TEXTILE WASTE

Andreas BARTL

 # Technische Universität Wien, Institute of Chemical, Environmental & Biological Engineering, Getreidemarkt 9/166, 1060 Vienna, Austria

Abstract

Annual fiber production has already reached almost 100 Million t. Further significant growth is expected for the near future. Textiles represent the most important market for fibers, with apparel and home textiles being of major importance. In view of the large quantities, resource management should focus on this important product cycle. It is thus incomprehensible that European policy does not currently focus on end-of-life textiles. Due to low quality and rapid fashion cycles, massive overconsumption of apparel ensues and causes waste of energy and resources. The situation is aggravated by the fact that the bulk of the textile processing chain has left Europe and is predominantly concentrated in low-wage countries. Europe is mainly a consumer but hardly a producer of textiles. In some European countries a fairly high rate of collection and subsequent re-use has been established for end-of-life textiles. Separate collection and sorting of second-hand clothes is state of the art and a prerequisite for any reuse. Today, however, this scheme is financed by selling second-hand clothes, resulting in collection being focused on exclusively functional items. The system shows room for further improvement. On the one hand, alternative funding regimes such as extended producer responsibility could extend collection to damaged and worn clothing and decrease the amount of textiles that end up in municipal solid waste. On the other hand, recycling technologies for items that cannot be re-used must be promoted. Last but not least, the circular economy idea must also be implemented in the field of textiles. The question is whether the EU can realize a circular economy in a globalized industry or whether the EU must undertake a retrieval of the textile processing chain to Europe.

Introduction

Clothing represents a basic human need. Maslow (1943) placed it at the bottom of the pyramid of needs for life along with food and shelter, underlining its vital importance. However, in many industrialized countries clothing is far from being merely a basic need. It has become subject to fashion and style, and frequently items are disposed of even if they are fully functional. This rapid turnover of apparel is a key driver for the textile industry. However, this practice results in an overconsumption of clothing and causes an excessive use of energy and resources and, finally, is significantly responsible for waste generation.

Facts and data

Fibers

Clothing and textiles consist of fibers. Fiber is a morphological term for materials characterized by their flexibility, fineness and high ratio of length to cross sectional area (BISFA, 2009). Over centuries mankind has used fibers from nature, originating from both crops and animals. As outlined in Figure 1, natural fibers can be further differentiated. It was not before the end of the 19th century when the first man-made fibers were produced. The term man-made refers to the fiber production process but not to the material. As also outlined in Figure 1, man-made fibers may consist of natural polymers as well as synthetic polymers and, furthermore, can be inorganic.

