smarter utilization of cotton textiles

considerations in the conversion to a circular textile value chain

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preface

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summary

The aim of this guide is to emphasize the challenges and possibilities for a smarter use of biobased fibers, and in particular cotton. The guide exemplifies potential products and cycles for both virgin and recycled cotton. Further, the guide highlights what to consider in the conversion towards a circular value chain, and what other biobased textile fibers that can be used to replace cotton in textile apparel.

First, the structure of cotton and its inherent properties are described and compared against the properties of other biobased fibers, such as viscose, modal and lyocell. These fibers may have the potential to substitute cotton and by that decrease the environmental impact of textiles.

Further, a smarter utilization of cotton is discussed. The conversion from a linear to a circular textile value chain is illustrated and discussed, including synergies with other value chains, such as the plastic industry, pulp and paper industry or chemical producers. Recycling possibilities of cotton is explained in terms of challenges and opportunities depending on the different steps of a recycling process, and the quality of the incoming cotton material.

Eventually, recommendations of what to consider and what actions that can be made to ease the present and future sustainable use of biobased textiles, and in particular cotton, are presented.

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introduction

Cotton is the most commonly used biobased fiber in textile apparel and corresponds to 27% of the total global market share of produced textile fibers (Sandin et al. 2019a). The excellent mechanical properties, such as strength and moisture absorption, in combination with the tactical sensation of a cotton fabric is unique and, so far, difficult to compete with when evaluating other types of biobased fibers. However, the cultivation and production of conventional cotton possess a large environmental burden, which makes it necessary to be willing to pay for sustainably produced cotton, find a better way of using the already produced cotton and to find practical substitutes. Also, the textile market already contains a large amount of cotton material of varying quality, which provides an opportunity for utilizing the already produced cotton to its full extent. The first option for already produced cotton garments should always be reuse since doubling the use of a garments will decrease its environmental impact by 49% (Sandin et al. 2019b). This is also in line with the next option, after reduce, in the waste hierarchy developed by the EU (figure 1). However, when reuse no longer is a feasible alternative, recycling of existing materials should replace production of new material from virgin resources. Today, only 1% of the fibers produced for clothing is recycled, which must be increased (MacArthur Foundation 2017).

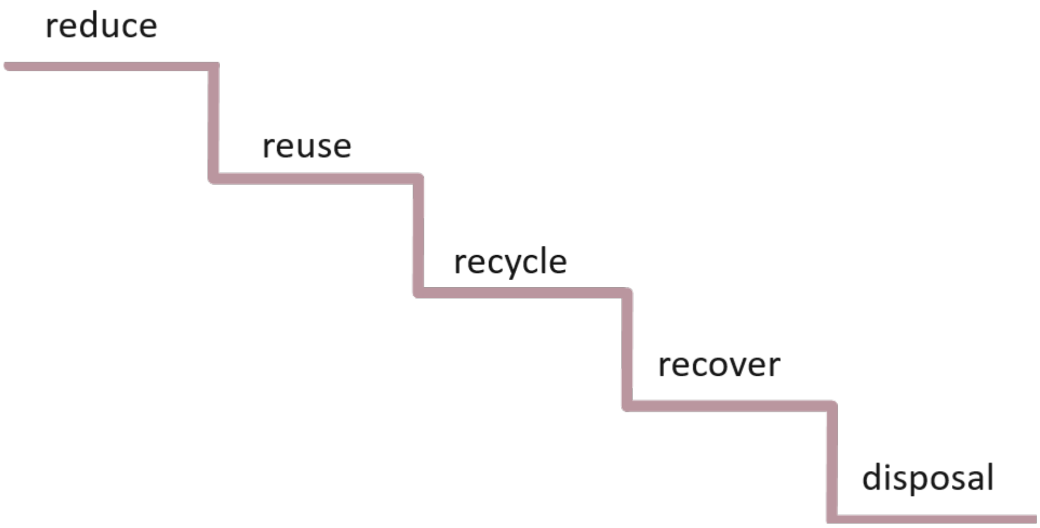

figure 1. The EU waste hierarchy directive. Picture adapted from (EU 2019).

the exceptional properties of cotton

Cotton is a natural fiber arranged in a complex structure that consists of several layers built up by cellulose (figure 2). The cotton plant thrives in warm climates and requires a large amount of water, which in combination with the need for pesticide to secure high yield of the harvest is the reason to the large environmental impact of conventional cotton cultivation.

