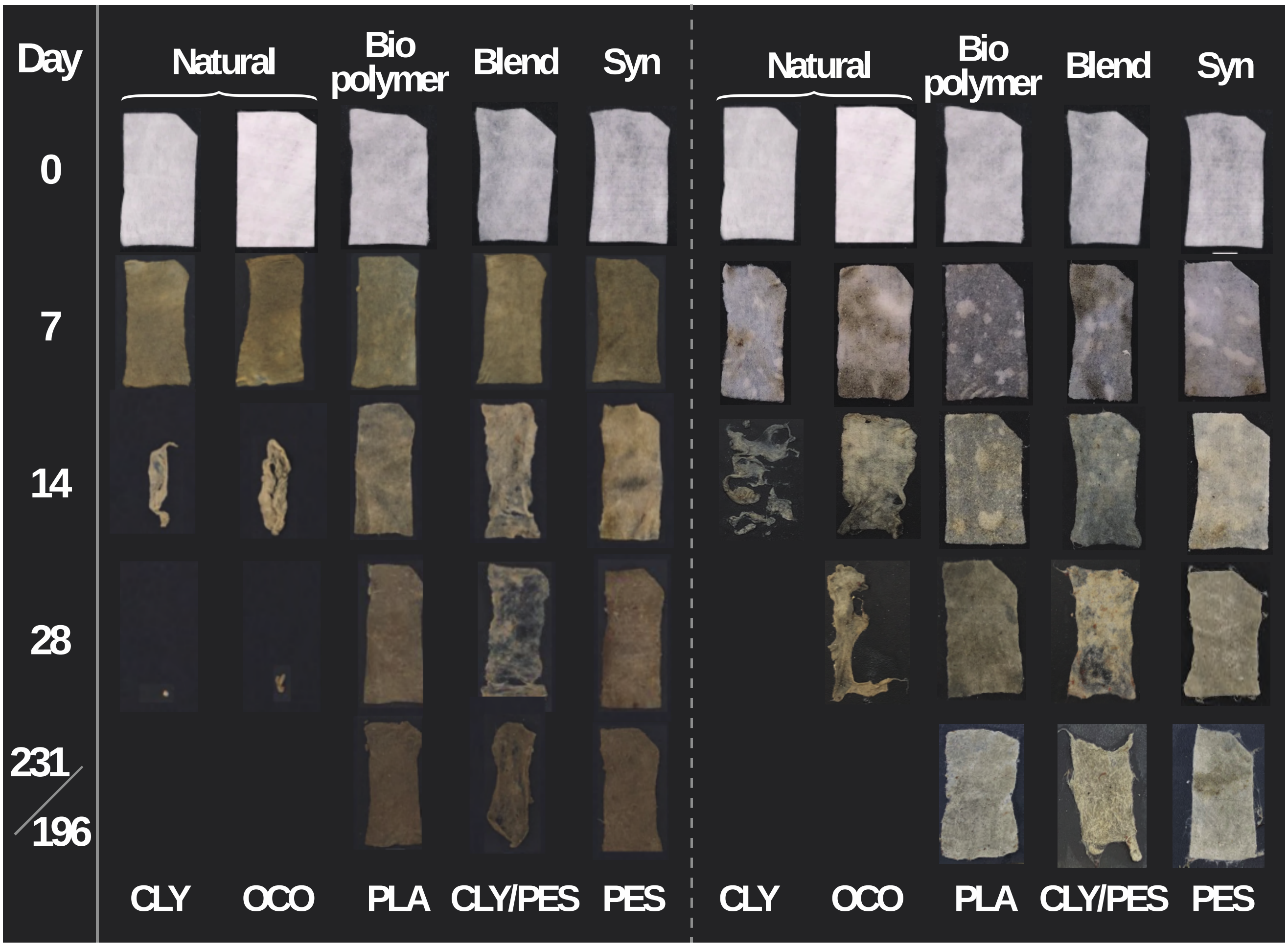

Figure 8: Result ocean surface & ocean floor experiment. CLY, lyocell. OCO, organic cotton. PLA, polylactate. PES, polyester (polyethylene terephthalate).

Normec OWS

Standardized seawater tests confirm biodegradation of certified LENZING™ fibers

In 2016 and 2018, laboratory experiments in seawater according to ASTM D6691 (2009) conducted by Normec OWS show the biodegradation or mineralization of LENZING™ TÜV certified biodegradable and compostable fibers*. (Mineralization is the degradation of biomaterials to their mineral components, mainly CO_2 and water). Additionally, novel research was conducted on the (bio)degradation of different natural, wood-based, bio-based, and synthetic materials in real conditions in the ocean.

