Unit 4.3 Technologies for textile recycling

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4.3.1 Some definitions [8]

- Textile recycling: Reprocessing pre- or post-consumer textile waste for use in new textile or non-textile products.
- Closed loop recycling: Process in which the recycled textile material is used in the textile industry (yarns, textile e.g.).
- Open loop recycling: Process in which the textile recycled material is used in another product (textile to bottles e.g.).

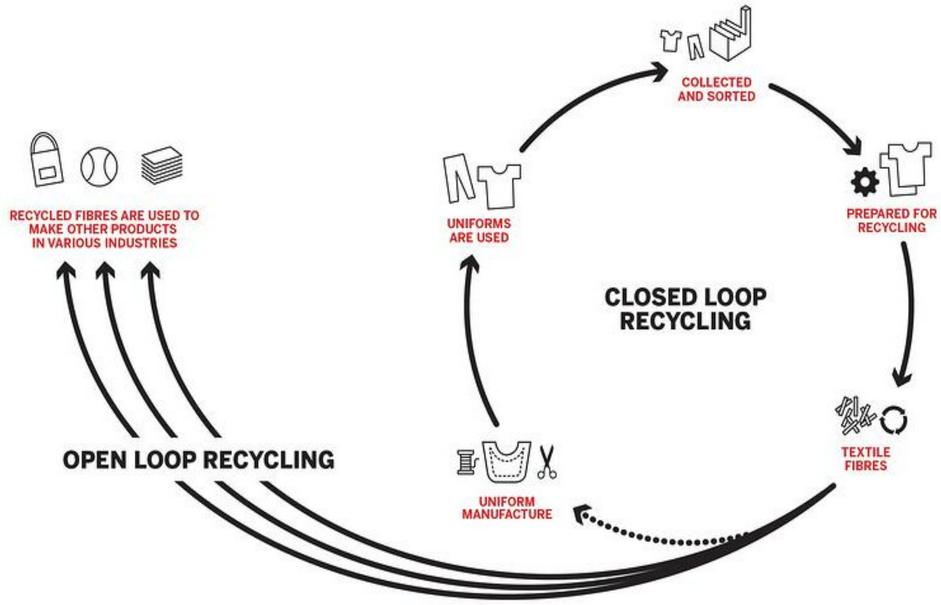

Figure 2. Closed and open loop recycling paths [7]

4.3.2 Mapping and review of recycling processes

- Choice of scale: Possible to recycle textile into fibers, polymers or monomers. Some other processes recycle textile into molecules (different from monomers).
- Two major families of recycling methods : mechanical and chemical.

Monomer: Small and simple molecule that can be linked together to form a polymer.

Polymer: Chain made of several linked monomers (up to millions).

