focus paper

End of product use

Issue 02/April 2023

Naturally positive

Lenzing
Innovative by nature

Table of Contents

We have some problems!

- → On average, every minute, worldwide one garbage truck of plastic is dumped into the ocean[2]
- → On average, every second, worldwide one garbage truck of clothing is landfilled or burned[3, 10]
- → On average, 8 mil. tons of plastic waste end up in the ocean every year[4, 10]
- → By 2050 there could be more plastic in the ocean than fish[5]
- → Of 53 mil. 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[6]
- → About 500,000 tons of disposable wet wipes are used in the European Union per year – mostly consisting of plastic[7]

Naturally positive

Lenzing
Innovative by nature

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 -100 "micro-seasons" per year at some retailers[1]. Reduced costs, in the realms of raw materials and labour costs, as a result of mass production have enabled this trend towards fast fashion.

As a result, the usage phase of garments is becoming ever shorter and unwanted items are being disposed of more quickly. 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.[2,3,4,5,6,7]

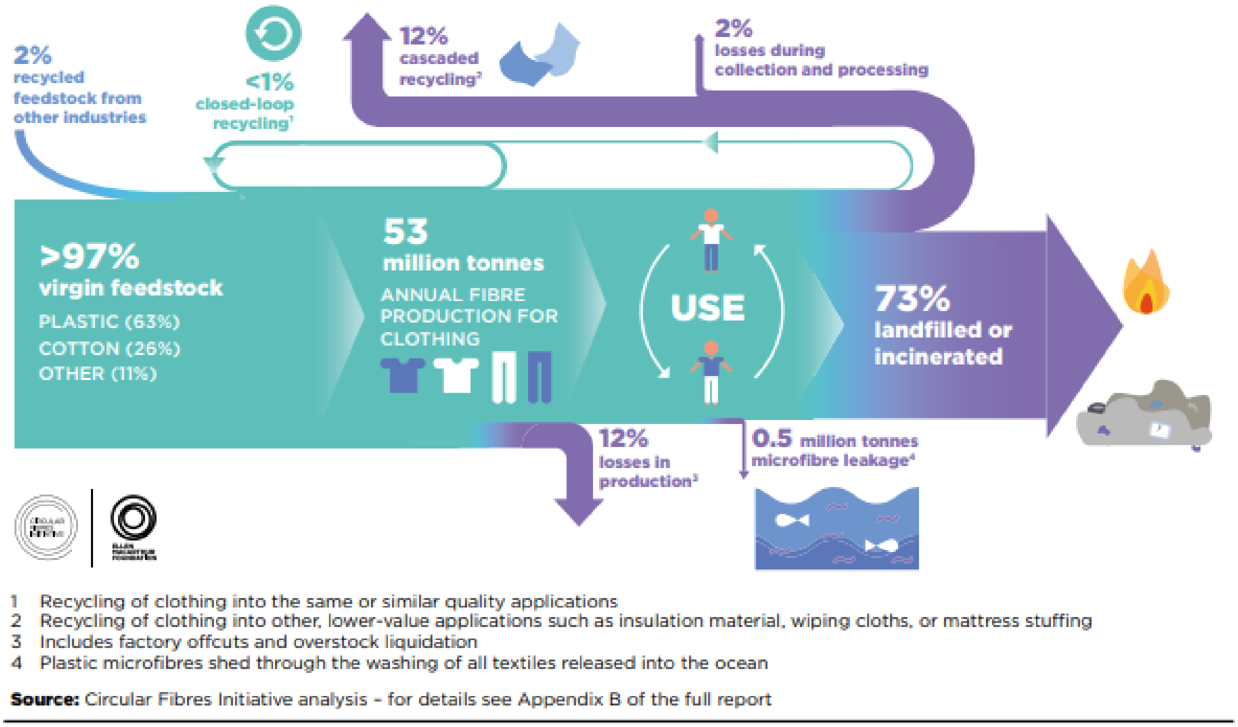

Figure 1: Global material flows for clothing in 2015, source Ellen Mac Arthur Foundation

But that's not all. According to the European Environment Agency, textile purchases in the EU in 2017 generated about **654 kg of 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[8,9].

The impact of plastic litter, particularly in the oceans

Plastics, materials mainly from produced from fossil fuels, are described as "the ubiquitous workhorse material of the modern economy"[10] 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[10]. Nowadays synthetic fibers, like polyester, acrylic or nylon, make up around 60 % of textiles for garments and 70 % of textiles for household items[11]. The production of synthetic fibers from fossil fuels accounts for 1.35 % of the global oil consumption[12]. 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 synthetic polymers, plastic litter accumulates when released into the environment. In 2019, 252 million tonnes of packaging were produced worldwide, the majority of this will be discarded in under 5 years. Packaging accounts for 40 % of the globally produced plastic[13], 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 tonnes of textiles every year, which equals approximately 11 kg per person.[14] Sources and applications of polymers, including plastics and natural polymers, and their fate in the environment are shown in figure 5/4.

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.[10]

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 usage phase of textiles and due to washing processes, fiber fragments are released from garments and find their way into the oceans. It is estimated that between 200,000 and 500,000 tonnes of microplastic from textiles reach marine environments every year[15]. The advantage of synthetic fibers such as polyester and nylon – their durability – then becomes a disadvantage and a major threat to the marine environment.

Cellulosic 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.

Regenerated cellulosic fibers, like the fibers from Lenzing are produced from natural cellulose in an industrial process. Figure 2 shows that two groups of fibers which consist of unmodified natural polymers: natural fibers and regenerated/wood-based cellulosic 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[16].

