Textile recycling

Textile and Clothing Materials Course

Kirsti Cura, PhD, postdoctoral researcher, FTF Research group, Aalto University

October 18, 2023

Status of textile waste in Europe

- 7 million tonnes of textile waste (15 kg per person) is generated in EU and Switzerland annually, with 2% increase every year, 85% comes from discarded clothes and home textiles of consumers, 99% of textile waste is of virgin material
- by 2030, the amount discarded textiles is estimated to be at least 8.5 million tonnes, with separate collection requirement it could increase by another 50% by 2030
- about 30-35% gets currently separately collected
- less than 1% is fibre-to-fibre (F2F) recycled to textiles
- 1.7 million tonnes used textiles were exported to Africa in 2019
- reuse, resale and repair are of first priority according to the waste hierarchy, but recycling is also needed
- fibre-to-fibre recycling can be an economically viable option once technologies are fully matured
    - up to 70% of textile waste could be fibre-to-fibre recycled
    - the remaining 30% would be open loop recycling or thermo-chemical recycling

McKinsey & Company, 2022; European Environmental Agency, 2023

Large scale **collection, sorting, reuse and recycling infrastructure** is needed to enable transformation to closed loop recycling

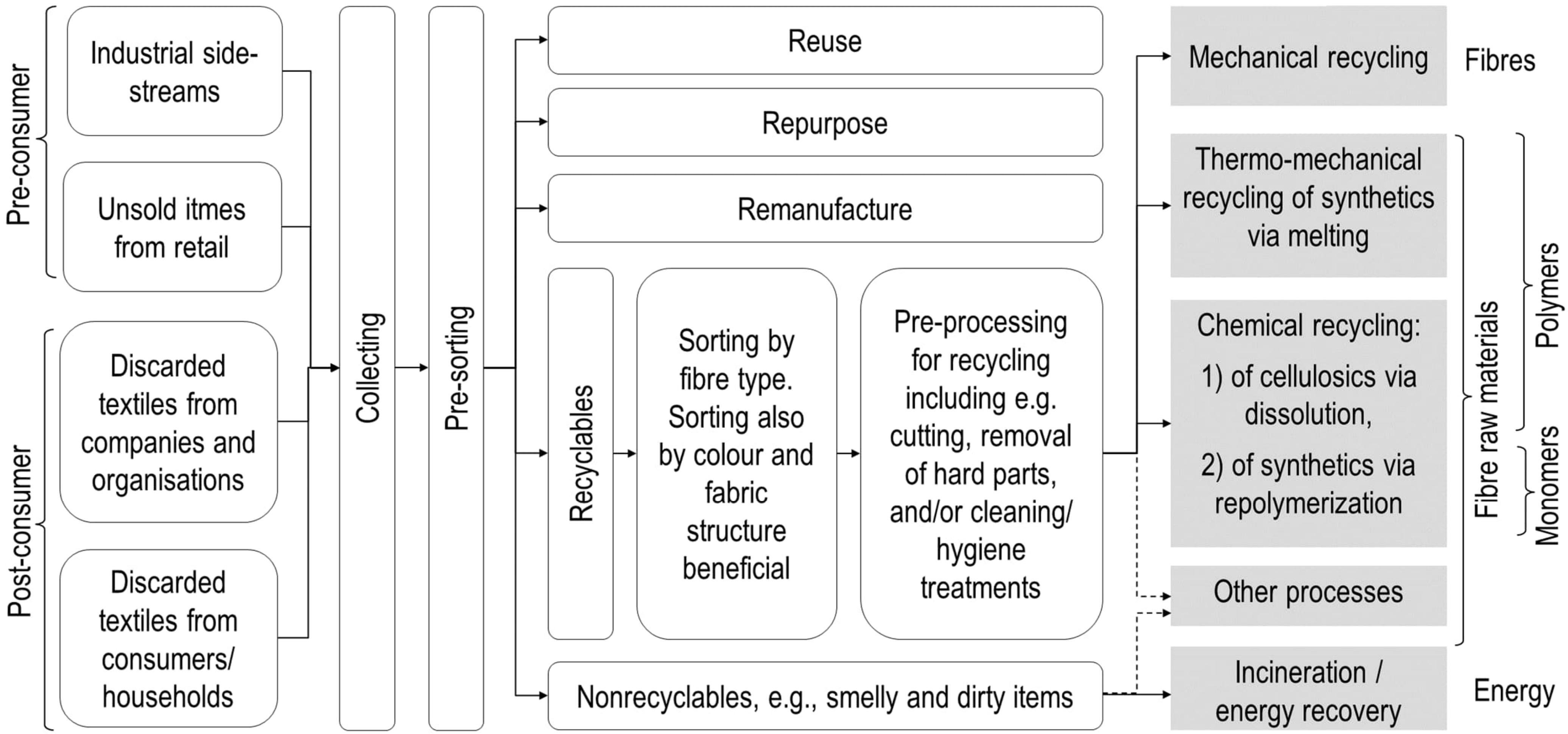
- **higher collection rates** and **less export** to outside EU
- **development of recycling technologies** (mechanical, thermal, chemical); current recycling technologies **have strict feedstock requirements** for fibre composition and purity
- zippers, buttons, prints need to be removed before shredding/dissolving
- advanced and accurate automatic **fibre sorting and pre-processing need to be further developed and scaled**, questions on economic viability
- recycling technologies must **further expand their ability to handle blends**, **lower costs** and **improve output quality**