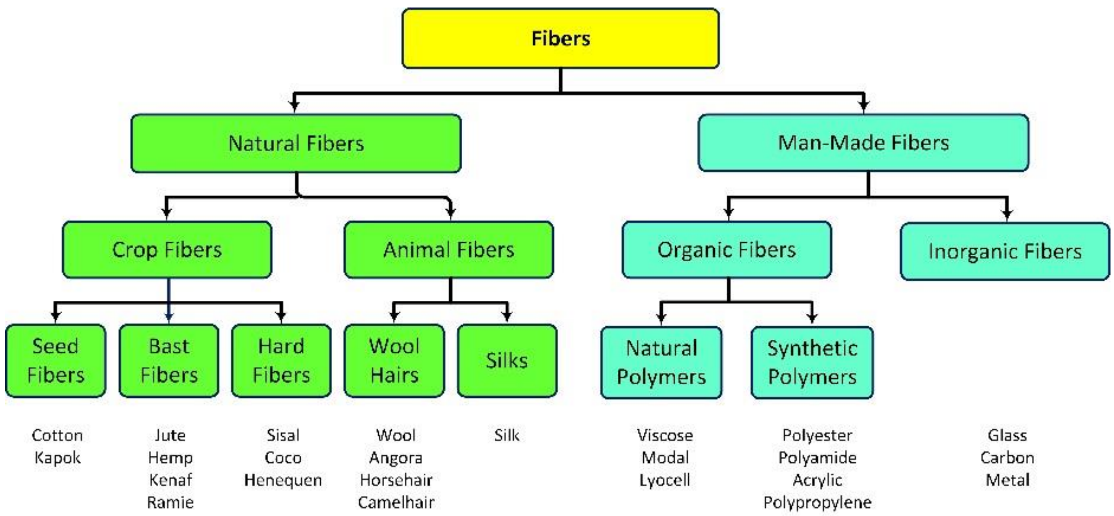

Figure 1 Categorization of fiber types (DIN, 2001; BISFA, 2009)

Quantities

Figure 2 plots the annual fiber production since 1980. Within this period, there has been a tremendous increase from 30 Million t, peaking at 93 million t in 2014 (CIRFS, 2016). The major reason for this growth is the increase in man-made fibers based on synthetic polymers (so-called synthetics). Their production rate roughly increased sixfold, from 11 Million t (1980) to 63 Million t (2015). Synthetic production is mainly based on fossil resources with respect to feedstock and energy.

Natural fiber cotton has been of major importance in the past. Until the 1990s the volume of cotton exceeded man-made fibers. However, since 2000 cotton production has stagnated and today it contributes to only 23 % of total fiber production (CIRFS, 2016). Even if cotton is a natural, renewable fiber, its production demands crop land and consumes large amounts of water, agrochemicals and fossil fuels (Paulitsch, 2004). As cropland is limited and optimization of agricultural technology is already exhausted, cotton production will stagnate in the future.

A rough estimation suggests that by 2025 total fiber production will exceed 140 Million t. This growth is based on an increase in both per capita consumption and world population. It is also clear that this increase will be based on man-made fibers. As a matter of fact, a distinct increase in the consumption of resources and energy will occur.

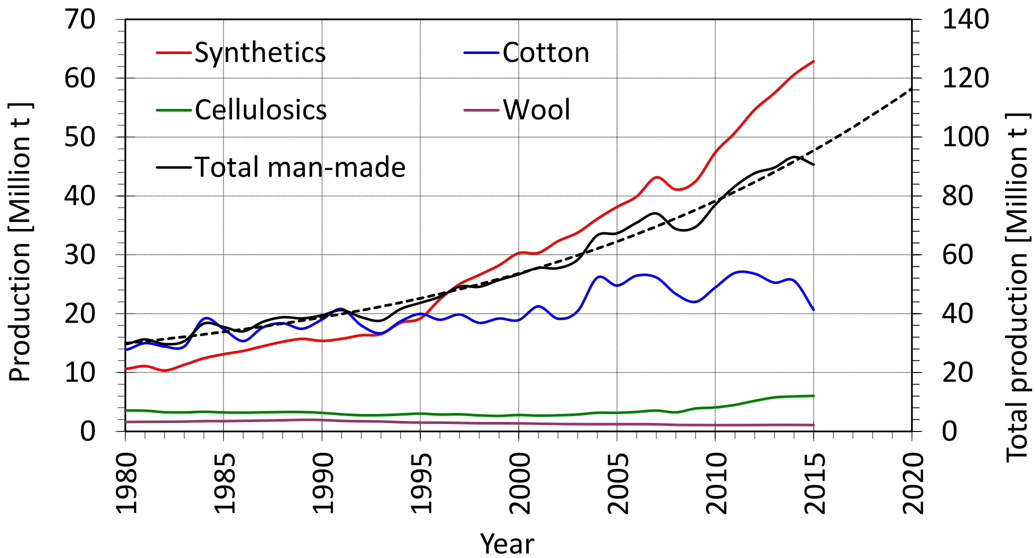

Figure 2 World fiber production from 1980 to 2015 (CIRFS, 2016) and a rough estimation until 2025.

