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guidance for fashion companies on design for recycling

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table of content

1. introduction

1.1. scope

Textile recycling is often framed as a solution to either one of two important questions:

1. What is the best use of textile waste, environmentally and resource-wise?
2. How do we make the textile industry (environmentally) sustainable?

The first question is ***material focused***. The goal is utilisation of the full potential of used textiles, for example in terms of economic value or some technical property such as fibre length. Here, "best" or "better" is in relation to the current situation, in which the majority of used textiles are either incinerated with or without energy recovery or consigned to landfill ***after their first use cycle (first owner)*** (Östlund et al. 2015; Schmidt et al. 2016).

The second question is ***textile-industry focused***. Textile recycling is one of many possible interventions that can be applied for reducing the total environmental impact of the textile industry. The impact-reduction potential or "efficiency" can be assessed in relation to other interventions, such as switching to renewable energy and less harmful chemicals along the whole textile life-cycle value chain, new business models and design strategies for prolonged use of clothing, to name a few (Roos et al. 2016).

Both questions are considered in this report. It is primarily intended to provide guidance into 1) opportunities for using recycled materials in new products, as well as 2) assuring that fashion products are designed to be recyclable at their end-of-life. The report discusses how to assure legal compliance (mainly for question 1), maximise the environmental benefits, optimise the scale and location of collection, sorting and recycling facilities, and it provides recommendations for moving towards a defined number of well-selected material blends that are also preferable from a use and wear perspective. Finally, the report describes the status of textile recycling today and what is needed to establish recycling on a larger scale and achieve circular material loops. Much of the content is relevant for any actor with an interest in textile recycling globally, but there is a specific focus on the Swedish and Nordic context.

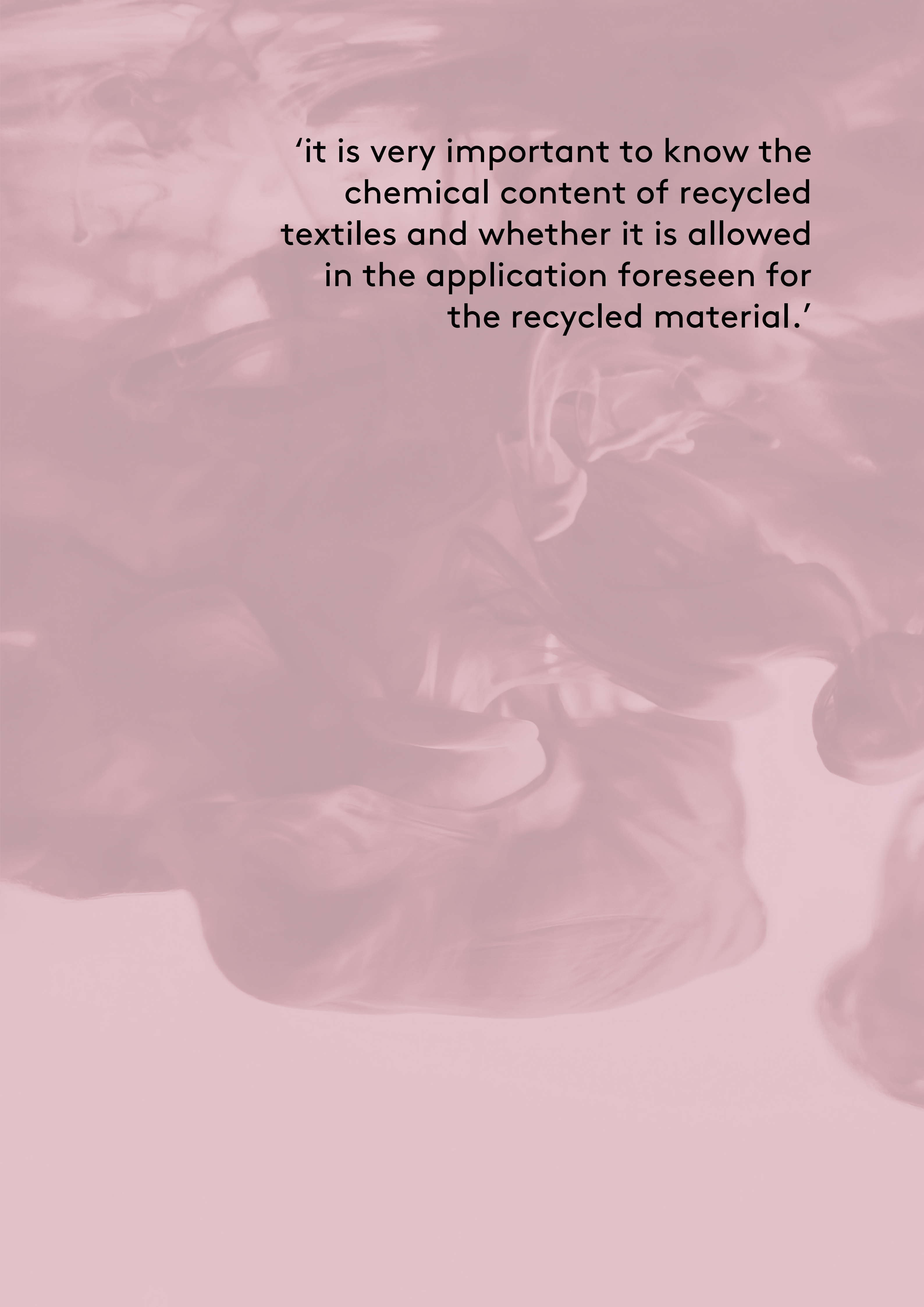
1.2. perspective

The authors of this report have noticed information in the media about textile recycling which contains conflicting messages, and which can be difficult to follow and interpret. Misunderstandings can arise from confusing what exists today with what is possible tomorrow and in the longer term.