The desirable properties of the cotton fiber stem from its native structure, where each layer of the fiber provides a specific feature. The result of this is a high-quality fiber with great mechanical strength, excellent moisture absorption, and breathability. If the fiber is damaged or degraded due to mechanical or chemical treatments, the sophisticated organization is lost and cannot be remade again. However, a damaged or degraded cotton fiber is an excellent raw material for other types of textile fibers, such as regenerated cellulose fibers, further described in the following sections.

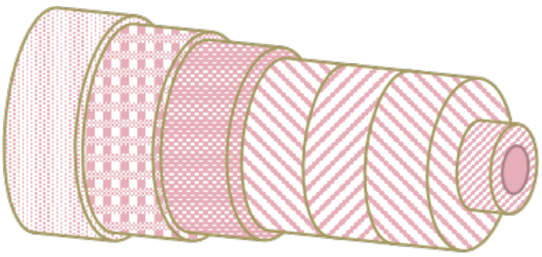

figure 2. Schematic representation of a cotton fiber.

quick facts about cotton

- The structure of cotton cannot be remade
- Damaged or degraded cotton is an excellent raw material for production of other biobased textile fibers

Although cotton belongs to the category of well-performing fibers it is also often used in fast-fashion apparel, which is an irresponsible use of high-quality material and contributes to the large environmental burden of a cotton garment. If a garment is to be used for a limited amount of times it might not be necessary to have such a high mechanical strength of the fiber. A fiber of less mechanical quality and decreased environmental impact could thus be an appropriate alternative. Important to remember though is that a substitutional biobased fiber is not synonymous with a decreased environmental impact since it has been shown that the production route and site is the determining factor for the total environmental impact of a garment (Sandin et al. 2019a).

properties of other biobased fibers

Biobased textile fibers based on cellulose is not only made from cotton, but from all plants that contain cellulose, such as different types of wood, agricultural crops and grasses. However, the cellulosic fibers obtained from these raw materials are sometimes too short to be spun into a yarn and are, therefore, in need of additional processing. The additional processing involves dissolution and precipitation of the cellulosic fibers and by varying the conditions in these processing steps, different properties of the textile fibers can be obtained. Viscose, modal and lyocell fibers are all commercial examples of this, made from cellulose derived from wood. The fibers are known as regenerated cellulose fibers and utilizes different processing routes, which is reflected in their mechanical properties (table 1). The degree of polymerization is an indication about the length of the fiber and is a property affected by wear and laundering. Cotton has a higher degree of polymerization and can, therefore, be used during a long period until it must be converted into a new product. The moisture regain reflects the uptake of moisture in the fiber. The regenerated fibers are, therefore, a better alternative than cotton when a high moisture uptake is wanted. The dry and wet tenacity of the fibers demonstrates the strength of the fibers in dry and wet condition.

The major challenge for regenerated cellulose fibers as a substitute for cotton is currently their decreased resistance against industrial laundry (Wedin et al. 2019). On the other hand, when industrial laundry is not a prerequisite, regenerated cellulose fibers could be a good alternative to cotton fibers. However, as mentioned earlier, a biobased fiber is not synonymous with a low environmental impact but is highly dependent on the specific production route and site. As stated by Sandin et al. "viscose produced with nearly closed chemical loops and renewable energy can be among the best alternatives, while viscose produced with poor or lacking chemical management and coal power can be among the worst" (Sandin et al. 2019a).

table 1. Mechanical and comfort properties of cotton, viscose, modal, and lyocell fibers. Adapted from (Lenzing 2008).