* LENZING™ fibers which are TÜV certified biodegradable (soil, fresh water & marine) and compostable (home & industrial) include the following products: LENZING™ Viscose Standard textile/nonwovens, LENZING™ Lyocell Standard textile/nonwovens, LENZING™ Modal Standard textile, LENZING™ Lyocell Filament, LENZING™ Lyocell Dry and LENZING™ Nonwoven Technology. An exception in certification exists for the LENZING™ Lyocell Filament fiber, for which the necessary tests to confirm biodegradability within a marine environment have not been conducted.

Replacing fossil carbon is essential for a sustainable materials industry - The Renewable Carbon Initiative

The chemicals and plastics industries, for example, have very high carbon requirements and are fundamentally dependent on carbon-based feedstocks. In contrast to the energy sector, these industries cannot be "decarbonized" as the molecules will continue to need carbon. However, so far, there is no political strategy for the resource base of these industries. It is therefore crucial to develop a new policy approach to optimize the source of carbon and carbon cycles to reduce the environmental impact and move to more sustainable chemicals and materials.

Lenzing is a founding member of the Renewable Carbon Initiative (RCI), which promotes the replacement of fossil carbon with renewable carbon sources such as sustainably sourced biomass, recycling and CO_2 utilization. Through this collaboration, Lenzing supports discussions on more circular approaches to carbon use in materials.

There are three main leverage points via which the initiative aims to deliver change.

- First, the initiative strives to create cross-industry platforms that will demonstrate the feasibility of renewable carbon.
- Second, another main target will be to advocate legislative taxation and regulatory changes to create a commercial level playing field for renewable carbon.
- Finally, the third avenue will be to create a wider pull for sustainable options by raising awareness and understanding of renewable carbon amongst the business community and the wider public.

Figure 8 illustrates different sources of renewable carbon for manufacturing materials. There are three routes for meeting the carbon demand for materials without extracting additional carbon from the ground: the use of biomass grown in a sustainable way, the recycling of existing materials and the capture and usage of CO_2. Although the focus of renewable carbon is on materials, the production of fuels from these sources is also an option.

