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The development of the Blend Re:wind process

by
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Anna Palme



CHALMERS

preface

In 2011, when Mistra Future Fashion started as a research program, the development of the polyester/cotton recycling method, called the Blend Re:wind process, begun with the Mistra Future Fashion funded PhD project of Dr. Anna Palme at Chalmers University of Technology. Besides the PhD project, the work on the recycling method has continued with additional diploma and post-doctoral projects. This report is a summary of the progress and results of the Blend Re:wind process, especially the work related to tasks 4.1.1, 4.1.2, 4.1.3 and 4.1.4 in the second phase of the Mistra Future Fashion program.

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A Mistra Future Fashion Report

Mistra Future Fashion is a cross-disciplinary research program, initiated and primarily funded by Mistra. It holds a total budget of SEK 110 millions and stretches over 8 years, from 2011 to 2019. It is hosted by RISE in collaboration with 15 research partners, and involves more than 50 industry partners.

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Summary

Present increase in use of textiles and clothing worldwide is responsible for a large waste stream of material, only being recycled to less than 1%. A major obstacle in the recycling of textiles is the blend of different fibers in many materials, and the separation process is complicated. Recycling of textiles is commonly done through mechanical separation of the fibers which directly leads to a decrease in the quality of the fibers. To obtain fibers with high quality properties, instead, chemical treatments can be used to separate fibers of different origin from each other. Each fiber fraction can then further be converted into new fibers. This is the concept of the Blend Re:wind process which has been developed within the program Mistra Future Fashion.

The Blend Re:wind process takes advantage of the different properties of the fibers in a fiber blend and uses a solvent which dissolves one of the fibers into its components while leaving the other one as solid fibers. More precisely, the fiber blend polycotton, which consist of 50% polyester and 50% cotton, can efficiently be separated into one solid fraction of cotton fibers and one liquid fraction containing the building blocks of polyester, by using sodium hydroxide dissolved in water as solvent. The solvent can be considered as a green solvent since sodium hydroxide is a common chemical used within e.g. forest industry and therefore recycling processes already exist.

Herein, we report on the developments made in the Blend Re:wind process and show how new fibers, namely viscose filaments, can be produced from separated and recycled cotton fibers and thereby demonstrates the potential for a circular textile material flow. The produced viscose filaments were proved to have the same strength as filaments obtained from regular dissolving pulp used for textile fibers. Furthermore, the report also points out the importance of fully understanding the properties of the materials put into a process for production of textile fibers, which already has been stressed in the early development of the Blend Re:wind process.

Lastly, an environmental assessment of the Blend Re:wind process was made in order to identify the environmental potential of the process. Important to keep in mind is though that the environmental assessment was made with data obtained from smaller pilot or bench scale conditions and energy and chemical demands has therefore not yet been optimized. Despite this, the environmental assessment can be used as a guiding tool in the further development of the Blend Re:wind process.

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1. introduction

Textiles and clothing is an essential part of everyday life, but the wasteful, polluting and almost linear value chain makes the textile industry one of the dirtiest industries in the world today. The industry is responsible for several negative impacts on the environment, such as use of non-renewable sources, greenhouse gas emissions, microfiber pollution in the ocean, discharge of water containing hazardous compounds etc., all thoroughly summarized in the recent report a new textiles economy: redesigning fashion's future by the Ellen MacArthur Foundation[1]. The production part of the textile life cycle is responsible for the major environmental impacts, of which the most important impacts are related to the use and emissions of toxic chemicals, as well as the use of water and energy[2]. The cotton cultivation is particularly problematic, requiring about 10,000 liters of water per kg cotton and 25% of the world's insecticide use, despite occupying only 2.5% of the world's arable land. Annually, the textile industry produces 53 million tons of textile fibers, and less than 1% of the material used to produce clothing is recycled into new clothing, evidencing the need for recycling improvement[1].

Waste prevention and reuse should be prioritized before recycling, according to the five-step waste hierarchy introduced by the European Union parliament to its waste legislation (directive 2008/98/EC). However, as the tremendous volumes of used textiles inevitably will reach an end-of-life sooner or later, the textile waste produced needs to be better recycled into new products and/or materials to prevent energy recovery and safe disposal, the last two options in the hierarchy.

Despite the clear need, there is no commercially viable recycling of general textile waste world-wide, converting the waste into new high quality fibers according to a circular economy. The recycling plants operating today are either larger mechanical recycling plants, converting general textile waste into lower grade rags, or rather selective recycling plants that recycle controlled waste of higher qualities into new fibers. There are numerous reasons why commercial textile-to-textile recycling is practically absent on the market, many of them technical, but not only as many recycling issues are related to upstream actions. It must thus be emphasized that changed mindsets and decisions throughout the whole value chain is a must to close the loop for textiles.

The recycling work of Mistra Future Fashion, and thus also the work of the Blend Re:wind process, focus on some of the technical challenges of chemical recycling, and to hold dialogue on the findings to contribute to a systemic change in fashion and textiles. The following chapter aims to give the reader an overview of chemical recycling and in particular recycling of textiles blends. The second chapter is reviewing the Blend Re:wind process and advancements. The concluding chapter aims to summarize the main findings of the recycling work and to provide guidance on operations to enable and facilitate a sustainable textile recycling.

'Despite the clear need, there is no commercially viable recycling of general textile waste world-wide, converting waste into new high quality fibers according to a circular economy.'

1.1 background

Chemical recycling of textiles comprises different processes where changes on the molecular level are made to the textile fibers, through chemical processing, to form new recycled fibers of high quality. Textiles may also be recycled mechanically, in processes where the textiles are mechanically defibrated to fibers, which may then be spun with or without the addition of virgin fibers into yarns for textile production. However, the mechanical recycling of most textile materials leads to fibers of inferior quality and may, thus, be regarded as down-cycling. The recycling work of Blend Re:wind, has focused on chemical recycling of textile fibers in order to recreate materials of qualities that can replace virgin fibers on the market, and thus fulfil a circular textile flow.