Fiber	Tenacity dry (cN/tex)	Tenacity wet (cN/tex)	Moisture regain (%)	Degree of polymerization
Cotton	2.4-2.8	2.5-3.0	8	3000
Viscose	2.5	1.3	13	430
Modal	3.5	2.0	11	640
Lyocell	3.7	3.0	11	850

smarter utilization of produced cotton textiles

The production of textiles has been found standing for 80% of the environmental impact of a garment. It is, therefore, evident that the already produced material must be utilized in a smarter way. A way of doing this is to expand the waste hierarchy, which Potting et al. have suggested by going from five to nine steps accordingly: refuse, rethink, reuse, repair, refurbish, remanufacture, repurpose, recycle and recover (Potting et al. 2017). Cotton textiles will degrade upon wear and laundering, which affects the inherent fibers (figure 2). The degradation is mainly reflected in a decreased length and, hence, mechanical strength of the fibers (Palme et al. 2014). However, severe degradation of cotton fibers only occurs after an extended period of use, which means that a large amount of the textiles, today regarded as waste, still has high-quality properties and should be considered for reuse rather than recycling or recovery.

The future textile value chain is a circular process with several side-streams where textiles are directed, preferable in a large-scale general sorting system, towards reuse or recycling depending on their present quality. Along with the circular textile value chain, synergies with other value chains are utilized in an equilibrium between receiving and delivering valuable products and materials. An example of this is the recycling of blended textiles where fossil and biobased garments are separated, which can provide building blocks for chemical production and raw materials used in nonwovens and composites or recirculated into the textile value chain again (figure 3).