Markets and processing chain

Fibers are not a final product but have to be further processed. Final fiber products have widespread uses but apparel, on the one hand, and interior and home textiles, on the other hand, absorb 75 % of that. Apparel comprises outerwear such as trousers, coats or dresses as well as underwear such as briefs, stockings or undershirts. Interior and home textiles are broken down into carpets and home textiles such as curtains, blankets or table-clothes. To process fibers into apparel and home textiles, the classical textile processing chain is commonly used. This comprises yarn formation, weaving or knitting, dying & finishing and garment making. As the processing chain is long, large amounts of energy and resources are consumed and considerable emissions and wastes are generated. Alternatively, fabrics can be produced without intermediate yarn processing: the so-called nonwovens.

Approximately 25 % of the fibers are used for industrial and technical textiles. The applications in this field are quite fragmented and range from transport, medical, pharma & health to protective clothing, building & construction and filters & membranes.

The energy consumption for fiber production ranges from 55 GJ/t (Cotton) to 126 GJ/t (Polyester) and adds up to 241 GJ/t (Cotton) or 330 GJ/t (Polyester) for the final garment (Woolridge et al, 2006). Figure 3 shows a rough scheme of the textile processing chain, including energy consumption. The sketch also shows routes for reuse and recycling, as discussed below.

In view of the large amount of fibers and the high energy consumption for garment production, it is obvious that textile waste is an important issue. It is striking that EU legislation covers waste streams such as vehicles, electric and electronic devices or packaging, but not textiles.