1.2 recycling of textile blends

Blending of different textile fibers is a commonly used technique in the textile industry to obtain materials with a profile suitable for specific applications. Some of the reasons for blending are to increase performance, aesthetics and decrease production costs. According to Ward et al.[3], more than a third of post-consumer textile waste is blended materials. However, it is probably even more common if trimmings e.g. sewing thread and labels are included.

There are several types of blending such as intimate blending, where a specific weight ratio of two or more fibers are used in the manufacturing of spun or filament yarns, mixture yarns made by plying yarns together, and fabric mixtures where different yarns are used for the different yarn systems in the manufacturing process e.g. warp and weft. Polyester, in particular polyethylene terephthalate (PET), and cotton are the most common synthetic and natural fibers, respectively, used in the world today[4]. The differences in their strengths and weaknesses make the two a perfect combination. Cotton contributes with softness and high water absorbency, and PET contributes with durability, strength, and a low price[5].

Furthermore, a LCA study of service textiles by Kalliala and Nousiainen[6] showed that 50:50 polycotton sheets in the hotel business had lower environmental impact compared to sheets of 100% cotton. By adding the strong polyester, the product life of garments will be extended. Additionally, less energy is needed to dry the garments due to the low moisture regain of polyester. This makes mixes of PET and cotton, in varying percentages, one of the most common textile materials, which are generally referred to as polycotton. Polycotton is used in the main part of all service textiles, such as sheets, towels, and workwear. Recycling of service textiles could be an important step of chemical textile recycling since the service sector uses large quantities of textiles with similar quality. Additionally, the service sector has a large impact on their material providers and does already control the life cycle of their textiles using RFID tags.

However, to recycle polycotton chemically, cotton and PET must be separated. This may be done by depolymerizing or dissolving one of the components while maintaining the other as solid fiber. If PET is to be maintained (Figure 1), it has been proposed that the cotton may either be depolymerized with acid[7] or with microbes[8], to obtain the monomer units cellulose, which is glucose. Dissolving cotton has also been proposed using different solvents, such as ionic liquids or N-methylmorpholine N-oxide (NMMO), and separating the two components with filtration[9, 10]. However, if PET is to be maintained and subsequently converted into new fiber grade PET, the lost quality of PET fibers during the use phase must be compensated, through for example condensation techniques, and possible impurities removed.

It has been shown within the Mistra Future Fashion program that polyester loose quality during the use phase and also becomes contaminated, making direct melt spinning without purification impossible[11]. Laundering is commonly performed under alkaline conditions, and the ester bonds in the PET fibers are sensitive to alkali, implying that it is probable that degradation will occur after many laundering cycles.

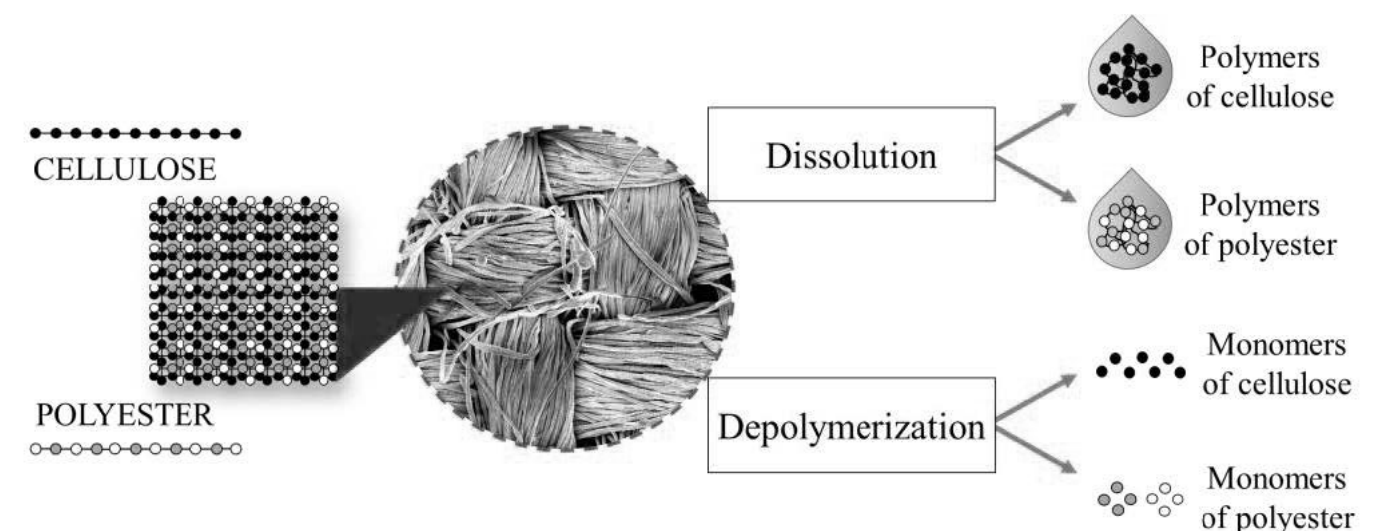


Figure 1 intimately blended woven textiles and the schematic overview of different separation routes of polycotton. Please note that this is a figurative illustration. Picture borrowed from the thesis of Stina Björquist[12].

The opposite approach is also possible, in other words, maintaining the cotton and dissolving or depolymerizing the PET fibers into its monomers terephthalic acid (TPA) and ethylene glycol (EG) (Figure 2). Recycling of PET through depolymerization has been extensively studied and reviewed due to the large volumes of PET bottles, which are creating a fast-growing waste problem[13-18]. There are three main chemical degradation methods for PET; hydrolysis (acid, neutral, or alkaline), alcoholysis[19], and glycolysis[20, 21]. However, only hydrolysis degrades the PET back to terephthalic acid (TPA) and ethylene glycol (EG), which are the monomers mainly used in PET production today[22].