The starting point for this report has been to create a common perspective between researchers that work with either of the two questions within the scope of this report. The result has been a "white paper" containing more details about the different matters described in this report (Roos et al. 2019). In this work, the following main points of our common perspective were agreed on fully and heartily by all authors:

- We see great potential in recycling textiles from a sustainability perspective, including environmental aspects and resource-efficiency.
- We want to reduce the confusion surrounding the field of textile recycling and answer common questions.
- We do not want to recycle textiles for the sake of recycling – it should always contribute to increased sustainability.
- Current textile value management processes are generally immature and not sustainable.
- We should not judge the future of textile recycling based on the current situation because many promising technologies and solutions are emerging.
- Sustainability is the overall goal of changing textile value management.

The authors foresee both closed-loop options, i.e. fibre-to-fibre, fabric-to-fabric recycling, as well as open loops in which a textile material is redeployed in other material applications such as the reinforcement of plastics in high-quality composites or its use for technical nonwoven materials. Similarly, a worn-out plastic bottle may be a sustainable raw material input to textile value chains.



‘it is very important to know the chemical content of recycled textiles and whether it is allowed in the application foreseen for the recycled material.’

2. legal compliance and policy instruments

This chapter gives a snapshot of the legal situation in relation to textile recycling as of Spring 2019. It should be noted that legislation is constantly developing, and no guarantee is given that this report covers all aspects.

2.1. restricted chemicals

A prerequisite for the production of a valuable secondary raw material is that the material is "toxic free". Thus, the constituent chemicals in feedstock need to be aligned with future customer and legal demands. In addition, chemical constituents that may disturb recycling processes[1] must be tracked, traced and removed for cost- and energy-efficient handling.

Within the European Union (EU), several hazardous chemicals are restricted in textile products via regulations such as REACH[2] (European Commission 2006), BPR[3] (European Commission 2012) and the POP[4] regulation (European Commission 2004). Many countries have chemicals legislation similar to the EU legislation, for example Canada and the USA. On the other hand, the legislative basis for chemicals management is lacking in many countries, especially in developing countries that dominate textiles manufacturing. Legislation *per se* is no guarantee for compliance (road speed limits does not mean that all drivers respect them). In addition, the EU chemicals legislation applies only to businesses and not to private citizens; the growing share of privately imported goods from online stores means that textile products with unknown chemicals content will eventually reach the waste collection points within the EU.

Although certain chemicals are restricted for certain textile applications, they may be allowed for others because of the value and function they bring to the to the final product. the legal differences between applications mean it is very important to know the chemical content of recycled textiles and whether it is allowed in the application foreseen for the recycled material. For example, flame retardants are allowed for some textile applications, but if these textiles are recycled the flame retardants must be removed if the recycled materials are to be used in, for example, children's wear.

[1] For example pigments in PES material that are to be melt spun in a second life.
[2] Registration, Evaluation, Authorisation and restriction of Chemicals
[3] Biocidal Products Regulation
[4] Persistent Organic Pollutants

2.2. fibre labelling

The EU regulation on fibre labelling applies to textile products as well as products and certain product components that are at least 80% textile fibre (by mass) (European Commission 2011). Depending on the product, between 95-98% of the fibre content must be declared on the label. This is not sufficient information to enable large-scale textile recycling, since the remaining fibre content may disturb certain recycling processes, for example low levels of elastane prevent melt spinning of synthetic material. Also, the regulation does not require labelling to distinguish between fibres at a sufficiently specific level, for example it does not distinguish between Nylon 6 and Nylon 6.6 which is necessary for certain recycling processes.

2.3. the waste framework directive

The waste framework directive (2008/98/EC) requires that Member States adopt waste management plans and waste prevention programmes (European Commission 2008). This directive has led the way for further actions towards a circular economy. The Directive introduced the "polluter pays principle" and the "extended producer responsibility" as two important policy tools. In addition, EU Member States shall apply as a priority order the waste management hierarchy shown in figure 1.

