CLEANTEX

Clean and Innovative Textiles Strategy for Circular Economy

MODULE 4
Waste Management and Recycling

Unit 4.3
Technologies for Textile Recycling

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Introduction and definitions

Textile recycling is the action of reprocessing pre- or post-consumer textile wastes and use it in new textiles or non-textile products. We can distinguish the closed loop recycling processes and the open loop recycling processes.[1] Closed loop recycling are processes in which the recycled textile material is used in a more or less identical product (For example, a t-shirt will be recycled into a yarn or another clothe). In the opposite, an open loop recycling process is a process in which the textile recycled material is used in a different product (For example, a t-shirt will be recycled into a bottle, or into insulation material).
It is possible to recycle the textiles at different scales (Figure 1). They can be recycled into fibers, into polymers, into monomers or into molecules different from monomers. In those different scales we can also separate the mechanical recycle processes and the chemical processes.

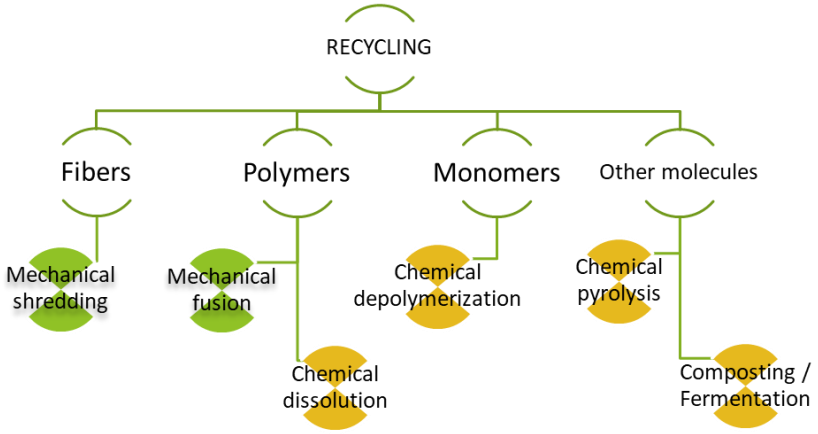

Figure 1 Possible recycling scales

Textiles to recycle can come from two origins: the pre-consumer and post-consumer deposits. The pre-consumer deposit is said to be well-known and homogeneous because textile comes directly from companies or industries. They can be production waste, unsold finished products, or unfinished products. The composition, the dyes used, the properties of the material are well known and it makes it easier to sort and recycle. The post-consumer deposit is said to be mixed and heterogeneous. The textiles come from discarded clothes most of the time so a lot of information is missing, like the exact composition of the textiles or the dyes that has been used. Moreover, the fibers are already damaged by usage, and so are more fragile.

Before each process some preliminary steps are required. An extensive sorting step is necessary in order to separate coated or laminated textiles, which are difficult to recycle. In a same way, having a mixture of colors or materials will lead to a poor-quality output. Removing all the hard parts (zips, buttons, thick seams…) is also an essential step to avoid them to get stuck in the recycling machines. It will lead to a better efficiency. However, those sorting and removing step are really complex and time-consuming because they are most of the time manual. Once everything is sorted, and once the hard parts are removed, the textiles are cuts into little pieces which are easier to process.

Recycling textile into fibers

The first recycling process is the mechanical shredding recycling process. This is the only process in which the output is a mix of fibers. Little pieces of textile are put in a shredding machine which has rotating drums with metal pins. The metal pins open the textile to recover the fibers. The output is a mix of fibers with different lengths. In theory this process can handle every textile in input but it is better to avoid coated, laminated textiles or blends with more than 10% of elastane, as they can stay stuck in the machine.

The main applications of the recycled mix of fibers are nonwovens and insulation. It can also be used as plastic processing inputs, as composite input, or as charge in plastic. When the fibers are really short, they can be used as flock. Those applications are open-loops. The only closed loop application is when the fibers are re-spun into a yarn. However, this is really complex because the length of the fibers is reduced during the process, so it's necessary to add a virgin material with the recycled material to ensure the mechanical properties of the yarn.