Dissolving or extracting PET from a textile mixture is not as present in the literature, however, a few articles and patents related to the topic can be found[23-26].

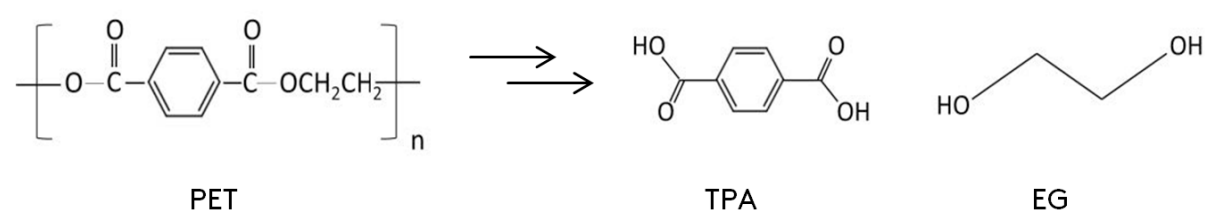


Figure 2 the chemical structures of the repeating unit of PET, and the obtained monomers after depolymerization of PET terephthalic acid (TPA) and ethylene glycol (EG). Please note that the reaction scheme is not complete, but an illustration.

The approach of maintaining the cotton and depolymerizing the PET fibers (Figure 3) was used in the Blend Re:wind project for two main reasons. Firstly, as PET is sensitive to alkali, it can be degraded to its monomers TPA and EG using alkaline sodium hydroxide (NaOH), a common chemical within the forest and viscose industries. Synergies and process optimizations with these processes can thus be found, and possibly overcome the relatively high cost related to full depolymerization.

Secondly, cotton is a cellulose-based fiber created by nature, and cannot be reproduced after use into its original superstructure. It can, however, be converted into a dissolving pulp and then further dissolved and regenerated into new textile fibers, such as the viscose or lyocell fibers normally produced from wood-based cellulose. The degradation of cotton already taking place during the use phase hinders the cotton to be recycled mechanically, as the quality of the obtained fibers will be insufficient. The degradation from the use phase does not, however, affect the regeneration into viscose or lyocell. The degradation is actually needed in those processes to decrease the chain length (the degree of polymerization, DP) and to get the cotton dissolving pulp into solution prior to regeneration into new cellulose-based textile fibers. The approach to maintain cotton and depolymerizing the PET has been proposed earlier, using both hydrolysis[27], alcoholysis[19] and glycolysis[21] of PET.