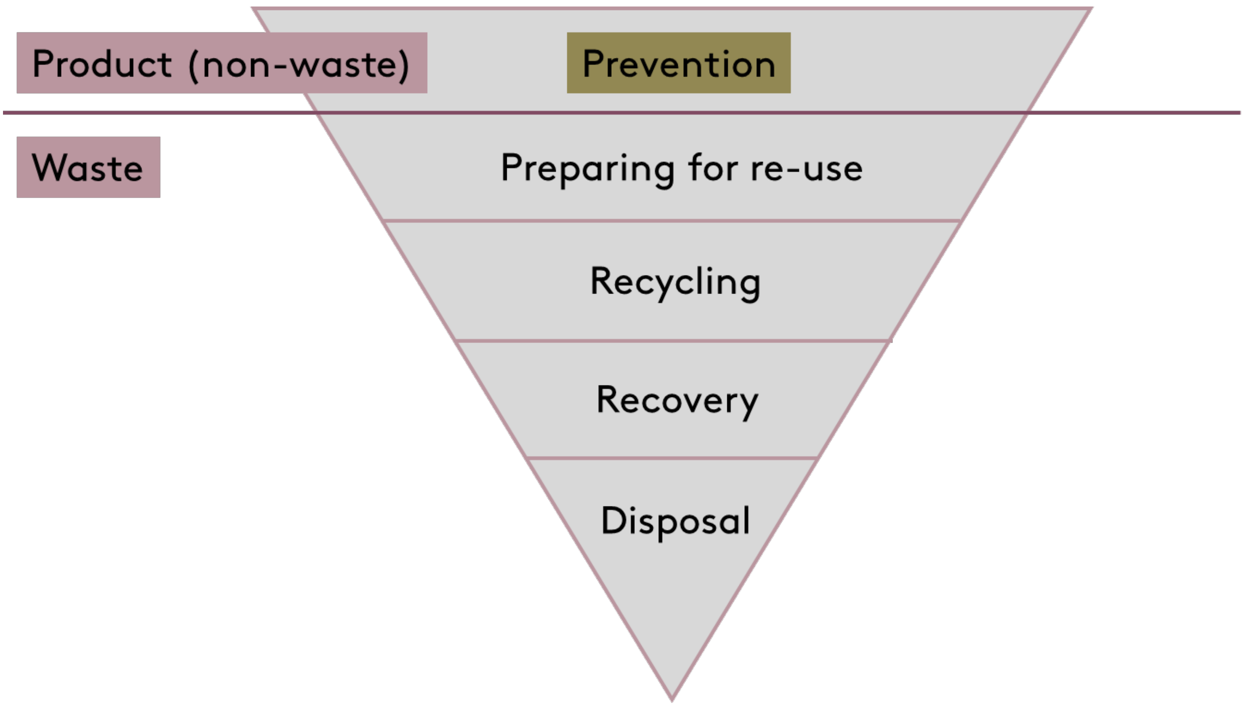


figure 1 The waste management hierarchy in European legislation.

2.4. policies related to the circular economy

On an EU-level, the Circular Economy Package was adopted in 2018 (European Commission 2018a). This package states that all member states must collect textiles separately by 2025. In addition, member states must consider by 2024 whether specific targets should be introduced in regard to reuse and recycling. The Swedish EPA has suggested targets that relates to collection as well as reuse and recycling, stating that by 2025, the volume of textiles in the household waste shall be reduced by 65% compared to 2015. The same year, 2025, 90% of the textile volume separately collected shall be prepared for reuse and recycling in alignment with the waste hierarchy (Figure 1). In January 2019, the Swedish government stated, in the January-agreement, that an EPR for textiles will be implemented by 2025 (Socialdemokraterna 2019), see below.

In a communication from the European Commission (European Commission 2018b), the implementation of the circular economy package in regard to options to address the interface between chemical, product and waste legislation is addressed. This communication highlights the need for information systems, innovative tracing technologies and strategies to share information along value-chains.

2.5. extended producer responsibility (EPR)

EPR is a policy tool for encouraging and enabling recycling, in which producers are given financial and/or physical responsibility for treating and disposing of post-consumer products. In the EU, EPR is currently mandatory for some product categories but not for textiles. France introduced EPR rules for textiles in 2008 (Watson et al. 2015) and as stated above, in Sweden the government has decided to work towards implementing EPR for textiles (Socialdemokraterna 2019).

3. environmental savings as rationale for recycling

The environmental benefits of recycling largely depend on ***which*** material is replaced, ***how much*** of that material is replaced (the so-called replacement rate), and the efficiency of the recycling processes.

3.1. replacing fibres or fabrics

If recycling leads to the replacement of a certain type of virgin fibre, it can help in mitigating the environmental issues associated with extraction of virgin raw materials and the subsequent fibre production processes. The replacement of cotton fibres reduces the use of freshwater, pesticides and fertiliser, and it mitigates water depletion, ecotoxicity, eutrophication and other impacts. In contrast, if polyester fibres are replaced, the benefits are primarily in terms of reductions in climate impact and fossil resource depletion.

Apart from impacts caused by land and water use, most of the impacts of the textile industry occur in production stages subsequent to fibre production: yarn spinning, weaving and knitting, finishing and dyeing (Sandin et al. 2019). These are not prevented by monomer, polymer/oligomer or fibre recycling (unless colour is retained due to sorting on colour, which means that subsequent dye processes are avoided) (see figure 2) but potentially by fabric recycling. In other words, fabric recycling can potentially mitigate more impacts (per kg recycled material) than recycling routes that disaggregate the recycled material to a greater extent. But fabric recycling may often be infeasible because the material is too worn out or because of difficulties in finding a suitable end use. To conclude, the question of what is replaced concerns both the replaced fibre type and whether other textile processes are prevented.