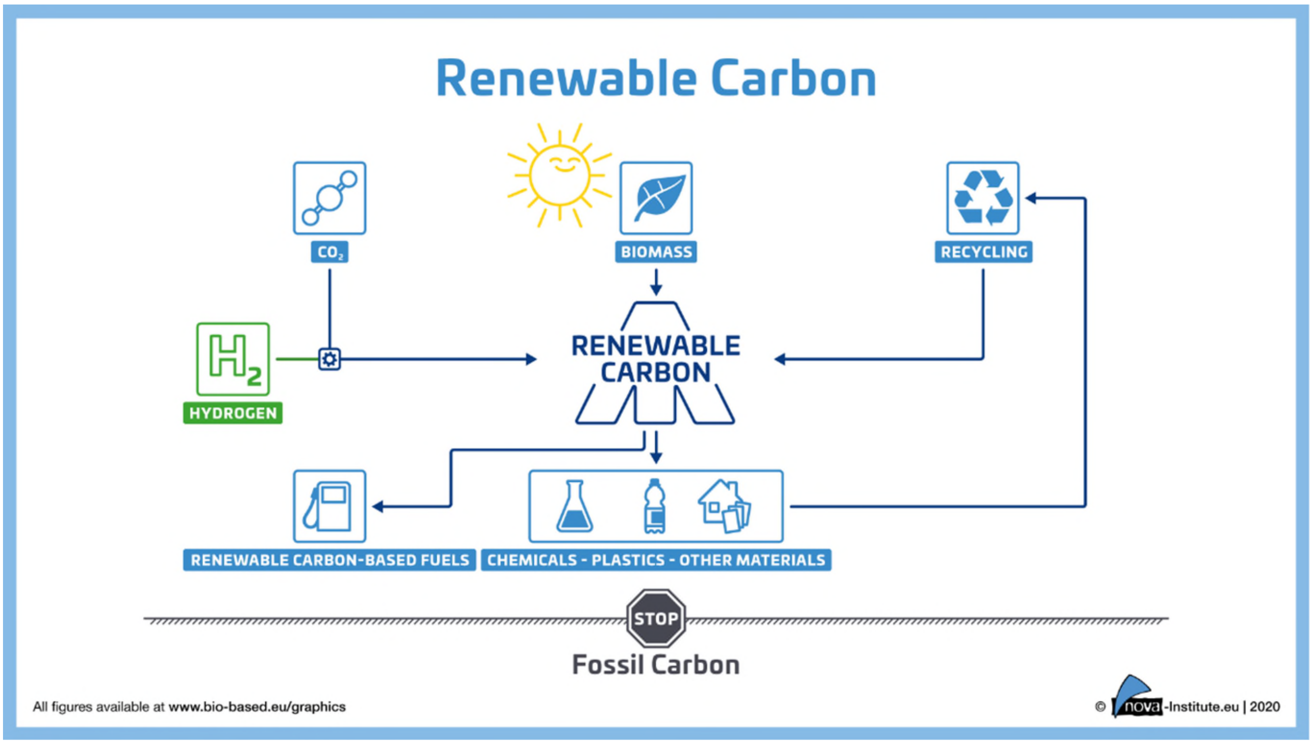

Figure 9: Different sources of renewable carbon, source: nova-institute.eu

The Renewable Carbon Initiative has made a powerful start with eleven international member companies and the personal support of more than 100 industry experts. In the meantime, the number of members has increased to around 80 by 2024 and now includes companies such as Beiersdorf (Germany), BASF (Germany), Cosun Beet Company (the Netherlands), Givaudan (Switzerland), Henkel (Germany), IFF (USA), IKEA (Sweden), Lego (Denmark), NESTE (Finland), TÜV (Austria), Unilever (UK), and UPM (Finland).

We have some problems!

- ➔ On average, every minute, worldwide one garbage truck of plastic is dumped into the ocean[28]
- ➔ On average, every second, worldwide one garbage truck of clothing is landfilled or burned[29, 36]
- ➔ On average, 8 million tons of plastic waste end up in the ocean every year[30, 36]
- ➔ By 2050 there could be more plastic in the ocean than fish[31]
- ➔ Of 53 million tons of fibers produced annually for garments, 12 percent is lost during production and more than 70 percent ends up in landfills as post-consumer waste[32]
- ➔ About 500,000 tons of disposable wet wipes are used in the European Union per year – mostly consisting of plastic[33]

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The impact of fast fashion

In the last 50 years, the consumption of clothing has increased dramatically. In the last 10 years especially, we have seen a rise in so-called "fast fashion". Instead of four seasons of new collections, there are now 50 to 100 "micro-seasons" per year at some retailers[26]. Reduced costs, in the realms of raw materials and labor costs, as a result of mass production have enabled this trend towards fast fashion.

As a result, the use phase of garments is becoming ever shorter and unwanted items are being disposed of more quickly. It is estimated that garments in landfills still have around 70 % of their useful lifespan ahead of them[27]. During the production of textiles, waste is generated in every phase, whether during spinning, weaving, dyeing, production of the garments or at the end-consumer stage. Five percent of all waste that ends up in landfills comes from the textile industry, making it the second largest producer of waste in the world.[28,29,30,31,32 33]