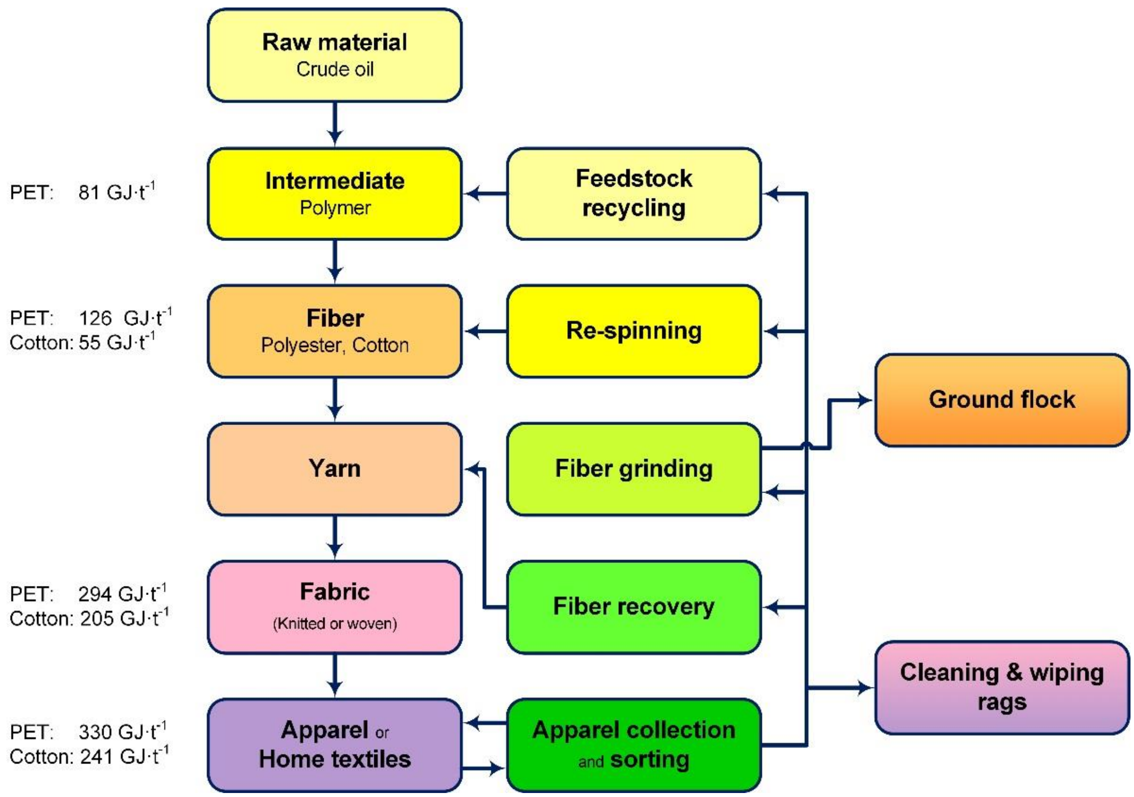

Figure 3 **Simplified textile processing chain and possible routes for reuse and recycling; the numbers indicate total energy consumption according to Woolridge et al. (2006) and Giegrich (2011).**

Textile Waste

Textile consumption and collection

There are detailed data available about the production volumes of fibers. However, in the case of textiles the data situation is less clear. For Germany, Korolkow (2015) has shown that the average life span of clothing is about one year only, with domestic consumption therefore corresponding to the potential collection volume. By 2013 in Germany the potential collection volume ranged between 1.15 and 1.35 Million t, depending on the calculation method (Korolkow 2015). The total domestic consumption is based on the balance of foreign trade, domestic production and private as well as illegal imports. By 2010 in Germany the per capita consumption was about 12 kg/Capita for clothing and 14 kg/Capita for interior and home textiles. For the potential collection volume Korolkow (2015) considered clothing and "light" home textiles such as curtains or bed linen but not carpets, which have been estimated at 3.5 kg/Capita.

Korolkow (2015) further shows that in 2013 a total of 75 % of textiles (i.e. 1.011 Million t) have been collected separately. As demonstrated in Figure 4, container collection is the most important collection procedure for end-of-life textiles, whereas street collection and other methods (e.g. fashion stores) are of minor importance.

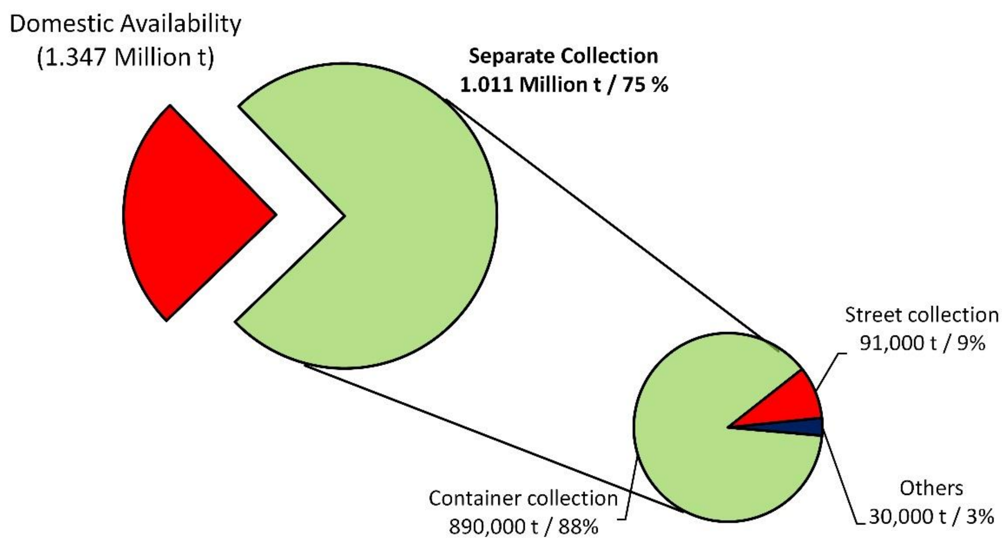

Figure 4 Domestic availability of textiles and separate collection in Germany by 2013 (Korolkow 2015).

Other countries report much lower collection rates, as outlined in Table 1. In terms of end-of-life collection, Germany is far ahead of other European countries, particularly the USA. It is further clear that data are not directly comparable. As mentioned above, the domestic consumption for Germany (1.35 Million t corresponding to 16 kg/Capita) does not consider carpets. For the USA, the EPA has calculated a total of 15.13 Million t of textile waste (i.e. 47 kg/Capita) including carpets (EPA 2015).