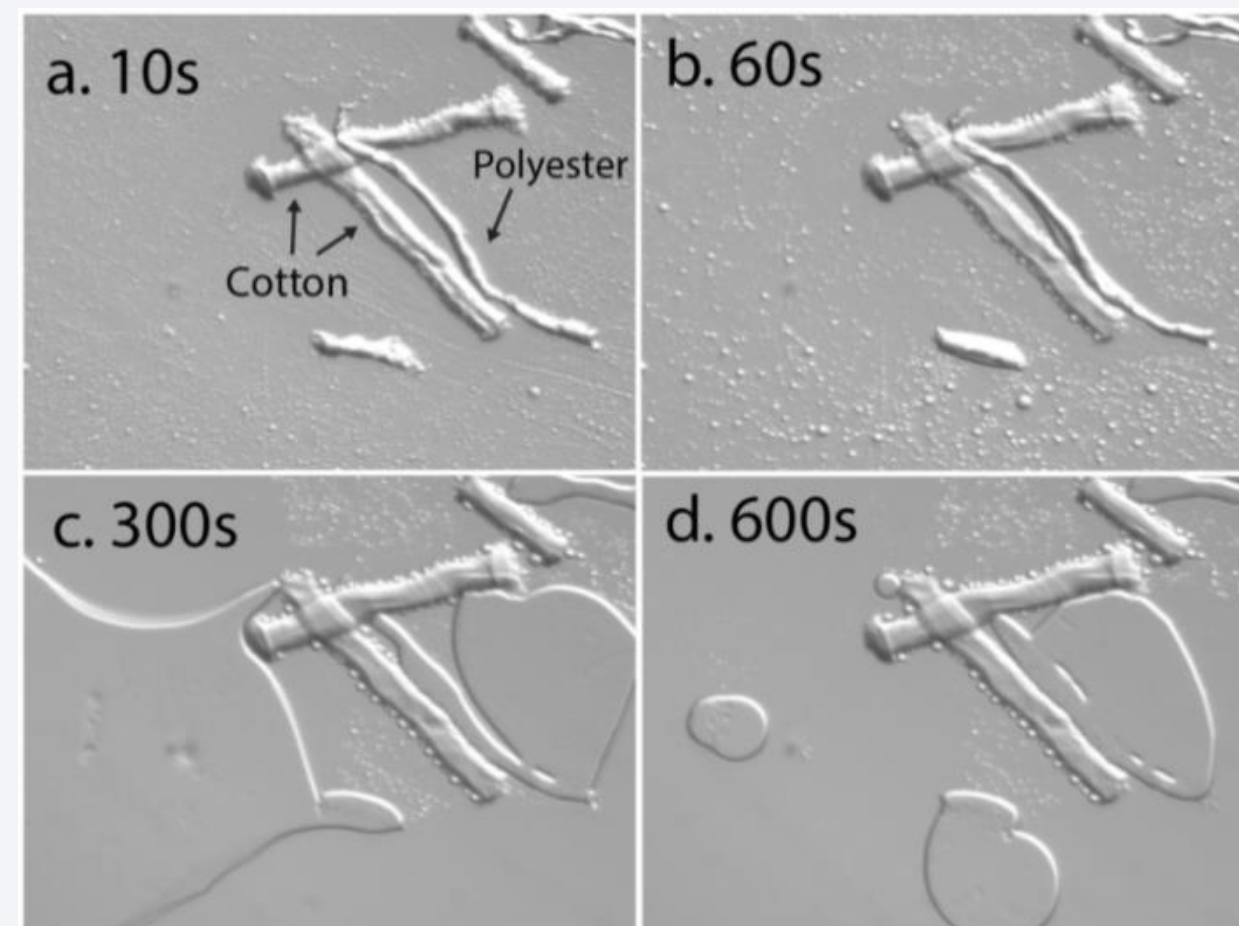


Figure 3 micrographs of selective hydrolysis of PET after 10 seconds (a) after 1 min (b) after 5 min (c) and after 10 min (d) of reaction time.

2. the development of Blend Re:wind

The development of Blend Re:wind started in 2011, with the PhD project of Dr Anna Palme at Chalmers University of Technology. The intention from the beginning was however not the recycle polycotton blends, but to understand the influence on cotton during the use phase, as well as investigating separation and recycling of bulk textile waste. The latter was early considered too complicated at time being, as the impure material samples in combination with the lack of sorting, characterization and efficient extraction methods made the research very difficult. Instead, the PhD work started with focus on pure cotton fibers, by a controlled investigation of 100% cotton sheets from a service company. After a couple of years, in 2014, the fact that most service textiles consist of polycotton blends made the project change direction into the development of polycotton recycling, as the need to handle the amounts of waste from the service companies appeared attractive.

Besides the use of large quantities of textiles with similar quality, the impact on their material providers and an already implemented RFID system mentioned above, also the lack of reuse options is a reason to investigate recycling of service textile waste better. Service textiles are used until they are considered to be worn-out (some service companies have in-house repairing to extend life cycles as well), or are contaminated from different uses, and the current end-of-life is therefore mainly incineration.

The following sections summarize both the results from the pure cotton investigations, as these have been crucial to later understand and develop the polycotton recycling, and the progress and results published from the polycotton recycling, i.e. the Blend Re:wind project. Many of the results summarized below are findings that can be read more extensively in the PhD Thesis of Dr Anna Palme[28] as well as the two diploma works of Anna Peterson[29] and Stina Björquist[12].

2.1 understanding post-consumer cotton


One important step on the road towards textile recycling is to understand the materials at hand. Since chemical recycling should mainly be performed when reuse is not possible anymore, the materials suitable for recycling are preferably laundered many times. However, it is probable that there will be a large variation in the number of times which the items have been laundered, since some items will be discarded after only a few launderings due to e.g. stains, malfunctions and contaminations. The investigation of post-consumer cotton was performed using 100% cotton sheets from a service company. The cotton sheets were taken out of service at the service company after different amounts of laundering and use cycles (0, 2-4, ~50, and >50 times). The sheets were then characterized and analyzed at Chalmers University of Technology to understand the changes, occurring during use and laundering, both at the molecular and fiber levels of cotton.

The investigation of cotton was divided into two main parts: the first part was investigating the impact of use and laundering, and the second part was studying different pre-treatments and swelling of cotton to enhance the dissolution before production of regenerated fibers.

The first part showed that laundering and use did not have a large impact on the hornification of cotton, due to the high initial hornification of virgin cotton. One change that could be observed on fiber level was that the pore structure of the cotton cellulose changed over long-term use. However, on the molecular scale, the cellulose chain length (DP) decreased to a level that would make it suitable for viscose or lyocell production. Long-term use and extensive laundering were found to decrease the mass-average molecular mass of cotton cellulose from 1323 kDa, in a new, never laundered sheet, down to 151 kDa of a sheet ready to be discarded after more than 50 use and laundering cycles.

The second part showed that the swelling, investigated in dilute CED (copper ethylene diamine) according to the method presented by Arnoul-Jarriault et al.[30], of cotton was much lower compared to swelling of two different dissolving pulps. It was found that the fibril aggregate size in the cotton samples was higher than in the dissolving pulp samples, and this probably contributed to the difference in swelling. The differences in swelling may say something about reactivity and that additional effort might be required to dissolve post-consumer cotton.

The results of the pure cotton study proved to be important later on in the Blend Re:wind process, as the structure of the cotton entering the process was well understood. Possible effects of the actual Blend Re:wind separation itself could thus be evaluated better as well.



'cotton is a cellulose-based fiber created by nature, and cannot be reproduced after use into its original superstructure. It can, however, be converted into a dissolving pulp and then further dissolved and regenerated into new textile fibers, such as the viscose or lyocell fibers.'

polycotton sheet
Image: Stina Björquist

2.2 early developments in the Blend Re:wind process

The first experiments on separation of polyester and cotton, published in the Master Thesis of Anna Peterson[29], tried the fundamental idea of using alkaline hydrolysis aided by a phase transfer catalyst (PTC) on 50:50 polycotton sheets in order to fully depolymerize polyester and obtain separated pure fractions of polyester monomers and cotton. To optimize the yield of the reaction the reaction parameters NaOH concentration, PTC concentration, temperature and time, were varied according to Table1.

The polyester reaction products from the separation are the polyester monomers TPA and EG, which was confirmed by ATR FT-IR and NMR spectroscopy. The crystalline structure of the cotton residue was analyzed using ATR FT-IR spectroscopy, revealing that no changes in the crystalline structure was observed except under the most harsh conditions, with temperatures above 80 °C and more than 10 wt% NaOH. A change in the crystalline pattern of cellulose might be of importance for the subsequent steps of recycling into regenerated fibers, and is thus of value to investigate.