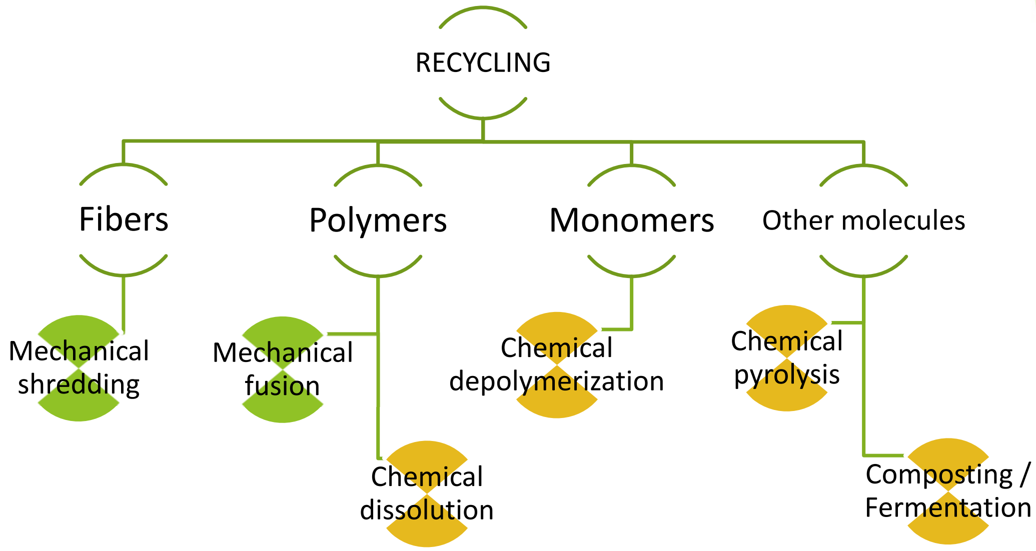

Figure 3. Map of the different recycling methods

Required preliminary steps for all recycling processes

- An extensive sorting step is necessary, as mixtures of different materials, colors, coatings will result in a poor quality output.
- Hard parts must also be removed (zips, buttons…) to facilitate recycling and have a better efficiency. This step is complex and time consuming because it is manual.
- Once sorted, textiles are cut in little pieces, which are easier to process.
- Discarded textiles:
  - Pre-consumer deposit: Well-known and homogeneous deposit. Textile comes directly from companies and industries (production waste but also unsold finished products). Composition, dyes and properties of the material are well known, which makes it easier to recycle.
  - Post-consumer deposit: Mixed and heterogeneous deposit. Textile comes from discarded clothes. Some information is missing, like the exact composition or the dyes used. The fibers are already damaged by usage, so it is harder to recycle.

Mechanical shredding recycling process

- Process : Little pieces of textile are shredded in a shredding machine[1].
- Inputs : Every textile in theory, except coated, laminated textiles, or blends with more than 10% of elastane.
  - Pre-consumer textile deposit: ok
  - Post-consumer textile deposit: ok
- Output: Mix of shredded textiles, with different lengths of fibers.

Figure 4. Shredding machine rotation drums with metal pins. [1]

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Mechanical shredding recycling process

- Applications:
  - Spun into a yarn. Complex because the length of the fibers is reduced during the process, so need to add virgin material. -> Closed loop
  - Nonwovens / Insulation material : main use -> Open loop
  - Plastic processing input (thermoplastic), composite fiber input or charge in plastic -> Open loop
  - Short fibers can be used as flock -> Open loop
- Environmental aspect : One of the most eco-friendly recycling process, because does not use water and chemicals. However, it uses mechanical energy.
- Drawbacks: Fiber length decrease. If you want to use the output in a closed loop, it is better to have a mono-material textile as input (100% cotton, wool, polyester…).
- Technological maturity: This process exists on an industrial scale. Most of the time, recycled fibers are used to make compounds or nonwovens [8].

Mechanical fusion recycling process

- Process: Textiles melted and spun directly (melt spinning) or recycled into granulates.
- Inputs: Only suitable for thermoplastic materials (polyester, polyamide, nylon 6…), as pure as possible, because the process is very sensitive to contamination.
  - Pre-consumer deposit: ok
  - Post-consumer deposit: impossible
  - Other thermoplastic deposit (e.g. plastic bottles)
- Output: Granulates of polymer or filaments.

Figure 5. Example of existing mechanical fusion process. [2]

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Mechanical fusion recycling process

- Applications:
  - Granulates can be used in other industries, like plastic processing -> Open loop
  - Granulates and filaments from textile deposit can be used in textile industry -> Closed loop
  - Granulates and filaments from other deposit can be used in textile industry -> Open loop
- Environmental aspects: Uses energy to heat the polymer.
- Drawbacks: Polymers are degraded each time they are melted, so the process is not infinite and virgin polymers must sometimes be added to ensure the mechanical properties of the output yarn or material. Input material should be as pure as possible, because impurities are really hard to remove once melted.
- Technological maturity: This process is used at an industrial scale mainly for recycling PET bottles and plastic waste[8]. (e.g. Repreve [2]).

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Chemical dissolution recycling process

- Process: Textile pieces are dissolved in a specific solvent. (Table 1)
- Inputs: This process is suitable for all fibers that can be solubilized. It's the case for synthetic polymers, as well as cellulosic fibers (cotton, viscose)..
  - Pre-consumer textile deposit: ok
  - Post-consumer textile deposit: ok
  - Paper deposit
  - Plastic deposit
- Output: Solubilized polymer, which can be spun using a solvent spinning process to recover the same fiber as the input one. Exception for cotton, recycled in cellulosic pulp, which can be spun to obtain viscose.