Recycling textile into polymers

The second process is the mechanical fusion recycling process. The pieces of textiles all melted and spun directly or recycled into granulates. Because textiles are melted this process is only suitable for thermoplastic materials (polyester, polyamide, nylon 6…). It's also a really sensitive process, the material should be as pure as possible. Removing an impurity from a polymer melt is like removing an impurity from modeling clay; it is almost impossible. This is why the post-consumer deposit is non-suitable, because there is more chance to get a contaminated textile. Other thermoplastic deposits (plastic bottles e.g.) are also suitable for this process.
The output granulates can be used in plastic industry, in an open loop process. When they are used in textile industry it can be a closed or open loop depending on the input (textile or plastic input). The major drawback of this process is the polymers are degraded each time they are melted. This process is not infinite and it is necessary to add some virgin materials to ensure the mechanical properties of the output material.
This process already exists at an industrial scale but mainly for recycling PET bottles and plastic waste[1].

In chemical dissolution process, the textile pieces are dissolved in a specific solvent (for example, for polyester the solvent used is ethyl benzoate and for nylon 6 it is formic acid). Almost every fiber can be dissolved, from synthetic polymers to cellulosic fibers (cotton, viscose e.g.), but it is more difficult for some fibers (wool e.g.). Pre- or post-consumer deposits are accepted, as well as paper deposits or plastic deposit. The output is a dissolved polymer which can be spun using a solvent spinning process to recover a fiber of the same nature as the input one. There is just an exception for cotton, for which we obtain artificial viscose.
The applications are closed or open loops as the output can be used in textile production, in paper production or in plastic production. The advantage of this process is it can handle contamination and fiber blends, as it is possible to dissolve only a part of the blend. It is also a solution to remove coatings, dissolving only the fiber or only the coating.
This process exists at a semi industrial scale mainly to recycle cotton into viscose.

Recycling textile into monomers

The next process is chemical depolymerization. Textile pieces are depolymerized and purified for dyes or chemicals. They can be depolymerized in various ways, like glycolysis, hydrolysis, methanolysis or enzymatic depolymerization. Only synthetic polymers can be depolymerized. The output are monomers that can be polymerized again to get a new polymer which will have the same quality as a virgin polymer.
The output monomers can be used in textile or in plastic processing industry, in open or closed loops. This process allows an infinite recycling loops because there is not degradation in quality and impurities are also well removed. It also allows recycling blends because only one part of the blend can be depolymerized.
This process exists at an industrial scale, but many research projects are still currently conducted on the subject.

Recycling textile into molecules

In chemical pyrolysis process pieces of textiles are heated at a very high temperature (more than a 400 degrees) to be degraded and converted to gas, oil and carbon. Any organic carbon-based material including biomass plastics and textiles can be used as an input of this process. At the output, a large share of the material is converted to condensable compounds. This desired product is referred to as pyrolysis-oil. Pyrolysis gas is also produced, it's a gas mixture consisting of hydrogen (H2), carbon monoxide (CO), carbon dioxide (CO2) and methane (CH4). Some carbon is also created during the process[2].
The oil can be used as fuel. The pyrolysis gas and carbon can be burned to eat or can be used as feedstock in the production of chemicals. Closed loop application doesn't exist with this process. The advantage is it allows recycling of fibers and blends of fiber that can't be recycled by any other technologies (aramid fibers e.g.). It's also a possible solution for contaminated and damaged textiles that cannot be recycled in any other way.
This is unfortunately not yet developed on an industrial scale for textiles but the pyrolysis of plastics already exists at industrial scale.

The last processes are composting and fermentation recycling. Microorganisms transform organic material into molecules, thanks to fungi, yeast or bacteria in the presence of oxygen, water and nitrogen. Mostly cellulose rich feedstock is accepted in input, as cellulosic textiles for example, but mixed textile waste are also accepted. The output is a range of fuel molecules and chemicals and non-cellulosic fibers are recovered, like polyester.
The fuel molecules can be used as fuel or burned to heat and chemicals can be used as input in other industries. This is a process that already exists in biorefineries to recycle agricultural wastes.

Examples of recycling manufacturers

Some examples of manufacturers mechanically recycling fiber from pre-consumer, and post-consumer textile waste:

- Supported by H&M and Levi's, the American start-up, **Circular Systems**: Texloop™ produces RCOT (recycled cotton fiber) with the longest possible staple length.[3]

- In India, **Geetanjali Woollens** collects used sweaters from all over the world and sorts them according to their fiber (acrylic, wool or cotton) and color. They guarantee a minimum of 70% Wool in their Wool Fibre Blends and about 70% Acrylic in their Acrylic Fibre.[4]

- In Spain, **Recover™** RCotton fiber is made from 100% recycled fibers, suitable for overdye, using minimal solvents and water.[5]
  - RPure comes from 100% cotton textile waste.
  - RMix is a recycled cotton fiber from cotton blended textiles. It contains traces of other fibers (up to 10%).
  - RDenim fibers are obtained by recycling pre- and post-consumer denim. They are mainly composed of cotton fibers with other fibers (up to 20%).
  - RColorblend is made of recycled cotton (30 to 70%) mixed with recycled fibers.