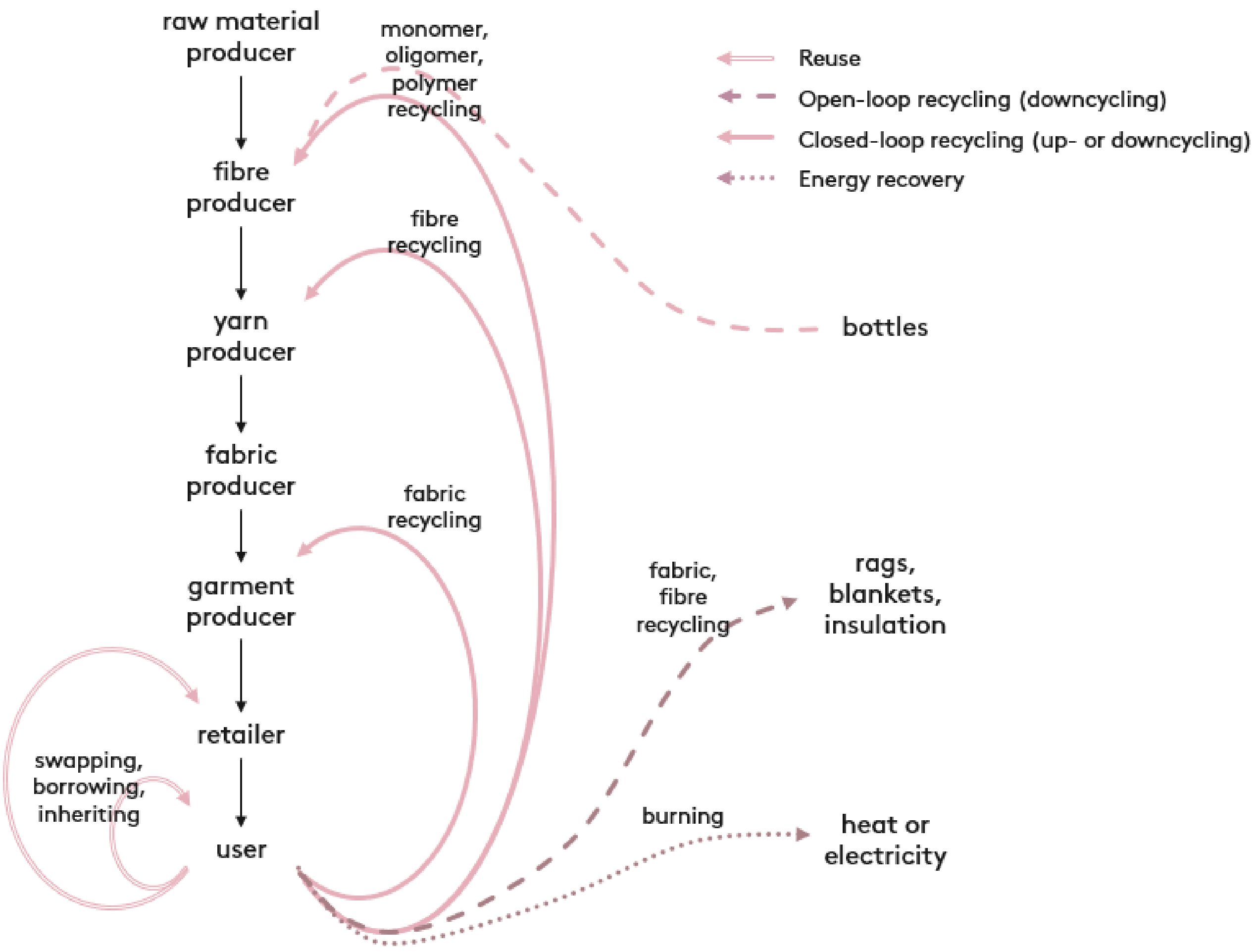


figure 2 Examples of routes for material reuse and recycling in the textile value chain. From Sandin & Peters (2018)

3.2. replacement rate

A replacement rate of 100% means that the recycled material fully replaces an equal amount of virgin (non-recycled) material, whereas a rate of 0% means that no displacement occurs, and the recycled material merely adds to a growing market. Unfortunately, there is a lack of knowledge of how large the replacement rates are for various recycling routes (Sandin and Peters 2018). There is reason to believe that the replacement rate for fibre or fabric recycling is lower than for polymer/oligomer or monomer recycling, due to a certain deterioration in fibre quality. So even if fabric recycling potentially prevents more stages of textile production compared to other recycling routes, a poorer quality may offset some of those benefits.

Although recycling is intended to reduce the use of fossil resources, a complication is that more recycling may increase global fibre supply, thereby reduce the price and increase the demand for fibres. In other words, some of the benefits of textile recycling might be offset by increased consumption, a so-called "rebound effect" (Figge, Young, and Barkemeyer 2014; Hertwich 2005). The potential scale of this effect is unknown.

3.3. process efficiency

To reduce environmental burdens, recycling systems must have environmental footprints (climate, water, toxicity and so on) that are lower than production of virgin materials. Thus, the design of a recycling system must consider material output efficiency, the quantities and types of energy and chemicals used, and emissions to water, soil and air.

‘the question of what is replaced concerns both the replaced fibre type and whether other textile processes are prevented.’

4. overview of recycling possibilities today

The main material recycling routes for textiles are chemical recycling (in figure 3: monomer, oligomer and polymer recycling) and mechanical recycling (in figure 4: fibre and fabric recycling). With the same input material, recycling processes can give different outputs, which is shown for the case of cotton in figure 3 and 4.

4.1. chemical recycling

Applicable for:

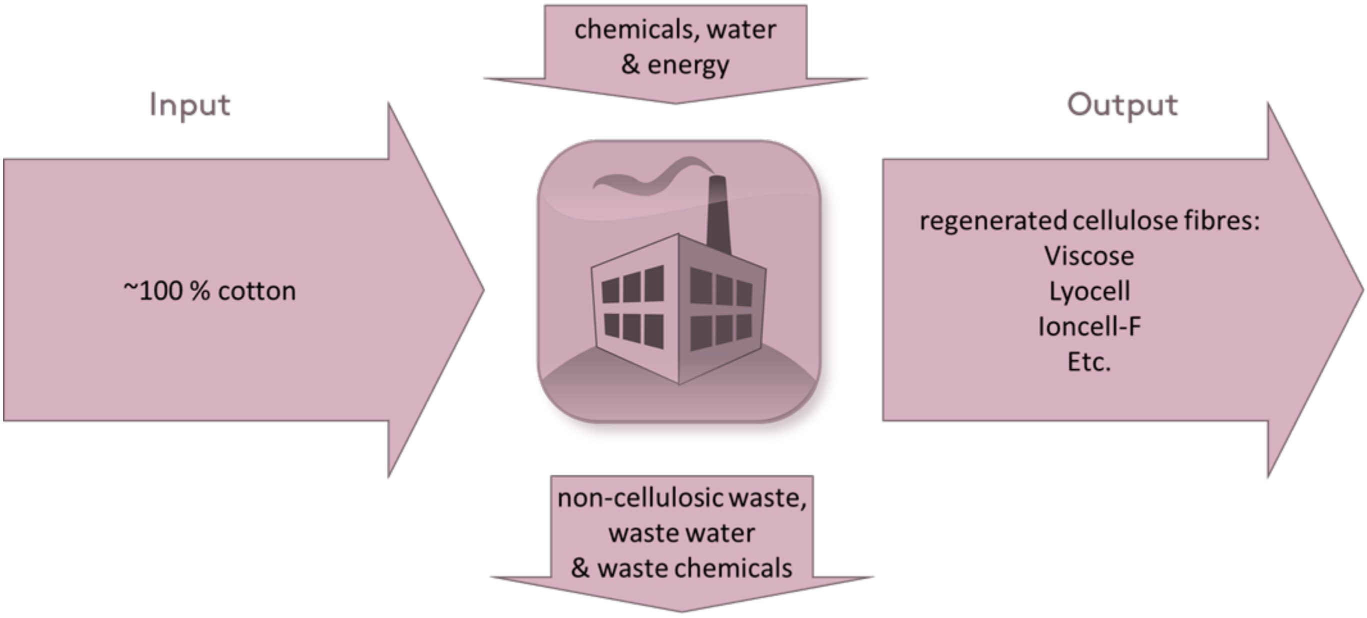
- Closed-loop or open-loop system for pure polyester (PET) and Nylon 6 materials
- Open-loop system for cotton materials

For some synthetic fibres chemical recycling by depolymerisation is a viable route. The polymer chains are broken down into monomers, which are separated and purified before being reunited into new polymers. Additives are removed during the purification (often distillation) process. The polyester polyethylene terephthalate (PET) and nylon 6 are today chemically recycled at a commercial, yet limited, scale. The polyester input material is generally post-consumer PET from food packaging materials and (pre-consumer) industrial waste. The nylon input is generally post-consumer nylon from carpets, fish farm nets and industrial waste. Recycled fibres have in principle the same properties as virgin synthetic fibres. Almost all polymers can be depolymerised in theory, however, an efficient, practical process has not (yet) been developed for all polymers, for example for nylon 6.6.

Some cellulosic fibres (e.g. cotton) can be chemically recycled by a pulping process followed by solution spinning to produce regenerated cellulosic fibres. At present, this is not a viable route for viscose and lyocell that are already regenerated cellulosic fibres. figure 3 shows a schematic picture of the process for chemical recycling of cotton (3a) respective nylon (3b) which is contrasted to mechanical recycling of cotton in figure 4. Additives are partly removed during the process. Chemical recycling of cotton produces regenerated cellulose fibres that in principle have the same properties as other regenerated cellulose fibres. The only such fibre commercially available today is a fibre blend with 20% recycled lyocell fibres from cotton and 80% regenerated fibres from virgin forest fibres (REFIBRA™).

A common feature of both synthetic and cellulose fibres is that the chemical recycling process gains higher efficiency the purer the input material. Any content other than the intended fibre for recycling is a contamination that reduces the yield or adds extra separation/purification steps and increases the cost in both environmental and economic terms.