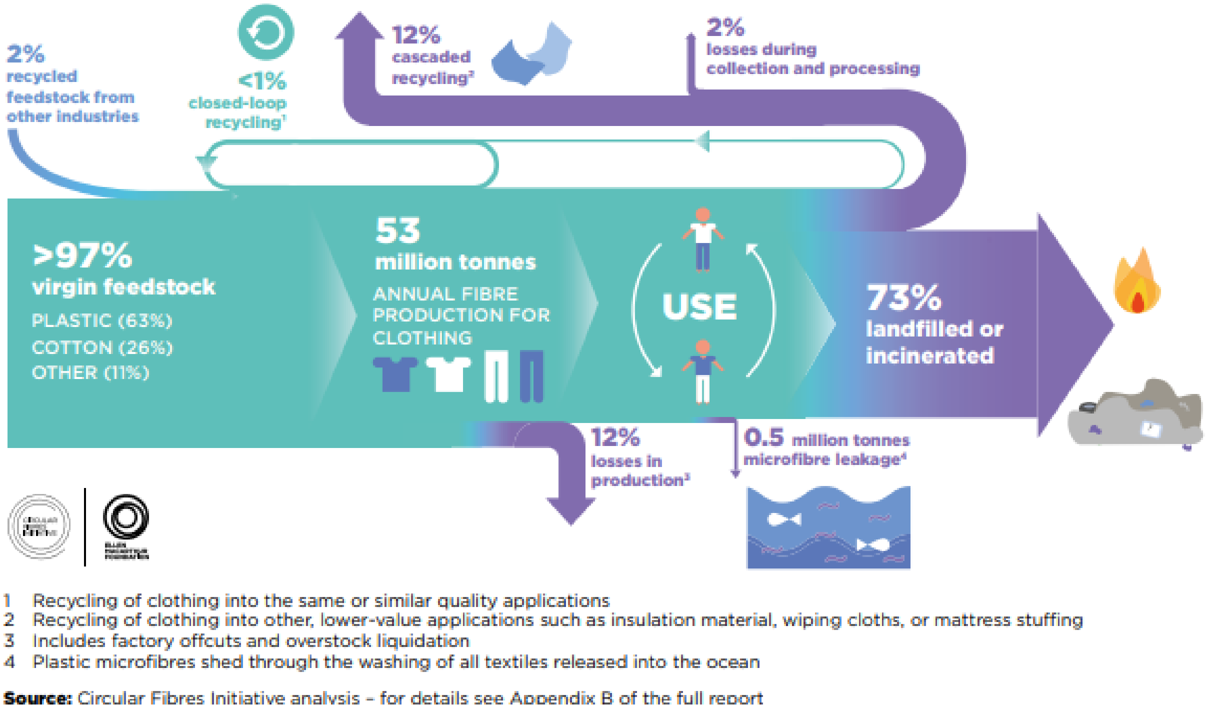

Figure 10: Global material flows for clothing in 2015, source Ellen MacArthur Foundation

But that's not all. According to the European Environment Agency, textile purchases in the EU in 2017 generated about **654 kg of carbon dioxide (CO_2) emissions per person**. It is estimated that the fashion industry is responsible for approximately 10 percent of global carbon emissions and 20 percent of the global water pollution, making it the fourth highest pressure on natural resources after food, housing and transport[34,35]. All of this highlights the importance of reusing already existing garments, either by re-wearing your own garments, swapping with your local community, renting temporarily, or buying second-hand items.

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The impact of plastic litter, particularly in the oceans

Plastics, materials mainly produced from fossil fuels, are described as "the ubiquitous workhorse material of the modern economy"[36] due to their functional properties and cost position. Unfortunately, society has been slow to anticipate the need for dealing adequately with end-of-life plastics. Plastic products are often very short-lived; e.g. about 95 percent of plastic packaging is discarded after the first use, with an estimated loss to the economy of 80 – 120 billion USD annually[36]. Nowadays synthetic fibers, like polyester, acrylic or nylon, make up around 60 percent of textiles for garments and 70 percent of textiles for household items[37]. The production of synthetic fibers from fossil fuels accounts for 1.35 percent of the global oil consumption[38]. Due to a low price for virgin raw material and the limited possibilities of recycling textiles, most of the discarded synthetic textiles are not recycled, but sent to landfills or incinerated. While it is possible to recycle, for example a plastic bottle into fiber for a t-shirt, textile-to-textile recycling is extremely rare at this point, as there is no economic incentive, since recycling is more costly than using virgin materials. The majority of plastics end up in landfill, and approximately 32 percent even end up in the environment. Due to the non-biodegradable nature of most conventional synthetic polymers, plastic litter accumulates when released into the environment. In 2019, 252 million tons of packaging were produced worldwide, the majority of this will be discarded in under 5 years. Packaging accounts for 40 percent of the globally produced plastic[39], but synthetic fibers for textile and nonwovens applications also account for a large amount of plastics production and resulting waste issues. EU consumers discard around 5.8 million tons of textiles every year, which equals approximately 11 kg per person.[40]

One problem area, which has only come into awareness in recent years, concerns the issue of microplastics in the oceans. Society has used the ocean as a convenient place to dispose of unwanted materials and waste products for many centuries, either directly or indirectly via rivers. From a global perspective, little effort has been made to prevent plastics from entering the marine environment. Consequently, a substantial volume of debris has been added to the ocean over the past 60 years, comprising a very wide range of particle sizes (meters to nanometers in diameter). It is truly a global problem. Estimates state that if current trends continue, by 2050 there will be more plastic in the oceans than fish.[36]