- **Re-Verso ™** is a company that collect, select and transform pre-consumer waste of wool and cashmere, for the creation of regenerated yarns and fabrics for the fashion sector. They are use in famous brands such as Stella Mac Cartney , Eileen Fisher , Filippa K and Patagonia.[6]

Some examples of manufacturers recycling cotton or cellulosic materials into new artificial cellulosic fibers:

- **Infinite Fiber Company.** The company will open a new plant in 2024. Infinna™, a premium-quality, circular textile fiber is made from used textiles, wood pulp, newsprint (Finland). It is a cellulose carbamate fiber.[7]

- **Asahi Kasei** in Japan. Bemberg™ is a regenerated cellulose fiber made from cotton linter, a pre-consumer material obtained from manufacturing process of cotton. It is a cupro fiber.[8]

- **Lenzing**. The pioneering REFIBRA™ technology involves upcycling cotton scraps from garment production. These cotton scraps are transformed into cotton pulp. A substantial proportion – up to 30%– of this is added to wood pulp, and the combined raw material is transformed to produce new virgin TENCEL™ Lyocell fibers to make fabrics and garments. [9]

- **Renewcell**. Circulose® is a branded dissolving pulp product that Renewcell makes from 100% textile waste, such as worn-out jeans and production scraps.[10]

Some examples of manufacturers using mechanical fusion to recycle Polyester, RPet, or Polyamide:

- **Nilit** in Israel. Sensil® EcoCare recycled Nylon 6.6 is made with pre-consumer waste providing fine denier, high-quality fabrics that last and last. They are transformed as multifilament texturized yarns.[11]

- **Fulgar** in Italy. More than half of Q-NOVA® fibre is made from pre-consumer polyamide 6.6 waste.[12]

- **UNIFI** is the world's leading, branded recycled fiber since 2007. REPREVE recycled polyester is created from plastic bottles. It is used to make filaments, staple fibers and fillers. Unifi also manufactures REPREVE nylon from "pre-consumer" waste.[13]

- **Asahi Kasei**. ROICA™ EF (German plant) is a world-first Global Recycled Standard (GRS) certified stretch yarn (Elastane) and one of the recycled stretch innovations, re-made from pre-consumer materials. [14]

Some examples of manufacturers using chemical recycling processes:

- **Jeplan**. BRING Technology™ depolymerizes PET in ethylene glycol solution to produce BHET. Clothing can be recycled any number of times through this technology.[15]

- **CARBIOS.** With its mastery of enzymatic depolymerization, Carbios enables the infinite recycling of all types of PET waste as well as the production of 100% recycled and 100% recyclable PET products, with no loss of quality. Following the excellent results obtained in the demonstration plant launched in September 2021, Carbios will build its first fully bio-recycled PET manufacturing plant in France.[16]

- **Teijin** Eco Circle™ is a commercially offered chemically recycled PET. ECOPET™ is polyester product (fibers, textiles, garments, and goods) made from recycled sources: various types of polyester waste, through the mechanical or chemical recycle process. It enables the effective use of the limited natural resources.[17]

- **Toray** group has developed a broad competence in plastics recycling and in particular in the chemical recycling of polyamide fibers. [18]

- **Aquafil**. Nylon waste, otherwise polluting the Earth, is transformed into ECONYL® regenerated

nylon. ECONYL® regenerated nylon is a product of Aquafil, a global leader in the synthetic fibres industry and a pioneer in quality, innovation and sustainability.[19]

Conclusion

In conclusion, in order to improve the processes that already exist today a solution must be found to effectively sort textile products which are mostly composed of several materials and therefore difficult recycle.
In addition, most recycling processes degrade the materials and the output material cannot be used completely as an input material in the new textile because the mechanical properties are degraded. Selecting the right process according to the desired application is important to keep the quality of the output product as high as possible.
Many recycling methods exist today and more will certainly emerge in the years to come. It is however important to remember that recycling is at the end of the product life and it's not recycling alone that will allow the textile sector to become responsible. It is necessary that each manufacturing step process be modified and generate less waste to be recycled or to better generated and facilitate its recycling.

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