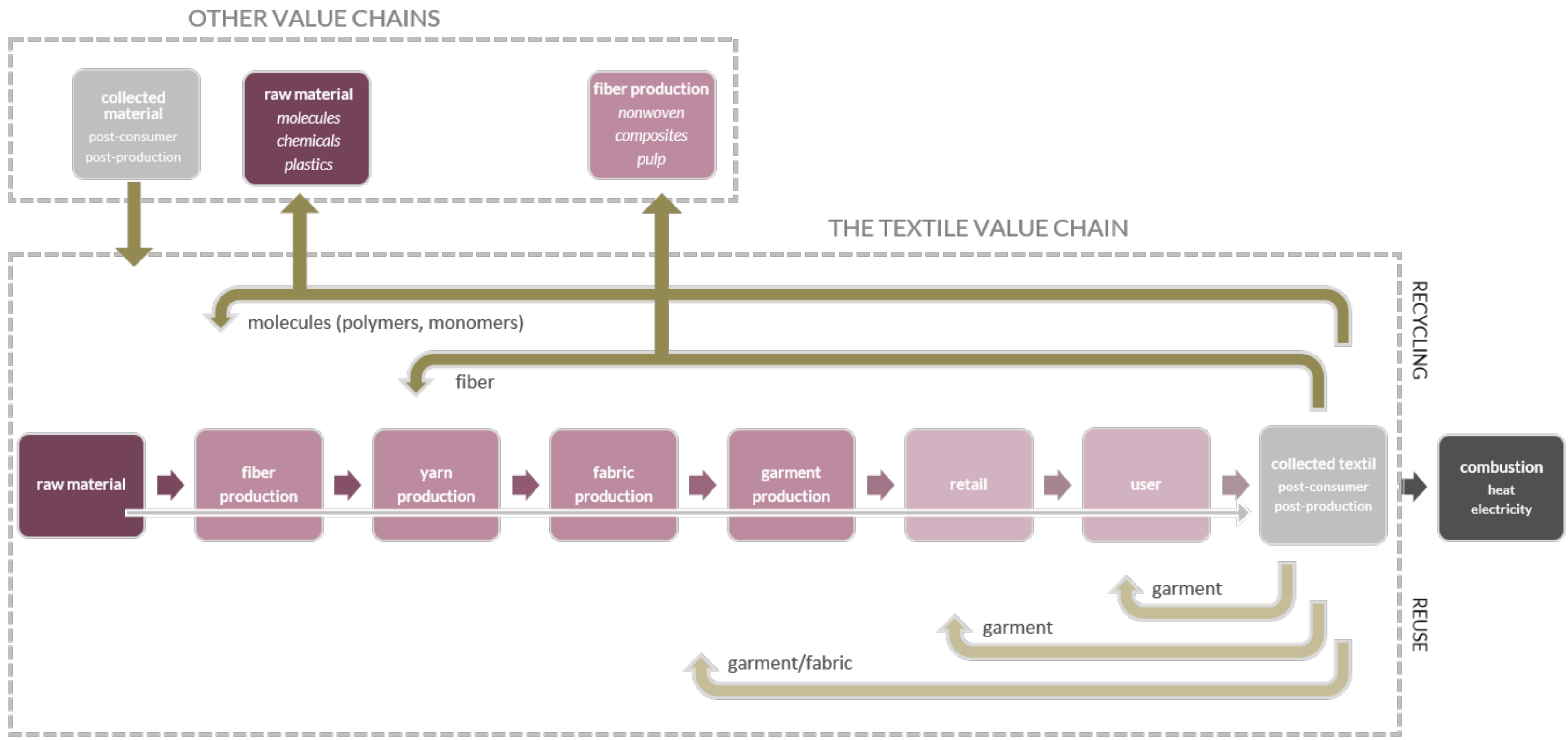

figure 3. Illustration of the future textile value chain and synergies with other value chains. Picture by RISE AB.

recycling of cotton textiles

Recycling of textiles is still under development and calls for both technical, logistical and political solutions. Depending on both the quality, the composition and the chemical properties of the textile garment, different recycling routes should be considered. A schematic representation of the technically available recycling routes is shown in figure 4. Due to the nature of cotton (i.e. inability to form a melt), mechanical and chemical recycling are the two alternatives for cotton-based garments.