The results of the Master thesis was further investigated and verified in the PhD work of Anna Palme, and published in the scientific paper Development of an efficient route for combined recycling of PET and cotton from mixed fabrics[31]. In particular, a more thoroughly examination of the correlation between the degradation rate of PET, the catalyst and the NaOH concentration was performed, as well as studies on the cotton changes. In the paper, it was concluded that PET can be completely hydrolyzed within 40 min in 10% NaOH at 90 °C with the addition of 52 mmol BTBAC/kg hydrolysis solution, and it can be recovered as pure TPA.

Increasing the temperature, NaOH concentration, and BTBAC concentration increase the reaction rate. Hydrolysis without BTBAC also yields pure streams; however, longer reaction times are required, and thus, the cotton yield will be lower. It was also clearly shown that the temperature highly effects the cotton degradation both on yield loss and on the decrease in DP. However, results from the milder treatments show that complete PET removal can be achieved without any severe degradation of the cellulose, or conversion of the crystallinity pattern of the cellulose.

Table 1 reaction parameters of alkaline hydrolysis of polycotton sheets

| reaction parameter | range |
|--------------------|-------------------------------------|
| CONCENTRATION NaOH | 1.5-15 wt% |
| CONCENTRATION PTC | 0.005-1 mol /mol repeating unit PET |
| TEMPERATURE | 80-90°C |
| TIME | 15-240 min |

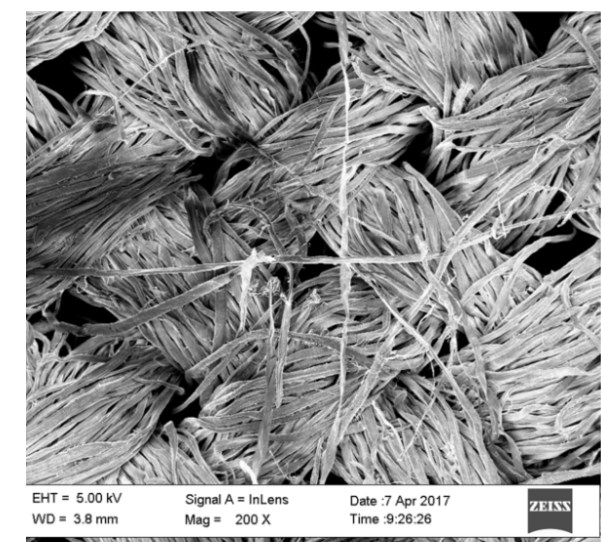
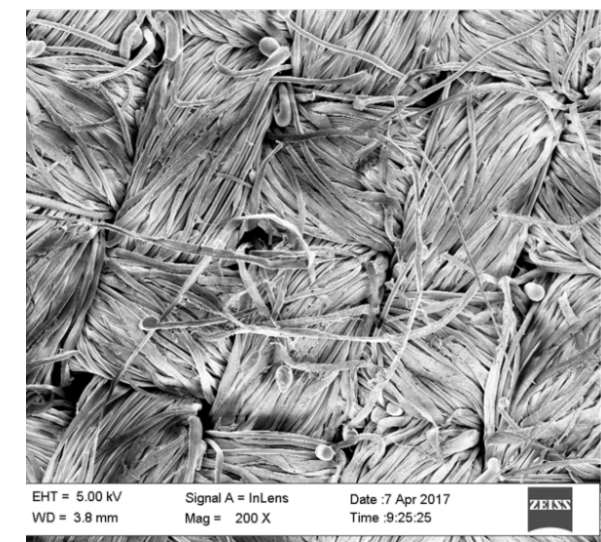
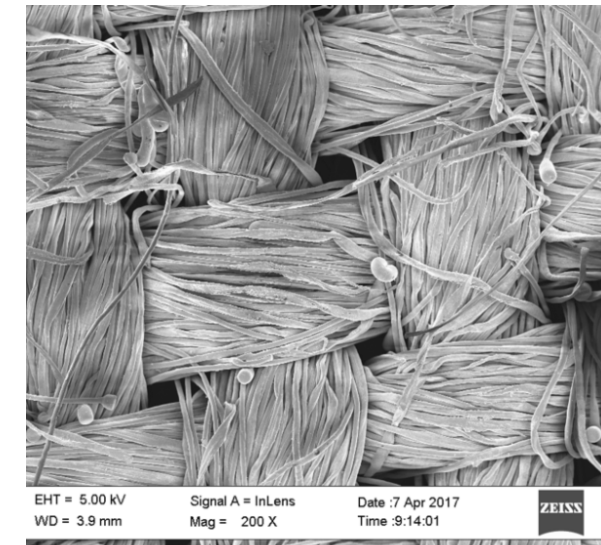


Figure 4 micrographs of the woven structure of new polycotton sheets (a) old polycotton sheets (b) and the pure cotton residue after separation of PET (c).

2.3 later improvements of the Blend Re:wind process

The findings in the early development of the Blend Re:wind separation process, elucidated the need of improvements of the process. Besides up-scaling of the process and experiments with more complicated textile samples, the quality control of the cotton residue was further studied, and the following regeneration of the separated cotton residue into filaments and fibers to prove the recycling concept performed. The experiment were now mainly conducted on sheets which had been used and laundered many times and were ready for incineration, whereas the early investigations were performed on new sheets. In addition, the ratio of polyester and cotton after cycles of use and laundry was investigated, as well as the impact of material fineness in experiments without the catalyst. Some of the later improvements of Blend Re:wind are not yet published, but the published work, particular the work of Master student Stina Björquist, published in her thesis Separation for regeneration - Chemical recycling of cotton and polyester textiles[12] is summarized below.