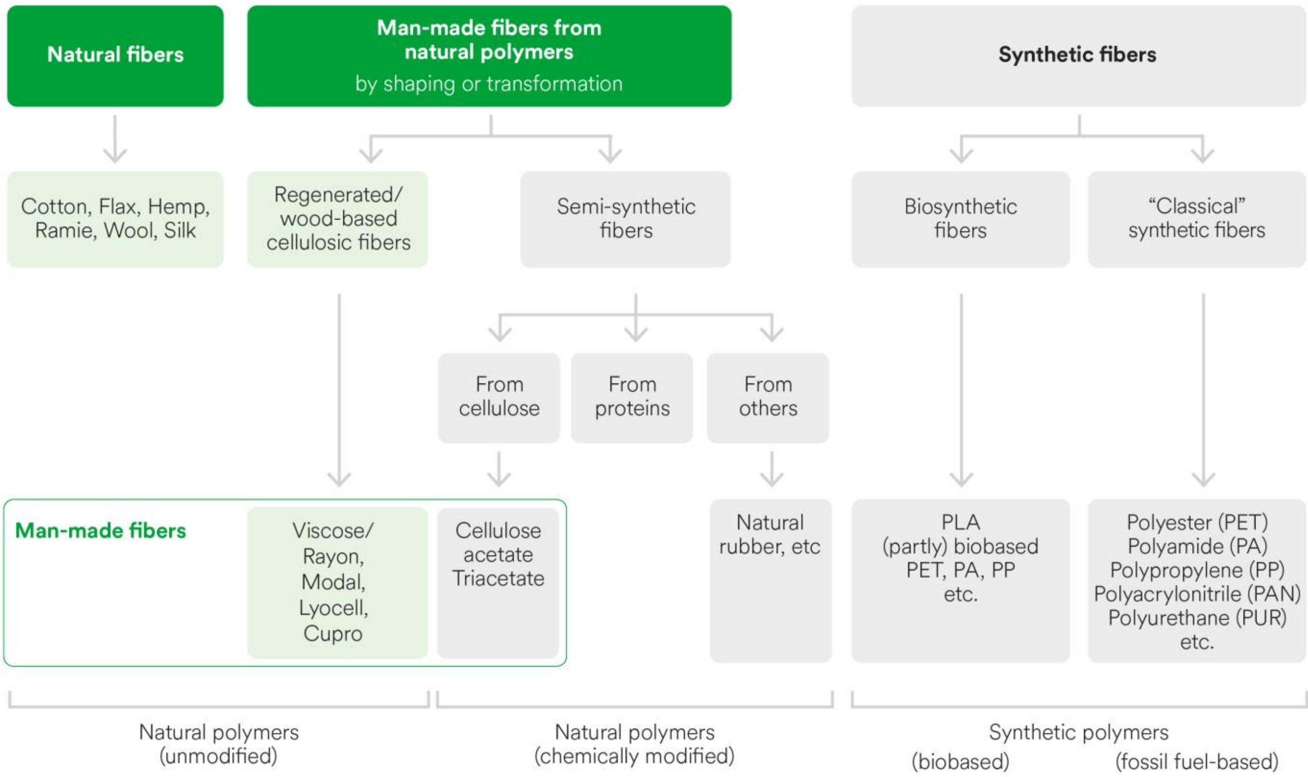

Figure 2: Fibers on the world market

The cellulose cycle forms the basis for the wood-based 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. Wood-based cellulosic fibers like LENZING™ fibers (viscose (CV), modal 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 forms the basis for Lenzing's business model and provides opportunities to address some of the most challenging societal topics.

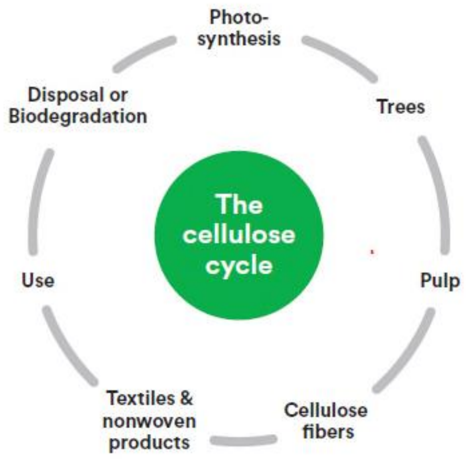

Figure 3: The natural cellulose cycle

The natural cellulose cycle has also the potential to provide climate neutral products for industry, provided that the wood comes from sustainably managed forests. Sustainable forest management makes[17] sure that the amount of wood harvested is always less or equal to the amount of wood growing. Also the amount of carbon removed from the forest is always at least balanced by same amount of carbon uptake from the atmosphere.

Biodegradation of wood-based cellulosic fibers in scientific literature

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[18]. As a result, materials of both origins are biodegradable due to their cellulosic backbone. The biodegradation of regenerated (wood based) cellulose materials from various producers has been investigated and presented by numerous scientific groups and has been demonstrated in different environments such as waste water treatment plants[19,20], anaerobic digestors[21], soil[22], compost[23], landfill[24], freshwater[25] and sea water[26].

End-of-use options for LENZING™ fiber applications

Looking at the end-of-life stage for 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 wood-based fibers can in principle be recycled and reused for fiber production at Lenzing, as shown by the example of LENZING™ fibers – Lenzing leverages 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[27]. 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 eco-toxicity[6].

- Alternatively, for certain products it may be appropriate to use anaerobic digestion with energy recovery (biomethane production) in waste treatment. LENZING™ TÜV certified biodegradable and compostable fibers are fully degradable in controlled anaerobic waste treatment conditions*.
- If composting is not an option, the final products can be incinerated and the embedded energy recovered. Since the fibers consist of natural polymer originating from sustainably managed forests, they are climate-neutral in terms of incineration, which means that only the amount of CO_2 that was stored in the plant is released (see Fig. 4). Either way, both composted materials and CO_2 provide input for plant growth, thereby closing the natural carbon cycle.

