Lyocell 2.0

The market expansion of man-made cellulosic fibers (MMCF) is unstoppable. The course is currently being set and new industrial structures are being established. At the forefront are the new process technologies for lyocell, which enable the conversion of the industry to sustainability and circularity: Lyocell 2.0.

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There is no doubt, and the trend is irreversible: The textile industry has recognized that sustainability has to be lived. Lip service is not enough. This is not out of a selfless motivation, but for very tangible economic reasons. Any news about a lack of sustainability or production deficits threatens the image of fashion brands, their greatest asset, much more than before. This is driven by the increasing transparency of social media and NGOs. In particular, one of the most important target groups, the young generation, who are already concerned about the future in view of the urging environmental problems, demands change. Fixing the grievances is costly but fixing the reputation is much more – and time-consuming.

The European Union (EU) addresses this problem, which is widely accepted in society, in its Green New Deal program. The "EU Strategy for Sustainable and Circular Textiles" launched in June 2022 aims for a sustainable circular textile economy. Among other things, it strives for environmentally and socially compatible manufacturing processes, recyclable fibers, fiber-to-fiber recycling, durable textiles and responsibility for textile producers along the entire supply chain, including textile waste. Further, the EU targets a reduction in CO_2 footprint and microplastics with the EU Directive 2019/904 for single-use plastics (SUP).

On top of all these changes in the strategic environment of the textile industry, the recent painful experiences of the Covid crisis and Russia's war against Ukraine have shown that the downside of supply dependencies has been underestimated.

All in all, this means a change towards environmentally and socially responsible manufacturing processes for CO_2-neutral, recyclable, plastic-free and high-quality textile, transparent and more robust production chains, and recycling which goes beyond resale as second-hand, and composting.

There is no doubt that this change will take place. The question is rather, how the new textile world will look, which products and structures will be established, who will be the winners and who will be the losers. The race is on.

All current established fibers have serious sustainability deficits: **Polyester (PET)** fibers do not meet the criteria of the textile world of tomorrow. They are fossil-based and generate microplastics. Even recycled polyester textiles still release microplastics with every wash cycle.

Cotton does not have the sustainability disadvantages of polyester, but its global production capacity is stagnating. Cotton's unbelievably high water consumption has almost completely dried up the Aral Sea and left behind a salt desert, and the traditional cultivation areas there have come under great pressure. Cotton's still good reputation is astonishing considering this huge sustainability deficit.

Man-made cellulosic fibers MMFC

For the above-mentioned reasons, interest in MMCF has increased significantly in recent years. They are based on renewable raw materials and are biodegradable. In addition, because MMCF are cellulose-based like cotton, and absorb moisture better than polyester, they are more comfortable to wear.

In the MMCF process, the cellulose is initially in the form of dissolving pulp or – if wood-based – dissolving wood pulp (DWP), respectively. The wood for the cellulose is mostly obtained from certified tree plantations or managed forests. However, the traditional MMCF do not achieve tenacities like PET fibers – but this is about to change. In addition, PET fibers are cheaper than MMCF. However, this does not take into account the increasing cost of the environmental damage caused by PET which must be borne by future generations.

VISCOSE

Viscose is the traditional and still most widespread MMCF. However, the manufacturing process faces severe reputational damage due to its health and environment risk potential. Nowadays, barely any new viscose plants are being planned. The viscose process first converts the dissolving pulp into a so-called xanthogenate, which is then dissolved in caustic soda. The viscous dope (hence the name "viscose") is then forced through a spinneret into an acidic precipitation bath, forming filaments or fibers. The formation of the xanthogenate (a so-called derivative) is a chemical reaction and is associated with a significant reduction of the cellulose polymer chains. For this reason, viscose fibers are not suitable for recycling.

LYOCELL

The most advanced fiber today that meets all of the above requirements is lyocell. The lyocell dissolution process is a physical process without any chemical reactions and without an intermediate step via a derivative. The pulp is directly dissolved with a non-toxic solvent called N-Methylmorpholine-N-oxide

(NMMO) without derivatization, resulting in a spinning solution (dope). This is pressed through a spinneret into a water bath, resulting in filaments or fibers. Due to the absence of a derivative, this process is also called a direct dissolving process.
Due to the absence of a chemical reaction, the molecular structure of the pulp remains largely unchanged and the cellulose polymer chains remain largely intact. It may appear to be a technological detail, but it is of strategic importance: The longer cellulose polymer chains also lead to higher fiber tenacities. Also, due to the preservation of the polymer chains, the fibers and filaments of the direct dissolving processes are also suitable for recycling.