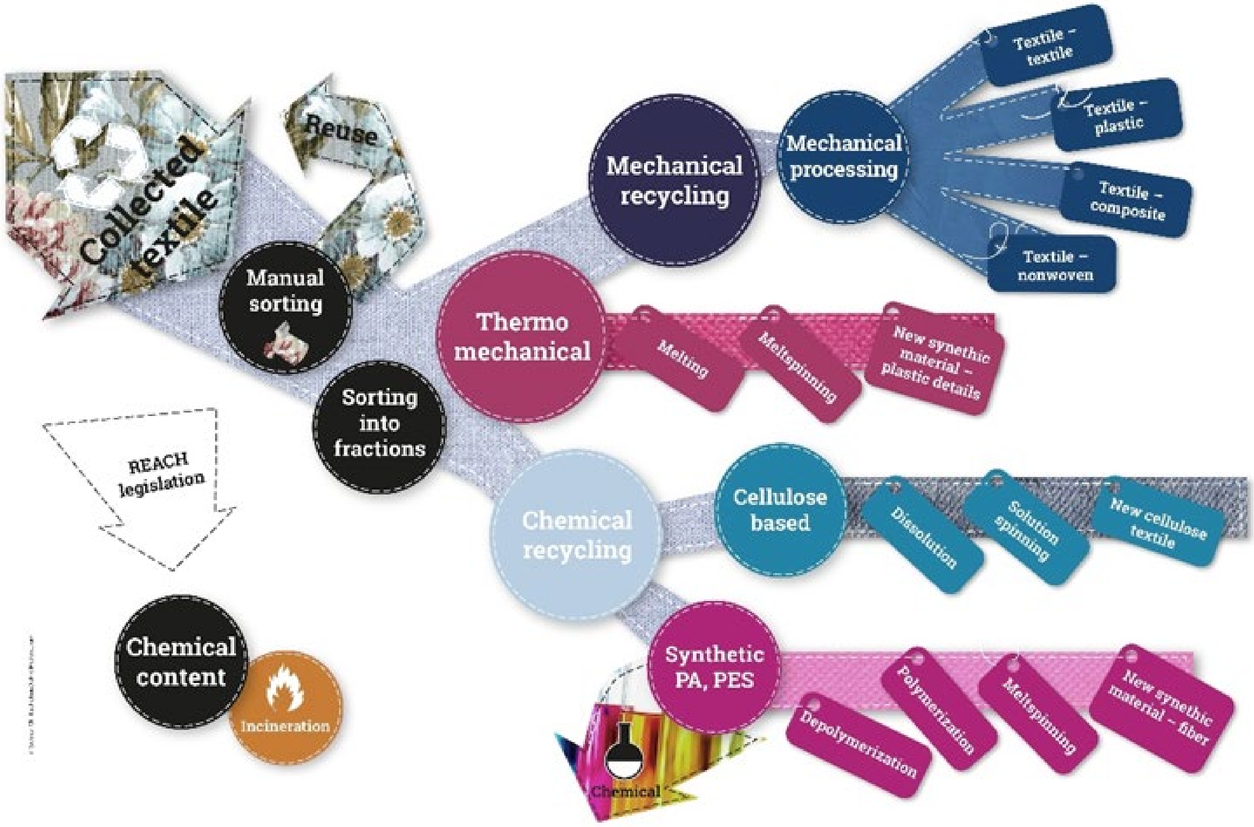

figure 4. The routes for recycling of different textile qualities. Picture by RISE IVF AB.

Recycling may include many different steps as illustrated in figure 5. These steps all need to be considered in the end of life of a textile.

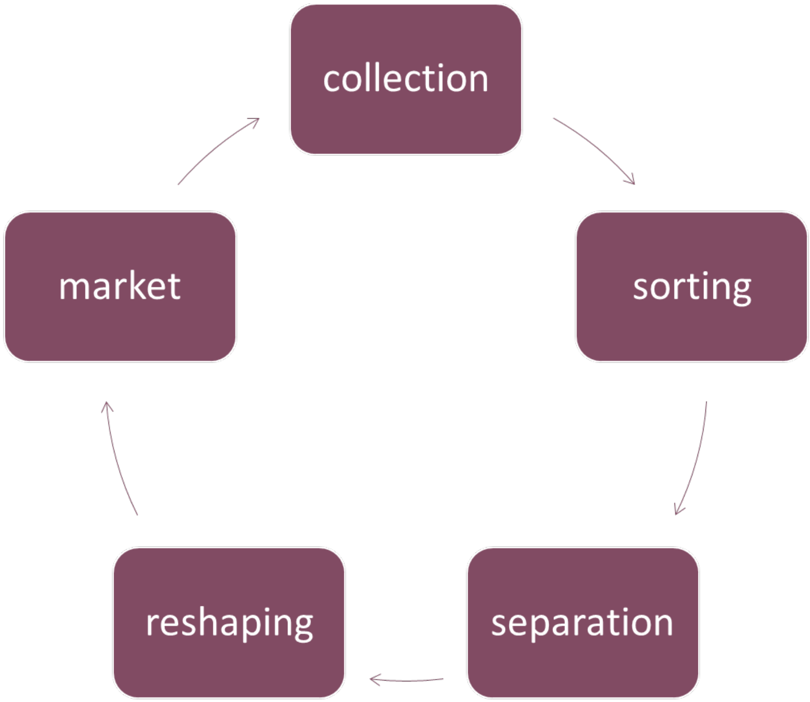

figure 5. Schematic representation of a circular textile recycling chain.