Table 1. Some fibres and an appropriate solvent

Fibre	Solvent
Cotton	N-Methylmorpholine N-Oxide
Polyester	Ethyl Benzoate [9]
Nylon 6	Formic Acide

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Chemical dissolution recycling process

- Applications: Textile production or paper (cellulosic pulp) -> Closed or open loop
- Environmental aspect: This process uses water, energy and chemicals that can be hazardous to dissolve the fibers.
- Advantages: Process can handle contamination and fiber blends. (Figure 6)[3]. Indeed, in choosing the right solvent, one fiber can be dissolved and not the other. It's also a solution to remove coatings, dissolving only the fiber or only the coating.
- Drawbacks: Cotton macromolecules are degraded during dissolution.
- Technological maturity: This process is mainly used for cotton at a semi-industrial scale.

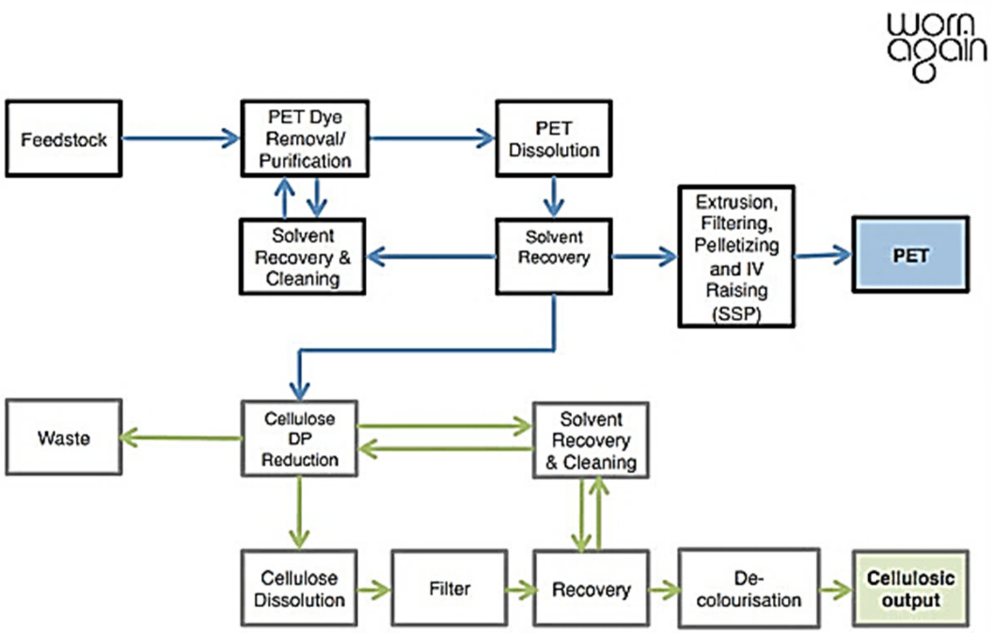

Figure 6. Example of recycling path for a cotton/polyester mix [3]

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Chemical depolymerization recycling process

- Process: Textiles pieces are depolymerized and purified for dyes or chemicals. There are various ways to depolymerize a material, but the most common involve glycolysis, methanolysis or hydrolysis (Figure 7)[4]. Enzymatic depolymerization also exists.
- Inputs: Only some synthetic polymer materials can be recycled this way (polyester, polyamide e.g.)
  - Pre-consumer textile deposit: ok
  - Post-consumer textile deposit: ok
- Outputs: Monomers, that can be polymerized to recover the original polymer. This polymer will have the same quality as a virgin one.

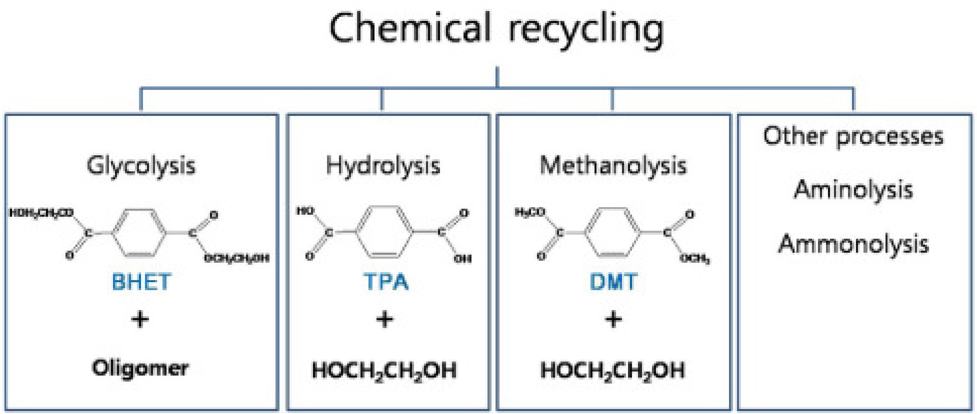

Figure 7. Most common depolymerization methods of polyester and product of each reaction [4]