However, the technical implementation of the NMMO processes requires special attention. NMMO is thermally sensitive at high temperatures (risk of an explosion due to autocatalytic decomposition) therefore precise temperature control requires great attention. In addition, NMMO is expensive, and an efficient NMMO recovery process is a decisive economic success factor. The viscosity of a lyocell dope is higher than that of viscose, so that different, more robust machines are required in the manufacturing process than in the viscose process.

Global fiber growth

When looking at the doubling of the production volume over the last 20 years (Fig. 1), it is impressive to see that the portion of PET fibers has grown disproportionately. The well-known "cellulose gap", the difference between cotton fiber demand and supply, which – as the name suggests – should be filled by MMCF but is mainly filled by PET. And the growth continues. Even to replace just the further growth of PET only partially with MMCF requires large increases in MMCF production capacities and raw materials. To absorb the global fiber growth completely, the MMCF production would have to grow annually by the MMCF capacity of 2001. The same growth rate would also apply to the production of dissolving pulp, which is currently entirely based on forestry, every other year. The need for an alternative biomass is imperative.

Alternative biomass

There are currently several initiatives to use alternative biomass as raw material for MMCF. They all have to undergo a development and target a dissolving pulp suitable to manufacture marketable fibers. However, it is also about acceptable procurement costs of the biomass. Biomass from agricultural waste – as an example – is more decentralized and more readily available than wood but, due to its low bulk density, the transportation costs are decisive for the business case.

EXAMPLE HEMP

Hemp is one of the oldest cultivated plants in the world with multiple uses, including fiber for rope. No wonder its cellulose has long polymer chains. Hemp originally experienced a revival as cellulose-rich agricultural waste and has proven to be a very suitable biomass for MMCF in several R&D projects. Not only the hemp fibers but also the hemp shives, which make up about 50% of the biomass, can be used. Hemp, like all non-woody celluloses, also has the advantage that hardly any lignin has to be removed in further processing. In addition, the long chain lengths even make it possible to produce lyocell fibers with higher tenacities than lyocell from regular wood pulp. For this reason, hemp cultivation is now also primarily aimed at use as a source of cellulose. Hemp also grows on poor soil and is therefore not in competition with food cultivation. It is a good example of an innovative, economically sustainable use of cellulose-rich biomass. Others will follow.

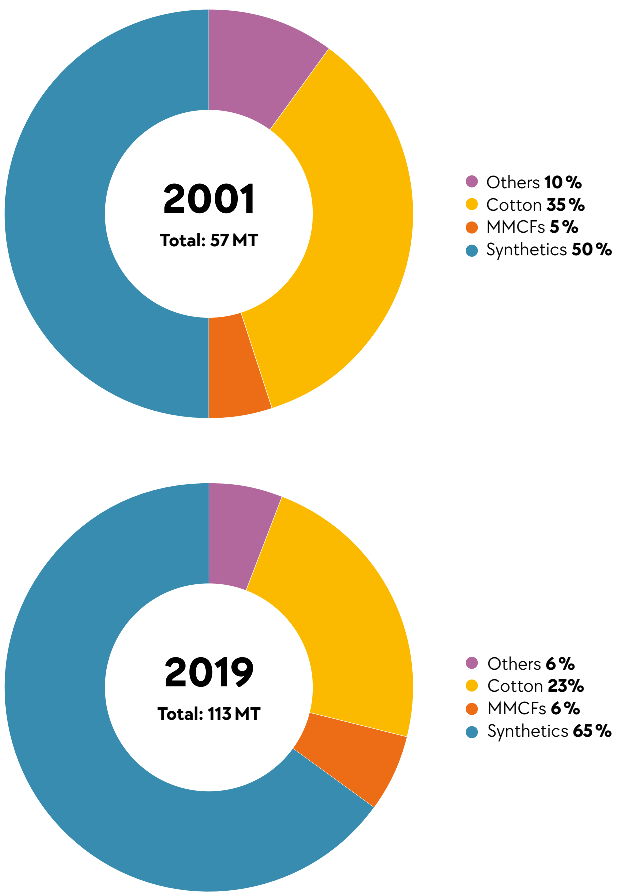
COTTON TEXTILE RECYCLING

Like hemp, cotton is a very old cellulose-rich crop for natural fibers with long cellulose polymer chains and is suitable as a high-quality cellulose for higher tenacity lyocell fibers. In view of this high suitability as a cellulose source for MMCF, the EU decision on textile recycling regulations will result in major industry changes.

A look at the annual capacities of global textile fiber production (Fig. 1) shows impressively that textile recycling has the greatest potential for biomass as an MMCF raw material: dissolving pulp from recycled (poly-)cotton textiles (RePulp). Recycling just 25% of global cotton production could replace all of today's wood-based dissolving pulp production. Recycling a global cotton production 3 times would provide the biomass for all (today's) production of all man-made fibers, i.e. PET and MMCF.