The study on the fiber ratio showed that the polyester ratio in old textiles increased slightly after repeated use and industrial laundering. Nevertheless, it may be concluded that worn-out polycotton textiles from the service sector still contain a large proportion of cotton that could be recycled into regenerated fibers. On average, the cotton ratio decreased to 44% after 50 launderings, compared to the originally content of 50% cotton.

Furthermore, the polycotton material fineness (i.e. using ground, shredded or cut materials) was studied in the process (Figure 5). The separation process was performed on new sheets with a low material concentration in the reaction mixture (1 wt%). From these experiments it was concluded that the polyester could be fully depolymerized without a catalyst at 90°C using 10% sodium hydroxide concentration after a process time of 390 min, regardless material fineness. The cotton yield was above 96% for all of the experiments. However, as mentioned above, the reaction time for complete depolymerization using the same conditions but also the catalyst was only 40 min. It is important to keep in mind that the time to reach full depolymerization is dependent on



Figure 5 ground, shredded and cut material fineness of polycotton sheets.
Picture by Stina Björquist.

the process set up and mainly serves as a comparison between different conditions. The process was then further evaluated using worn-out sheets, laundered around 50 times, with higher material concentrations (1 wt%, 3 wt% and 5 wt% of cut material in the reaction mixture). Higher material concentrations are needed in the up-scaling work to improve the environmental profile of the reaction. It was concluded that the lowest concentration led to full depolymerization of the polyester, but that even higher material concentrations are promising as well. However, to ensure a pure cotton residue of high yield, more efficient mass transfer conditions must be used as well as an optimized washing procedure to treat the cotton fiber residue after the process.

2.4 dissolution and spinning experiments

During the development of Blend Re:wind it was shown that the DP, and thus the related intrinsic viscosity, of the separated cotton residue was at a level that would make it suitable for viscose or lyocell production, still after long term use and the separation process. As the reaction conditions of Blend Re:wind are similar to the conditions of viscose production, conversion of the cotton residue into viscose was chosen to investigate the complete recycling concept of the polycotton material – from polycotton sheets to pure monomers of PET and a viscose filament of cotton.

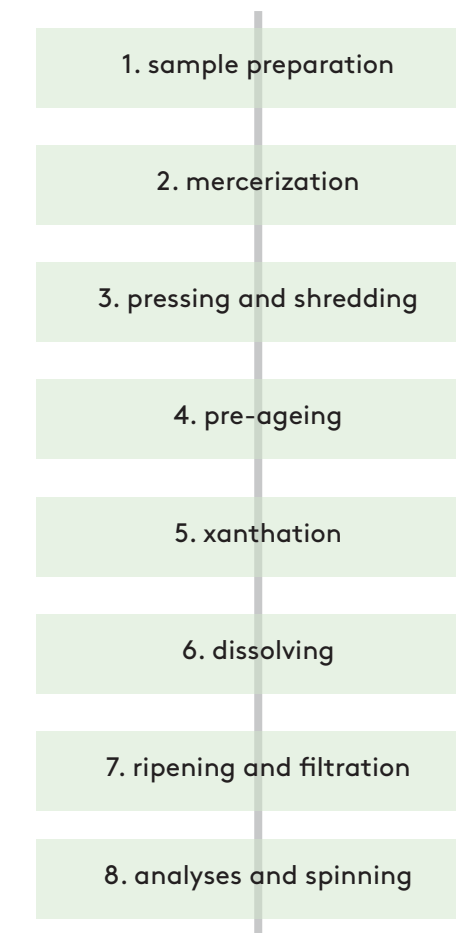
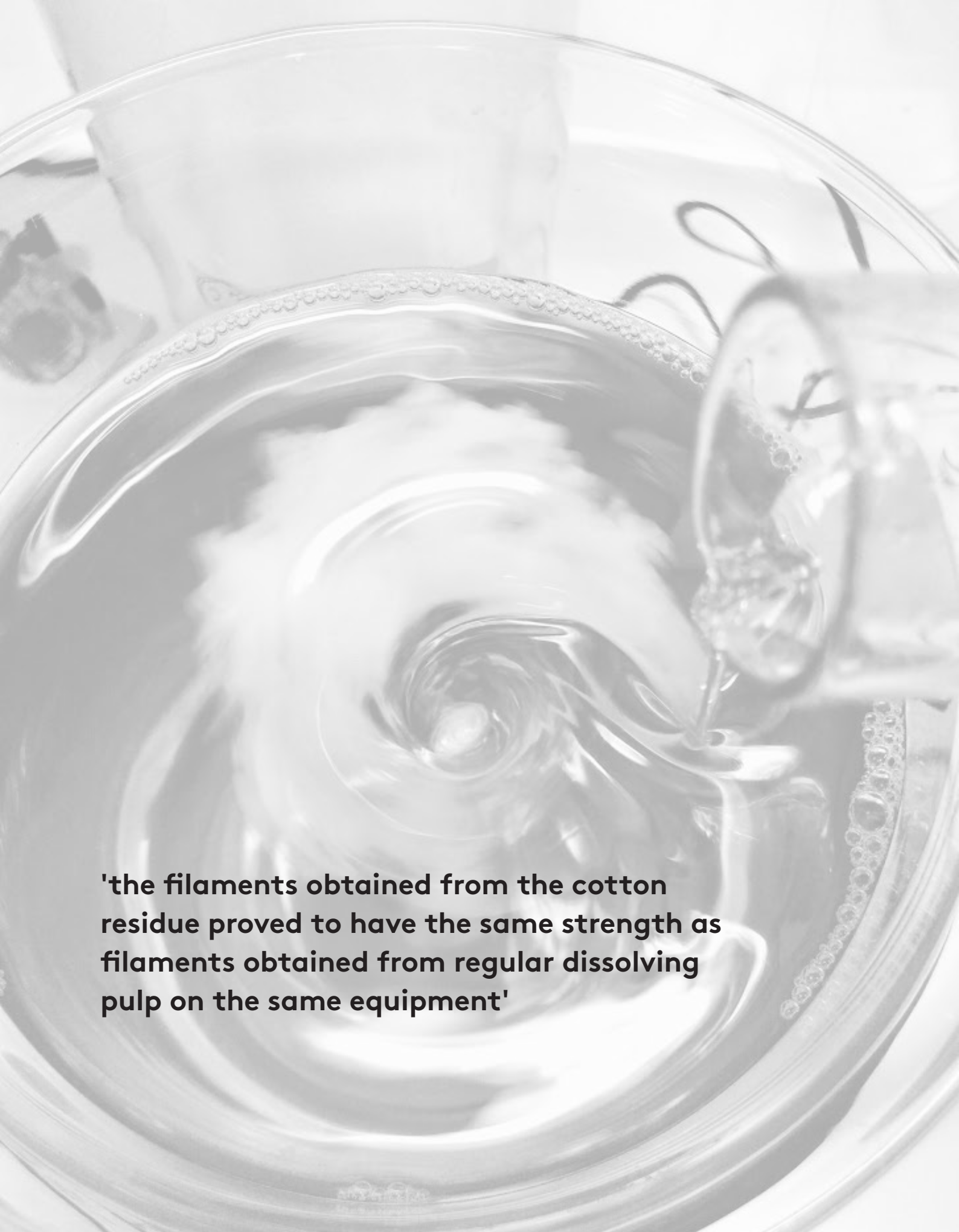