Despite the uncertainty in the data of textile waste, it is obvious that the amounts are large and significantly contribute to the total volume of municipal solid waste (MSW). In the USA MSW contains 6.0 % textiles (EPA 2015).

Table 1 Amount of collected post-consumer clothing and the collection rate (collected amount in relation to amount put on market) for selected countries.

Country	Year	Collected amount of end-of-life clothing [1000 t]	[mass %]	Reference
Denmark	2010	35	48	Tojo et al. 2012
Finland	2010	25	39	Tojo et al. 2012
UK	2008	523	24	Morley at al. 2009
Sweden	2010	26	22	Tojo et al. 2012
USA	2013	15,130	15	EPA 2015

In contrast to other waste streams such as packaging, apparel collection does not require any funding and is not commonly governed by extended producer responsibility schemes. Another difference is the fact that aside from municipalities and commercial companies, charity organizations are also active. A reason for voluntary collection seems to be that many people have ethical concerns about disposing of still functionally useful clothing and are consequently keen to donate for charity. However, the collected items are an asset and only a small fraction is distributed for free to people in need. The majority is sold on the market, where for Germany prices between 450 €/t (10/2013 – 6/2014) and 350 €/t (10/2014) are reported (Korolkow 2015). Moreover, charity organizations do not send second-hand clothing to Africa for free but use the profits from apparel collection and selling for developing aid programs (Derntl 2011).

Waste prevention

Prevention is the highest ranked option in the European waste hierarchy and must also be applied to textiles. However, the business model of the fashion industry is based on a rapid change of clothing. Customers are supposed to buy new items each year in order to comply with current fashions. As a matter of fact, fully functional apparel has to be disposed of to maintain this paradigm.

It has already been mentioned that Korolkow (2015) has determined an approximate lifespan of apparel of one year only. The study further showed that from 1998 to 2005 a significant decrease in the useful life of apparel occurred. It is obvious that the idea of waste prevention has still not found its way into the textile sector.

Reuse of textiles

Any reuse of textiles is only possible if they are not commingled with residual waste. During any contact with other waste, textiles will pick up humidity or dirt which hinders any further reuse. Second-hand clothes must be dry, clean and not worn.

Collected end-of-life textiles need to be sorted for reuse (Figure 3). The aim is to reject non- reusable items and waste from second-hand clothing. Reusable clothing itself is further divided into subgroups whereas the more sophisticated the sorting depth, the better customer demands can be satisfied. It is reported that in Germany an average of 154 subgroups are obtained with a maximum of 350 subgroups (Korolkow 2015). As sorting is a manual and labor intensive process, it is frequently carried out in countries with lower labor costs. ÖPULA, a large apparel collector in Austria, sends collected end-of-life textiles to Italy for sorting (Derntl 2011).

The separate collection of end-of-life textiles requires energy for transport, sorting and packing. Woolridge et al. (2006) determined that the energy consumption amounts to about 6 GJ/t and is thus about two magnitudes smaller than that required for apparel production.

The majority of second-hand clothing goes to developing countries, particularly Africa. There is an ongoing discussion about whether second-hand clothing for Africa is a blessing or a curse. Second-hand clothes can undermine local new-clothing production in Africa. In sub-Saharan Africa there has been a tremendous decrease in turnover and employment in the textile industry and an increase in the import of used clothing from the early 1980s. However, the decline of the sub-Saharan African textile industry can also be explained with the competition from imported Asian clothing (Brooks and Simon 2012). Many African people cannot afford new clothing and second-hand clothing is essential for them. In the Central African Republic the share of second- hand clothing can even reach 90 %. Furthermore, second-hand clothes create jobs in trade, distribution, repair, restyle and washing. In Senegal alone about 24,000 people are estimated to have jobs in the field of second-hand clothing (Baden and Barber 2005).