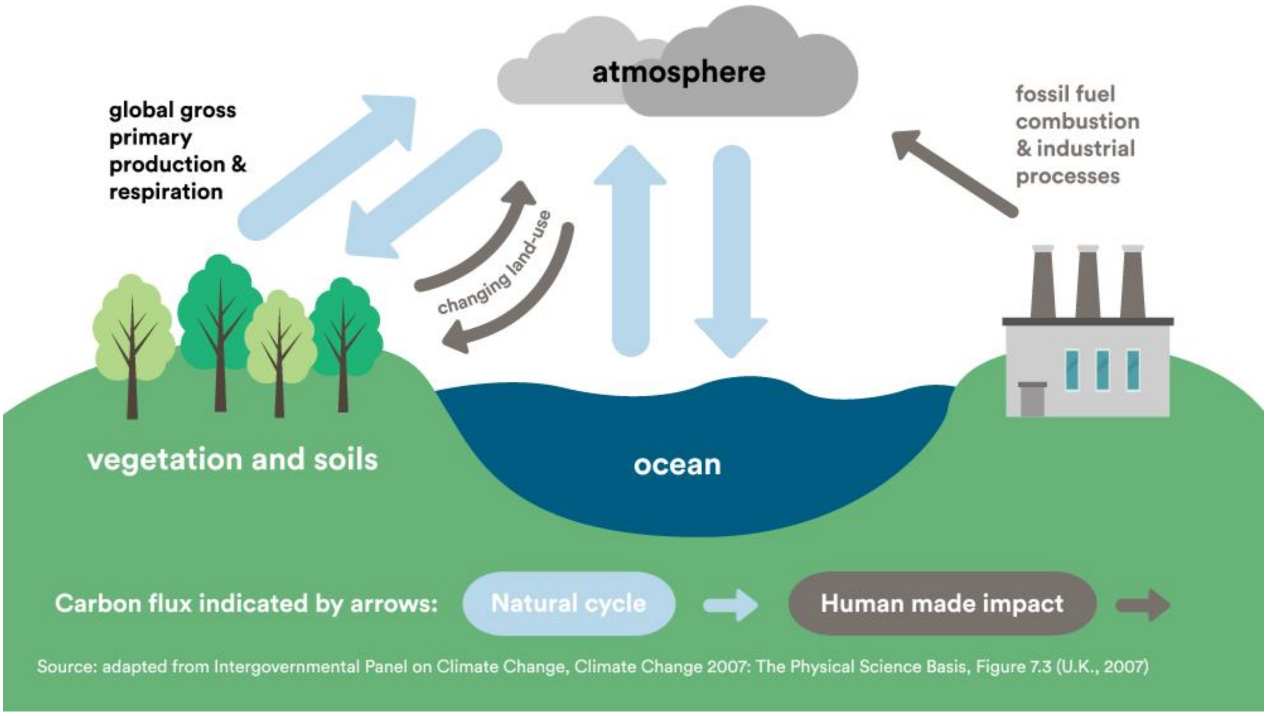

Figure 4: Natural carbon cycle

- 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 cellulosic fibers can biodegrade without releasing microplastic or toxic substances if conditions in the landfill favor biodegradation.
- The disposal of materials made of LENZING™ fibers after use does not contribute to persistent environmental pollution, unlike fossil-based plastics. LENZING™ TÜV certified fibers* can be recycled, biodegraded via home and industrial composting, anaerobic digestion, in soil, fresh water and marine environments (natural recycling) or incinerated for energy recovery without causing any negative environmental impact.

* LENZING™ FR Standard and LENZING™ FR Black are only industrial compostable. LENZING™ Lyocell Filament was not tested for marine biodegradability and LENZING™ Lyocell Dry is not compostable in salt water.

A contribution to the solution – biodegradable fibers from Lenzing

It has been recognized in various reports that the increased use of biodegradable fibers would help to reduce emissions of microplastics[10, 28, 29]. Government initiatives, such as the EU Plastics strategy, are addressing the issues of plastic consumption and pollution.

They include options for substitution with renewable, biobased and biodegradable polymers[30]. 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[10]. The transition from non-biodegradable plastics to biodegradable materials will require a change in waste management, with new systems for collection and treatment installed in order to enable a circular flow via innovative (bio-) materials [10, 30]. Cellulose is the polymer from which all LENZING™ fibers are manufactured. As such, nature is well equipped to deal with it as the material has to be biodegradable in order to maintain the biological cycles. As cellulosic fibers derived from the basic raw material wood, LENZING™ fibers form part of this natural material cycle.

Recycling of materials

Lenzing takes the progress of the circular economy – and specifically recycling – very seriously. Its proprietary Eco Cycle/REFIBRA™ technology is an essential step towards creating a circular economy for cellulose fibers on an industrial scale as it allows the manufacture of lyocell with recycled content, for example. 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 Eco Cycle/REFIBRA™ technology, making them truly circular materials. For details and more context relating to the concept of a circular economy, please refer to the "Circularity and resources" chapters in the Lenzing Sustainability Report 2022.

Natural recycling (biodegradability and compostability)

The main raw material for LENZING™ fibers is wood, while the pulp used for production is sourced from FSC® (FSC-C041246) and PEFC (PEFC/06-33-92) certified and controlled forests and plantations in accordance with the stringent guidelines of the Lenzing Group's Wood and Pulp Policy[31].

A range of LENZING™ fibers was tested for biodegradability at the independent research laboratory Normec OWS (former Organic Waste Systems (OWS)) in Belgium, one of the world's leading biodegradability and composability testing companies. The assessment was performed in accordance with existing and applicable international standards, reflecting most relevant natural and artificial environments where biodegradation can take place (Figure 4).