Figure 6 overview of the major steps of the viscose process.



'the filaments obtained from the cotton residue proved to have the same strength as filaments obtained from regular dissolving pulp on the same equipment'

The viscose experiments were performed together with MoRe Research Örnsköldsvik AB, who owns a viscose micro pilot in Örnsköldsvik, Sweden. The micro pilot includes the complete viscose process from mercerization to viscose dope, with the possibility to collect cellulose samples after each step for analysis. The viscose dope can then be regenerated into viscose fibers using the on-site spin pilot (owned by RISE Processum AB), dimensioned for 200-250 ml of viscose solution, where different spinning baths can be used as well as different stretching conditions.

Firstly, an ageing study (Figure 6, step 1-4) was performed to determine the efforts needed to obtain the desired intrinsic viscosity, of the input cotton residue, for the following steps in the viscose process. When the right conditions were found a complete aging of the whole cotton residue was performed, followed by xanthation and dissolution of the cotton into a viscose solution. During these steps the following analyses were performed on the cotton material: Cellulose content in alkali cellulose, Alkali content in alkali cellulose, Cellulose concentration in viscose solution, Alkali concentration in viscose solution, Ball fall (oc viscosity), γ -number (oc degree of substitution), Filter clogging value (Kr), Ripening Index (on viscose solution prior to spinning), Metal analysis, Reactivity of the cotton residue towards xanthation (Fock).

Based on the properties obtained by the analyses, the suitability of the cotton material for the viscose process and the potential of the later produced filaments could be determined. As the cotton material showed promising properties, the obtained viscose solution from the cotton was spun into filaments, on which fiber properties (titer, elongation, tenacity) were measured.

The results from the viscose trials were promising; the filaments obtained from the cotton residue proved to have the same strength as filaments obtained from regular dissolving pulp on the same equipment (Figure 7). However, as the intention of Blend Re:wind is to integrate as much as possible of the separation into existing industries, also blending of the separated cotton residue with commercial dissolving were performed. These experiments again proved the importance of understanding the full properties of the materials, in order to create an interacting blend for the viscose process. The detailed results from the viscose experiments are confidential and only accessible for involved process and business developers.

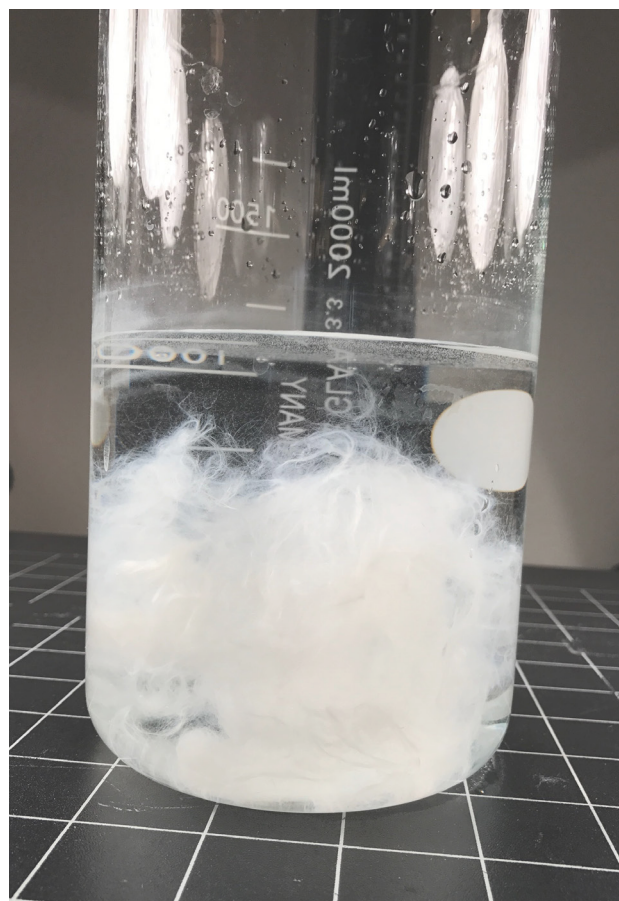


Figure 7 viscose filaments obtained from the Blend Re:wind cotton pulp

2.5 life cycle assessment of the Blend Re:wind approach

As mentioned in the section of later improvements of Blend Re:wind, higher material concentrations are needed in the process development to improve the environmental profile of the reaction. To early identify the environmental potential of the Blend Re:wind process, a prospective LCA was performed on the envisioned system. A preliminary LCA is however associated with certain limitations as data largely represents smaller pilot or bench scale conditions, which means that energy and chemical use has not yet been optimized.