It is evident that second-hand clothing shows the largest potential to save energy and resources. As the complete production chain for new clothing can be avoided, up to 330 GJ/t of energy can be saved (Figure 3, Woolridge et al. 2006). As sketched in Figure 5, the fraction of reusable items is limited and slightly exceeds 50 %. Reuse means using the items again for the same purpose for which they were conceived (EC 2008). When clothing is considered to be the product, the prerequisite of re-use is fulfilled if the items are used again for apparel purposes. However, eventually the fabric could be seen as a product, thus the production of cleaning & wiping rags (CWR) belongs to the wider category of' reuse. As the production of new fabric can be avoided, the energy savings are around 200 GJ/t (Figure 3).

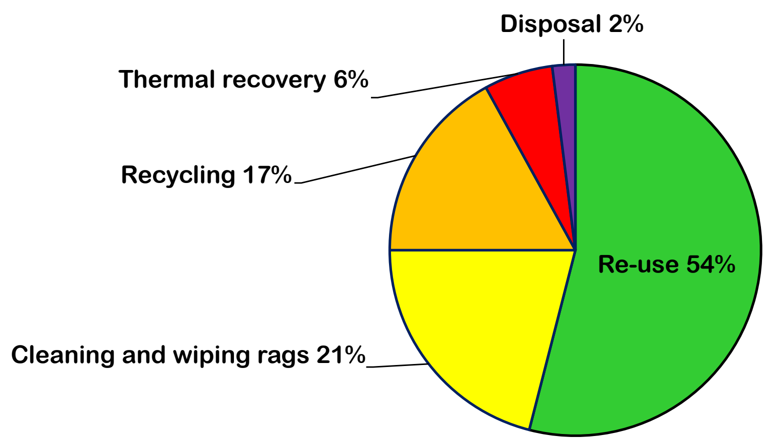

Figure 5 Routes of collected end-of-life textiles in Germany by 2013 (Korolkow 2015).

In the course of converting end-of-life clothing to CWR all hard components such as fastenings, eyelets or zippers have to be detached and a certain size (approx. 30 x 30 cm) has to be obtained (DIN, 2005). CWR must basically consist of hydrophilic fibers such as cotton, linen or viscose but hardly contain synthetic fibers. The price for cleaning and wiping rags depends on the quality and is within the range of 1.6 €/kg and 3.4 €/kg (Sperger 2017). It has to be considered that the production of cleaning & wiping rags is labor intensive und thus quite expensive.

Recycling of textiles

Fiber recovery means that the garment is disintegrated into fibers which can be processed into a yarn again, as sketched in Figure 3. As fibers can be substituted, the savings potential for energy is between 55 and 126 GJ/t, depending on the fiber type. The equipment, a Garnett machine, consists of rotating drums with metal pins that break down the textile structure. End-of-life textiles that are not feasible for re-use or CWR can be used as input material. The process shows some distinct disadvantages. Fiber length as well as fiber strength are reduced and the material contains a considerable portion of dust (Gulich, 2006). If not sorted previously, recovered fibers contain different materials and colors. Yarns made of recovered fibers are of inferior quality and will result in low quality textiles. In Germany 95 % of all reclaimed fiber are not processed into yarn but directly into nonwovens (Gulich, 2006).

Flock is a term for fibers which are not feasible for spinning as the length is too low (BISFA, 2009). Commonly, flock is produced intentionally from virgin fibers. Alternatively, however, a broad range of end-of-life fiber products can be used as input material. Such material includes textiles that are not convenient for re-use and even fiber waste from non-textile applications. Flock can be produced by means of a fiber grinding process. A cutting mill reduces the fiber length to less than 3 mm approximately. As a matter of fact, all fabrics and yarns are disintegrated into individual fibers. Among other applications, ground flock can be used in liquid and pasty products to adjust viscosity and flow properties or as an additive in construction materials (Reinthaller et al. 2011).