If these bottlenecks can be overcome, by 2030:

- fibre-to-fibre recycling could reach 18-26 % of gross textile waste
- 6-7 million € investments become a profitable industry with an annual profit of 1.5-2.2 billion €
- create 15 000 green jobs
- 4 million tons of CO_2eq. emission savings

- "Transform Waste into Feedstock" by Texaid is the first project by ReHubs initiative, addresses current sorting technologies, **50 000 t capacity by 2024** https://euratex.eu/139/rehubs-2022-circulating-textile-waste-into-value/

Ecosystem of textile recycling



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Heikkilä, 2024

Input (feedstock) for textile recycling

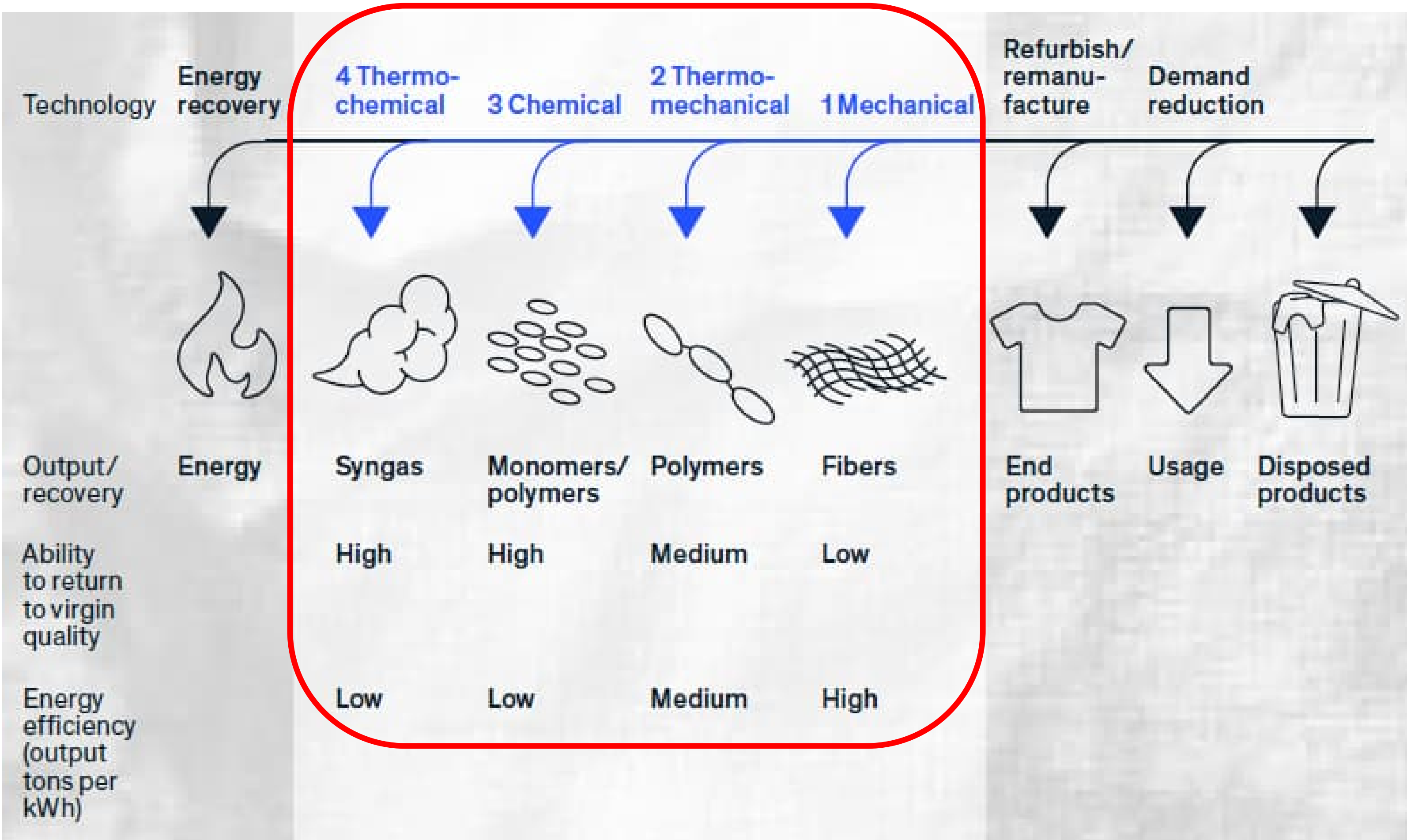
Pre-consumer i.e. post-industrial i.e production textile waste

- industrial side streams: homogeneous by composition and type, big batches of known material, and same colour
- unsold items from retails: similar to post-consumer

Post-consumer i.e. post-consumption textile waste

- discarded textiles from companies (hospitals, hotels, etc.): fairly homogeneous by composition and type, large batches
- discarded textiles from consumers/households: very heterogeneous waste stream by composition, type and volume, varies according to season and area
- textiles that are not fit for reuse because worn-out or damaged, or of low-value