FIG. 1

Global fiber growth



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The direct dissolving of RePulp using modern dissolving technologies leads to strengths that even come close to the strength of PET fibers.
By reclaiming the raw material (textile waste) at the consumer's location, regional supply chains close to the end consumer market are possible – in contrast to the location of most wood pulp industries. Since a lot of RePulp from off-cuts and textiles that have never been sold (pre-consumer waste) is generated in the vicinity of textile processing, large integrated pulp-fiber production plants can also be expected. These are suited to meet the high market demand and reduce costs through economies of scale and vertical integration. This requires lyocell plants that can process 100% RePulp.
Traditional state-of-the-art lyocell plants are only able to admix about 30% of high quality alternative biomass (RePulp or hemp pulp). For 70%, i.e. more than twice as much, tree felling is still necessary. This is one of the main reasons why there are hardly any lyocell textiles made from 100% recycled textiles available today. The same applies to lyocell made from hemp.

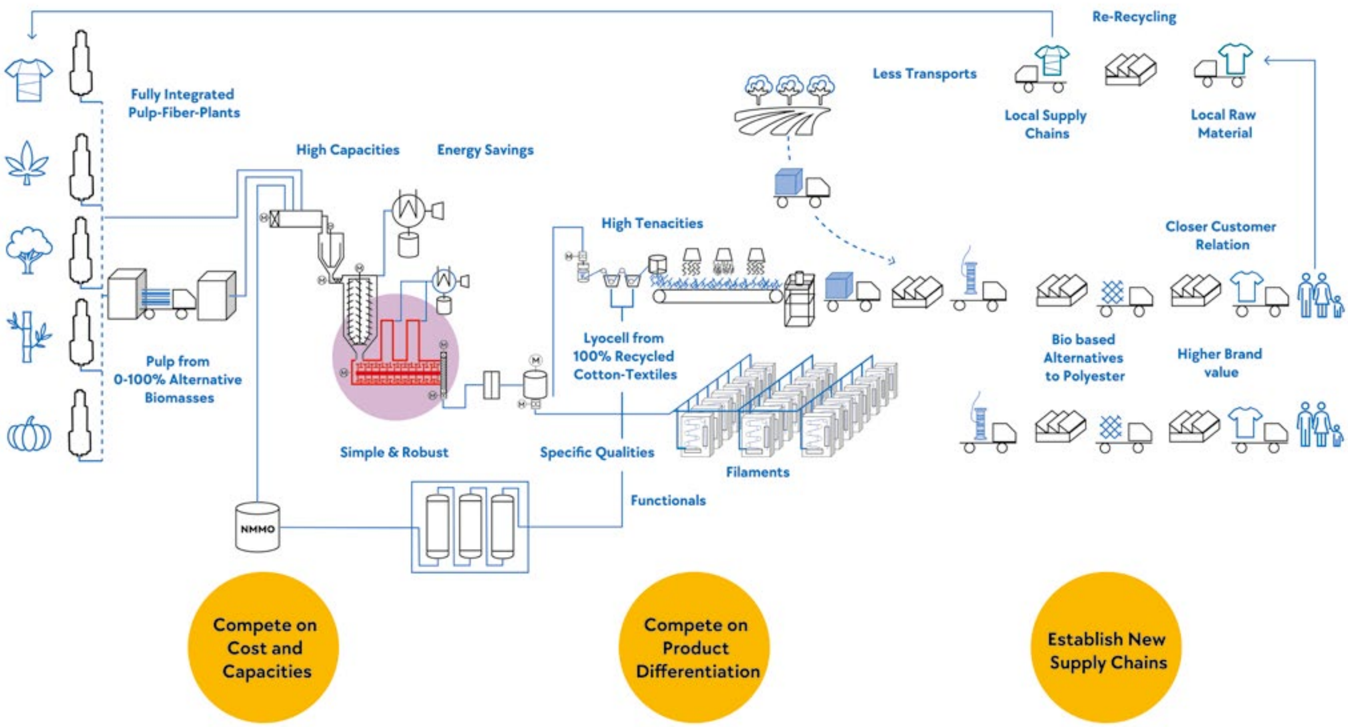
Novel spinning solution processing technologies