Re-spinning means that the fibers from end-of-life textiles are molten or dissolved. The melt or the solution is subsequently used for another fiber spinning process which is in principle the same as for virgin polymers. As textiles are commonly a mixture of different fiber types, the applicability of the process is limited. Even if the “fiber to fiber” (F2F) process is not often used, the “bottle to fiber” (B2F) process is common practice. Polyester is derived from beverage bottles and is used as feedstock for fiber production (ecofi 2017). Recycled PET shows some differences to virgin PET in terms of intrinsic viscosity, crystallinity, opacity or presence of co-monomers (Gurudatt et al. 2003).

There have been different attempts to circumvent the problem of multi-material systems. It has been reported that cellulosic fibers such as cotton can be selectively dissolved from a fiber mixture in an aqueous solution of NMMO ready for the spinning of new Lyocell fibers (Firgo et al. 1998). Only recently has it been announced that the procedure will soon allow the processing 3,000 t of textile waste annually (McGregor 2016). Alternatively, cellulosic fibers can be degraded into glucose by means of enzymes (Kim et al. 2014; Villares et al. 2017). The remaining fiber material can subsequently recycled much more easily.

Feedstock recycling means that the polymers are broken down into smaller molecules. One group of processes such as pyrolysis, hydrocracking and gasification take place at elevated temperatures and are feasible for all kind of polymers and thus also textiles (e.g. Miranda et al. 2007). The reactions are quite unspecific and, in the end, a broad spectrum of gasses, liquids and solids is obtained. The products can be used as feedstock for the production of fuels, new polymers or chemicals. Another group of processes is based on chemical reactions. The reactions are very specific and the reagent has to be adjusted to the polymer. Alcoholysis, glycolysis, hydrolysis, aminolysis, acidolysis and alkalolysis are feasible means of breaking down PET into oliogomers and monomers (Nikles and Farahat, 2005) for a de novo polymerization. Finally, biochemical reactions can be used. Elaborate enzyme mixes can selectively degrade certain polymers into their constitutive components such as PET into terephthalic acid and glycol, which can subsequently be used for a new polymerization (Biundo et al. 2016).

Conclusions

- ► Annually, about 90 Million t of fibers, which are predominantly used for textiles, are produced. This amount represents a considerable fraction of total waste.
- ► The textile processing chain is globally dislocated and concentrated in countries with low social and environmental standards. Europe is mainly a consumer of textiles only.
- ► Commonly, pre-consumer textile waste is generated outside Europe and not affected by EU legislation.
- ► Most textile products have a fairly short lifespan and the portion of fibers within the product cycle is correspondingly low.
- ► Quickly changing fashions and low quality products are the major drivers for textile overconsumption.
- ► In several industrialized countries a separate collection for end-of-life textiles has been established. The highest collection rate of 75 % is reported in Germany, whereas most other countries lag behind.
- ► Most collection schemes for end-of-life textiles are funded by selling second-hand clothes.
- ► Recycling schemes for non-reusable items are not cost effective.
- ► As non-reusable items are not cost beneficial, apparel collectors demand fully functional textiles only.

Recommendations

- ► Owing to the large quantities, textiles must become a topic of concern within the EU Commission.
- ► Waste prevention must be promoted by a significant increase in the lifespan of textiles.
- ► A consistent implementation of "design for recycling" in the field of apparel and textiles is essential to facilitate recycling.
- ► Expanded producer responsibility systems could increase the collection rate. First, latecomers must catch up with best practice countries. Second, a cost-effective collection scheme for damaged and worn textiles will further increase the collection rate and thus reduce the fraction of textiles in MSW.
- ► The development of new and economically feasible recycling processes must be encouraged. They can generate a pull factor for end-of-life textiles.
- ► In order to promote the circular economy in the field of textiles, the retrieval of the textile processing chain to Europe must be supported.

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