Despite this, LCA was still introduced and utilized as guidance in the process development (rather than a later certification), to early indicate parts of the system that appeared to dominate, parts that seemed to be negligible, parts that were particularly uncertain, or to tell the environmental consequences of different actions or changes in the process. The full LCA report is confidential, but an extended summary entitled LCA on a potential future recycling system for polyester[32] is available.



Three product streams from the process; viscose fibres, terephthalic acid and ethylene glycol.

Image: Hans Theliander

'In the future development of the Blend Re:wind process, a further scale up of the process together with optimization of the conditions are in focus.'

The security of output qualities is particular important, as the output should be attractive for the industries converting them into valuable end products, such as new textile fibers.'

3. concluding remarks and future guidelines

The main published results that can be concluded from the Blend Re:wind project development are that a large decrease in the degree of polymerization (DP) of cotton was observed after laundering and use, and also that the swelling of cotton is less than for regular dissolving pulp. These are both important parameters to take account of in the development of a cotton recycling system based on regeneration into man-made cellulosic fibers, such as viscose or lyocell fibers.

Furthermore, the fundamental idea of using alkaline hydrolysis aided by a phase transfer catalyst (PTC) on 50:50 polycotton sheets in order to fully depolymerize polyester and obtain separated pure fractions of polyester monomers and cotton proved to be successful. Full separation was possible at 40 min in 10% NaOH at 90 °C with the addition of PTC. Without the catalyst, the separation was still successful but after a process time of 390 min at 90°C using 10% sodium hydroxide concentration.

The fineness of the input 50:50 polycotton material was not critical in the current process set up. Cut samples resulted in the same separation results as ground or shredded samples. The ratio of polyester and cotton does not change much during use and laundering, cotton might decrease slightly but the amounts are still relevant for recycling.

A higher wt% of the polycotton material is possible in the reaction; however the mass transfer and work up procedures need to be improved. Higher material concentrations are needed in the process development to reduce the environmental impact of the reaction.

In the future development of the Blend Re:wind process, a further scale up of the process together with optimization of the conditions are in focus. The security of output qualities is particular important, as the output should be attractive for the industries converting them into valuable end products, such as new textile fibers. Besides, the future development has to guarantee that five main challenges of textile recycling, according to us, are achieved:

1. To control and characterize the textile input
2. To fully separate the blended textile material
3. To restore lost fiber qualities
4. To remove and purify dyes and additives, and handle the obtained waste stream
5. To ensure full sustainability (social, environmental and economic) of the process/es

An important part of Mistra Future Fashion is to provide knowledge on necessary operations to enable and facilitate sustainable actions within sustainable fashion and textiles. To promote circular recycling of textile fibers, specifically polycotton blends, the below learnings and guidance can be extruded from the Blend Re:wind development.

One important lesson from the project is how important the fundamental characteristics of the input materials of a chemical recycling process are, together with rigid analyses during the process to understand and control material properties. In particular cotton, a natural polymer with an advance structure not possible to recreate in vitro.

Another good lesson is the benefit of utilizing the incredible competence present in the industry, and within related research areas (such as recycling of other materials), which has accelerated and given substance to the work of Blend Re:wind. Such existing competence can also be utilized to accelerate the success of the fifth challenge above. By utilizing knowledge from adjacent commercial products and their sustainability assessments, the overall sustainability of a new recycling process can be better understood and improved faster.

The regeneration of used cotton fibers into viscose or lyocell can for example be performed using very similar process conditions as for virgin cellulose fibers. However, the challenges 1-4 above figure 6, all related to the vast heterogeneity of textiles, elucidate the complexity of textile recycling; as existing processes producing textile fibers from virgin feedstocks are based on rather homogenous inputs, the recycling processes need to be more advanced and tolerant. To create such processes, but not at the expense of sustainability, will be a major puzzle also in the further development of Blend Re:wind.

Some other valuable points for future guidance to facilitate textile recycling could be given from the LCA work related to the project. LCA is today often used rather late in process development. However, if it is used as a continuous tool to early identify environmental soil pits and guide process development, costly changes later on could be avoided. It is also important to understand that new chemical processes will not alone solve the end-of-life issues with textile waste, and that upstream actions and changed mind-sets are critical as well. An open dialogue between textile design and materials science should be conducted as these two are connected in a circular economy by both working with the actual textile materials with their hands, but from different perspectives[33].

Actions within the supply chain is also of great importance, in particular to increase transparency (including for example a better control of chemical and fiber contents) [2], which would accelerate recycling technologies. Also innovative business models[34] and better policy measures with potential to have large positive impacts on fiber-to-fiber recycling as well as overall recycling of textiles, such as a mandatory EPR or a RVP system[35], would be important contributions. Improved transparency is also required towards users[36], who need to be well informed on recycling development and possibilities to avoid misunderstandings and boost positive and scientifically motivated state-of-the-art actions towards a sustainable fashion and textile industry.

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Mistra Future Fashion is a research program that focuses on how to turn today's fashion industry and consumer habits toward sustainable fashion and behavior. Guided by the principles of the circular economy model, the program operates cross disciplinary and involves 65+ partners from the fashion ecosystem. Its unique system perspective combines new methods for design, production, use and recycling with relevant aspects such as new business models, policies, consumer science, life-cycle-assessments, system analysis, chemistry, engineering etc.

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