Textile recycling technologies



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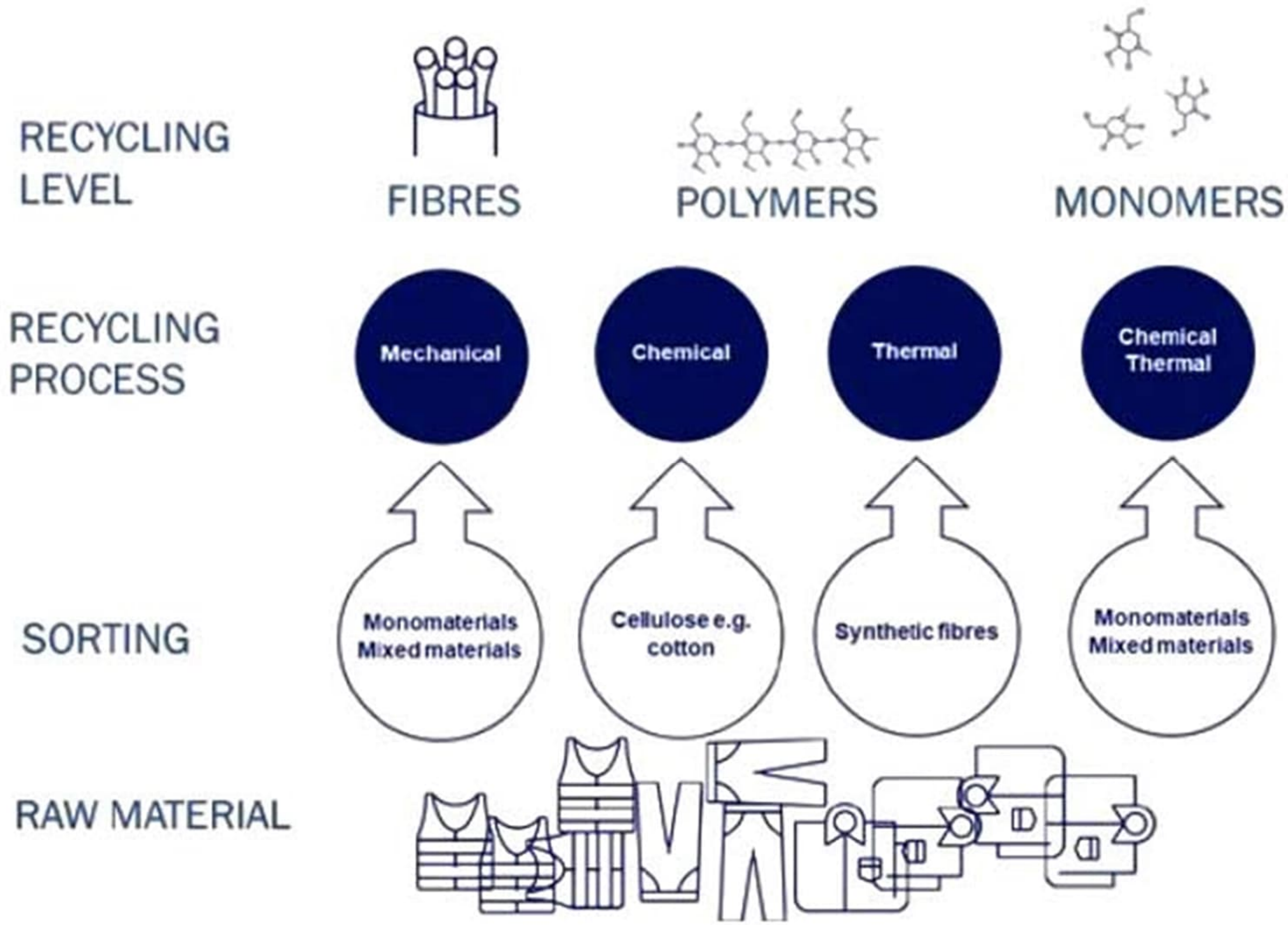
McKinsay & Company, 2022

Levels of textile recycling



Chemical recycling is also called molecular recycling or advanced recycling

NB! Thermal is the same as thermo-mechanical.

https://cris.vtt.fi/en/publications/telaketju-towards-circularity-of-textiles

Sorting

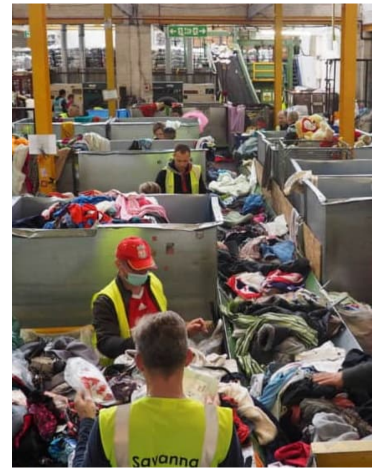
Before recycling, there are always (pre)sorting and preparation steps
Essential for successful recycling – no matter which recycling technology