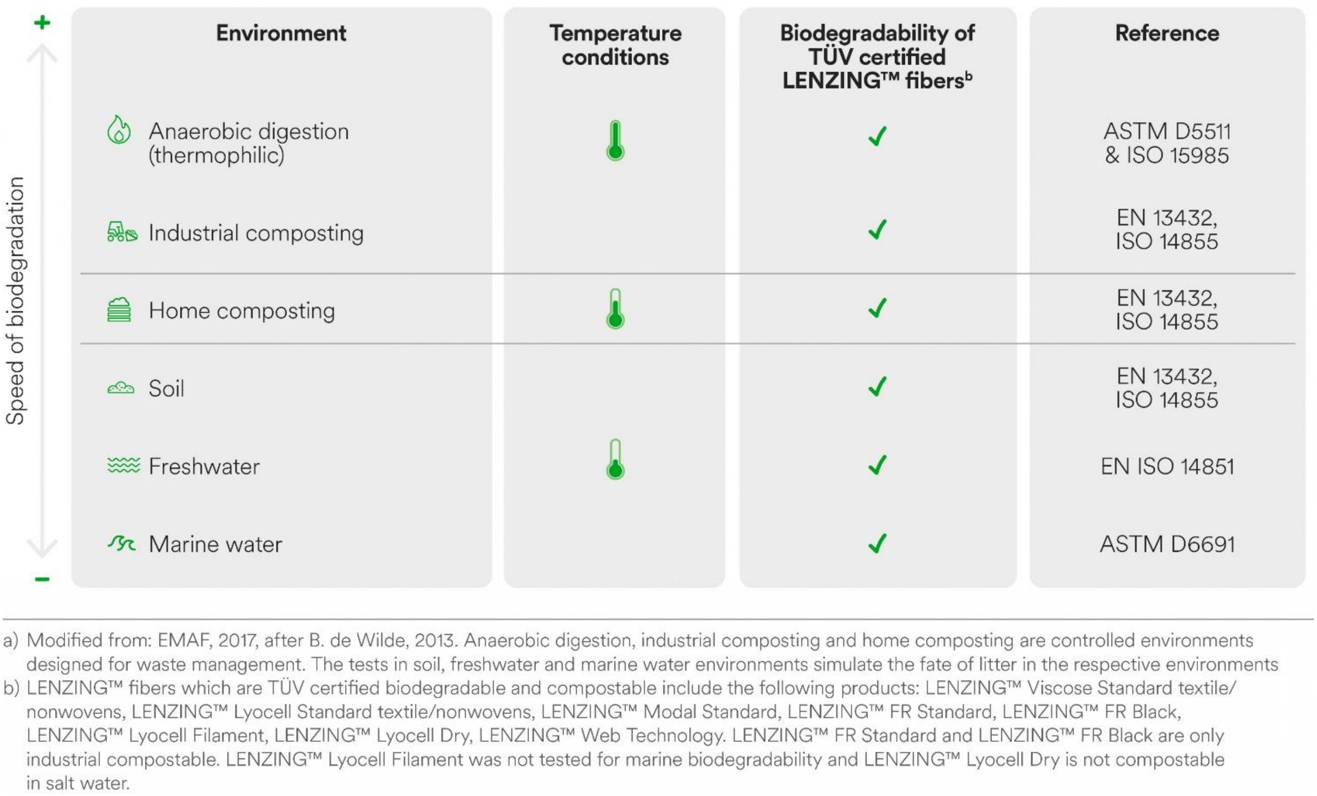

Figure 5: Biodegradation of fibers in various environments (graphics after de Wilde 2013[32])

It has been proven that a range of LENZING™ TÜV certified biodegradable and compostable fibers biodegrade relatively rapidly in all natural environments, including seawater environments, and in industrial waste treatment targeting biodegradation*. TÜV certified fibers from Lenzing for textile applications (viscose, modal, lyocell) and nonwoven applications (viscose, lyocell) have earned OK Compost certification from VINCOTTE, now renamed as TÜV Austria.

The certificate includes

- biodegredation
- disintegration
- ecotoxicity
- chemical characterization

For more details, figure 6 shows the components of the testing process for obtaining certification.

* LENZING™ FR Standard and LENZING™ FR Black are only industrial compostable. LENZING™ Lyocell Filament was not tested for marine biodegradability and LENZING™ Lyocell Dry is not compostable in salt water.

Biodegradability
The ability of a material to be broken down by micro-organisms (bacteria, fungi) into carbon dioxide, water, and biomass, or compost, so that it can be consumed by the environment.

Compostability
Capability of being biodegraded at certain temperatures (industrial: 58°C; home: 28°C) in soil under specified conditions and time scales. Besides biodegradation, physical disintegration, chemical characteristics, and eco-toxicity (effect on plants) are tested.

Test components of the "OK biodegradable Marine" certificate table 5/2

Test	Norm/s	Testing requirement	Standard 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	TS-OK-23 VINÇOTTE standard ASTM D7801 (2012)	90% of testing material must be disintegrated within 12 weeks (= 84 days) according the Vinçotte Standard and pass through a 2 mm 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)	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	✓ Compliant with EN 13432

Figure 5: Test components of the "OK biodegradable Marine" certificate

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.

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, industrial compost, home compost, freshwater and marine*).

Figure 6: Certificates TÜV Austria

* LENZING™ FR Standard and LENZING™ FR Black are only industrial compostable. LENZING™ Lyocell Filament was not tested for marine biodegradability and LENZING™ Lyocell Dry is not compostable in salt water.

Energy recovery (incineration)

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 can be offset by a sustainable circular bioeconomy, including the carbon removal by plants like trees (see Figure 3). 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 – i.e. they are made from carbon that is not extracted from fossil sources.

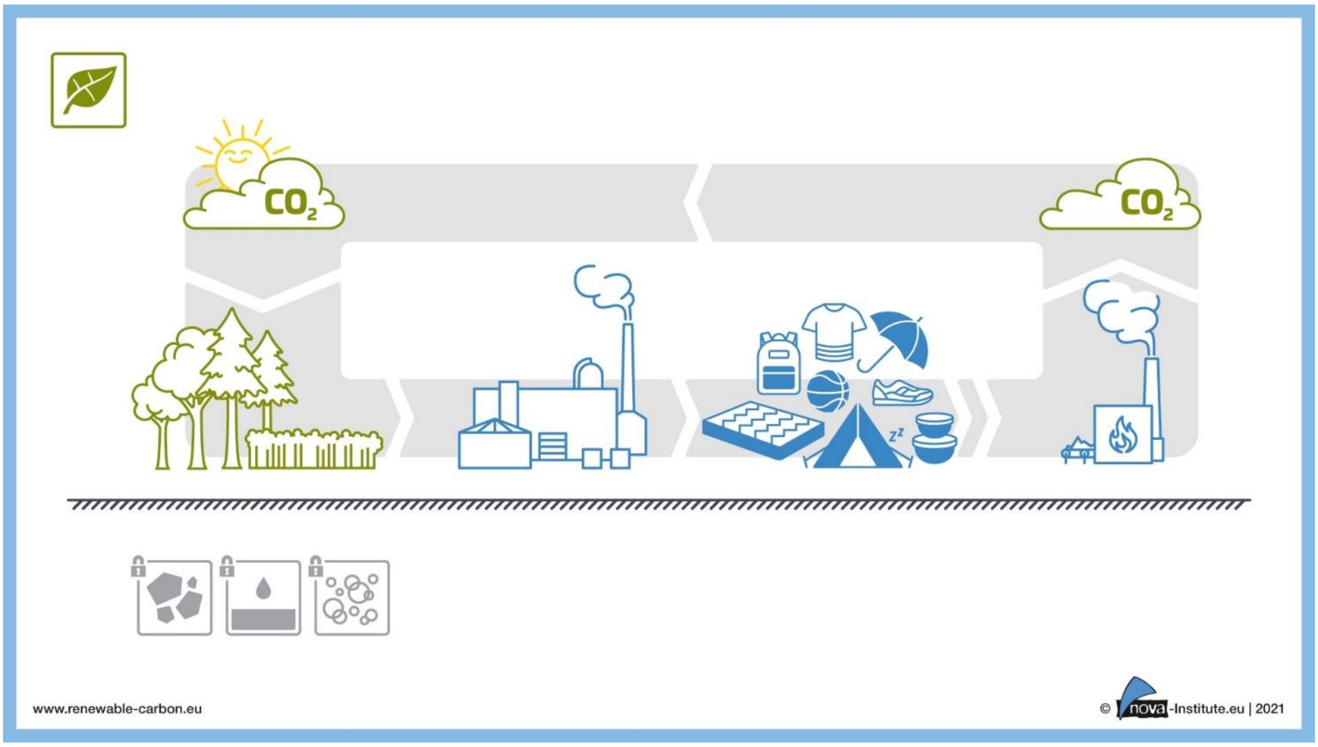

Figure 7: Biogenic waste treatment with energy recovery by incineration as part of the natural cycle – source: nova-institute.eu