sorting of textiles

The recycling chain starts from the collection of waste textiles (figure 5). The textiles then need to be sorted into each fiber type, or similar fractions, to identify proper recycling routes and applications for the textiles. The wide variety in quality and fiber composition calls for both automated and manual sorting to obtained efficiency and accuracy. The use of several different fibers in a garment might be an obstacle since the automatized sorting equipment of today often is based on spectroscopic techniques (Sysav 2019; Wargön Innovation 2019). These techniques cannot distinguish between fibers that have similarities in their chemical fingerprints. The use of only one fiber type in garments would then be preferred to improve the quality of the automatic sorting, however, mono-materials are not always synonymous with more sustainable or functional textiles. Instead, it is likely that better transparency and information technology (such as RFID tags) must be included in a future accurate sorting system.

separation of textile fibers

If cotton is blended with another fiber type, a separation might be needed. Mechanical separation is an alternative and consists of liberating the fibers by tearing the garment apart. Mechanical separation provides a simple solution with no need for pre-treatments or usage of chemicals in the recycling route. This method is well suited for textiles that contains only one type of fiber or when high purity is not a demand for the final application.

Another alternative is chemical separation, which is beneficial when a garment consists of more than one type of fiber or when there is a demand to obtain a certain purity of the separated fibers. Chemical separation utilizes the feature to only affect materials of a certain kind. An example of this is the separation of fibers in the most common fabric blend, consisting of polyester and cotton. Solvents can efficiently break the bonds that hold the polyester together while having no effect on the cotton fibers. The result is one solid fraction of cotton fibers and one liquid fraction of dissolved polyester. The solid and liquid fraction can then easily be separated from each other using filtration. This is the concept of the Blend Re:wind process, which was developed within the Mistra Future Fashion program (de la Motte and Palme 2018). The solid cotton fibers are then, depending on their quality, suitable for different types of applications, while the dissolved polyester can be repolymerized into virgin polyester again (figure 6). Chemicals that are introduced during from the processing of cotton, such as dyeing and finishing treatments, would probably need to be separated from the cotton fibers as well, to obtain recycled cotton materials with attractive properties. However, in a chemical separation, these chemicals might be removed simultaneously as other fibers by the addition of suitable chemistry.

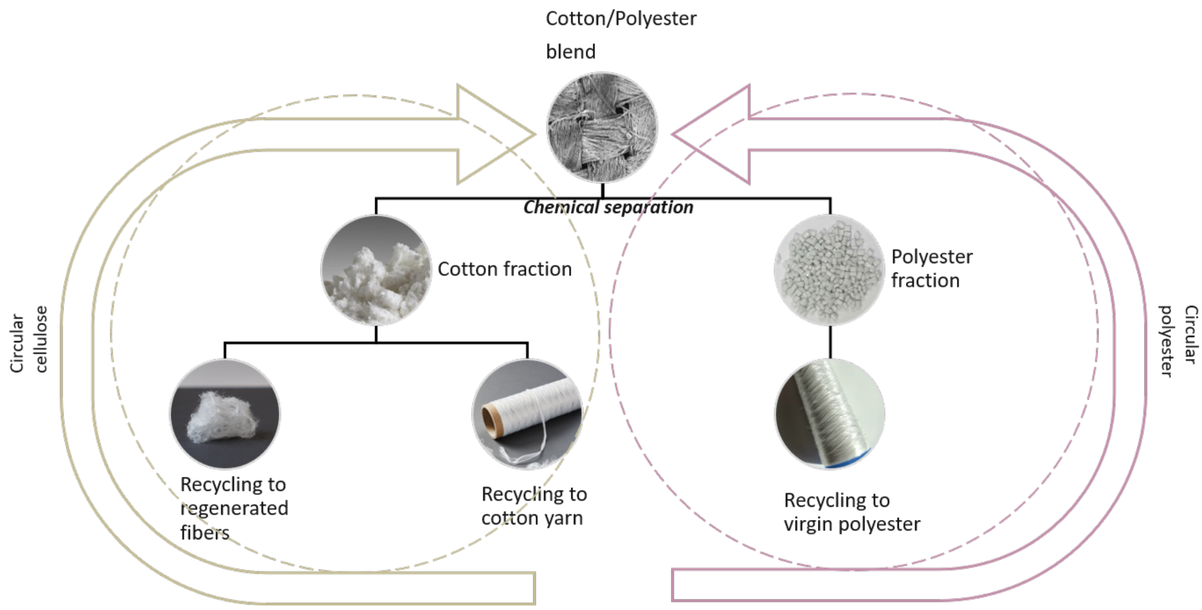

figure 6. Schematic illustration of the circular chemical separation process developed for cotton/polyester textiles in the Blend Re:wind process. Picture by RISE AB.