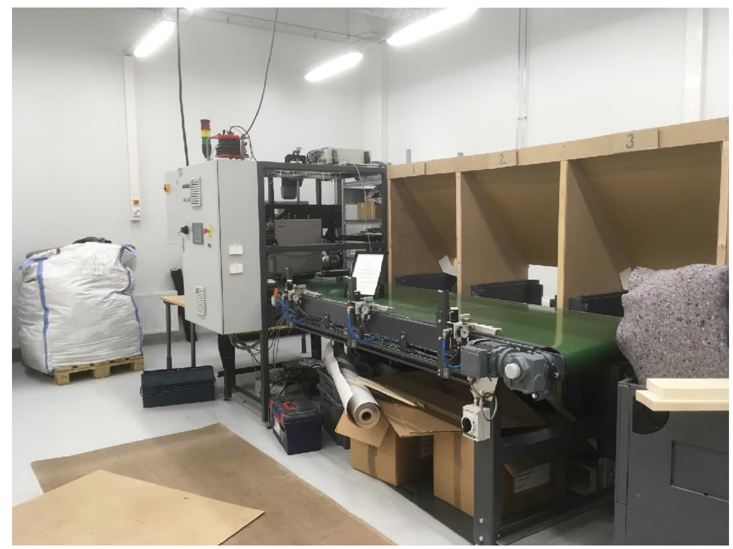
Manual sorting – widely used

- Wet, moudly, dirty, smelly textiles are sorted out – preferably at source
- Reusable textiles are collected for resale and charity
- Textiles containing zippers, buttons, tags, embroidery, large prints and coatings, non-textile parts are removed
- Pre-processing before recycling: such as cutting into smaller pieces, cleaning, and hygiene treatment may be needed
- Sorting based on product, colour, textile structure, shape, fashion, material

Automated sorting incl. material identification – getting scaled, has technology limitations

- Material identification is carried out using optical devices; a measurement is non-contact, non-destructive, safe, but on the surface only
    - Issues with multimaterial (esp. small amounts of elastane), black/dark colours, multi-layers, large prints, textile structures, chemicals
- Automated sorting is under commercialization, many technology providers
    - There is not enough machinery for increasing volumes of textile waste once separate collection in EU really starts
    - €€€€€ question: how to make it economically profitable?





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Mechanical recycling

Established technology and currently **the most common recycling technology** for textiles

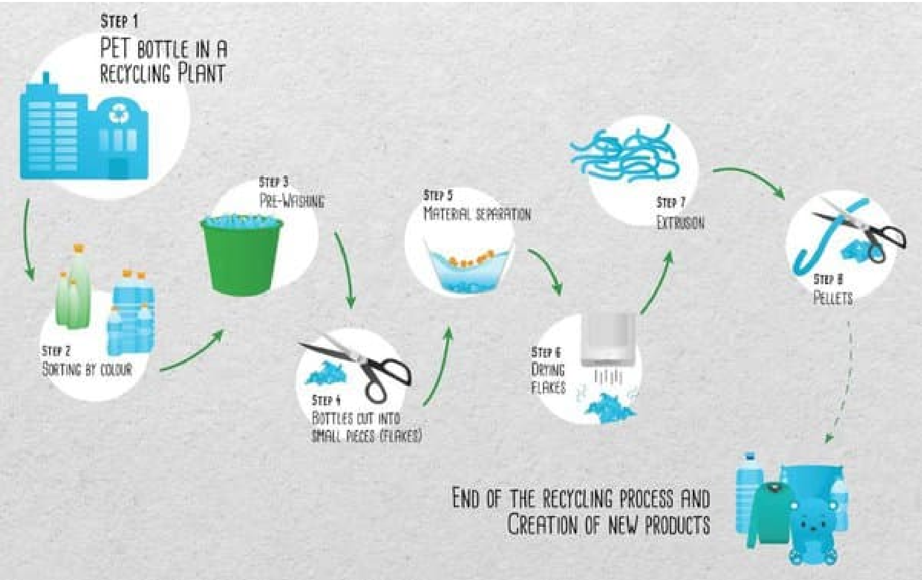
- Textiles are opened by tearing, hacking, shredding or brushing to separate fibers – mechanical work!
- In the fibre opening process, the **fibres are shortened**, which leads to **lower quality fibres** compared to virgin fibres
- **The composition of textile material is not changed** (for example cotton stays as cotton), **colour and finishes remain** in fibres
- Post-consumer waste can bring issues with hygiene, colours and finishes
- Opened fibres are used for insulation, padding, nonwovens and composites (downcycling)
- Better quality fibres can be spun into fibres (recycling, upcycling)
- In principle, **all kinds of textiles and textile blends can be mechanically recycled**; textile structure determines the required machinery and output
- Needs **large quantities** to be profitable; **post-industrial waste is OK, post-consumer is more challenging**
- Mechanical recycling is the most CO_2 emission friendly recycling technology