Microplastics, plastic particles less than 5 mm in size, constitute a large part of the marine litter problem. These particles can be ingested by organisms in the sea and have the potential to cause negative effects on both physical and chemical pathways, such as blocking the food uptake of animals, enriching toxins in organisms, as well as entering the food chain all the way through to the human consumption of fish. The fiber industry is well aware that microplastics produced from the fragmentation and weathering of fossil-based fiber products can enter the oceans. During the use phase of textiles and due to washing processes, fiber fragments are released from garments and find their way into the oceans. Additionally, personal hygiene products like menstrual products, wipes or diapers, can also release microplastic fibers when disposed in landfills[41]. It is estimated that between 200,000 and 500,000 tons of microplastic from textiles reach marine environments every year[42]. Synthetic fibers make up the highest cause (35 percent) of microplastics in the ocean, followed by car tires (28 percent) and city dust (14 percent)[43]. These microplastic particles can also reach humans, either through the

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food chain or through inhalation. It is estimated that humans ingest 39,000 to 52,000[44] microplastic particles per year, this equals one plastic credit card. The effects of long-term exposure to the human bodies are not yet fully understood.

Glossary

Degradation	Change in properties (tensile strength, color, shape etc.) of a polymer under the influence of one or more environmental factors such as **heat**, **light** or **chemicals** (acids, alkalis or some salts).
Biodegradation	Breakdown of polymers by **microorganisms** (bacteria & fungi) into H_2O, CO_2/CH_4, energy and new biomass. **Biodegradability**: The ability of a material to be broken down by microorganisms (bacteria, fungi) into carbon dioxide, water, and new biomass, or compost, so that it can be consumed by the environment. Conditions must be defined to make the term relevant. Standardized test methods exist for most environments, describing the specific environment and the time permitted [Fehler! Textmarke nicht definiert.].
Compostability	Capability of being biodegraded at certain temperatures (industrial: 58°C; home: 28°C) in soil under specified conditions and timescales. Compostability comprises more than just biodegradability. A product that is compostable is always biodegradable, but a product that is biodegradable cannot necessarily be transformed into good quality compost. To be labeled compostable, certain scientific standards have to be met **Compostability**: When biodegradability takes place under certain conditions such as microorganism population, temperature and humidity, it can be called composting. During this process there are limits for harmful chemical content such as heavy metals and biological testing is done via the assessment of plant growth. A distinction is made between home compost (uncontrolled conditions) and industrial compost (controlled conditions), which achieves much higher temperatures. There are different testing standards available and preferences vary from region to region, with standard EN 13432 being one of the most used. Four requirements are specified in international standards on compostability. Besides biodegradation, disintegration, chemical characteristics, and ecotoxicity (effect on plants) are tested. All tests are performed under defined conditions and within a defined time span. Physical disintegration assesses whether the material breaks down into smaller pieces, which is important for the process and for compost quality. Ecotoxicity testing

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	ensures that no residues with negative effects on plant growth are present after composting. Chemical characterization mainly tests for heavy metals, but also for fluorine, volatile solids and ash content. Industrial composting takes place at elevated temperatures that are typical for industrial facilities, while home composting simulates the situation in garden compost, mostly by using lower temperatures for biodegradation and disintegration. For more details, please see the test details below and descriptions on the Normec OWS website.[45]
Mineralization	Complete breakdown of polymers as a result of the combined abiotic and microbial activity, into CO_2, H_2O, CH_4, H_2, ammonia & other simple inorganic compounds.
Technosphere	The technosphere (also known as anthroposphere) is the part of the environment that is made or modified by humans and includes any technologically derived product manufactured by humanity. It is the youngest of all the Earth's spheres, yet has made an enormous impact on the Earth and its systems by converting more than three-quarters of wild Earth in a very short time by using technology. In contrast to the biosphere, the technosphere is currently highly inefficient at sustaining itself. It is maintained by a flow of material and energy from the geosphere, biosphere, and sun.

Background information

How are tests for biodegradation and compostability carried out?

1. **Chemical characteristics: Heavy metals, fluorine, volatile solids and ash content analyses**

2. **Biodegradation (chemical degradation)**

- **Compost (ISO 14855, EN 13432)**
  The test item is mixed with the inoculum (= stabilized and mature compost derived from organic fractions of municipal solid waste) and introduced into static reactor vessels where it is intensively composted under optimum oxygen, temperature and moisture conditions.