3a



3b

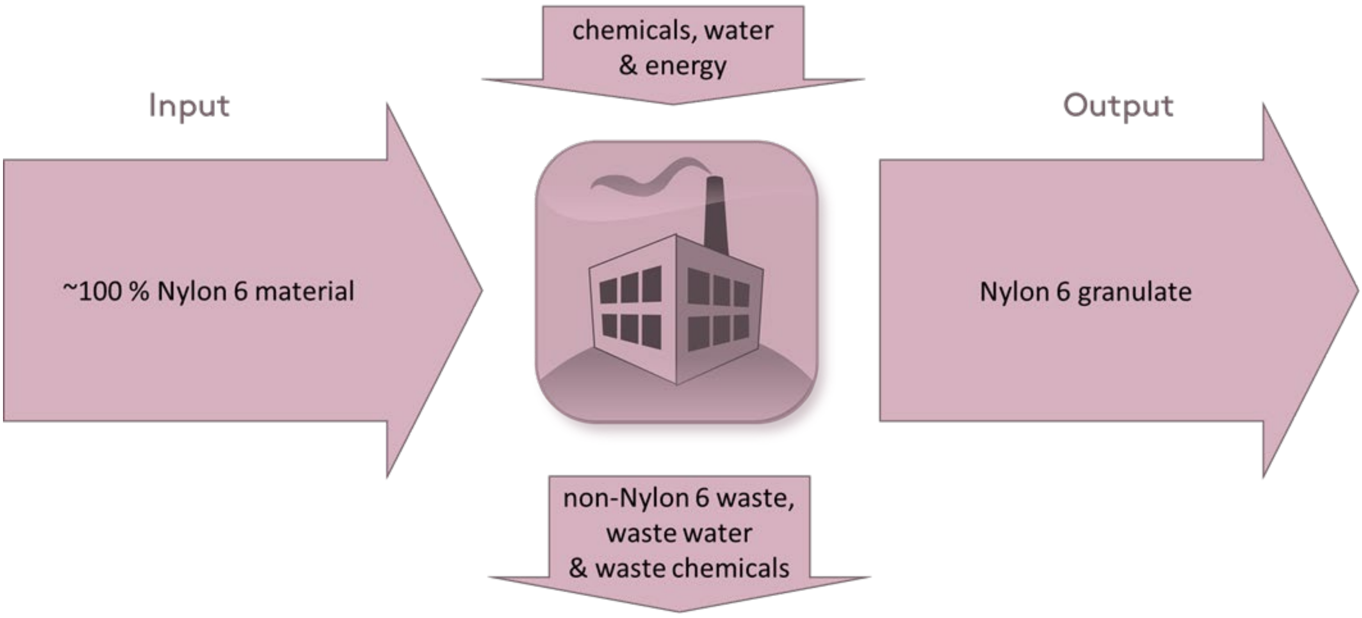


figure 3 Chemical recycling of cotton (3a) gives regenerated cellulose fibres that in principle have the same properties as other regenerated cellulose fibres from forest- or plant-based resources. Chemical recycling of Nylon 6 (3b) gives PA6 granulate that have the same properties as virgin PA6.

4.2. mechanical recycling

Applicable for:

- Closed-loop or open-loop system for pure synthetic materials
- Open-loop system for all textile materials

Mechanical recycling is either performed by 1) melting synthetic fibres producing granules that are used for spinning new fibres (thermomechanical recycling), or 2) tearing fabrics to recover the fibres (mechanical processing). The remelting method does not tolerate any contamination in the form of certain surface treatments, dust or dirt. Fibre blends (e.g. nylon 6 and Nylon 6.6) and polymers that are not possible to melt (e.g. elastane) cannot be recycled this way.

In the second case, the textile material is first freed from metal and plastic parts such as zippers and buttons. Subsequently, the material is cut into smaller pieces that are fed into a textile tearing machine which opens up the textile structure and releases the fibres. When recycled to yarn, the textile fibre mass is carded and may also pass through additional steps to remove short fibres. A so-called sliver is produced, which is processed into a yarn by for example ring spinning or rotor (open-end) spinning. In mechanical recycling by tearing, the fibre properties are retained with the exception of fibre length. By colour sorting the feedstock, re-dyeing can be avoided, reducing the environmental impact of the textile product manufacturing process. figure 4 shows a schematic picture of the process for mechanical recycling of cotton, though this process can be applied for basically any textile material. In reality, mechanical recycling is a very important route for blended fibre qualities.

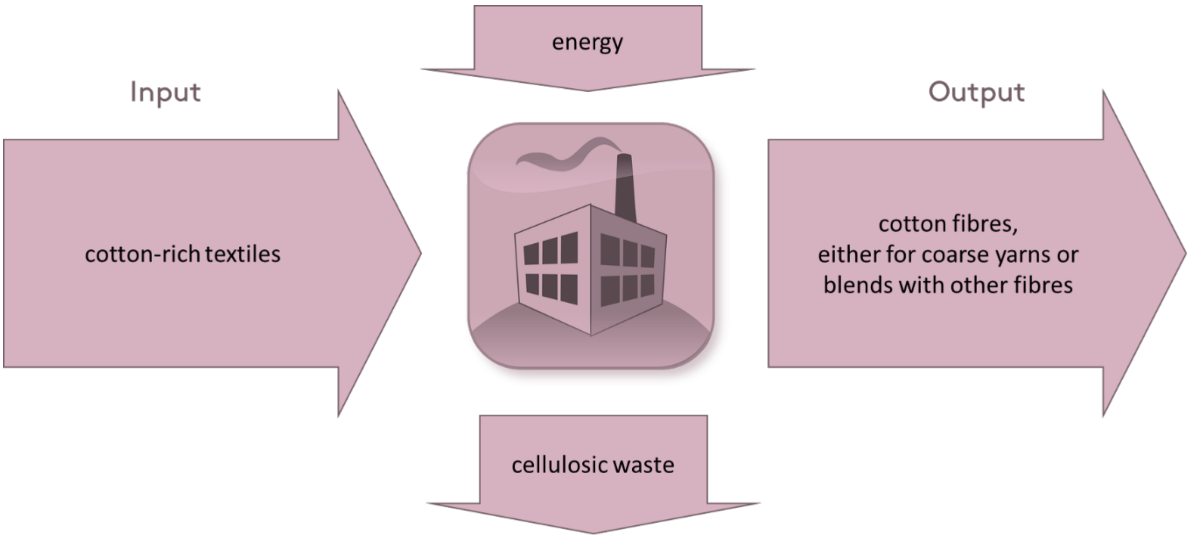


figure 4 Mechanical recycling of cotton produces cotton fibres with shorter-fibre lengths, making end-uses such as coarse yarns or blends with other fibres feasible. The figure shows the cotton case but the same process can be applied for basically any textile material.

5. overview of future possibilities

The quality of raw materials is controlled by input material

5.1. today's situation is far from the future vision

Since textiles are very complex materials, it is unlikely that a single technology will solve the global need for efficient textile recycling. To utilise the potential of end-of-life textiles in the best possible way, a range of recycling technologies must be applied - mechanical and chemical (figure 4). The current situation is characterised by a lack of infrastructure, low collection rates, manual sorting, low recycling rates and relatively low-value recycled products. To move forward, we need to focus on increasing the recovery rates and achieving high-quality products. It is imperative to demonstrate the potential of new material to reduce waste streams, increase resource efficiency and recycling while guaranteeing economic and environmental sustainability.