Mechanical recyclers: Boer Group (GE), Synergies TLC (FRA), SOEX (GE, FRA), Frankenhuis (NL), Altex (DE), Wolkat (NL), Re-Verso (Italy), Pure Waste (IN), Rester (FIN)

Thermo-mechanical recycling (thermal)

- Recycling of **synthetics via melting**, suitable for thermoplastic textiles, e.g. **polyester (PES), polyamide (PA), polypropylene (PP)**
- Textile material is melted by heat, the polymer stays intact, and processed to granulates by extrusion to **make composites,** or **new fibers** (staple and filament fibres) by melt-spinning – can be melted and melt-spun several times
- Fiber length can be restored, hygiene issues are dealt with high processing temperatures, colours can remain
- Material properties tend to decrease in the melting process, impurities may cause degradation
- In the future, textile-to-textile PET (currently 1% of all rPET textile) is preferred, the use of PET bottles as input for textiles should be avoided
- Not suitable for natural fibres, acrylics, PVA (polyvinyl alcohol), aramids

Recycling of PET bottles



https://www.recycletheone.com/recycle-now/how-does-pet-plastic-recycling-work

Recycling of polyamide fishnets

https://en.pcabrazil.com/2749/circular-ocean-fishnets-recycled-polyamide/

Chemical recycling

Cellulosics - Dissolution into a solvent and spinning yarns from it

- Cotton is converted to regenerated cellulose (viscose-like) called **man-made cellulosic fibres (MMCF)** as staple or filament fibers
  - Viscose, lyocell, Ioncell are MMCFs – as is bamboo/bamboo viscose
  - Regenerated cellulosic fibres are typically at least as strong as virgin fibres and have good dye uptake
- Hygiene issues are solved by chemical treatment – chemicals are not a bad thing!
- cause environmental impacts (water and solvent use)
- Impurities may cause unexpected reactions

Synthetics, i.e. man-made fibres

Monomer level:

- **polymers are broken down into monomers** by chemicals or enzymes and repolymerised into new polymers to make new fibres
- many PES recycling processes

Polymer level:

- **polymers stay intact** and fibres are spun from a solution to new fibres, the polymer is extruded and spun into fibres -> fleece, swimwear, sportswear, etc.
- recycled filaments and fibres can reach the same strength as virgin ones, sometimes even better
- technologies are commercial (polyamide) or under development (PET)

Chemical recycling processes require high volumes of feedstock, and are often energy intensive -> environmental impacts are often high, and the process may not be sustainable

Ioncell production at Aalto CHEM: cellulose solution is pressed through the nozzles into a spinning bath, and fibers are formed

Chemical recyclers
Cellulosics: Infinna by Infinited Fiber Company, Spinnova, Kuura by Metsä Spring, Circulose by Renewcell, OnceMore by Södra, REFIBRA by Lenzing,, Ioncell by Aalto, SaXcell by Saxion UAS
Synthetics: Teijin (PES), CuRe Technology (PET), Econyl (PA6) by Aquafil, Cycora (PES) by Ambercycle, Carbios (PET)
CO/PET blends: Worn Again, NuCycl by Ervnu, CIRC Technology, BlockTexx (AUS)