Industry transition and consumer education

Lenzing is interested in helping its industry partners to transition products from fossil-based sources into cellulosic solutions, both in daily consumer good products and in textile applications. The textile brand TENCEL™ and the nonwovens brand VEOCEL™ are also key drivers of active consumer awareness programs, such as the initiative for the environmentally responsible consumption of personal care and hygiene products, "#ItsInOurHands".The aim is to divert consumer preference to products made with cellulosic ingredients derived from the natural carbon cycle.

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

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 Eco Disperse technology combine both features: high strength during usage, and rapid disintegration and biodisintegration after flushing down the toilet.

LENZING™ for Packaging

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 decompose within eight weeks and can be disposed of quite easily with other organic waste. For example, 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 uses 6.5 million tons of plastic products per year worldwide. 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.

European Union Single Use Plastics Directive

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 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.

The Lenzing Group collaborates in industry and multi-stakeholder initiatives – including the Microfiber Consortium of the European Outdoor Group, the Cross Industry Agreement of the textile and detergent industries, and the "Textile Mission" project within the German research program on plastics in the environment

Plastik in der Umwelt). Lenzing provides fiber and textile intermediate materials for testing and developing new textile constructions, and gives feedback on drafts of reports and guidance documents.

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: Twenty brands worldwide already feature the VEOCEL™ logo to provide this transparency to their consumers.

Partnerships for systemic change

Research cooperation on biodegradation

Bilateral research is also 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.

Laboratory experiments in seawater show the biodegradation or mineralization of LENZING™ TÜV certified 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™ Lyocell Filament was not tested for marine biodegradability and LENZING™ Lyocell Dry is not compostable in salt water.

It 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.”[33]

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

UC San Diego

- Ranked 6th in the world by Nature for high-quality science research
- $ 1.16 billion in research awards

Scripps Research is global, with investigations into the impact on every continent and in every ocean.

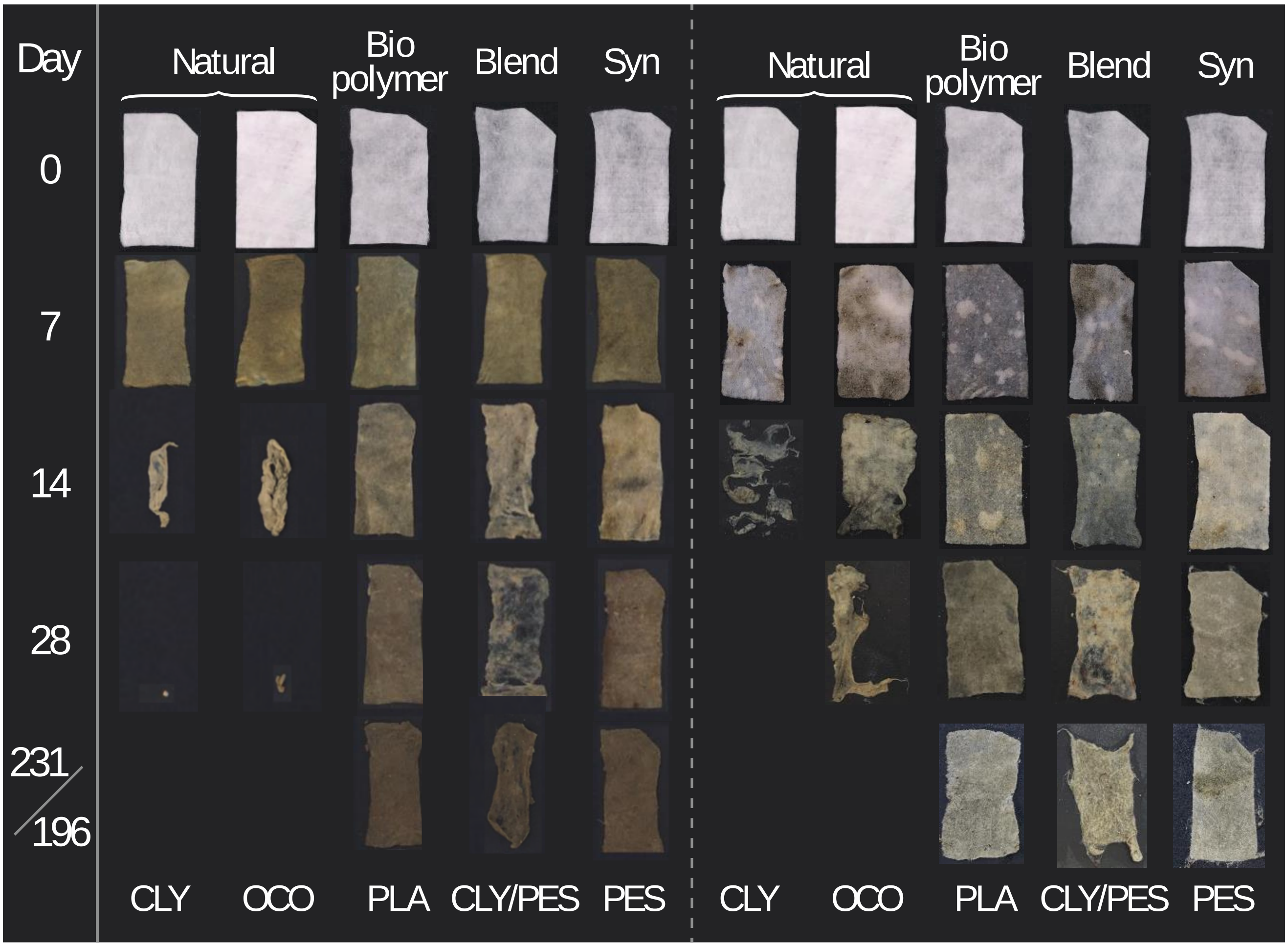

Figure 8: Result ocean surface & ocean floor experiment. CLY, lyocell. OCO, organic cotton. PLA, polylactate. PES, polyester (polyethylene terephthalate).