5.2. prerequisites for optimised value capture

Two important prerequisites for optimising value capture and suppling the different recycling processes with suitable feedstock are appropriate collection systems and efficient, material-specific sorting of textiles destined for material recycling. **A resource-efficient system would make use of an exchange of materials between textile, plastic, composite and nonwoven applications.** As the fabric is used and exposed to wear, it breaks down, which may make it inappropriate for the original product, but suitable for another product type. There are cases where recycled textile materials hold a much higher economic value in another industry sector. One example would be a thermoplastic biocomposite for the automotive industry, reinforced with low-grade recycled textile fiber. Therefore, closed-loop recycling is not automatically "better" than open-loop recycling, as sometimes assumed.

figure 5 possible routes for collected textiles, (PA short for polyamide, PES short for polyester).

6. short discussion of challenges

Please see the white paper for deeper discussions (Roos et al. 2019).

6.1. from bench to factory – challenges of scale

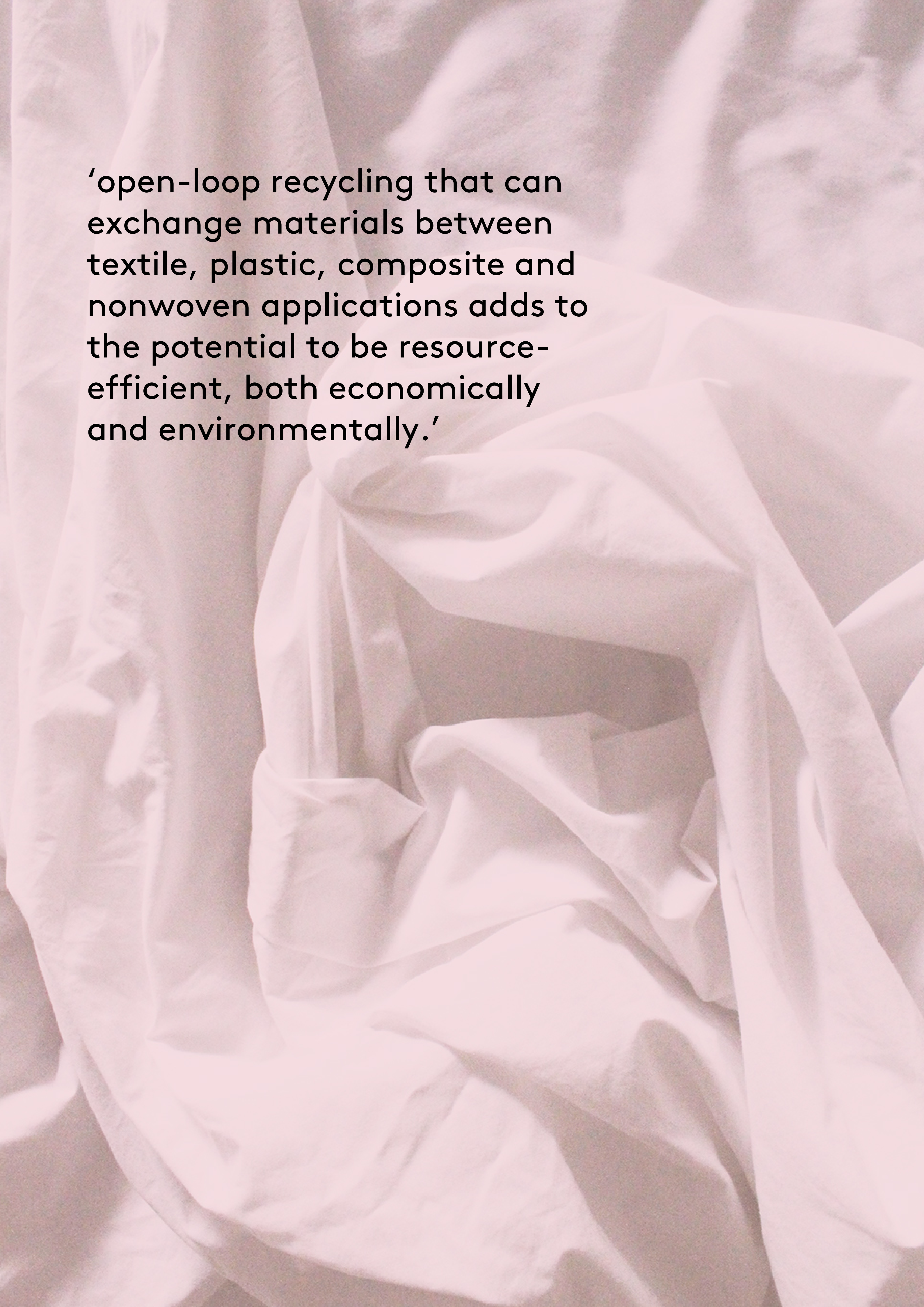
Apart from technical problems that might need to be solved when scaling up a process from bench to pilot scale and further on to commercial scale (yield, waste, cooling needs etc.), scale-up also presents other challenges. Feedstock availability, uncertain environmental performance and a lack of venture capital are just some obstacles that make it difficult to compete with existing systems for end-of-life treatment and production of virgin fibres, which have been fine-tuned over many years with an invaluable accumulation of know-how.