The novel dissolving technologies are capable of producing lyocell fibers from 100% RePulp and 100% hemp pulp. Dissolving hereby refers to the process step, which generates a spinnable dope from pulp. Dissolving hereby refers to the process step, which generates a spinnable dope from pulp. Traditional lyocell plants can be upgraded – provided there is suitable space. This makes it possible to close the fiber-textile loop completely and to use high-quality alternative biomass for lyocell without restriction. No trees will have to be cut to wear lyocell jeans from RePulp.
Fashion brands can explain to the end consumer that their lyocell textiles made from recycled cotton fabrics not only increase sustainability, but also are higher quality.
The sustainability NGOs, which have so far been very effective in driving the fashion industry along, and the governmental authorities can now commit the fashion industry to a sustainable and circular economy much easier given the technical possibilities and the available biomass.
Fashion brands could prove to be the biggest beneficiaries of this new textile cycle. They now have the chance to add value to their brands by making a virtue of necessity and embedding end-consumer engagement in their supply chain. The end-consumer becomes the supplier of raw materials. And this much closer relationship with the end consumer can be used for a higher customer loyalty. The control over the cycle gives the brands the opportunity to create transparency for their customers across their entire value chain. Yet it also holds them accountable and eliminates any room for excuses.
Thus, the novel spinning solution processing technologies enable a new concept for lyocell: Lyocell 2.0 (Fig. 2).

The novel dissolving technologies are based on the use of kneading reactors by List Technology AG. They enable higher fiber qualities, higher capacities per production line and thus cost reductions thanks to economies of scale. In addition, the List processing equipment, which applies the same processing principle at all scales, ensure a consistent development and processing support from lab to world scale.

FIG. 2

Lyocell 2.0



Source: List Technology

The usual manufacturing process of a lyocell spinning solution (dope) from dissolving pulp starts with a mixture of pulp, NMMO and an excess of water, allowing the NMMO to fully penetrate the pulp without dissolving it. The NMMO, water and pulp thus form a suspension. With the addition of energy (i.e. heating), the water begins to evaporate until the water content is sufficiently low (whereby water and NMMO form a monohydrate) that the pulp begins to dissolve. A thin-film evaporator specialized for elevated viscosities is suitable for this phase of evaporation. It spreads the suspension with wipers over its heated inner surface.

When the monohydrate starts to dissolve the dissolving pulp, the viscosity increases sharply and the suspension becomes a homogeneous solution so that it is suitable for spinning involving dissolving and homogenizing.
In this phase of dissolving and homogenizing, the novel dissolving processing technologies use a List kneading reactor, where a very good high-viscosity mixing and kneading is crucial for the success of the process, while some of the water is still evaporating. Undissolved particles and insufficient homogeneity disrupt the very sensitive spinning process and quickly clog the interposed filters.
The traditional lyocell process is capable of dissolving traditional wood pulp in the lower section of the thin-film evaporator. However, the high-viscosity mixing capabilities and the residence time available in the lower section of the thin-film evaporator are both very limited and are not capable to dissolve pulp from biomass with long cellulose polymer chains such as hemp or recycled cotton textiles.
Thus, the new dissolving technology uses a List kneading reactor for this process step of dissolving and homogenization. They are specialized in mixing highly viscous substances and evaporating volatile components at the same time. In addition, there is almost unlimited time and mixing intensity that can be set with the shaft speed to achieve the necessary homogenization and spinning solution quality.

The thorough mixing of the product in the kneading reactor ensures a homogeneous temperature distribution and avoids temperature peaks. The heat is frictional heat, which depends directly on the rotation speed of the kneading reactor shaft and, thus, allows the control of the product temperature precisely. In an emergency, the shaft rotation can be quickly and significantly reduced or even stopped completely, which immediately stops the energy input. This frictional energy input is an advantage compared to a thin-film evaporator, where the energy input occurs mainly via heated surfaces, which remain hot even after the heating energy has been switched off and can continue to heat the product.

Due to the temperature sensitivity of the NMMO, in the traditional process, the lower section of the thin-film evaporator is no longer heated, or even cooled. This means, that not all heating surfaces are used for evaporation, and cooling means an energy loss. As the new process transfers the temperature sensitive part of the process in the kneading reactor, all surfaces of the thin-film evaporator can now be used for water evaporation and the evaporation capacity and thus the capacity of a production line increases. The decoupling of the efficiency-relevant water evaporation in the thin-film evaporator and the quality- and safety-relevant dissolving and homogenization in the kneading reactor goes hand in hand with an increase in capacity and an increase in quality. Further it means to widen the range of processable biomass as pulp source towards long-chain biomass and towards higher fiber strength or higher dope homogeneity. Lyocell plants equipped with List kneading reactors (Fig. 3) enable their plant owner to change the pulp source and adjust the relevant process parameters without having to rebuild the plant. Lyocell producers can thus confidently follow the dynamic developments on the pulp side and react flexibly at any time, regardless of whether they aim for cost leadership with pulp from low-cost alternative biomass or seek product differentiation with high fiber quality.

FIG. 3

List kneading reactor