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. For more details on biodegradable LENZING™ fibers, see the “Circularity and resources” chapter of the latest Sustainability Report.

The Renewable Carbon Initiative

Tackling climate change and environmental pollution are key topics in the European Green Deal published in the Commission’s communication paper in 2019[34]. A major focus is on the energy sector and the shift from fossil based towards renewable energy sources – in this context, decarbonization is a widely known and accepted term. For materials fundamentally based on carbon in their chemical structures, a different situation applies as carbon is the main element. These materials themselves cannot be “decarbonized” in a verbatim sense as they are made up of carbon as a main element. So the potential environmental impact is huge depending on the source of the carbon embedded in these materials.

Lenzing therefore supports the **Renewable Carbon Initiative**, which was founded under the leadership of the nova-Institute (Germany) in September 2020. The RCI paper “Renewable Carbon as a Guiding Principle for Sustainable Carbon Cycles” was published in February 2022[35].

The Renewable Carbon Initiative (RCI) addresses the core problem of climate change, which is the extraction and use of additional fossil carbon from the ground. Its vision is clear: by 2050, the complete substitution of fossil carbon by renewable carbon, which is carbon from alternative sources such as biomass, direct CO_2 utilization and recycling. The founders are convinced that this is the only way for chemicals, plastics and other organic materials to become sustainable, climate-friendly and part of the circular economy – i.e. part of the future.

Lenzing is one of the founding members of the Renewable Carbon Initiative (RCI)[36] because we believe that the renewable carbon concept can deliver the same results for materials as decarbonization does for energy – a way to fight climate change and environmental pollution. Within the RCI, Lenzing will focus particularly on promoting the “greening up” of textile and nonwoven businesses. In this regard, we will promote this concept and encourage our partners to become a part of our vision.

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.

The Renewable Carbon Initiative has made a powerful start, with eleven international member companies and the personal support of more than 100 industry experts; by March 2022 the number of members had already more than tripled to 35. The initiative hopes to gain many additional members and supporters in the coming months to maintain its strong momentum. Working together, the RCI will support and accelerate the transition from fossil to renewable carbon for all organic chemicals and materials.

“In order to fight climate change, we need to curb our consumption of fossil resources. This has been shown in many studies and several of them even quantify how much of the remaining fossil resources need to be left in the ground. In the energy sector this is possible through “decarbonization”. However, this strategy is not feasible for organic chemistry, which is defined by the use of carbon. For the important chemical and plastic industries, we need to find alternative carbon sources in order to shift towards a more sustainable and climate-friendly production and consumption. We call these alternative carbon sources “renewable carbon”[37] states Michael Carus, founder and managing director nova-Institut.

Figure 10 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.

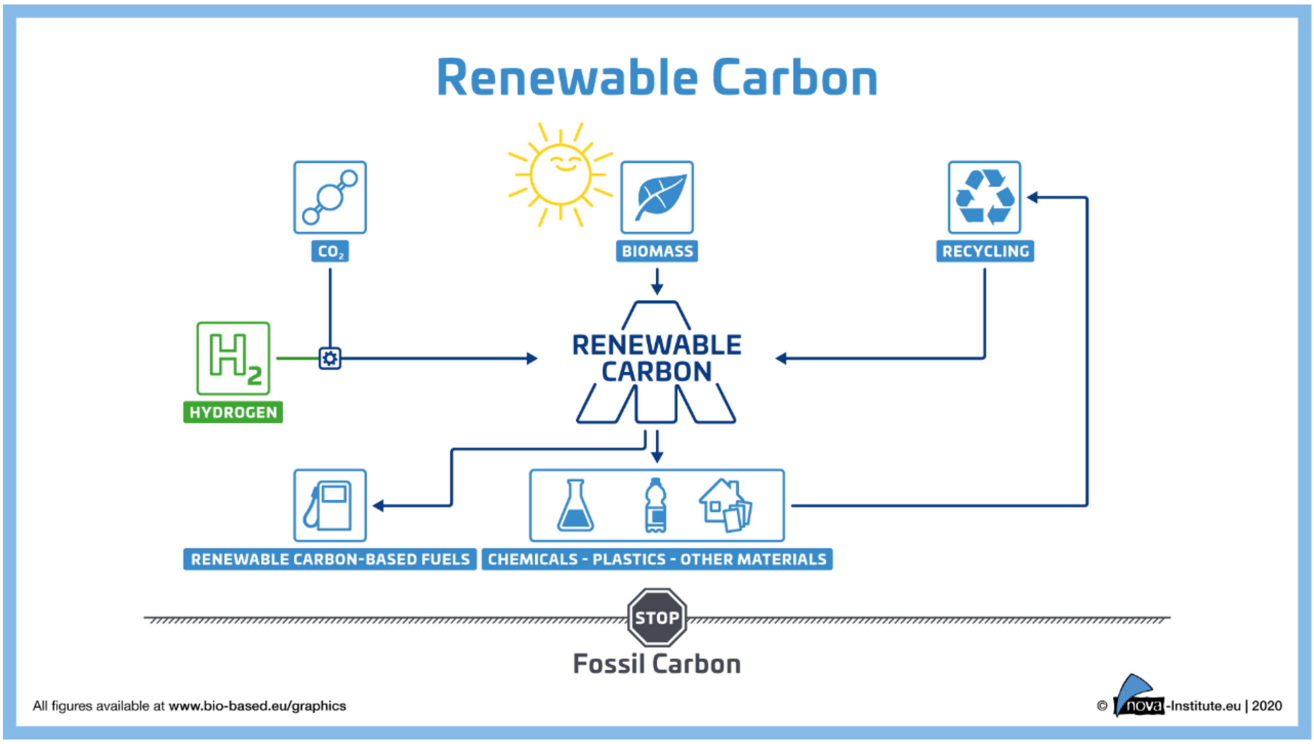

Figure 9: Different sources of renewable carbon, source: nova-institute.eu

Figure 8 (on page 12) shows in more detail the natural carbon cycle for the bio-based route. Here it is important to note that even if the carbon from the materials is released at their end of life, no additional fossil carbon is brought into the atmosphere as this carbon is part of the natural carbon cycle (as a precondition, it is necessary to make sure that all bio-based carbon material is grown, harvested and processed in a way that keeps the natural carbon stocks at least constant[38]).