Chemical depolymerization recycling process

- Applications:
  - Textile industry -> Closed loop
  - Plastic processing industry -> Open loop
- Environmental aspects: This process uses chemicals that can be hazardous and energy.
- Advantages: This process allows an infinite recycling loops, as there is no degradation in quality. The output polymer has the same quality as a virgin one. Impurities are well removed. This process allows recycling blends.
- Drawbacks: Very expensive.
- Technological maturity: This process is available at an industrial scale. Many research projects are currently being conducted on the subject.

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Chemical pyrolysis recycling process

- Process: Textiles is heated at very high degree (>400°C) to be degraded and converted to gas, oil and carbon.
- Inputs: Any organic / carbon-based material, including biomass, plastics (thermoplastics as well as thermosets) and textiles.
    - Pre-consumer textile deposit: ok
    - Post-consumer textile deposit: ok
- Output (Figure 8) [5,6]:
    - A large share of the material is converted to condensable compounds. This desired product is referred to as pyrolysis-oil.
    - Pyrolysis gas is produced, it's a gas mixture consisting of hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2) and methane (CH_4).
    - Some carbon is also created during the process.

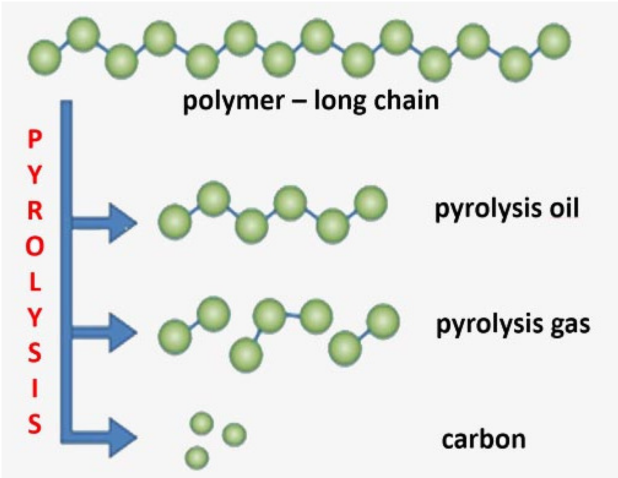

Figure 8. Products of pyrolysis [5,6]

Chemical pyrolysis recycling process

- Applications:
  - Pyrolysis-oil can be use as fuel. -> Open loop
  - Pyrolysis gas and carbon can be burn to heat or can be used as feedstock in the production of chemicals. -> Open loop
- Environmental aspects: Use of thermic energy
- Drawbacks: High costs (energy, investment and operational) and high temperature
- Advantages: This process allows recycling of fiber and blends of fibers that can't be recycled by any other technology, like aramid fibers. It's also a possible solution for contaminated and damaged textiles.
- Technological maturity: This process is not yet developed on an industrial scale for textile. However, pyrolysis of plastics exist at industrial scale.

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Composting and fermentation recycling process

- Bio-valorization
- Process: Biological processes where microorganisms transform organic materials into molecules. The processes can happen thanks to fungi, yeast, bacteria, in the presence of oxygen, water and nitrogen.
- Inputs: Mostly cellulose rich feedstocks, as cellulosic textile, but can also be mixed textile waste. Bio-based input can be recycled this way.
- Outputs: This process allows production of a range of fuel molecules and chemicals (ethanol, lactic acid, citric acid, succinic acid, butanol…). Non cellulosic fibers can be recovered (e.g. polyester).
- Applications: Fuel molecules can be used as fuel or burn to heat. Chemicals can be used as inputs in other industries. -> Open loop
- Technological maturity: This process is already used in bio-refineries, to recycle agricultural waste.

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4.3.3 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 to recycle.
- In addition, most recycling processes degrade the materials. Choosing the right process based on the input product, its composition, its initial quality and the desired application is important to keep the quality of the output product as high as possible.
- Many recycling methods exist, 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 cycle and that it is not recycling alone that will allow the textile sector to become responsible. It is necessary that each manufacturing step process be modified to generate less waste to be recycled, or to better generate it and facilitate its recycling.

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