  Through biodegradation, solid C is converted and CO_2 is produced. Gas leaving each reactor is continuously analyzed for CO_2 and O_2 concentrations. The percentage of biodegradation is determined as the percentage of solid C that is converted to gaseous, mineral C in the form of CO_2[7].

[7] A rate of 100% of biodegradation cannot be achieved for this test. A certain amount of carbon is always used by the microorganisms for cell growth and hence cannot be released as CO_2.

Maximum permitted test duration: 6 months (industrial), 12 months (home compost).

Home composting: 28°C
Industrial composting: 58°C

- **Water (fresh: ISO 14851 & marine: ASTM D6691):**
  Samples are placed in bioreactors and the biodegradation is determined by measuring the amount of CO_2 produced and captured in a potassium hydroxide (KOH) solution during the test. The test is considered valid if the reference item cellulose is more than 70% biodegraded at the end of the experiment.

  Maximum permitted test duration: 180 days (marine), 56 days (aquatic).

  Aquatic conditions: 21°C
  Marine conditions: 30°C

3. **Disintegration (physical degradation)**

- **Compost (ISO 20200):**
  The purpose of this test is to evaluate the disintegration of a material at an ambient (home) or elevated temperature (industrial) in compost. The test item is mixed with compost and incubated in the dark. Moisture content is verified and adjusted on a regular basis. At the same time, the compost is manually stirred and the test item is visually monitored. The amount of disintegration is expressed as the percentage of the used test item that passes the 2.0 mm sieve at the end of the test.

  Maximum permitted test duration: 26 weeks.

  Home composting: 28°C
  Industrial composting: 58°C

- **Water (fresh: ISO 14851 & marine: ASTM D6691):**
  This determines the degree of disintegration of test items under laboratory conditions via incubation in seawater. Samples (2 x 2 cm) are placed in reactors which are put on a shaking device and incubated in the dark at a constant temperature (fresh water: 21°C, seawater: 30°C). The remaining residuals are sieved using a 2.0 mm sieve at the end of the test. The amount of disintegration is expressed as the percentage of the used test item that passes the 2.0 mm sieve at the end of the test.

Maximum permitted test duration: 12 weeks (84 days)

4. Ecotoxicity (effects on model organisms that are representative for the respective environment)

- **Compost (ISO 13432):**
  At the end of the composting process, the compost is sieved by means of a vibrating sieve over 10 mm. The compost obtained at the end can be used for further measurements such as chemical and physical analyses and ecotoxicity tests (cress and barley plants). The compost is added to biowaste in a 10% concentration. The germination rate and plant biomass of the test compost should be more than 90% of those from the corresponding blank compost.

- **Water (fresh & marine: OPPTS 850.1010 & OECD 202):**
  The test material is introduced into a chemically defined (mineral) liquid medium and spiked with microorganisms. The immobilization (lack of movement) of Daphnia magna by biodegradation residuals of the test item and/or by the remaining parent compound is determined.
  After 24 and 48 hours, the number of dead and immobilized neonates is recorded.

5. Landfill (ISO 15985 & ASTM D5511):

The biodegradability of products in a sanitary landfill or in a solid-state anaerobic digestion system is determined through high-rate dry anaerobic batch fermentation. This method simulates and accelerates the biodegradation process that takes place in a landfill because it involves stationary (no mixing) and dry fermentation under optimal conditions. The incubation temperature was 37°C.

A small amount of the test item is added to a large amount of highly active inoculum. During the anaerobic biodegradation of organic materials, a mixture of gases, principally methane and carbon dioxide, are the final decomposition products while some of the organic material will be assimilated for cell growth. The volume of the biogas produced is measured and the amount of CH_4 and CO_2 produced per weight unit of test item is calculated.

List of LENZING™ fibers with TÜV certificates

LENZING™ fibers which are TÜV certified biodegradable (soil, fresh water & marine) and compostable (home & industrial) include the following products:

LENZING™ Viscose Standard textile/nonwovens,
LENZING™ Lyocell Standard textile/nonwovens,
LENZING™ Modal Standard textile,
LENZING™ Lyocell Filament,
LENZING™ Lyocell Dry and
LENZING™ Nonwoven Technology.

An exception in certification applies for the fiber

LENZING™ Lyocell Filament

for which the necessary tests to confirm biodegradability within a marine environment have not been conducted.

Annex

List of figures

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