CO_2 and other greenhouse gases are the main cause of anthropogenic[39] climate change – most people, including scientists, clearly agree on this statement. However, what is at the core of the climate problem? Wouldn't it make sense to investigate where the additional CO_2 is coming from? In the first part of the IPCC Sixth Assessment Report published in August 2021, scientists particularly emphasized the increasingly serious threat of greenhouse gas emissions to our planet as a result of fossil fuel combustion. UN Secretary-General António Guterres described the published report as a "code red for humanity". "The alarm bells are deafening, and the evidence is irrefutable: **greenhouse gas emissions from fossil fuel burning** and deforestation are choking our planet and putting billions of people at immediate risk"[40]. This statement is confirmed by the latest climate data, showing that 72% of human-induced climate change is directly caused by the extraction of fossil carbon. The other 28% comes from agriculture and forestry, mainly due to land-use change and livestock production[41].

This means that CO_2 itself is not the fundamental cause of the climate problem, as it can be cycled between the atmosphere, biosphere and technosphere. The main issue is the carbon coming from fossil sources (crude oil, natural gas or coal), which is utilized in the technosphere and then emitted into the atmosphere as additional CO_2 and other gases. If the inflow of this additional carbon and the associated CO_2 emissions are prevented, the CO_2 level in the atmosphere will no longer increase. Given the current extraction of 10-11 Gt of additional carbon per year, the remaining carbon budget for reaching the climate goals will be used up entirely in the next 7 to 15 years (1.5 °C) or 25 to 50 years (2 °C)[42]. Another way of illustrating the importance and urgency of this issue is that the consequences of climate change will have a negative impact on every single one of the 17 UN sustainable development goals (SDGs).

To mitigate climate change and reach the global goal of reducing greenhouse gas emissions, the inflow of additional fossil carbon into our system must be vigorously and rapidly reduced. Among other things, decarbonization of the energy and transport sector is required via the rapid expansion of renewable energies, hydrogen and electro mobility. The EU has already implemented and is continuing to push an ambitious agenda in this area, for example with the recently announced “Fit for 55 Package”. However, policymakers have largely ignored many industries that extract and use fossil carbon. 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.

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 [32].
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 is not necessarily compostable ● To be labeled compostable, certain scientific standards have to be met **Compostability**: A special condition for biodegradability plus additional criteria, including limits for chemical content such as heavy metals and biological testing via the assessment of plant growth. A distinction is made between home compost (uncontrolled conditions) and industrial compost (controlled conditions). 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, physical 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 ensures that no residues with negative effects on plant growth are present after composting. Chemical characterization mainly tests for heavy metals. 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 OWS website.[43]
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 metal 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.

      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 (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 (status end 2022)

LENZING™ fibers which are TÜV certified biodegradable and compostable include the following products:

LENZING™ Viscose Standard textile/nonwovens

LENZING™ Lyocell Standard textile/nonwovens

LENZING™ Modal Standard,

LENZING™ FR Standard[a]

LENZING™ FR Black[a],

LENZING™ Lyocell Filament[b],

LENZING™ Lyocell Dry[b],

LENZING™ Web Technology

a) LENZING™ FR Standard and LENZING™ FR Black are only industrial compostable.

b) LENZING™ Lyocell Filament was not tested for marine biodegradability and LENZING™ Lyocell Dry is not compostable in salt water.

List of graphics

References

---

[1] https://changingmarkets.org/wp-content/uploads/2021/01/FOSSIL-FASHION_Web-compressed.pdf
[2] Pennington, C (2016). Every Minute one garbage truck of plastic is dumped into our oceans. This has to stop. Retrieved from https://www.weforum.org/agenda/2016/10/every-minute-one-garbage-truck-of-plastic-is-dumped-into-our-oceans/
[3] Circular Online (2017). Truck Of Textiles Landfilled Or Burned Every Second, Says EMF Report. Retrieved from https://www.circularonline.co.uk/news/one-truck-textiles-landfilled-burned-every-second-says-new-macarthur-report/#:~:text=The%20Ellen%20MacArthur%20Foundation%20explained,barely%20worn%20and%20rarely%20recycled.
[4] Jambeck, J. R., et al. (2015). Plastic Waste Inputs from Land into the Ocean. *Science,* 347, 768–771, doi:10.1126/science.1260352
[5] Connor, S. (2016). How scientists plan to clean up plastic waste threatening marine life. Retrieved from https://www.independent.co.uk/environment/nature/how-scientists-plan-to-clean-up-the-plastic-waste-threatening-marine-life-a6820276.html
[6] S. Aishwariya, S. & Jaisri, J. (2020). Harmful Effects of Textile Waste. Retrieved from https://www.fibre2fashion.com/industry-article/8696/harmful-effects-of-textile-waste
[7] Cabrera, A. & Garcia, R. (2019). Single-use menstrual products, baby nappies & wet wipes. Retrieved from https://zerowasteeurope.eu/wp-content/uploads/2019/12/bffp_single_use_menstrual_products_baby_nappies_and_wet_wipes.pdf
[8] European Parliament (2021). The impact of textile production and waste on the environment. Retrieved from https://www.europarl.europa.eu/news/en/headlines/society/20201208STO93327/the-impact-of-textile-production-and-waste-on-the-environment-infographic
[9] https://changingmarkets.org/wp-content/uploads/2021/01/FOSSIL-FASHION_Web-compressed.pdf
[10] Ellen MacArthur Foundation (2017). The New Plastics Economy: Rethinking the Future of Plastics & Catalysing Action. Retrieved from https://emf.thirdlight.com/link/cap0qk3wwwk0-l3727v/@/#id=1
[11] https://www.eea.europa.eu/themes/waste/resource-efficiency/plastic-in-textiles-towards-a
[12] https://changingmarkets.org/wp-content/uploads/2021/01/FOSSIL-FASHION_Web-compressed.pdf
[13] https://www.oecd.org/environment/plastic-pollution-is-growing-relentlessly-as-waste-management-and-recycling-fall-short.htm
[14] https://www.eea.europa.eu/themes/waste/resource-efficiency/plastic-in-textiles-towards-a
[15] https://www.eea.europa.eu/themes/waste/resource-efficiency/plastic-in-textiles-towards-a
[16] Nova Institute (2020). Biodegradable Polymers in Various Environments. Retrieved from https://www.biocycle.net/wp-content/uploads/2020/10/Biodegradability-of-Biopolymers-Poster.pdf
[17] Food and Agricultural Organization of the United States (2022). Sustainable Forest Management. Retrieved from https://www.fao.org/sustainable-forests-management/en/
[18] Bechtold, T. & Schimper, C. (2010). Hydrolysis of regenerated cellulose fibers for textile and other applications. *Advances in textile biotechnology*, 312.
[19]Park, C. H.,Kang, Y. K & Im, S.S. (2004). Biodegradability of cellulose fabrics. *J. Appl. Polym. Sci.*, 94, 248-253.
[20] Sang, Y.C., Hee, P.C., Yun-kyung, K., Im, S.S.(2005). *J. Korean Soc. Clothing Text.*, 29, 470.