Thermo-chemical recycling

Thermal conversion process

- Polymers are broken down into short-chain hydrocarbons or other molecular structures

Pyrolysis

- Process temperature 300-1200 deg C in anaerobic conditions
- Produces liquid products containing solid carbon 15-25% and gaseous compounds (10-20%) called syngas

Gasification

Process temperature 800-120 deg C with controlled oxidation

- Produces about 85% of gaseous product called syngas, 10% solids and 5% fluid

Use

- Products of these processes can be used in chemical industry to make new polymers, plastics, textiles, etc.
- At development phase for textiles and plastics
- Needs large volumes of feedstock to be economically profitable
- Very energy intensive -> challenges to achieve sustainability targets

https://cris.vtt.fi/en/publications/telaketju-towards-circularity-of-textiles

Challenges in textile recycling

Issue	Constraints
Recycling	• Fibre blends contained in textiles. • Costs of sorting and logistics. • Presence of contaminants in mixed textiles (metals, plastics, dyes, etc.).
End markets for recycled textiles	• Lack of demand for recycled textiles. • Lack of demonstrable economic viability of textile sorting. • Lack of demonstrable economic viability of textile recycling. • Low incentives for investment. • Costs associated with trying to achieve single fibres free of dyes, metals and other contaminants.
Recycling and sorting technologies	• Relative immaturity of chemical recycling technologies. • Similar relative immaturity of automated textile sorting needed to increase volumes of appropriate textiles available for fibre to fibre recycling. • Low investment in automated textile sorting technologies. • Quality limitations in mechanical recycling processes for processing post-consumer textiles (fibre length reduction), and the limited availability and evidence for the effectiveness and scalability of chemical recycling.

Lack of transparency and traceability in the textile supply chain – T&T technologies under development and testing, regulation is not ready, lack of skills, lack of trust between different actors

WRAP – Fibre to fibre recycling: An economic & financial sustainable assessment (2019); Cura et al. (2022)

Circular design approaches and textile recycling

According to circular models, new products are more robust, more adaptable, have more comprehensive range of properties, specially designed to to be extendable, recyclable and remanufacturable (Bocken et al. 2016).
In closed-loop systems, recycling is always the last option, and reuse, repair, refurbish, remanufacture and repurpose are prioritised.

Design for Recycling

- Products are designed in such a way that they can be recycled at the end of the product's lifetime – use of monomaterials if possible ("fit for purpose"), easy to disassemble/dismantle, avoid zips, buttons & large prints, rivets, etc.
- Product designers should know different textile recycling technologies and understand how material and assembly selections affect recyclability

Design from Recycled materials

- The product design process is carried out based on the recycled materials' composition, properties and availability
- Product designers should know the limitations but also recognize new opportunities about what recycled textile materials can bring to a designer's table

Design for Sorting and **Intentional Fashion Design by Recycling Technologies**

- new strategies for textile circularity (Karell & Niinimäki, 2019; Niinimäki & Karell, 2019)

Circular economy strategies

Circular economy

Increasing circularity

	Strategies	
Smarter product use and manufacture	R0 Refuse	Make product redundant by abandoning its function or by offering the same function with a radically different product
	R1 Rethink	Make product use more intensive (e.g. by sharing product)
	R2 Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials
Extend lifespan of product and its parts	R3 Reuse	Reuse by another consumer of discarded product which is still in good condition and fulfils its original function
	R4 Repair	Repair and maintenance of defective product so it can be used with its original function
	R5 Refurbish	Restore an old product and bring it up to date
	R6 Remanufacture	Use parts of discarded product in a new product with the same function
	R7 Repurpose	Use discarded product or its parts in a new product with a different function
Useful application of materials	R8 Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality
	R9 Recover	Incineration of material with energy recovery

Linear economy

Potting et al. (2017); Kirchner et al. (2017)

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