reshaping of textile fibers

Once an efficient separation has been achieved, the fibers need to be reshaped into a yarn before they once again become a fabric. In terms of cotton, the mechanical and chemical separation method cause different types of damage to the fibers, which sets the prerequisites for the following reshaping method.

Mechanical separation might cause shortening of the fiber length due to the applied forces in the tearing and the fibers lose some of its strength. It is therefore common to mix the mechanically recycled fibers with a fraction of virgin fibers to increase the mechanical strength and to be able to spin the fibers into a yarn again. Important to notice is that additional processing of the fibers, such as bleaching if the color of the recycled fiber is not satisfying, will cause further degradation of the fibers. The tearing of the fibers can also give rise to defects in the produced yarn which gives an uneven appearance. However, the reshaping of mechanically separated fibers has the the great advantage of not demanding a high level of pureness, which greatly simplifies the process and where mixing with virgin fibers solves the issue of obtaining too weak fibers for the yarn production. In cases where the incoming cotton material is of high purity and quality, mechanical reshaping into new yarn of decent quality for certain areas, not only clothing but also composite materials or non-woven, could be obtained.

When the length and strength of the cotton fiber is too low for the fibers to be spun into a yarn again, the fibers become a good raw material for other types of textile fibers, namely regenerated fibers such as viscose or lyocell fibers. The reshaping of cotton into a regenerated fiber demands a dissolving and precipitating step, which results in a textile fiber that can be converted into a yarn. The method enables conversion of severely degraded textile into new textile of high quality at least one more time before it can continue as raw material for other types of products, such as additives or chemicals.

However, the reshaping of recycled cotton into regenerated fibers puts high demand on the pureness of the fibers that is obtained in the separation process or subsequent purification treatments. Dyes and finishing agents could be difficult to remove from the cotton fibers depending on the interactions that are formed between the cotton and the dye or finishing agent (Wedin et al. 2018). An insufficient removal of such impurities could cause malfunction in the reshaping process and, thus, becomes an obstacle in the recycling route. On the other hand, when efficient purification is reached, the reshaping method provides the opportunity to create fabrics with high quality properties, both in terms of mechanical properties and its appearance.

quick facts about reshaping of cotton

- The degree of fiber damage determines the reshaping method
- Reshaping into regenerated fibers demands high pureness of the recycled fibers
- Dyes and finishing treatments can hinder efficient reshaping

recommendations

- Reuse should always be considered prior to recycling or recovery of a textile material
- Cotton is an exclusive high-quality fiber that should be used when its properties is a prerequisite for the wanted application
- Consider using other biobased textiles instead of cotton if they provide sufficient properties
- Increased knowledge regarding recyclability of regenerated fibers into new regenerated fibers or other suitable application is needed
- In the design of a garment, avoid using several types of textile fibers to facilitate upcoming recycling. If fibers are mixed, it should be for sustainable reasons, such as extending the life
- Avoid using textile finishes that are difficult to remove from the fibers, which influences the pureness of recycled materials because of problematic handling in a recycling process
- Cotton waste of higher quality can be mechanically recycled and reshaped into a recycled yarn that for certain areas is of an attractive quality, or mixed with virgin cotton to obtain a yarn of even better quality
- Cotton waste of lower quality can be reshaped in a chemical recycling process into regenerated fibers to obtain new high-quality biobased textile fibers

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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 60+ 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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