6.2. from Kristinehamn to Matsuyama – challenges of geography

Recycling relies on diffuse sources: collecting and sorting discarded textiles from hundreds of thousands of factories and billions of users. In contrast, virgin production relies on concentrated point sources in both time and geography: pumping oil from the ground, harvesting cotton at farms.

6.3. collecting used textiles – too much transport?

How far can used textiles be transported for recycling to make sense from an environmental point of view? If we focus on climate impact – one of the main issues of transportation – some generalised calculations suggest roughly 1.0 kg CO_2 eq. is avoided per kg of material that is recycled (Östlund et al. 2015; Schmidt et al. 2016). The additional environmental impacts of transport should be compared with this benefit. While transport from collection site to sorting facility by truck is efficient and generally not an issue climate-wise, the user's transport of discarded textiles to a local recycling station may not be equally efficient. As a rule of thumb, if 10 kg of textiles are transported by car to the local recycling station, a distance up to 20 km makes sense climate-wise – beyond that, the benefits of recycling are questionable.
In a sustainable future recycling system, collection must therefore be wisely organised to avoid excessive environmental from unnecessary user transport.



'open-loop recycling that can exchange materials between textile, plastic, composite and nonwoven applications adds to the potential to be resource-efficient, both economically and environmentally.'

7. design for circularity – textile fibres

Some current opportunities for using recycled materials in new fashion products, and guidance for assuring that fashion products are designed to be recyclable at end-of-life, are provided for the most commonly used fibre types: polyester, cotton and nylon.

7.1. opportunities for using recycled materials in new fashion products

generic

- Make use of recycled material, see to that it is certified recycled content (e.g. GRS[5]) to avoid green-washing.
- In the dialogue with the supplier(s):
  - discuss the rationale behind choosing the specific quality, is it a suitable material for the application?
  - dialogue regarding chemicals content, compliance and suitability for the application.

polyester fibres

- Make use of recycled polyester (chemical or mechanical recycling).

cotton fibres

- Make use of recycled cotton (mechanical recycling).

nylon 6

- Make use of recycled nylon 6 (chemical or mechanical recycling).

nylon 6.6

- Make use of recycled nylon 6.6 (mechanical recycling).

trims

- Use your own production’s waste fibres for trims to your garments.

7.2. design fashion products to be recyclable at end-of-life

generic

- Avoid finishing with e.g. water repellent coatings and anti-bacterial treatment.
- Create monomaterial design (unless this shortens life length of product):

polyester

- Use 100% polyester (PET) in fabric, membranes, coatings and trims.
- Collaborate with a polyester yarn producer:

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[55] Global Recycle Standard, a certification standard for recycled content

    - check with producers of virgin fibre regarding which additives and dyestuffs may be present, to avoid a potential problem for the recycling process and ensure the recycler can use your products as input.
    - engage with one of the few polyester fibre-to-fibre recyclers that exist on an industrial scale, e.g. Teijin/Jiaren.

cotton

- Use 100% cotton and/or regenerated cellulose in fabric and accessories
- Collaborate with a cotton yarn producer:
    - encourage the expansion of pilot plants that are available for post-consumer textiles, e.g. Re:newcell.

nylon 6

- Use 100% Nylon 6 in fabric (other names are polyamide 6, PA 6)
- Accessories should if possible also be made of nylon 6 – check all items on the request
- Nylon 6.6 is NOT the same fibre, in terms of recycling it is rather a contamination.
- Collaborate with a nylon 6 producer:
    - check with producers of virgin fibre regarding which additives and dyestuffs may be present, to avoid a potential problem for the recycling process.
    - Engage with one of the few nylon 6 fibre-to-fibre recyclers that exist on an industrial scale, e.g. Aquafil.

nylon 6.6

- Today, post-consumer nylon 6.6 (polyamide 6.6, PA 6.6) waste is not recyclable into textile fibres. Consider replacing this fibre until this situation changes.

8. conclusion

This report has addressed the questions of what to do with discarded textiles (the best use, environmentally and resource-wise) and how recycling can aid in making the textile industry (environmentally) sustainable.

Environmental benefits of recycling largely depend on what material is replaced and how much of that material is replaced. We want to stress that to maximize the environmental benefit, the first steps involve materials being used and reused, with recycling being the option when materials are discarded after a prolonged life in alignment with the waste hierarchy. In this way, reuse and recycling are not competing strategies but rather both necessary and complimentary in a circular economy.

To establish textile recycling on a larger scale, we should not judge the future based on the current situation. There is a great potential for environmental benefits from textile recycling if high recovery rates are achieved and high-quality products are produced. Therefore, we recommend viewing textile waste not only as a resource that should be "returned" to the textile value chain alone. Open-loop recycling that can exchange materials between textile, plastic, composite and nonwoven applications adds to the potential to be resource-efficient, both economically and environmentally.

For use of recycled materials in textiles, some examples are provided for the main fibre types: polyester, cotton and nylon. To ensure that fashion products are designed to be recyclable at end-of-life, the current recommendations are to create monomaterial design (unless this shortens the life length of product) and avoid chemical treatments that may disturb the recycling process or contain restricted chemicals.

More details about textile recycling today and in the future can be found in the white paper connected to this report (Roos et al. 2019).

8.1. circular economy – bust or boom?

Recycling is a key component of the so-called circular economy, commonly defined as the "closing of material loops to preserve products, parts, and materials in the industrial system and extract their maximum utility" (Zink and Geyer 2017). However, as many as 114 different definitions are known (Kirchherr, Reike, and Hekkert 2017), whereof some are more comprehensive in scope. We recommend that circular economy is seen as a means to achieve sustainability, and not as a goal in itself.

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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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