[21] Jeihanipour, Azam; Aslanzadeh, Solmaz; Rajendran, Karthik; Balasubramanian, Gopinath; Taherzadeh, Mohammad (2013), *J. Renewable Energy*, 52, 128-135, DOI: 10.1016/j.renene.2012.10.042.
[22] Warnock, M., Davis, K., Wolf, D., & Gbur, E. (2011). *AATCC Rev.*, 11, 53.
[23] Schneider, M., Sohngen, H., Bohringer, B., Marzinkowski J. (2020). Biological degradability and the influence of finishes on the biodegradation of textiles. *Melliand Textilberichte*, 80, 645-647.
[24] Smith, G. P., et al. (1990). Degradation ranking of plastics in a landfill environment. *Polym. Mater. Sci. Eng*., 63, 867-871.
[25] Zambrano, M.; Venditti, R; Pawlak, J.; Daystar, J; Ankeny, M; Cheng, J. (2018). The Generation and Aquatic Biodegradation of Microfibers Produced from Laundering Fabrics. *International Cotton Conference, Bremen , 21-23 March 2018*, Retrieved from https://baumwollboerse.de/wp-content/uploads/2018/03/Venditti_R_Bremen2018-to-submit.pdf
[26] Andrady, A.L., Pegram, J.E. & Olson, T.M. Research and development of two marine degradable biopolymers. David Taylor Research Center, Technical Report A150452 for the US Office of Naval Technologies. Retrieved from: http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA254051
[27] Bauchmüller, V.; Carus, M; Chinthapalli, R; Dammer, L.; Hark, N.; Partanen, A.; Ruiz, P. & Lajewski, S. (2021). Bio Sinn. Products for which biodegradation makes sense. *Nova Institute.* Retrieved from https://renewable-carbon.eu/publications
[28] Research project “Textile mission” Retrieved from http://bmbf-plastik.de/sites/default/files/2018-01/TextileMission_Praesentation_Auftaktveranstaltung_Veroeffentlichung.pdf
[29] Henry (2018), Retrieved from http://www.hioa.no/Om-HiOA/Senter-for-velferds-og-arbeidslivsforskning/SIFO/Publikasjoner-fra-SIFO/Microplastic-pollution-from-textiles-A-literature-review
[30] EU Plastics Strategy, 2018
[31] Lenzing Group Wood and Pulp Policy, https://www.lenzing.com/sustainability/production/resources/wood- and-dissolving-wood-pulp
[32] de Wilde 2013: De Wilde, B., Mortier, N., Verstichel, S., Briassoulis, D., Babou, M., Mistriotis, A., Hiskakis, M. (2013). Report on current relevant biodegradation and ecotoxicity standards. Knowledge Based Bio-based Products‘ Pre-Standardization. http:// www.ows.be/wp-content/uploads/2014/04/KBBPPS-Deliverable-6.1-overview-biodegradation-standards.pdf
[33] Royer, S.-J., Wiggin,K., Kogler, M.,. Deheyn, D.D., (2021). Degradation of synthetic and wood-based cellulose fabrics in the marine environment: Comparative assessment of field, aquarium, and bioreactor experiments. *Science of The Total Environment,* 791, 148060, https://doi.org/10.1016/j.scitotenv.2021.148060.
[34] Communication from the Commission to the European Parliament, the European Council, The Council, The European Economic and social committee and the committee of the regions, The European Green Deal; Brussels 11.12.2019
[35] vom Berg, C. & Carus, M. et al. (2022). Renewable Carbon as a Guiding Principle for Sustainable Carbon Cycles. Editor: Renewable Carbon Initiative (RCI), Retrieved from www.renewable-carbon-initiative.com
[36] Other RCI board members: COSUN BEET COMPANY, COVESTRO, GIVAUDAN, HENKEL, LANZATECH, NESTE, NOVA-INSTITUT, SHV ENERGY, STAHL, UNILEVER, UPM RCI partners: CO2 VALUE EUROPE, EUROPEAN CIRCULAR BIOECONOMY FUND, GLOBALCO2INITIATIVE, I2I LLC/GO!PHA, TEXTILE EXCHANGE, WWF DEUTSCHLAND
[37] Carus, M. et al. (2020). Renewable Carbon is Key to a Sustainable and Future-Oriented Chemical Industry, Hürth. Retrieved from www.bio-based.eu/nova-papers
[38] Focus paper wood and pulp Lenzing Group, March 2021, page 6-7 https://www.lenzing.com/index.php?type=88245&tx_filedownloads_file%5bfileName%5d=fileadmin/content/PDF/04_Nachhaltigkeit/Broschueren/EN/focus-paper-wood-pulp-EN.pdf
[39] A glossary of many renewable carbon related terms can be found at https://renewable-carbon-initiative.com/renewable-carbon/glossary/
[40] Secretary-General's statement on the IPCC Working Group 1 Report on the Physical Science Basis of the Sixth Assessment https://www.un.org/sg/en/content/secretary-generals-statement-the-ipcc-working-group-1-report-the-physical-science-basis-of-the-sixth-assessment
[41] Based on data from https://www.pbl.nl/sites/default/files/downloads/pbl-2020-trends-in-global-co2-and-total-greenhouse-gas-emissions-2019-report_4068.pdf
[42] The CO_2 budget left is shown online and updated here: https://www.mcc-berlin.net/fileadmin/data/clock/carbon_clock.html (2021-09-15): 7 years and 10 months for surpassing the limit to stay within 1.5°C target.
[43] https://www.ows.be/lc_divisions/biodegradability-compostability-ecotoxicity-bce/

Imprint
Lenzing Group, Focus Paper End of use
Issue April 2023

Editorial team:
Innerlohinger Jo-Ann
Kogler Michaela
Lange Berit
Matiz Thomas
Rahbaran Shayda
Schmid-Schlager Stefanie
Schuster K. Christian
Waldow Luise

Inquiries to: sustainability@lenzing.com